Technical Volume

# 39th Indian Engineering Congress

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*Theme*

## Irresistible India - a Global Engineering Powerhouse

*Organised by*

The Institution of Engineers (India)
8 Gokhale Road, Kolkata

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TECHNICAL VOLUME

# 39th Indian Engineering Congress

20-22 December 2024, Kolkata

*theme*

## Irresistible India:
## A Global Engineering Powerhouse

The Institution of Engineers (India)
8 Gokhale Road, Kolkata 700020

# Technical Volume
# 39th Indian Engineering Congress, Kolkata
## Irresistible India: A Global Engineering Powerhouse

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**Biomedical Science & Technology**

# AI/ML in Biomedical Research & Technology

81_IEC64426

# FelAug, WaterAug: Superpixel-based Medical Image Augmentation Methods for Improving Accuracy and Reducing False Predictions in Dermatological Image Classifications

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***Abstract***: *Identification of skin diseases of Indian patients using publicly available datasets fails due to the difference in skin tones and the nature of the disease. Training with clinically acquired datasets presents a big problem due to the reluctance of patients to be filmed, getting approval from the Human Ethics Committee, and the involvement of dermatologists for data labeling. Moreover, data from a single clinic is often very low as the maximum number of patients are revisited cases. Because of this, we have developed four superpixel-based augmentation methods to increase the dataset. Our research has shown that this augmentation method not only increases efficiency but also reduces false predictions which can be detrimental to patients' safety.*

***Keywords:*** *FelAug; WaterAug; InceptionV3; MobileNetV2; Superpixel, Machine-learning*

## INTRODUCTION

Although skin and subcutaneous diseases are responsible for a high morbidity rate throughout the world, due to their low mortality rate skin diseases are often neglected by national health programs. Despite the low mortality rate, skin and subcutaneous diseases in India have a significant impact on disability, surpassing that of cardiovascular diseases in terms of non-fatal burden. The occurrences of skin disease have greatly increased in the last few decades and are a significant contributing factor in the health care system in the world [1]. With a population of over 1.1 billion, there are only 50,000 dermatologists in India, with an insignificant number of dermatologists in rural areas. Correct management of skin disease requires an accurate diagnosis of the disease. Due to inadequate dermatology training in the undergraduate medical curriculum, primary healthcare physicians face a big challenge in the correct identification of skin diseases[2]. Binod kr. Patro et al in a research paper published in the Indian Dermatology Online Journal showed that the effectiveness of identification of proper skin disease during a trial on telemedicine is quite low. Their research showed that there is only 56 % agreement between decisions made by the primary healthcare physician and a dermatologist on the pictures taken during telemedicine[3]. Skin Disease models trained with publicly available datasets fail to predict Indian skin diseases due to the wide difference in skin tones and the nature of the disease. Patients' reluctance to be photographed, getting approval from the Human Ethics Committee, and the high cost of data labeling due to the involvement of dermatologists are the biggest drawbacks of developing datasets from clinically acquired images.

## METHODOLOGY

### Dataset

This study was performed following the principles of the Declaration of Helsinki. Approval was granted by the Hurip Independent Bioethics Committee (Date 27.01.2023, Protocol No Dib/H/001/01). Approval was obtained from the Human Ethics Committee before the experiment began. The images were collected from the Manju Memorial Doctor and Skin Clinic, Kolkata under the supervision of a dermatologist.

The patients were selected irrespective of age, or sex. The photographs are then converted to JPEG (Joint Photographic Expert Group) format with a color depth of 24 bits per pixel. Since the highest-recorded disease in that clinic was psoriasis, we developed our study on the diagnosis of psoriasis.

50 psoriasis photographs were collected. 40 random images were selected to form the training dataset. 10 images were used for testing. The non-psoriasis dataset contained both healthy images and other diseased images.

Contrast Limited Adaptive Histogram Equalization(CLAHE) was applied to all the training images as a preprocessing step to increase the contrast of the images without increasing the noise. Each image was then segmented using the Superpixel Segmentation method proposed by Felzenszwalb[3], and Watershed Segmentation[4].

We modified all four segmentation algorithms to produce augmented images to increase the size of the training image dataset. In the FegAug method, we randomly chose 20% of the segments done with Felzenszwalb's method and replaced each pixel of those segments with the mean pixel value of that segment. A similar technique was used to obtain images by the WaterAug method, using Watershed's segmentation method instead of Felzenszwalb's segmentation method.

After augmentation, our new training set contained 80 images, 40 images were each derived by the FelAug, and WaterAug, methods. In the next sub-section, we compare image characteristics between the original image and various augmented images. 40 original images were then added to this dataset making the total training dataset images 120.

**Comparison of Images**

**Figure 1** shows segments chosen randomly with FelAug, and WaterAug, methods, and the corresponding augmented image. In **Figure 1b**, the green areas are the randomly chosen 20% of the Felzenszwalb segmented area whose pixel value will be changed to μI. **Figure 1d** is the image formed after every I(i,j) has been replaced by μI. In **Figure 1c** the green areas are the randomly chosen 20% of the Watershed segmented area whose pixel value will be changed to μI. **Figure 1e** is the image formed after every I(i,j) has been replaced by μI. **Figure 1a** is the original image. **Figure 1f** shows the augmented rotated image by the classical augmented method.

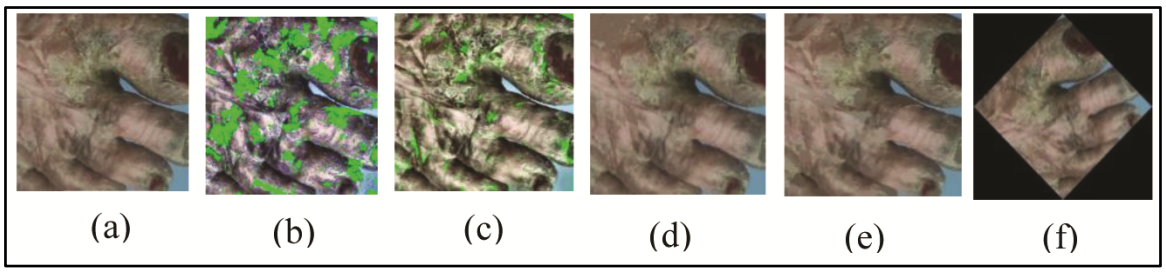


**Figure 1** a) Original Image b) Segmented Image by Felzenszwalb segmentation and green areas are 20% randomly selected segments c) Segmented Image by Watershed segmentation and green areas are 20% randomly selected segments d) Augmented by FelAug e) Augmented byWaterAug f) Rotated Image

We compare the augmented image with the original image using standard available techniques such as Structural Similarity Index(SSIM), Mean Square Error(MSE), Peak Signal to Noise Ratio(PSNR), Histogram Correlation, and Feature-based comparison using Scale-Invariant Feature Transform (SIFT). The results are tabulated in **Table 1**.

Images obtained by FelAug, and WaterAug, methods show an SSIM value of approximately 0.74 which shows that although the images are not very structurally different from the original image, they are also not the same. Compared to the original image, the rotated image shows an SSIM value of 0.55, indicating less than 50% structural similarity with the original image. An SSIM value of 1 indicates that the images are identical and an SSIM of 0 indicates that the images are completely non-identical.

The tables also show that compared with the original image, all the augmented images have an MSE value of approximately 99. An MSE value of 0 indicates similar pixels for both images, whereas 99 indicates a considerable difference.

A PSNR value of approximately 28 for all augmented images shows that they are visually similar although they are different.

**Table 1** Similarity Comparison between the FelAug, QuickAug, WaterAug, SLICAug, and augmentation by rotation method with the Original image

| Serial No | Name of the Method | Augmentation by FelAug Vs Original Image | Augmentation by WaterAug Vs Original Image | Augmentation by Rotation |
|---|---|---|---|---|
| 1 | SSIM | 0.7398 | 0.7319 | 0.5531 |
| 2 | MSE | 99.6428 | 99.9959 | 103.6496 |
| 3 | PSNR | 28.1463 | 28.1310 | 27.9751 |
| 4 | SIFT (Fig 2) No. of key points in the original image | 988 | 988 | 988 |
| | No of key points in the matched image | 20508 | 18817 | 948 |
| | Matched key points | 494 | 565 | 631 |

According to **Table 1**, the original image has 988 key points, but the image produced with FelAug has 20508 key points with 494 matched key points. Similarly, 18817 key points were created with the WaterAug techniques with only 565 corresponding matched key points. This shows that new key points are made using all the augmentation methods. The data in column 5 shows that with rotated images number of key points is less, with more matched key points, indicating less key point generation during augmentation by rotation.

A directory of augmented images was formed with 2 augmented images for each original training image. The First training set was formed with 80 augmented images together with 40 original images. The second training set was formed with 40 original images only. The first training set has 120 non-psoriasis images comprising both healthy and other skin disease images.

**Network used**

We used MobileNetV2, and InceptionV3 with network weights = Imagenet, an Adam optimizer, and a learning rate of 0.0001. There were 100 epochs, with a batch size of 32 used for training and validation and Earlystopping to prevent overfitting. Normal Augmentation methods such as rotation, width shift, height shift, zoom, horizontal flip, and others were applied on the fly to both the training datasets.

Both Networks were trained with the superpixel-augmented dataset and tested with the test dataset. The results so obtained were labeled as S_Aug. The networks were also trained with the second dataset applying normal augmentation methods like rotation, flip, and others on the fly and tested with the test dataset. The results so obtained were labeled as N_Aug.

**RESULTS AND DISCUSSION**

From **Table 2** we see that InceptionV3 performs better compared to MobileNetV2 for both normally augmented and superpixel augmented datasets. With both the transfer learning models there was a substantial increase in accuracy with the dataset formed by the superpixel augmentation method. Both the models show a drastic reduction in False Positive and False Negative values with S Aug compared to N Aug datasets. This shows that by augmenting images

with FelAug, and WaterAug methods we were able to lower the False Positive (FP) and False Negative (FN) prediction rates.

**Table 2** Comparison of Training, Test, TP, TN, FP, and FN Results for different Neural Net

| | Train Accuracy | | Test Accuracy | | True Positive (TP) | | False Positive (FP) | | True Negative (TN) | | False Negative (FN) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N_ Aug | S_ Aug | N_ Aug | S_ Aug | N_ Aug | S_ Aug | N_ Aug | S_ Aug | N_ Aug | S_ Aug | N_ Aug | S_ Aug |
| Inception V3 | 0.98 | 1.00 | 0.65 | 1.00 | 10 | 10 | 7 | 0 | 3 | 10 | 0 | 0 |
| MobileNet V2 | 0.98 | 1.00 | 0.90 | 0.95 | 10 | 9 | 1 | 0 | 9 | 10 | 0 | 1 |

We then segmented the original image, rotated image, FelAug image, and WaterAug, images by the K means segmentation technique. The segmentation results show that while there is some increase in the number of segments during the rotation of an image, the total number of segments greatly increased from 585 segments in the original image to 935 segments in the FelAug image and 690 in the WaterAug image.

## CONCLUSION

It is evident from **Table 2** that there was a reduction in FP (False Positive) and FN (False Negative) detections when images produced by FelAug, and WaterAug were used for training. This reduction in FP and FN has been arrived at without compromising the test accuracy results. Results in **Table 2** show a significant increase in test accuracy when using FelAug, and WaterAug augmented image datasets in training the model. From **Table 1**, we can see high SSIM values for images produced with the FelAug, and WaterAug models compared to images produced by rotation although they have very similar MSE values. We also see that new features in the images are added if the images are augmented by FelAug and WaterAug techniques. Comparing this with the high number of segments produced in the images augmented by the FelAug, and WaterAug techniques, we can conclude that although the superpixel augmented images are structurally similar to the original image, the images produced by FelAug and WaterAug techniques can create more feature maps in Deep Neural networks. Hence training by the FelAug, and WaterAug, augmented image datasets provides more robust training for Deep Neural Networks and Machine Learning networks. This also explains the low FPs and FNs obtained when the network is trained with images augmented by FelAug, and WaterAug methods.

In recent years generative adversarial networks(GAN) [5] have shown remarkable progress in generating artificial images for data augmentation and have been applied to various medical images [6]. However, GANs are affected by issues such as learning instability, convergence difficulties, and mode collapse [7]. In response, a novel deep generative model known as diffusion models (DMs) [8] [9] has been created to address these challenges. However, DMs have high computational costs and high sampling times. Our data augmentation model can be applied to various medical images to reduce false positive and false negative predictions while maintaining a high accuracy rate and low computational costs.

## DECLARATION

Approval from the Human Ethics Committee has been taken before handling patient data.

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206_IEC44754

# Prediction of Post Operative Complications from Pre and Peri Operative Statistics using Artificial Neural Network

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***Abstract***: *India being one of the most populated countries conducts more than 50 million surgeries annually. Thus, it becomes challenging for medical organizations to accurately predict the post-surgery risks of every individual patient. Accurate prediction of the risk of the same is important for patient selection prior to surgery and for guiding perioperative decision-making. Accurate assessment of post-surgery risk will make the patient as well as their medical escort to be more vigilant, as well as directing early interventions. Eventually, it will reduce the overuse of hospital resources as well as reduce morbidity and mortality in high-risk patients. In this study, an Artificial Neural Network model to accurately predict post-surgery complications using pre and perioperative parameters is developed. This model is implemented on a cohort of 7908 patients and observed post-surgery infection in 1128 of them. The data set was divided into training and testing sets to train the predictive model and assess generalization performance respectively. The Artificial Neural Network displayed potential performance in predicting the presence of postoperative complications. Further clinical studies are required to confirm its applicability in routine clinical practice.*

***Keywords***: *Artificial Neural Network (ANN); Cohort; Infections; Logistic Regression; Post Operative Complications (PoCs); Prediction*

## INTRODUCTION

India with over 1.4 billion population and limited medical resources becomes a challenging job for medical practitioner to accurately predict critical condition of medically susceptible individuals. Thus, often unproper assessment of patient risks make them vulnerable for post operative morbidity and mortality. Medical practitioner often uses conventional risk calculator which are often not very accurate and leads to failure in proper assessment of the patient risk. Modern Machine Learning (ML) approach and model helps to tackle this situation by bearing more pre and peri operative factors [1].

Researchers in [2] studied SUMPOT (an ANN based tool) for predicting PoCs. It utilizes ANN for risk assessment. They have compared SUMPOT's performance with binary decision tree models. They predicted from their data that high-risk patients require tailored postoperative care strategies. Accurate risk prediction improves patient outcomes and reduces healthcare costs. Reference [3] concluded that while AI shows promise in forecasting PoCs, its clinical application is delayed by low AUC-ROC values and the need for optimal datasets. The diversity of AI algorithms complicates direct comparisons of study outcomes, highlighting the importance of balanced data sets for accurate predictions. Future research should focus on external validation, implementation strategies, and cost-benefit analyses to enhance the clinical utility of AI in surgical situations. They also concluded different ML approaches leads to different AUC-ROC value.

The dummy indication technique for imputation yielded the best performance in predicting pneumonia, while preoperative data alone performed nearly as well as combined data [4]. The study found that adding features with greater missing rates consistently improved AUROC across all complications. Thy also stated gradient boosting trees (GBT), and deep neural networks (DNN), gives superior performance due to complexity of input data. The study underlines the importance of considering the timing of data obtainability during surgery for better predictive capabilities. GBT emerged as the best-performing model for pneumonia, acute kidney injury, deep vein thrombosis, and delirium, while DNN excelled for pulmonary embolism, with high AUROC values reported for each complication.

Researchers in [5] predicted that models trained solely on intraoperative data exhibited the lower predictive uncertainty across all PoCs, suggesting that intraoperative data may provide more stable predictions. They also stated that for predicting sepsis, heart rate emerged as the most important feature, while other expected indicators like fever and leucocytosis may be obvious later in the postoperative course. Serum creatinine was identified as the primary interpreter for acute kidney injury, emphasizing its dependability over urine output measurements. The study highlighted the importance of assessing model performance using metrics like AUPRC, particularly for rare event predictions, to avoid misleading accuracy rates.

Reference [6] stated effective management of temperature during combined regional and general anesthesia requires the use of multiple warming methods to prevent hypothermia. Due to this, it is required to closely inspect the last reading temperature and end case temperature during surgery which can also be combined into a time-weighted average of temperature (TWATemp) during surgery to asses a better understanding of temperature's role in PoCs. Thus, TWATemp becomes an important parameter for our study.

Taking motivations from all the above-mentioned pieces of literatures this study was deliberately designed to consider as many as pre and perioperative parameters to predict PoCs. The data set was taken from Kaggle [7]. The pre-surgery parameters considered are Age, Sex at birth, BMI, Charlson score, the occurrence of Congestive heart failure, Vascular disease, Renal failure, Liver disease, Cancer (metastasized), Cancer (non-metastasized) Coagulopathy, Fluid or electrolyte disorders, Chronic blood loss anemia, and deficiency anemia. Along with preoperative parameters peri-operative (during surgery) parameters like the use of Steroid drugs and Immunosuppressive drugs before surgery, Duration of the surgery, Open or minimal invasive type of surgery TWATemp is also considered (**Figure 1**). In course duration, few of the most important parameters were predicted using logistic regressions and went forward with only those (**Figure 1**).

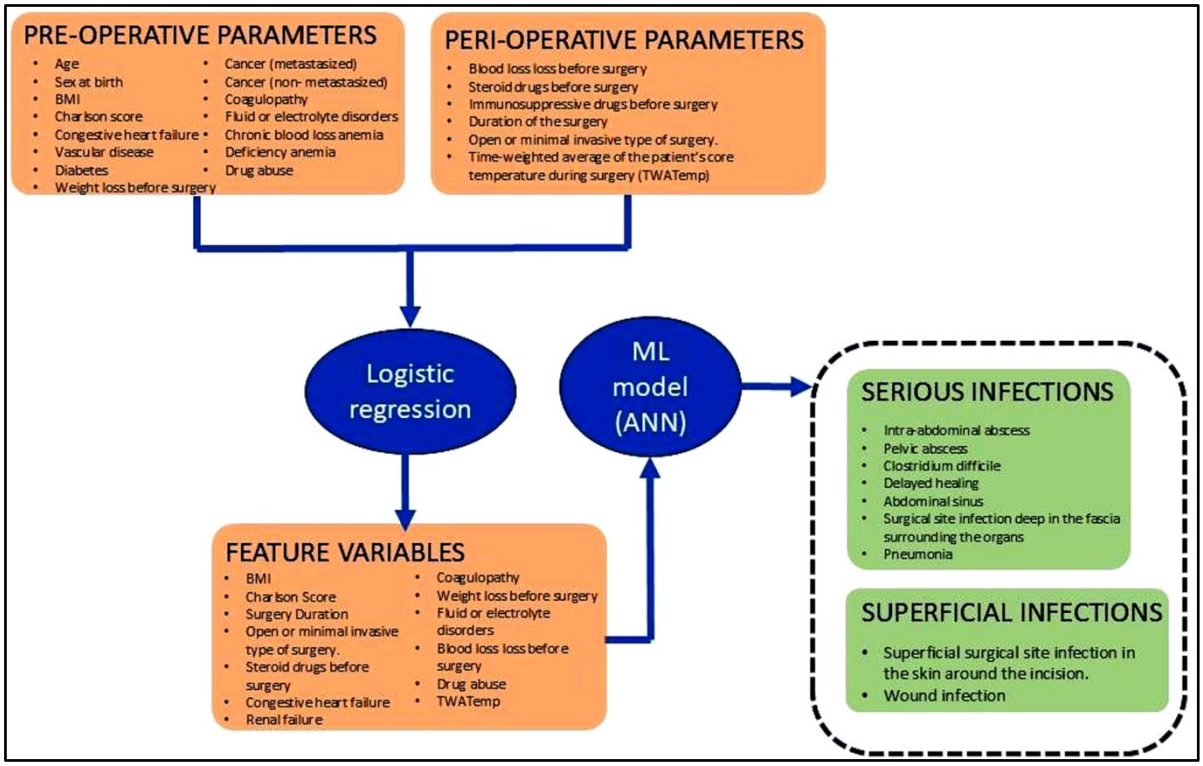


**Figure 1** Graphical Abstract: Overview of the predictive model for post-operative complications using Artificial Neural Networks. Pre- and peri-operative data are used as input to the ANN model, which forecasts the likelihood of post-surgery complications

These parameters values were fed into an ANN model to predict PoCs like Intra-abdominal abscess, Pelvic abscess, Clostridium difficile, Delayed healing, Abdominal sinus, Surgical site infection deep in the fascia surrounding the

organs and Pneumonia. All the diseases are broadly categorized into Serious Infections (Infection deep inside our body) and Superficial Infection (Infection on the skin). At the conclusion of the study accuracy and model loss plots were obtained to come up with a generalized discussion. Along with this an AUC-ROC plot was also obtained which is one of the most important parameters for assessment as false negative predictions can lead to serious medical consequences. A detailed pictorial abstract of the whole study is represented in **Figure 1**.

## METHODOLOGY

### Background

Machine Learning (ML), a subfield of artificial intelligence is the study of a computer program that learns from experience, instead of being explicitly programmed by rules. Over the last few decades ML is extensively used in many fields, including healthcare, energy, transportation, robotics etc. ML algorithms identify patterns in data and use these patterns to make predictions, classify information, or generate insights. There are several types of machine learning, including supervised learning, where the algorithm is trained on labelled data to predict outcomes; unsupervised learning, which identifies hidden patterns in unlabelled data; and reinforcement learning, where models learn by receiving rewards or penalties based on their actions.

As an example, an architecture that generates a certain output in correspondence to an input, trained using a series of input data according to a functional relationship. The whole data set is divided into 2 parts, training set and testing set. An established training set is used to train the system i.e. to generate a surrogate model of the function to approximate the behaviour of the system. This course is known as the training phase. The model is then used to predict unknown output for any different input combinations i.e. the testing set and generalization is obtained. The training phase is a challenging task, as. If not optimized properly may lead to one of the main difficulties i.e. the overfitting phenomenon. When overfitting occurs, the resulting model is extremely accurate in replicating the training data but quite poor in terms of generalization. Another issue can be the imbalance of the data classes or lack of any actual functional relationship between input and output.

### Logistic Regression

Logistic regression was incorporated as a statistical modelling technique to identify and quantify the impact of several pre-surgical features on the possibility of post-surgical infections, especially focusing on serious and superficial infections in broad categories. By fitting the logistic regression model to our dataset, the coefficients associated with each covariate are inspected, which provide insights into the direction and magnitude of their effects on the risk of infection. Additionally, $p>|Z|$ statistics were also assessed to which covariates significantly influence the likelihood of PoCs. This study will not only help us to understand the correlation between all the feature variables (**Figure 2**) but also help clinical decision-making by highlighting key risk factors that are most commonly associated with post-surgical infection. After performing this study those feature variables which are most significant in further studies were extracted. The variables are BMI, Charlson Score, Surgery duration, Open or minimally invasive surgery, use of Steroids, Congestive heart failure, Renal failure, Coagulopathy, Weight loss, Fluid and electrolyte disorder, chronic blood loss anemia, Drug abuse and a time-weighted average of temperature during surgery. This study and the extraction of significant variables were specifically conducted to simplify our ML process and make the model more computationally economical.

### Overview of ANN

ANNs are characterized by a learning mechanism inspired by biological neurons. ANNs are generally structured as networks of interconnected digital neurons, in which the neurons are processing units organized into ordered layers, while the connections between neurons are weighted and oriented to specify the direction of information flow. The connections are oriented from the input layer to the output layer. Hence, an ANN works as an input-output system that receives input signals and produces an output. The output is the result of the propagation of the input signals from the input layer to the output layer. During this whole process of operation, each neuron processes the weighted sum of input signals coming from its incoming connections by means of activation functions and then produces an

output signal to subsequent outgoing neurons. Eventually it is required to minimize the so-called loss function, which measure the discrepancy between output produced in training phase and their corresponding actual output.

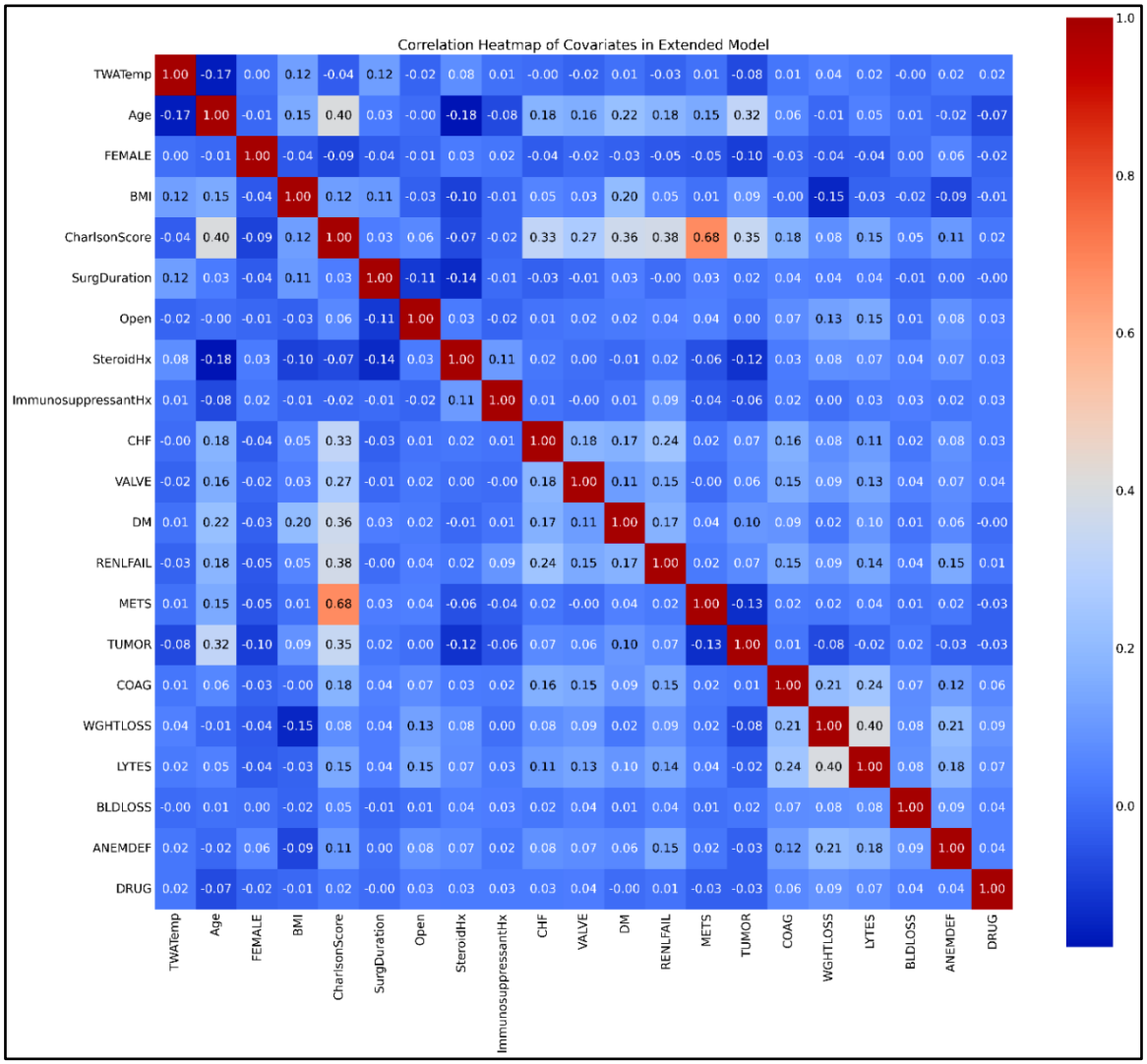


**Figure 2** Heatmap: Correlation between several pre- and peri- operative covariates

**Overview of ANN**

ANNs are characterized by a learning mechanism inspired by biological neurons. ANNs are generally structured as networks of interconnected digital neurons, in which the neurons are processing units organized into ordered layers, while the connections between neurons are weighted and oriented to specify the direction of information flow. The connections are oriented from the input layer to the output layer. Hence, an ANN works as an input-output system that receives input signals and produces an output. The output is the result of the propagation of the input signals from the input layer to the output layer. During this whole process of operation, each neuron processes the weighted sum of input signals coming from its incoming connections by means of activation functions and then produces an output signal to subsequent outgoing neurons. Eventually it is required to minimize the so-called loss function, which measure the discrepancy between output produced in training phase and their corresponding actual output.

**ANN model**

Artificial Neural Network (ANN) designed for multi-label binary classification to predict PoCs based on pre- and peri-operative parameters is incorporated. The architecture consists of two hidden layers, the first with 64 neurons

and the second with 32 neurons, both using ReLU activation functions to introduce non-linearity. To ease overfitting, L2 regularization with a penalty factor of 0.01 is applied to both layers, and dropout layers with a 30% dropout rate are added after each dense layer. The output layer uses a sigmoid activation function to predict probabilities for each label (serious and superficial infections), making it suitable for the multi-label classification problem.

The model is compiled using the Adam optimizer with a learning rate of 0.0001, which adjusts learning rates adaptively for efficient training. The binary cross-entropy loss function is used, as it fits the multi-label binary nature of the problem. The model is evaluated using accuracy and AUC (Area Under the ROC Curve) metrics, where AUC measures the model's performance in distinguishing between classes. To enhance training stability, Early Stopping is implemented with a patience of 5 epochs to stop training if validation loss does not improve, and the best model weights are restored to avoid overfitting. The model is trained for a maximum of 100 epochs with a batch size of 32 samples. These hyperparameters were carefully chosen to balance model complexity, prevent overfitting, and optimize performance for predicting PoCs from pre-surgery parameters.

## RESULTS AND DISCUSSION

From the cohort, the following data was retrieved (mean [standard deviation] Age; 55.7 [16.7], BMI; 26.5 [6.2]; Surgery Duration in minutes; 213.9 [99.9] and TWATemp; 36.02 [0.52]). From the data set it was also observed that among 7908 patient samples, 674(8.5%) patients developed serious infection and 640(8.09%) patients developed superficial infection. To be more specific on the analysis, from the cohort of 7908 it was observed that 174(2.2%) patients developed intra-abdominal abscess, 201(2.5%) developed pelvic abscess, 88(1.1%) developed clostridium defficile, 53(0.67%) developed fascial dehiscence, 15(0.18%) patients suffered from delayed healing, 5(0.06%) patients developed sinus and 82(1.02%) suffered from pneumonia. Apart from these 154(1.9%) patients suffered from sepsis, 328(4.13%) developed a surgical site infection deep in the fascia surrounding the organs, 332(4.19%) patients developed infections in the skin and 535(6.7%) of them suffered from wound infections. After incorporating the ANN model, results were extracted i.e. the accuracy, loss function, and area under the ROC curve. The maximum testing accuracy of 57% and a loss of 23% was achieved. Validation accuracy and loss were achieved at 55% and 24% respectively. The plot of the same is mentioned in **Figure 3**.

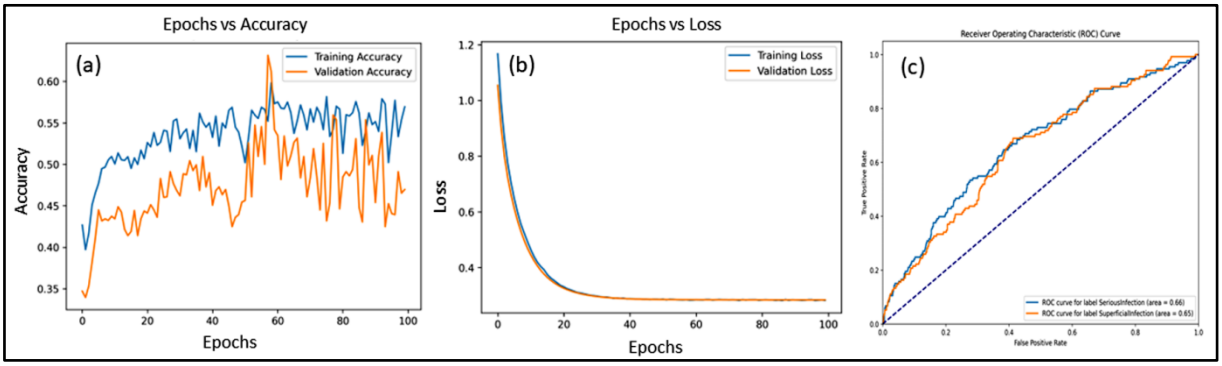


**Figure 3** Retrieved Model Results: (a) Accuracy vs Epochs (b) Model Loss vs Epochs (c) Area under ROC curve

## CONCLUSION

By leveraging machine learning, the prediction of post-surgery infection was successful. Along with machine learning, logistic regression was also employed as a subsidiary tool to predict each feature variable's weightage and direction of influence from a set of 21 variables available in the data set. The results from this study contribute to the development of predictive models for improving patient outcomes, aiding clinicians in risk assessment and decision-making. Future work can extend this analysis by incorporating larger datasets and advanced machinelearning techniques, further enhancing the accuracy and generalizability of the model. Ultimately, this research underscores the potential for data-driven approaches to optimize surgical care, reduce infection rates, and improve the overall quality of healthcare delivery. Further studies may include disease-wise prediction and considering more parameters.

This study is predominantly based on core biological parameters. Thus, in several scenarios' numerous latent variables (like genes, mutations, etc) also come into the picture which is not formally documented. Due to the presence of several underlying variables, it is quite challenging to foresee principal biological predictions even with the strongest computational models. All the parameters tabulated in the data set are mostly superficial parameters like gender, BMI, age, etc. Due to this limitation the accuracy achieved by the computational model is comparatively low than accuracy achieved in other machine learning applications like robotics, transport etc.

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221_IEC56641

# Machine Learning-Driven Scaffold Design: Advancing Tissue Engineering with Stem Cells

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***Abstract:*** *Machine Learning (ML) is transforming the field of tissue engineering by improving the design of scaffolds for stem cell applications. This study focuses on how deep learning, particularly Convolutional Neural Networks (CNNs), can optimize the 3D scaffold architecture to enhance human Mesenchymal Stem Cell (hMSC) differentiation and tissue growth. By integrating biological data into the scaffold design process, ML predicts scaffold structures that mimic natural tissue environments, significantly boosting cell attachment, proliferation and differentiation. The study shows that scaffolds by ML significantly enhance tissue formation compared to traditional designs and also offering more efficient and cost-effective solutions for regenerative medicine. This approach not only improves cell functionality but allows personalized treatments tailored to patient-specific needs. Our results highlight the transformative potential of AI-assisted scaffold design in tissue engineering, with a lot of scope for development of more advanced and personalized therapies.*

***Keywords****: Scaffold Design; Tissue Engineering; Machine Learning, Stem Cells, Regenerative Medicine*

## INTRODUCTION

Tissue engineering uses scaffolds that provide structural support for stem cells to proliferate, differentiate, and form tissues. Traditionally, scaffold design has faced significant challenges, including achieving balance between mechanical strength, porosity, and biocompatibility. Machine learning, especially deep learning models, offers new opportunities to address these challenges by analysing large sets of data and making predictions for optimised scaffold designs.

This paper aims to explore how machine learning can be used to revolutionize scaffold design for stem cell differentiation in tissue engineering. Specifically, it focuses on using Convolutional Neural Networks to predict scaffold features that can enhance the biological outcomes for human Mesenchymal Stem Cells (hMSCs). The study also compares the effectiveness of scaffolds designed through machine learning with those that are created using traditional methods.

## LITERATURE REVIEW

Integrating scaffold engineering with ML holds immense potential to transform tissue engineering. ML algorithms, especially supervised learning and deep learning, are being used to predict and optimize scaffold properties like porosity, mechanical strength, and degradation rates based on input parameters like material composition and fabrication techniques.

As more experimental data emerges and ML techniques advance, this synergy promises breakthroughs in personalized scaffolds and a faster, more effective regenerative solutions, reducing the time and cost.

## METHODOLOGY

### A. Data Collection

Numerous datasets of scaffold architecture, mechanical properties and stem cell differentiation are gathered from prevailing studies and in-house experimental data.

**Table 1** Survey on machine learning models incorporated for scaffold engineering

| S. No | Author and year of publication | Title | Methodolgy | Limitation |
|---|---|---|---|---|
| 1. | Maryam Rahmati et al., 2018 | Bioengineered Scaffolds for Stem Cell Applications in Tissue Engineering and Regenerative Medicine | Reviewing biomaterials and their role in mimicking the stem cell microenvironment. | Limited control of stem cell behavior post-transplant and challenges in creating biomaterials that replicate native tissue environments. |
| 2. | Rixiang Quan et al., 2024 | Machine Learning-Driven Optimization of 3D Printing Parameters for PLA Bone Scaffolds with Enhanced Mechanical Properties | Linear - Polynomial Regression, Random Forest, Support Vector Regression, Gradient Boosting, Neural Networks | Neural Network performed poorly compared. Dataset only 224 data points, limiting model generalization. |
| 3. | Maliheh Gharibshahian et al., 2024 | Recent Advances in Artificial Intelligent Strategies for Tissue Engineering and Regenerative Medicine | Supervised learning, neural networks, and deep learning models, biomaterial selection, predictive modelling. | Availability of high-quality datasets. AI integration with complex biological systems in tissue engineering is in early stages. |
| 4. | Silvia Ibrahimi, et al., 2024 | Machine Learning Approaches for the Design of Biomechanically Compatible Bone Tissue Engineering Scaffolds | Linear Model Non-linear Model and Non-linear Model with Constraints. | Dataset consisted of synthetic data, potentially missing real-world accuracy. Computational costs were high for large-scale simulations |
| 5. | Samantha M. McDonald et al., 2023 | Applied Machine Learning as a Driver for Polymeric Biomaterials Design | Property prediction and structure generation using random forests, recurrent neural networks, and deep learning algorithms. | 1. Limited high-quality datasets for ML training in biomedical polymers.<br>2. Encoding complex polymer structures, like copolymers, poses challenges for ML. |
| 6. | Rohith Varikoti et al., 2022 | Machine Learning-Driven Molecular Design for Therapeutic Discovery | AI-driven iterative design and Molecular docking and 3D-Scaffold models. | Limited data for training ML models on real-world biological systems. Difficulty in generalizing models across protein structures due to complex biological interactions. |
| 7. | Aditya Menon et al., 2019, 3D | Optimization of Silicone 3D Printing with Hierarchical Machine Learning | Hierarchical ML | Small dataset reliance may limit model generalization to other systems or materials. Complexity in capturing all interactions may not cover variables affecting outcomes. |
| 8. | Yakubu Adekunle Alli et al., 2024 | Optimization of 4D/3D Printing via Machine Learning: A Systematic Review | Predictive Algorithms for 4D/3D printing optimization | The challenges in generalizing across different materials and printing techniques. |
| 9. | Hongyi Chen et al., 2023. | Machine Learning in Predicting Printable Biomaterial Formulations for Direct Ink Writing | Random Forest, Deep Learning , and Decision Tree | Required large datasets for accurate model training. Limited generalization for biomaterials beyond studied formulations. |
| 10. | Ghayadah Al-Kharusi et al., 2022. | The Role of Machine Learning and Design of Experiments in the Advancement of Biomaterial and Tissue Engineering Research. | Neural Networks, Support Vector Machines, Bayesian Optimization, Hierarchical Machine Learning, Convolutional Neural Networks. | Lack of large datasets for ML in tissue engineering. Challenges in applying ML to high-dimensional data like images and 3D structures. |
| 11. | Jaemyung Shin et al., 2022 | Optimized 3D Bioprinting Technology Based on Machine Learning: A Review of Recent Trends and Advances. | Machine Learning, Convolutional Neural Networks, and Optimization Algorithms. | Limited datasets hinder effective training in 3D bio printing. ML models may struggle to generalize across various 3D bioprinting systems. |
| 12. | Chi Wu et al., 2021. | A Machine Learning-Based Multiscale Model to Predict Bone Formation in Scaffolds. | Neural Networks, Finite Element Analysis, and Multiscale Modeling. | High computational cost associated with finite element analyses for large scaffolds. Limited generalizability across different biological systems and scaffolds. |
| 13. | Shuangjia Zheng et al., 2021 | Deep Scaffold Hopping with Multimodal Transformer Neural Networks | Multimodal deep generative model, Transformer architecture, 3D graph neural network | Limited diversity due to reliance on existing bioactive compounds. Difficulty in fully utilizing protein 3D structural information. |
| 14. | Jason L. Guo et al., 2022 | Machine Learning in Tissue Engineering | Predictive modeling, Neural networks, Random forests, Support vector machines. | High computational costs for training. Limited datasets for training complex biomedical models. |
| 15. | María Dolores Bermejillo Barrera et al., 2021 | Artificial Intelligence Aided Design of Tissue Engineering Scaffolds Employing Virtual Tomography and 3D Convolutional Neural Networks | 3D Convolutional Neural Networks, Digital tomography, Computer-aided design , Finite element modeling, Data augmentation. | Limited to simple CAD geometries that may not capture real-world biological complexity. Dependent on high-quality digital tomography data for accurate predictions. |

### B. Machine Learning Model

Convolutional Neural Networks are chosen for their capability to handle complex data structures and relationships. The model is trained using required datasets such as scaffold porosity, mechanical strength, and biocompatibility. The input datas are given into the CNN to predict scaffold architectures that are most compatible to stem cell differentiation. In order to ensure the model's generalizability, K-fold cross-validation is performed.

### C. Scaffold Fabrication

The scaffold fabrication process involves 3D printing technology to produce CNN-optimized scaffold designs. These designs, created using biocompatible materials such as Poly Lactic-co-Glycolic Acid, offer necessary structural and biological properties for tissue engineering. After the scaffolds are printed, they are seeded with human mesenchymal stem cells (hMSCs) and cultured in-vitro. This process allows the scaffolds to support stem cell growth and differentiation, promoting tissue regeneration in a controlled laboratory environment.

### D. Performance Evaluation

The performance of the developed scaffold is evaluated through several key factors. First, cell differentiation analysis is conducted by measuring the degree of cell differentiation into specific lineages, such as osteogenic and chondrogenic pathways. Secondly, tissue formation is assessed using histological and molecular techniques to evaluate the extent of tissue regeneration within the scaffold. Finally, mechanical testing examines properties like stiffness and tensile strength to ensure the scaffold meets the necessary structural requirements for tissue support.

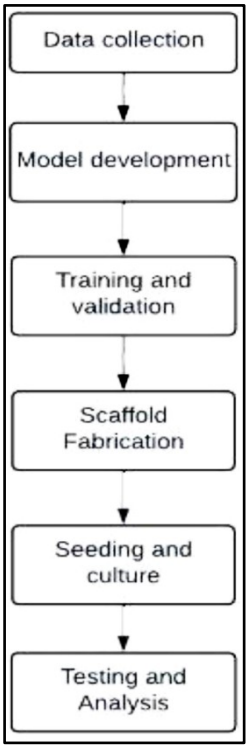


**Figure 1** General Machine Learning Architecture for Scaffold Engineering

## RESULTS

CNN-based models significantly improved scaffold designs by optimizing porosity and surface geometry, leading to better cell adhesion and stem cell differentiation. Scaffolds created with machine learning showed enhanced differentiation of human mesenchymal stem cells into osteogenic and chondrogenic lineages compared to traditional

designs. They also demonstrated improved mechanical stability and elasticity, making them more suitable for long-term tissue engineering applications.

## CONCLUSION

This research highlights the impact of machine learning, especially convolutional neural networks, in optimizing scaffold design for tissue engineering. By refining scaffold structures, machine learning promotes better stem cell differentiation and tissue growth, creating valuable opportunities in regenerative medicine. Integrating ML not only improves scaffold effectiveness but also speeds up the transition of innovations from the lab to clinical practice, making them more accessible and beneficial for patient care.

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251_IEC22776

# Lung Cancer Detection using Deep Learning

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***Abstract:*** *Lung cancer is the second leading cause of cancer-related deaths, is primarily caused by long-term tobacco consumption (85% of cases). Surprisingly, 10-15% of cases occur in non-smokers. In 2020, approximately 2 million people were affected globally, resulting in 1.5 million deaths. The survival rate, at around 20%, lags behind other cancers, partly due to late-stage symptom manifestation. Lung cancer, a prevalent and deadly disease, necessitates early and accurate detection for effective treatment. Performance metrics such as accuracy, precision, recall (sensitivity), and F1-score are calculated to provide a comparative study of each model's capabilities. By comparing these metrics, this study offers insights into the strengths and limitations of each approach, contributing to the advancement of lung cancer detection techniques. In this paper, different deep learning algorithms - InceptionV3, MobileNetV2, VGG16, and ResNet152 — are explored for their efficacy in classifying lung cancer cases. But our Proposed Model, which is a 16 hidden layers architecture based on CNN model has better accuracy. The proposed model for lung cancer detection using deep learning exhibits several key highlights that contribute to its novelty. Firstly, the model incorporates 2D Convolutional layers, enabling it to capture spatial and temporal dependencies in the input data. By integrating multiple layer types such as convolutional, pooling, flatten, dropout, fully connected and dense layers, the model leverages the strengths of each layer to enhance its predictive capabilities. Novelty of our proposed model is that its accuracy is increasing consistently with the increasing no of epochs. We have tested the model performance up to epoch no 30. Our proposed model also overcomes the overfitting problem.*

***Keywords****: Lung Cancer; Deep Learning; CNN; 2D Convolutional Layer; Accuracy*

## INTRODUCTION

Lung cancer, the second leading cause of cancer-related deaths, is primarily linked to long term tobacco smoking (85% of cases). Surprisingly, 10-15% of cases occur in non-smokers. Mainly two types of lung cancers are there - Small Cell Lung Cancer (SCLC) and Non-Small Cell Lung Cancer (NSCLC). Also there are three types of NSCLC - adenocarcinoma, large cell carcinoma and squamous cell carcinoma[19]. In 2020, approximately 2 million people were affected globally, resulting in 1.5 million deaths. The survival rate, at around 20%, lags behind other cancers, partly due to late-stage symptom manifestation [18].

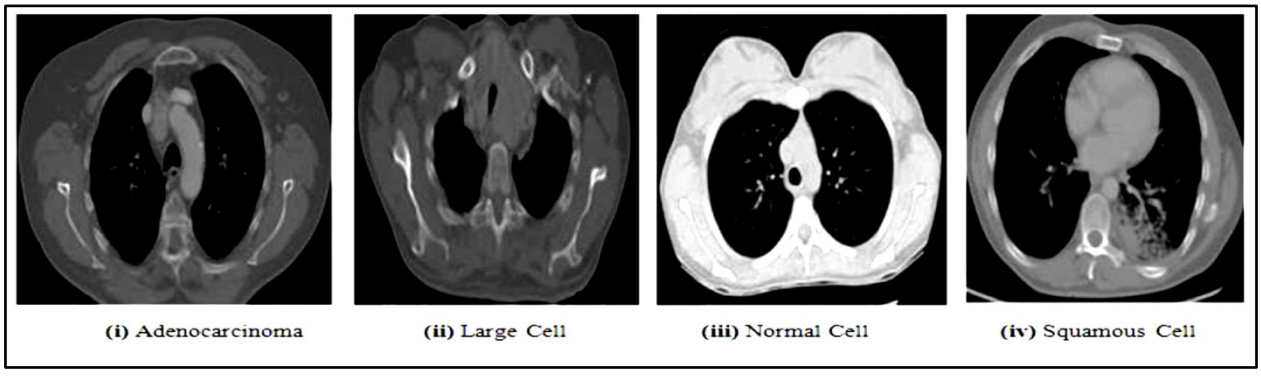


**Figure 1** Images of 4 Classes of the Dataset

In this work, I have taken an image dataset as input. Then I have used five different CNN models by increasing the hidden layers respectively. Also build a Proposed Model to classify. After that I have checked the difference between the outputs of the different CNN models mainly the prediction accuracy.

If clinical experts and technicians have lack of knowledge and skills, the experimental result may be wrong. And also the instrument which has been used in the clinic for experiment that instrument maybe old version /model and most of the instrument are maybe damage for lack of regular cleaning and maintenance. And the most serious problem is the clinical experts are not getting their required lab for work. Above all this problem patient are not getting their accurate result .Most of the time patients get false positive and false negative results for that they are suffering a lot of problem, like if any patient has not lung cancer but result comes false positive for that doctor gives the patient anti-cancer medicine and radio therapy after taking those medicines and treatments patient suffer different types of side effects. False negative results are also dangerous for patient because patient has cancer but the result comes negative the doctor would not treatment the patient. For that cancer cells will grow in the patient body day by day, which is very fatal for the patient. In this project we are trying to reduce this type of problem and gives accurate result for the patient.

In this paper, we have made a lung cancer detection model using deep learning model. One of the significant advantages of the proposed model is its ability to introduce non-linearity with the ReLU activation function, allowing it to learn complex patterns and improve prediction accuracy. Moreover, the model incorporates feature extraction and dimensionality reduction techniques through convolutional and max pooling layers, aiding in the extraction of salient features and reducing the overall data dimensionality [14]. The consideration of temporal dependencies is another noteworthy aspect of the model. By employing LSTM layers, the model can capture long-range temporal dependencies and effectively incorporate temporal patterns into the prediction process [15]. This enables the model to make informed predictions based on the temporal dynamics of the input data. Furthermore, the proposed model is designed to be interpretable and explainable. Its architecture allows for result interpretation and feature analysis, providing valuable insights into the factors influencing lung cancer prediction. This interpretability aspect enhances the model's practicality and applicability in real-world scenarios.

Overall, the proposed model exhibits novelty in its effective utilization of convolutional layers, integration of various layer types, consideration of feature extraction and dimensionality reduction capabilities, and interpretability. These qualities make it a promising approach for lung cancer detection, offering the potential to deliver accurate and interpretable predictions. With further research and validation, our proposed model holds promise for advancing the field of lung cancer detection using deep learning and ultimately contributing to improved healthcare outcomes.

## REVIEW OF LITERATURE

The paper [1] introduces a CNN model for detecting lung cancer from thoracic CT scans. The dataset consisted of thousands of CT images. Data augmentation and transfer learning were utilized to improve model performance. The CNN architecture included multiple convolutional layers for feature extraction. An accuracy of 95% was achieved. The use of transfer learning helped mitigate overfitting. Sensitivity and specificity metrics were also favorable. The model demonstrated significant potential for early lung cancer detection. Key techniques included advanced feature extraction and classification. The study addressed common challenges in medical imaging. The authors emphasized the importance of high quality training data. The model's robustness was tested on different datasets. Performance metrics showed promising results. The study highlights the importance of early intervention. Clinical implications were discussed. Future research directions were suggested.

The paper [2] systematic reviews and explores various deep learning architectures for lung cancer diagnosis. Models such as VGG-16, ResNet, and Inception were analyzed. The review highlights advancements in pulmonary nodule detection. Multimodal data integration was a key focus. High sensitivity and specificity rates were reported. The strengths and limitations of different models were discussed. Comprehensive datasets were deemed crucial for model training. The study emphasizes the role of data preprocessing. Results from different studies were compared. The review provides insights into clinical applications. Challenges in implementing deep learning in healthcare were addressed. Future research directions were identified. The review concludes that deep learning significantly enhances diagnostic accuracy. It also emphasizes the need for interdisciplinary collaboration. Clinical applicability and potential improvements were discussed.

The paper [3] developed a deep learning model for early-stage lung cancer detection using CT images. The model achieved a prediction accuracy of 97%. Early detection capabilities were a major focus. Advanced image preprocessing techniques were employed. Data augmentation helped improve model robustness. The model demonstrated high precision in identifying early cancer signs. Validation was performed on a large dataset. Transfer learning was used to enhance generalization. Sensitivity and specificity metrics were favorable. The study underscores the importance of early intervention. Clinical implications were discussed. Overfitting issues were addressed through regularization techniques. The approach showed potential for real-world applications. Performance metrics were promising. Future improvements were suggested.

This paper [4] explores deep feature extraction combined with ensemble learning for cancer detection. Both lung and colon cancers were addressed. The hybrid model achieved high accuracy. Large datasets were used for training and validation. Advanced feature extraction techniques were employed. Ensemble learning improved model robustness. The study highlights the benefits of multimodal data integration. Results demonstrated significant diagnostic potential. Computational efficiency was also considered. Data preprocessing played a crucial role. Sensitivity and specificity metrics were favorable. The approach was validated on clinical data. The study underscores the importance of comprehensive datasets. Clinical applicability is emphasized. Future research directions were suggested.

The paper [5] introduces DFD-Net, focusing on denoising CT scan images before detection. The model significantly improved accuracy by reducing noise. Enhanced image clarity was achieved. Lung nodule detectability was improved. The importance of preprocessing was highlighted. Results showed high accuracy metrics. Validation was performed on multiple datasets. Computational requirements were optimized. The study addresses common challenges in medical imaging. Performance metrics were promising. The model's robustness was tested extensively. Sensitivity and specificity were favorable. The research underscores the role of image quality. Clinical implications were discussed. Future improvements were suggested.

The paper [6] proposes a dual-stage classification model for lung cancer detection and staging. Advanced CNN architectures were used. The model first detects cancer and then stages it based on severity. High sensitivity and specificity were achieved. The approach aids in treatment planning. Robust feature extraction techniques were employed. Validation was performed on clinical data. The study emphasizes comprehensive cancer management. Results showed significant diagnostic accuracy. Data augmentation helped improve model performance. Overfitting was addressed through regularization. Performance metrics were favorable. The study highlights the importance of early detection and accurate staging. Clinical implications were discussed. Future research directions were suggested.

This paper [7] did comparative study evaluates various deep learning networks for lung cancer detection. CNNs and RNNs were primarily considered. The study highlights the superior performance of deep learning models over traditional methods. Hybrid CNN-RNN models showed the highest accuracy. Data augmentation techniques were used. Overfitting issues were addressed. Results demonstrated high diagnostic potential. Sensitivity and specificity were favorable. Validation was performed on large datasets. The study underscores the importance of model comparison. Computational efficiency was also considered. Performance metrics were promising. The research highlights the need for continuous improvement. Clinical applicability was discussed. Future research directions were suggested.

The paper [8] presents a modified Inception Recurrent RCNN for lung carcinoma diagnosis. Histopathological images were used. The model achieved high accuracy and efficiency. Data preprocessing techniques were employed. Feature extraction was enhanced. Validation was performed on a reduced dataset. Early cancer detection capabilities were a major focus. Performance metrics were promising. Sensitivity and specificity were favorable. The study highlights the importance of advanced image processing. Clinical implications were discussed. Overfitting issues were addressed through regularization techniques. Results showed significant diagnostic potential. The research underscores the importance of early intervention. Future research directions were suggested.

This paper [9] develops a deep learning algorithm for lung cancer detection from chest X-rays. CNNs were used for feature extraction. High accuracy rates were achieved. Large-scale screening potential is emphasized. Advanced

preprocessing techniques were employed. Validation was performed on large datasets. Results demonstrated significant diagnostic accuracy. Sensitivity and specificity were favorable. The study addresses overfitting issues. Regularization techniques were used. The model's robustness was tested extensively. Performance metrics were promising. The research underscores the importance of chest X-ray imaging. Clinical applicability is emphasized. Future improvements were suggested.

This paper [10] combines the Tuna Swarm Algorithm with deep learning for cancer detection. Both lung and colon cancers were addressed. High accuracy and reduced complexity were achieved. Advanced preprocessing techniques were employed. Large datasets were used for training and validation. Results demonstrated significant diagnostic potential. Computational efficiency was optimized. Sensitivity and specificity metrics were favorable. The study highlights the importance of multimodal data integration. Clinical implications were discussed. Overfitting issues were addressed. The model's robustness was tested extensively. Performance metrics were promising. The research underscores the role of advanced algorithms. Future research directions were suggested.

The paper [11] presents a multimodal fusion approach for lung cancer detection. CT images and clinical data were integrated. A deep neural network was used. High sensitivity and specificity were achieved. Advanced preprocessing techniques were employed. Results showed significant diagnostic accuracy. The approach enhances robustness. Large datasets were used for validation. The study underscores the importance of comprehensive data integration. Sensitivity and specificity metrics were favorable. Performance metrics were promising. Overfitting issues were addressed through regularization. Clinical applicability was emphasized. The research highlights the potential for real-world applications. Future improvements were suggested.

The paper [12] reviews and analyzes recent advancements in deep learning methods for lung cancer detection. Various architectures, including CNNs and RNNs, were considered. Advancements in feature extraction techniques were highlighted. Multimodal data integration was a key focus. High sensitivity and specificity rates were reported. Strengths and limitations of different models were discussed. Comprehensive datasets were crucial for training robust models. Preprocessing techniques were vital. Results from multiple studies were compared. Clinical applications were explored. Implementation challenges were addressed. Future research directions were outlined. Clinical implications and potential improvements were discussed.

The paper [13] proposes a hybrid deep learning model for lung cancer detection. The model combines CNN and LSTM architectures. High accuracy and efficiency were achieved. Data augmentation techniques were employed. Large datasets were used for training. Advanced feature extraction methods were implemented. Sensitivity and specificity metrics were favorable. Validation was performed on clinical datasets. Robustness was a key focus. Overfitting was addressed through regularization. The study emphasizes the importance of hybrid models. Clinical applicability was discussed. Performance metrics included precision, recall, and F1-score. Future research directions were suggested. The study emphasizes importance of hybrid models.

## METHODOLOGY

Designing an accurate and reliable model for lung cancer detection is crucial in the healthcare domain. Deep learning has emerged as a powerful approach for handling complex medical data and extracting meaningful patterns. In this study, we propose a novel deep learning (CNN-Based) model specifically tailored for lung cancer detection. Our model is designed to leverage the strengths of deep learning techniques.

We have chosen the above architecture for chest CT scan image analysis because it progressively reduces spatial dimensions while retaining important features, enhancing pattern detection and robustness. The 2D convolutional layers with ReLU activation capture spatial hierarchies, and max-pooling reduces dimensionality and computational load. Repeating this combination five times ensures deep feature extraction. The flatten layer converts the 2D feature maps to a 1D feature vector. The flatten layer transitions to fully connected layers for high-level reasoning. Adding dropout layers prevents overfitting. Repeat this twice for robust feature learning. And the final dense layer with Softmax activation function provides classification probabilities for accurate diagnosis.

**RESULT**

The results for CNN model InceptionV3 with convolutional layer and max pool layer gives Training accuracy 87.70% and Test accuracy is 42.86% on the epoch no 30. Dataset is same for all five CNN model in this project . The result of deep learning CNN model MobileNetV2 with convolutional layer and MaxPooling layer gives Training accuracy 96% and Test accuracy is 61% with epoch number of 30. The result for CNN model VGG16 with convolutional layer and maxpool layer gives Training accuracy 97.04% and Test accuracy is 75.24% with the epoch no of 30. VGG16 achieving the test accuracy 62.54% with epoch number of 10, which is even better than previous two models (InceptionV3, MobileNetV2) achieving at epoch number 30. The result for the model of CNN is ResNet152 with convolutional layer and MaxPooling layer gives Training accuracy 99.85% and Test accuracy 77.78% with the epoch no of 30. ResNet152 model is achieving test accuracy 75.56%, which is also better result than previous three models including VGG16 at epoch number 10. Among these four inbuilt CNN model ResNet152 is providing best result. But their accuracy is not improving always with the number of epochs increment. The result for our Proposed Model with various types of layer gives Training accuracy 99.85% and Test accuracy is 84.44% with epoch no of 30, which is providing best result among all these 5 models. The result among these five CNN models - InceptionV3, MobileNetV2, VGG16, ResNet152 and our Proposed Model adding more epoch Training and Test accuracy are increased in the model VGG16 and Proposed Model but InceptionV3, MobileNetV2, and ResNet152 in these three models adding more epochs sometimes also decreased Training accuracy and Testing accuracy in the dataset of Chest CT Scan images. So here our Proposed Model is providing best result and also constantly improved accuracy with no of epoch increment. Also computation time is lesser than ResNet152, which is an inbuilt CNN model provides second best result with Chest CT Scan Kaggle dataset.

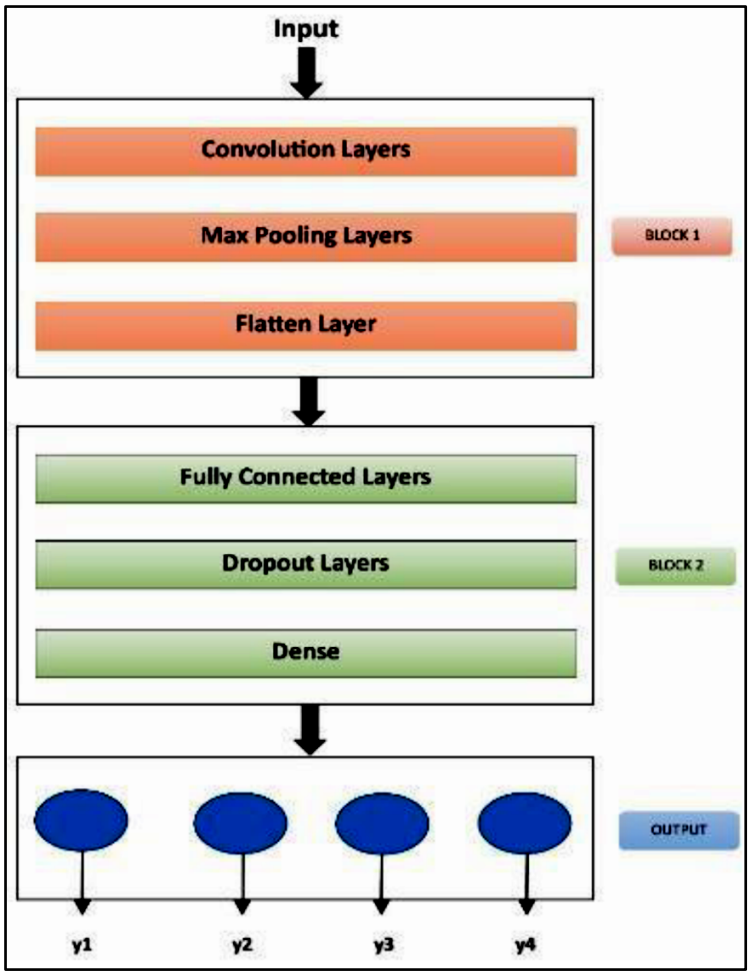


**Figure 2** Flowchart of Proposed Model

**Table 1** Summary table to compare all the used models

| Model Name | Epoch No. | Train Loss | Train Acc | Val Loss | Val Acc | Test Loss | Test Acc | Precision | Recall | F1 Score | RMSE | Acc Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Inception V3** | 10 | 0.6493 | 0.8504 | 0.6929 | 0.8358 | 9.2560 | 0.3651 | 0.44 | 0.45 | 0.39 | 1.4265 | 0.3651 |
| | 20 | 0.8626 | 0.8267 | 0.8621 | 0.7985 | 11.9857 | 0.4571 | 0.51 | 0.53 | 0.47 | 1.7229 | 0.4571 |
| | 30 | 0.7596 | 0.8770 | 0.6689 | 0.8731 | 12.4272 | 0.4286 | 0.49 | 0.55 | 0.45 | 1.4939 | **0.4286** |
| | | | | | | | | | | | | |
| **MobileNet V2** | 10 | 0.4129 | 0.8815 | 0.4198 | 0.8582 | 0.9290 | 0.5841 | 0.65 | 0.66 | 0.62 | 1.3916 | 0.5841 |
| | 20 | 0.3159 | 0.8993 | 0.3235 | 0.8955 | 1.2249 | 0.5206 | 0.67 | 0.62 | 0.55 | 1.3464 | 0.5206 |
| | 30 | 0.1971 | 0.9600 | 0.2233 | 0.9403 | 0.9228 | 0.6127 | 0.65 | 0.69 | 0.64 | 1.2574 | **0.6127** |
| | | | | | | | | | | | | |
| **VGG16** | 10 | 0.4714 | 0.8133 | 0.4403 | 0.8209 | 1.3323 | 0.6254 | 0.63 | 0.66 | 0.63 | 1.2737 | 0.6254 |
| | 20 | 0.2159 | 0.9348 | 0.2157 | 0.9403 | 0.8649 | 0.6794 | 0.69 | 0.70 | 0.69 | 1.2742 | 0.6794 |
| | 30 | 0.1248 | 0.9704 | 0.1162 | 0.9701 | 0.7083 | 0.7522 | 0.76 | 0.75 | 0.75 | 1.1533 | **0.7522** |
| | | | | | | | | | | | | |
| **ResNet152** | 10 | 0.2287 | 0.9407 | 0.5643 | 0.7556 | 0.5643 | 0.7556 | 0.77 | 0.80 | 0.78 | 1.1561 | 0.7556 |
| | 20 | 1.0216 | 0.7733 | 1.1359 | 0.7910 | 1.6644 | 0.6508 | 0.78 | 0.67 | 0.62 | 1.4387 | 0.6508 |
| | 30 | 0.0718 | 0.9985 | 0.0710 | 1.000 | 0.5303 | 0.7778 | 0.78 | 0.81 | 0.79 | 1.0954 | **0.7778** |
| | | | | | | | | | | | | |
| **Proposed Model** | 10 | 0.5242 | 0.8044 | 0.4913 | 0.8060 | 0.6794 | 0.6349 | 0.67 | 0.70 | 0.67 | 1.4606 | 0.6349 |
| | 20 | 0.0459 | 0.9881 | 0.0331 | 0.9925 | 0.9572 | 0.7079 | 0.73 | 0.76 | 0.73 | 1.3117 | 0.7079 |
| | 30 | 0.0088 | 0.9985 | 0.0032 | 1.000 | 0.6405 | 0.8444 | 0.85 | 0.87 | 0.86 | 0.9562 | **0.8444** |

## CONCLUSION

Our proposed model for lung cancer prediction using deep learning possesses several notable qualities that contribute to its novelty, allowing it to capture both spatial and temporal dependencies in the input data. In our proposed model we have used 5 2D convolution layers with ReLU activation function, and after every Convolution layer there is a MaxPooling layer. So, total no of MaxPooling layer is also 5. Flatten layer is also applied after those 10 layers. Then we have used 2 Fully Connected Layers again with ReLU function, and each layer is followed by a dropout layer. Lastly Dense Layer with Softmax activation function is added. By incorporating these layer types, the model can effectively learn intricate patterns and enhance its predictive accuracy. A key advantage of the proposed model is its ability to introduce non-linearity through the use of the ReLU activation function. This non-linearity enables the model to learn complex relationships and improve its prediction performance. Additionally, the model integrates various layers such as convolutional, pooling, flattening, and fully connected layers, harnessing the strengths of each layer type to optimize its predictive capabilities. Our Proposed Model is also providing the best result among all the models we have used in this project. Furthermore, the model incorporates feature extraction and dimensionality reduction techniques through convolutional and max pooling layers. These techniques help in identifying relevant features and reducing the overall data dimensionality, which can enhance the model's prediction accuracy. Novelty of the proposed model is consistency in the accuracy both for training and testing dataset as it is strictly increasing with the increment of epoch no. And we have examined it up to epoch no 30.

Overall, the novelty of the proposed model lies in its effective utilization of convolutional and integration of various layer types, consideration of feature extraction and dimensionality reduction capabilities, and interpretability. These qualities make the proposed model a promising approach in the field of lung cancer detection using deep learning, with the potential to provide accurate and interpretable predictions. We may also add some more image as input to get better result. We will also increase the no of epoch. It's crucial to address ethical and legal considerations in the development and deployment of these models, ensuring privacy, fairness, and transparency. Conducting clinical validation studies is essential to validate model efficacy, safety, and real-world applicability.

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292_IEC18634

# Revolutionizing Healthcare: Unleashing AI and ML for Next-Gen Disease Detection

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***Abstract***: *Thisreview study explores the application of machine learning (ML) and artificial intelligence (AI) in cancer prediction and research. Utilizing factors such as genetics and imaging, AI and ML algorithms are designed to analyze patient information and predict cancer. As a result, early detection and treatment could be improved. In detection of breast cancer, an AI system based on Google's Deep Mind algorithm outperformed human specialists. The research indicates that AI and ML greatly influence healthcare, especially in oncology, offering the possibility to enhance cancer prognosis, diagnosis, and treatment which ultimately results in more effective care.*

*However, there are challenges associated with AI, including the need for diverse data to train models to prevent medical bias and the need for additional research and clinical trials to validate AI in clinical settings. Explainable AI is essential for integrating these technologies into medical workflows. These technologies have the potential to improve cancer prognosis, diagnosis, and treatment, ultimately leading to more effective care. Further research is needed to ensure the clinical utility and validity of these ever-evolving algorithms.*

***Keywords***: *Artificial Intelligence, Machine Learning, Diagnosis, Prevention, Techniques*

## INTRODUCTION

This review paper is on AI/ML intervention in Biomedical Research and Technology. Its primary focus is on the applications, constraints, and potential future uses of artificial intelligence (AI) and machine learning (ML) algorithms in cancer prediction.

Cancer represents a global health emergency, and while progress has been made in terms of diagnosis, prognosis, and treatment, it remains difficult to provide patients with tailored, data-driven care.

Artificial intelligence has the power of prediction and automation through risk assessment, diagnosis at an early stage, time estimation and therefore is improving the accuracy in biomedicine. ML can be regarded as a subset of AI enabling the computers to learn from a set of existing training data which is used to effectively predict various types of cancer (including breast, brain, lung, liver etc) with higher accuracy. The deep learning technology is useful for detecting a range of chronic diseases and supporting medical decision-making for physicians across several industries. A review states that the five types of cancer that the deep learning system was able to classify were lung adenocarcinoma (LUAD), kidney renal clear cell carcinoma (KIRC), breast invasive carcinoma, and prostate and colon adenocarcinoma.

AI and ML algorithms are designed in such a way that they intend to solve various challenging tasks of predicting the possibility of cancer-based on the patient's molecular, genetic and tumor-based features. By analyzing the various available resources such as the pathology profiles, and imaging studies the ML and other models can convert these into their corresponding "Mathematical Sequences". These are then further analyzed and developed to predict certain traits.

An artificial intelligence system built on the "Google DeepMind algorithm" was created in January 2020 by researchers, and it was able to outperform human "breast cancer" detection specialists.

The University of Pittsburgh created a machine learning method based on AI systems in July 2020 that has the best accuracy in prostate cancer diagnosis, with a 98% specificity and 98% sensitivity.

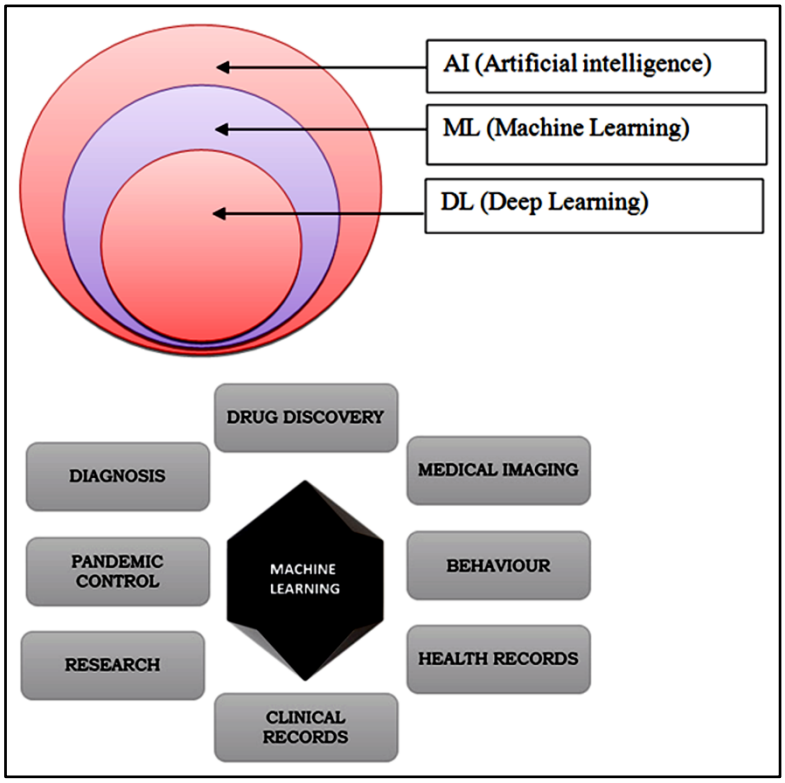


**Figure** A general schematic representation of the fields of Healthcare Services related to Machine Learning

**METHODOLOGY**

In cancer imaging, patient-acquired images undergo pre-processing and transformation (for data consistency) before being used as inputs for developing ML algorithms and models. A machine learning model or algorithm interprets the input images and grasps a straightforward or intricate mathematical formula that is connected to the desired outcome, like a medical or research finding. Usually, a training dataset is used to construct the ML algorithms, followed by a validation dataset for improvements, and an independent test dataset from a different organization to determine the algorithms' efficacy.

Certain ML models are utilized more frequently in imaging research compared to others. The most common form is the predictive model, in which the objective is to forecast y by figuring out how x and f relate to one another. Early models might simply attempt to establish a connection between the input x data (such as an imaging characteristic) and the output y data (such as gene expression).

Regression models such as Linear, Cox (Proportional Hazards), Regression Trees, Lasso, Ridge, and ElasticNet can be used when working with continuous variables. Regarding discrete variables, classification models like Naïve Bayes, Decision Trees, Support Vector Machiness, KNN (k-nearest neighbours), Random Forest, Generalized Linear Models, Bagging, and similar techniques are applicable. These models have the potential to guide cancer diagnosis, disease understanding and classification, treatment effectiveness, and disease progression. The decision on which ML algorithm to use could vary based on the size of the data. Classical ML algorithms like Logistic Regression, Naïve Bayes, decision trees, and support vector machines are commonly used when dealing with smaller datasets (e.g. <1000 patients/examinations/images based on the specific use case). When dealing with bigger datasets, it might be more beneficial to use advanced ML models like convolutional neural networks (CNN) which excel at learning from images but require more computational resources. CNN is a type of deep learning, a type of machine learning technique that relies on artificial neural networks, which mimic the arrangement of neurons in the brain and copy

neural connections to solve problems.ML algorithms can either be supervised, where data is labelled with correct answers, or unsupervised, where the algorithm discovers information on its own. The latter refers to advanced CNN algorithms that can identify patterns in imaging data without human involvement.

## RESULTS

### Opportunities and Challenges for AI in Cancer Research

The use of AI offers a unique opportunity to make rapid progress in understanding cancer biology and improving patient care. However, if the data used to train AI models are not diverse and representative of the wider population, these models can perpetuate medical biases. It is essential to establish widely accepted standards for developing AI and machine learning models to address bias and ensure reproducibility.

Furthermore, there is a need for more randomized clinical trials to validate the use of AI and machine learning technologies in clinical practice. Additionally, it will be crucial to enhance explainable artificial intelligence to integrate AI and machine learning technologies into clinical workflows effectively.

## CONCLUSION

AI and ML have significantly impacted healthcare, and this trend is only going to continue. Oncology has enormous potential and applications in nearly every area of cancer research, including prognosis, treatment, and diagnostics.

This article discusses the most recent developments in AI, ML, and deep learning. Their incorporation into different cancer prognostic, diagnostic, and predictive models may eventually result in a more effective cancer treatment.

It can improve hospital care standards for cancer patients and all patients.

These ever-growing algorithms will undoubtedly assist in overcoming the difficulties caused by this debilitating sickness shortly. Considering these objectives, additional study in these areas is required to preserve clinical utility and analytical validity.

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303_IEC7939

# Medical Applications of Graph Convolutional Networks using Electronic Health Records: A Survey

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***Abstract:*** *Graph Convolutional Networks (GCN) capture complex relationships present in Electronic Health Records (EHR) to deliver valuable insight from patient data. By constructing graph representations of patient data and performing convolution operations on neighborhoods of nodes, GCNs can capture intricate relationships and deliver clinically meaningful insights for decision making. This review surveys the landscape of GCN applications in healthcare, identifying common medical domains, benchmark datasets, and architectural strategies. We analyze recent developments across multiple medical domains, identifying key trends in model architectures, common prediction tasks, and frequently used benchmark datasets. Our findings reveal that while GCNs are increasingly being applied to analyze EHR data, many implementations utilize hybrid approaches that combine GCNs with other deep learning models to enhance performance. While still in its early stages, work in this area shows that GCN-based methods, often combined with other deep learning architectures, can effectively harness the complexities of EHR data. As healthcare continues to generate vast amounts of electronic data, GCNs show significant potential for advancing medical decision support systems and improving patient care through effective analysis of EHR data.*

***Keywords****: Graph Convolutional Networks; Electronic Health Records; Machine Learning; Medical Informatics; Hybrid Models*

## INTRODUCTION

Electronic Health Records (EHRs) are comprehensive digital systems that store a variety of patient data, including demographics, medical history, diagnoses, medications, and test results [1]. These systems serve as critical tools for healthcare decision-making, quality management, and outcomes reporting. Moreover, EHRs represent one of the most valuable resources for medical research, enabling the application of artificial intelligence (AI) and machine learning (ML) to uncover actionable insights. However, the heterogeneous nature of EHR data, comprising both structured and unstructured formats, poses significant challenges to traditional ML approaches [1].

Graph Neural Networks (GNNs), a novel class of deep learning models, have emerged as a promising solution for analyzing complex and interconnected data like EHRs. By representing EHR data as graph structures—where nodes represent entities such as patients or clinical events, and edges denote relationships—GNNs enable the modeling of intricate dependencies [2][3]. A specific type of GNN, Graph Convolutional Networks (GCNs), performs convolutional operations on graphs, aggregating information from neighboring nodes to generate node feature vectors [4]. This unique capability allows GCNs to better handle the complexity and interconnectedness of medical data compared to other methods [5].

This study explores the application of GCNs to datasets such as MIMIC-III, a large critical care database [19]. By leveraging GCNs, the goal is to enhance predictive healthcare models for outcomes such as hospital readmission rates and patient mortality. The study highlights how GCNs effectively utilize the structural properties of EHRs, offering new perspectives in medical analytics and decision-making [5].

## METHODOLOGY

This study involved a comprehensive review and analysis of the application of Graph Convolutional Networks (GCNs) to EHR data. The primary dataset utilized was MIMIC-III, which contains detailed information about critical care patients [19]. EHR data were pre-processed into graph structures, where individual patients served as nodes and edges represented medical interactions, such as shared diagnoses or co-treatment histories.

The literature search followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines and was conducted using databases such as MEDLINE Ultimate, Academic Search Ultimate, and Business Source Complete. The search was limited to peer-reviewed articles from the last five years, using keywords including: ("graph convolutional" OR "GCN") AND ("Electronic Health Record" OR "EHR" OR "Electronic Medical Record" OR "EMR" OR "electronic health data") [2][5]. Eligibility criteria included studies that applied GCN models to EHR data for tasks like patient readmission, mortality, or diagnosis prediction [12][5]. Studies were excluded if they did not involve GCN models, lacked EHR data, or were not available in full text.

A total of 56 papers were identified, and 25 were selected for full review after screening. Key criteria for inclusion focused on methodologies, medical domains, and the use of hybrid models combining GCNs with techniques such as Long Short-Term Memory (LSTM) networks or Recurrent Neural Networks (RNNs) [5][12][7]. Evaluation metrics included accuracy, F1-score, and AUC-ROC, offering insights into model performance relative to traditional methods like Random Forests and XGBoost [41]. RStudio Version 2022.12.0 was employed for data synthesis and visualization.

**RESULTS**

Our review revealed significant advancements in the use of GCNs for predictive modeling tasks in medicine. Of the 25 studies reviewed, many applied GCNs to diverse medical domains, including General Medical Informatics, Critical Care, Hematology, and Oncology. Common tasks included diagnosis prediction, code classification, mortality forecasting, and medication recommendations [12][5][22][30]. Notably, models applied to the critical care domain frequently addressed patient mortality, readmission, and decompensation prediction [33][32].

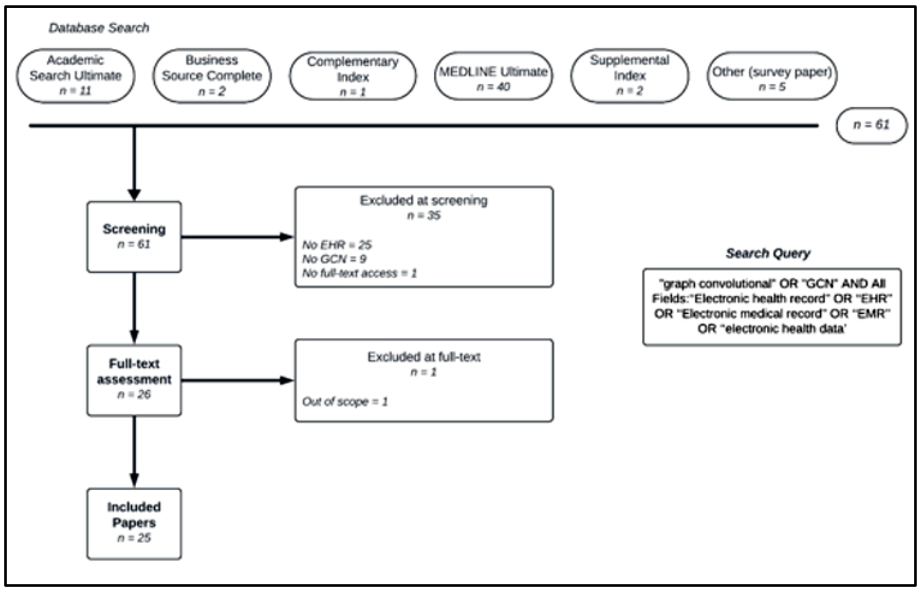


**Figure 2** PRISMA flowchart for the literature search and selection process for the review

Hybrid models emerged as a dominant approach, with 15 studies integrating GCNs with complementary architectures such as BERT, LSTMs, or RNNs [5][7]. These hybrid systems demonstrated superior performance, particularly for tasks involving complex temporal or structural data dependencies. For instance, BERT was often used to process unstructured textual data within EHRs, while GCNs captured structural relationships. Such hybridization highlighted the importance of combining models optimized for different data modalities.

Publicly available benchmark datasets like MIMIC-III and MIMIC-IV were utilized in 10 studies, while 8 studies employed real-world EHR data. The reliance on real-world data underscores its importance for validating model utility and generalizability [19][20].

Datasets played a central role in model evaluation. Publicly available benchmark datasets, such as MIMIC-III and MIMIC-IV, were used in 10 studies. These benchmarks facilitated comparisons across studies, while real-world EHR data, employed in 8 studies, offered critical insights into model performance in practical settings [19][20]. Studies using real-world datasets emphasized the necessity of testing models on authentic patient data to ensure their clinical relevance.

The evidence also indicated a growing trend toward employing GCNs for text-based tasks. For example, several studies incorporated BERT to extract semantic meaning from clinical notes, using GCNs to model relationships within the resulting representations [26][27]. Other tasks included terminology base enrichment, relation classification, and similar patient retrieval, demonstrating the versatility of GCN applications in healthcare [31][28].

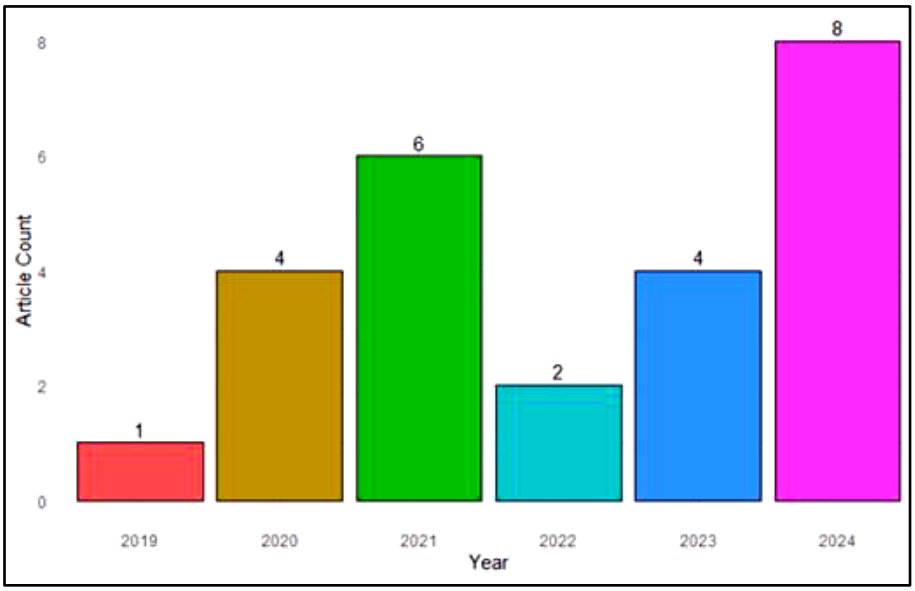


**Figure 3** Distribution of included articles by year. The cutoff date for selection was April 27, 2024

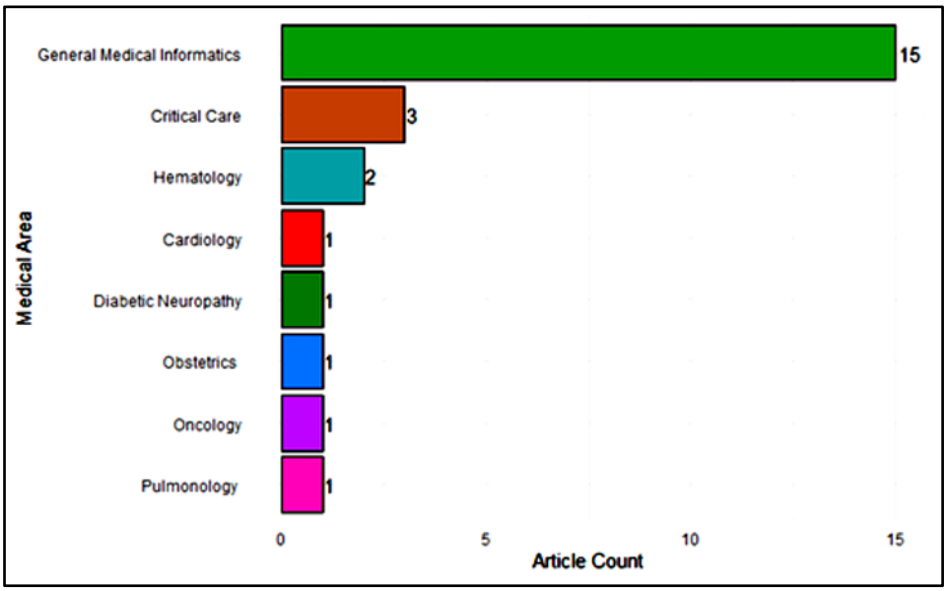


**Figure 4** Distribution of the application of GCNs to various medical fields identified by the review

## CONCLUSION

This review underscores the transformative potential of Graph Convolutional Networks (GCNs) in analyzing Electronic Health Records (EHRs). GCNs excel at modeling complex relationships and extracting valuable insights, making them well-suited for tasks in medical informatics, critical care, and beyond. Hybrid approaches, combining GCNs with other machine learning models such as BERT and LSTMs, further enhance predictive performance, particularly in cases involving heterogeneous or unstructured data.

The findings highlight that while GCNs offer significant advancements, challenges persist. Applying deep learning to tabular data remains non-trivial, as evidenced by the continued dominance of tree-based models like Random Forests and XGBoost in structured data analysis [41]. However, emerging architectures like Graph Convolution Transformers (GCTs) present promising directions for integrating tabular data into deep learning workflows. Additionally, the limited availability of real-world EHR data remains a barrier to progress, underscoring the need for further collaborative efforts to share and standardize datasets.

Future work should focus on developing innovative architectures and methods for transforming tabular data to improve deep learning performance. Moreover, expanding the scope of GCN applications to new medical domains and refining hybrid model designs could unlock further breakthroughs in healthcare analytics. This review provides a foundation for future research, highlighting current trends and opportunities to advance the use of GCNs in medicine.

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304_IEC88727

# Investigation of Time-Frequency Features for the Detection of Epileptic Seizures through Machine Learning Approaches

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***Abstract**: Epilepsy is a long-term brain disorder that impacts many people across the globe. Effective identification is primarily employed to observe these conditions, enabling the diagnosis of the disorder. However, the perceptual analysis of electroencephogram (EEG) signals is a tedious and time-consuming process, leading to the development of various automated techniques. Many different studies have analysed the different features individually including time, frequency and time frequency techniques. In this study we extracted the five time-frequency discrete wavelet transform, Haar, Daubechies, Symlet, Coiflet and Biorthogonal wavelet coefficients and extracted the six statistical features from this coefficient. The extracted features with statistically significant one is tested with the random forest classifier model over the Bonn EEG dataset, demonstrating the model's efficiency and the significant features achieves a higher accuracy rate than contemporary pioneering approaches with an accuracy of 88% in 5 class dataset using 5-cross validation.*

***Keywords**: EEG; Discrete Wavelet Transform; Machine Learning*

## INTRODUCTION

Epilepsy is a long-term neurological disorder defined by recurrent seizures, which can disrupt an individual's quality of life [1]. Effective diagnosis is critical for optimal treatment and management techniques. Electroencephalography (EEG) [2], is a fundamental tool in clinical diagnostics, as it tracks the electrical activity of the brain, yielding real-time insights into neural processes. This non-invasive approach is particularly effective for spotting abnormal brain wave patterns that indicate seizures, making it crucial for epilepsy diagnosis. The visual interpretation of EEG data is often complex and time-consuming, leading to the development of automated analysis techniques. These innovations aim to enhance diagnostic accuracy and lessen the burden on healthcare providers. A timely and accurate EEG diagnosis can facilitate targeted treatment interventions, ultimately improving patient outcomes.

Identifying epileptic versus non-epileptic EEG signals constitutes a classification task. This involves the extraction of distinctive features from the EEG data followed by their classification. Therefore, it is critical to choose the appropriate features from the raw data. Machine learning and deep learning methods have recently surged in popularity for the classification of seizures associated with epilepsy. Typically, machine learning methods [3] depend on pre-defined features that are manually extracted from different domains, such as the time [4], frequency [5] and time-frequency [6] domains of EEG signal. The present study investigates the use of time-frequency features from various methods and use for the classification.

## METHODOLOGY

In this part, we first discuss the dataset utilized, followed by an explanation of the pre-processing techniques, the proposed feature extraction method, and finally the classification method. The detailed framework of the study is given in **Figure 1**.

### Dataset and Preprocessing

In this study, publicly available EEG from Bonn university is utilized [7]. The Bonn dataset has five categories (namely A, B, C, D and E), containing a 100 single-channel EEG chunks, measuring 23.6 s with 4097 samples from each chunk. These chunks are curated from multiple-channel continuous EEG files after a visual inspection. In category A, the recordings are made with the eyes open; category B includes those with the eyes closed. Categories C and D encompass hippocampal and epileptogenic signals from healthy portions of the brain, and category E pertains

to seizure activity. The visual representation of the Bonn dataset is as shown in the **Figure 1**. Since the Bonn data is preprocessed and segmented from the clinical dataset, no further preprocessing is carried out in this study.

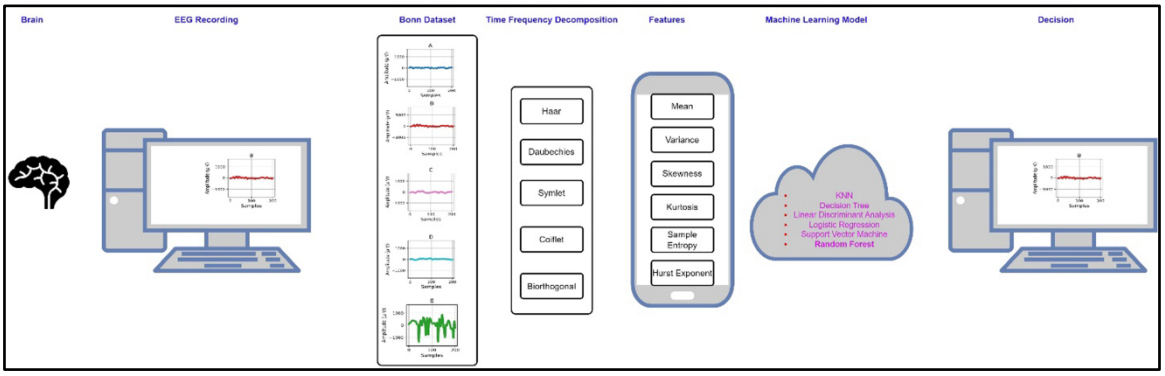



**Figure 1** Framework of proposed study

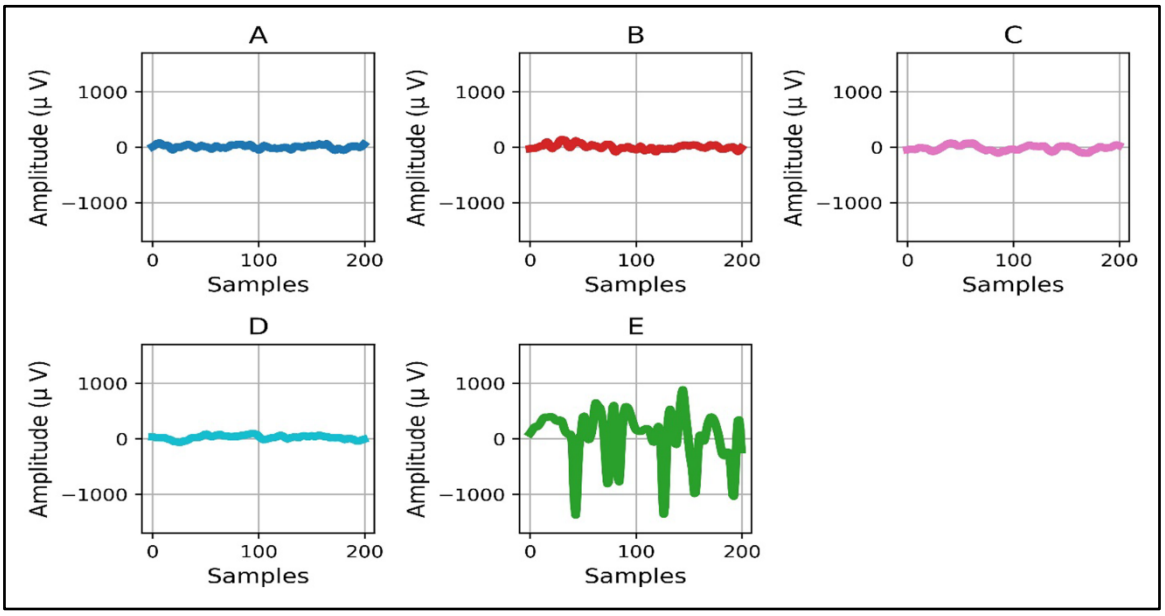
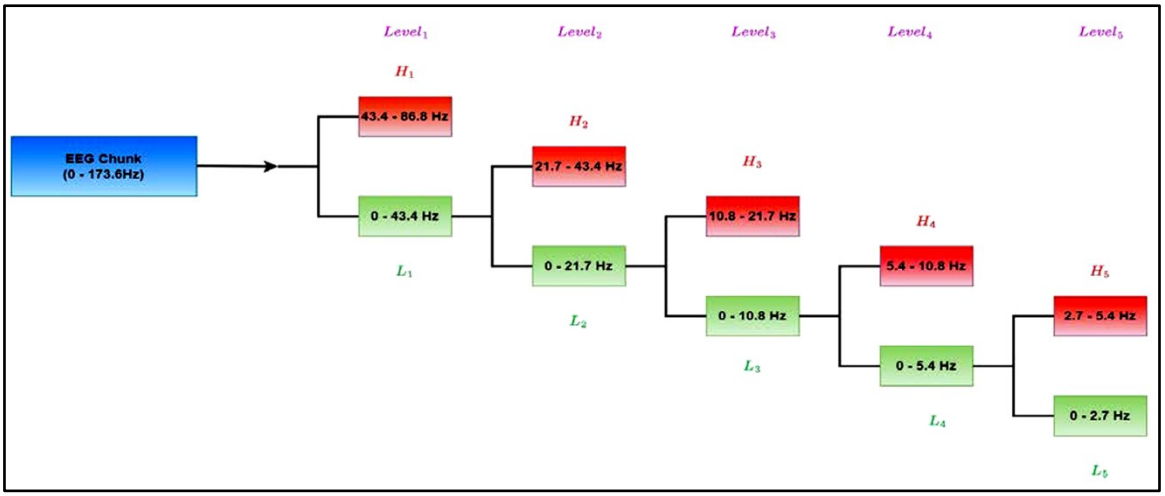



**Figure 2** The visual representation of the Bonn dataset [7]



## Methodology

In this section, after the preprocessing the most important part of the EEG studies is to extract the features for the classification. This study extracts the features from time-frequency method that is from the discrete wavelet transform (DWT) [6], In this we extracted the time-frequency components from the Haar, Daubechies, Symlet, Coiflet and Biorthogonal transforms.

From the extracted coefficients, calculated the mean, variance, skewness, kurtosis, sample entropy and hurst exponent [8]. The mathematical representation of the features is given as:

**Mean ($\mu$):**

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i$$

**Variance ($\sigma^2$):**

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2$$

**Skewness ($Sk$):**

$$Sk = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{x_i - \mu}{\sigma}\right)^3$$

**Kurtosis ($Kr$):**

$$Kr = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{x_i - \mu}{\sigma}\right)^4 - 3$$

**Sample Entropy ($SEn$):**

$$SEn(m,r) = -\ln\left(\frac{A}{B}\right), Where\ A = data\ of\ length\ m$$
$$B = data\ of\ length\ m+1, r = tolerance$$

**Hurst Exponent (H):**

$$H = \frac{\log\left(\frac{R}{\sigma}\right)}{\log(N)}, Where\ R = data\ of\ length$$
$$\sigma = standard\ deviation$$

Next, the extracted features are trained and validated on the Bonn multi-class dataset by using the six machine learning classifiers KNN, decision tree, logistic regression, support vector machine, linear discriminant analysis and random Forest models. For classification analysis the 5 cross validation is employed and the classification results are tabulated in **Table 1** and **Table 2** showcases a comparison study of the proposed method versus existing state-of-the-art solutions.

**Table 1** Different classifier performance on the extracted Bonn dataset

| Dataset | Model | Accuracy |
|---|---|---|
| **A-B-C-D-E** | KNN | 72.40 |
| | Decision Tree | 75.60 |
| | Linear Discriminant Analysis | 56.20 |
| | Logistic Regression | 64.40 |
| | Support Vector Machine | 41.60 |
| | **Random Forest** | **88.00** |

**Table 2** State of art models on Bonn dataset

| Dataset | Model | Accuracy |
|---|---|---|
| **A-B-C-D-E** | DWT+RF [9] | 82.25 |
| | **DWT fusion features + Random Forest** | **88.00** |

## CONCLUSION

This research demonstrates the effectiveness of feature fusion from different mother wavelets for the detection of epilepsy. By extracting features from the decomposition coefficients at various levels of the wavelet transform, we were able to capture diverse and complementary characteristics of EEG signals. The fusion of these features significantly improved the performance of machine learning classifiers. Our evaluation on multiple classifiers shows promising results, indicating that wavelet-based feature extraction is a robust method for epileptic seizure detection. This approach paves the way for more accurate and reliable automated diagnosis systems.

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337_IEC5959

# Mind Controlled Bionic Arm with Sense of Touch

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***Abstract:*** *This paper presents a cost-effective and innovative mind-controlled bionic arm that integrates a sense of touch to restore complex hand functions for individuals with amputations or paralysis. The system employs a non-invasive EEG-based control mechanism to process brain signals into PWM commands, enabling precise servo motor operation. Additionally, a tactile feedback system allows users to experience a natural sense of touch, enhancing safety and dexterity. The AI model for activity classification, trained on EEG data using transfer learning with YamNet, achieved an accuracy of 80.64%. Simulations using MATLAB validated the interaction between AI models and a 3-degree-of-freedom robotic arm. Future directions include hardware integration, real-time EEG acquisition, and advanced tactile feedback systems, aiming to provide an intuitive, natural, and efficient solution in prosthetic robotics.*

***Keywords:*** *Bionic Arm; Robotics; Biotechnology; Mind Control; Prosthetics*

## INTRODUCTION

This paper presents a novel design for a cost-effective bionic hand intended to restore hand function in individuals with hand amputations or partial paralysis. The proposed design leverages a gripper as the end effector, like commercially available options [1]. However, it distinguishes itself by incorporating a touch sensor within the gripper, aiming to provide a sense of touch comparable to a natural hand. This feature can significantly improve user safety and dexterity when grasping objects [2]. The hand is an intricate and vital component of the human body, responsible for a vast array of tasks essential for daily living [3]. Notably, the central nervous system dedicates a significant portion (approximately 30%) of its resources to controlling the hand, highlighting its critical role in sensory and motor function [3]. Traditionally, regaining hand function after amputation has been primarily limited to hand transplantation, a complex and resource-intensive surgical procedure first introduced in 1963 [4]. Bionic hands offer a more practical and accessible alternative for individuals with hand impairments.

The proposed bionic hand design prioritizes four key functionalities:

— Integrated Sensory Feedback: A distinctive feature of this design is the incorporation of a touch sensor within the gripper. This sensor aims to provide the user with a sense of touch, mimicking the functionality of a natural hand. This capability is crucial for safe object manipulation and preventing injuries [2].
— Mind-Control Potential: EMG sensors detect electrical signals generated by muscles, which can be translated into control signals for the bionic hand [5]. And EEG sensors detect the brain-wave signals generated by the person's brain.
— Signal Acquisition and Processing: The design proposes utilizing an EMG sensor to capture data on muscle activity. The Laplace transform, a mathematical tool employed to analyse signals in the frequency domain, will then be applied to process the acquired EMG signal [6]. Similarly, there would be a hand band type of thing which would be worn in by the patient to record the brain signals (EEG Signals), then it would be transferred to the machine to be decoded by the AI models.
— Control Mechanism: The processed EEG and EMG signal will be used to generate a pulse width modulation (PWM) signal. This PWM signal will subsequently control a servo motor, actuating the robotic arm and enabling movement of the bionic hand [7].

The design strives to replicate the anatomical structure of a natural hand, encompassing the wrist, palm, and fingers. The human hand possesses 27 bones and boasts a wide range of motion, including significant wrist rotation [8]. While the specific details of the bionic hand's structure are not explicitly provided, it is likely to incorporate mechanisms that replicate these features to the greatest extent possible. The paper acknowledges the critical role of nerves in hand function and provides a brief overview of the median, ulnar, radial, and digital nerves. These nerves are responsible for transmitting sensory information and controlling muscle movement within the hand. However, the proposed bionic hand design does not delve into the specifics of how it directly interfaces with the user's nervous system.

## METHODOLOGY

### Data Collection and Preprocessing

1. Initial Data Acquisition:

o Standard Datasets: Utilize existing EEG datasets from public repositories to establish a baseline.
o Sensor Selection: Choose EEG sensors that are most sensitive to hand and arm movements.

2. Data Sampling and Feature Extraction:

o MATLAB: Employ MATLAB's signal processing toolbox to sample EEG data and extract relevant features.
o Feature Engineering: Consider creating custom features based on domain knowledge and neurophysiological insights.

### Model Development and Optimization

1. Initial Model:

o Machine Learning Algorithm: Select a suitable algorithm (e.g., SVM, etc) based on the extracted features.
o Model Training: Train the initial model using the sampled data and extracted features.
o Evaluation: Assess the model's performance using appropriate metrics.

2. Hyperparameter Tuning:

o Optimization Techniques: Experiment with different to improve model performance.
o Grid Search or Randomized Search: Employ optimization techniques to efficiently explore the hyperparameter space.

### Real-Time Implementation

1. EEG Signal Acquisition:

o Hardware Integration: Connect an EEG sensor to a laptop or a dedicated microcontroller.
o Data Streaming: Establish a real-time data stream from the sensor to the MATLAB environment.

2. Signal Processing and Classification:

o Feature Extraction: Apply the same feature extraction techniques used during training.
o Model Inference: Use the trained model to classify the incoming EEG data and predict the intended hand or arm movement.

3. Control Signal Generation:

o Command Translation: Convert the predicted movement into control signals that can be understood by the bionic arm.

**Funding and Open-Source Development**

1. Grant Application: Prepare a comprehensive grant proposal highlighting the project's potential impact, technical approach, and resource requirements.

2. Open-Source Collaboration:

o Code Repository: Share the project's code, data, and documentation on a public platform (e.g., GitHub).
o Community Engagement: Encourage community contributions and feedback to foster collaboration and innovation.

**Table 1** Results of Classification Learning

| Model Type | Status | Accuracy % (Validation) | Total Cost (Validation) | Accuracy % (Test) | Total Cost (Test) | Preset |
|---|---|---|---|---|---|---|
| Tree | Tested | 100 | 0 | 100 | 0 | Fine Tree |
| Tree | Tested | 100 | 0 | 100 | 0 | Medium Tree |
| Ensemble | Tested | 100 | 0 | 100 | 0 | Bagged Trees |
| Naive Bayes | Tested | 99.02263 | 38 | 99.76798 | 1 | Gaussian Naive Bayes |
| Naive Bayes | Tested | 97.17078 | 110 | 97.21578 | 12 | Kernel Naive Bayes |
| SVM | Tested | 94.98457 | 195 | 96.98376 | 13 | Linear SVM |
| SVM | Tested | 94.98457 | 195 | 96.98376 | 13 | Quadratic SVM |
| SVM | Tested | 94.98457 | 195 | 96.98376 | 13 | Cubic SVM |
| SVM | Tested | 94.95885 | 196 | 96.75174 | 14 | Medium Gaussian SVM |
| SVM | Tested | 94.95885 | 196 | 96.98376 | 13 | Coarse Gaussian SVM |
| Neural Network | Tested | 94.95885 | 196 | 96.98376 | 13 | Medium Neural Network |
| Neural Network | Tested | 94.95885 | 196 | 96.98376 | 13 | Wide Neural Network |
| SVM | Tested | 94.90741 | 198 | 96.75174 | 14 | Fine Gaussian SVM |
| Kernel | Tested | 94.85597 | 200 | 96.75174 | 14 | SVM Kernel |
| Kernel | Tested | 94.67593 | 207 | 96.75174 | 14 | Logistic Regression Kernel |
| Neural Network | Tested | 94.47016 | 215 | 96.98376 | 13 | Trilayered Neural Network |
| Neural Network | Tested | 94.1358 | 228 | 96.98376 | 13 | Narrow Neural Network |
| Neural Network | Tested | 94.11008 | 229 | 96.98376 | 13 | Bilayered Neural Network |
| Efficient Logistic Regression | Tested | 92.12963 | 306 | 94.19954 | 25 | Efficient Logistic Regression |
| Efficient Linear SVM | Tested | 84.28498 | 611 | 93.03944 | 30 | Efficient Linear SVM |
| Tree | Tested | 68.93004 | 1208 | 69.37355 | 132 | Coarse Tree |
| Ensemble | Tested | 12.86008 | 3388 | 13.6891 | 372 | Boosted Trees |
| Ensemble | Tested | 12.86008 | 3388 | 13.6891 | 372 | RUSBoosted Trees |

**Future Directions**

1. Data Augmentation: Explore techniques to increase the size and diversity of the dataset, improving model generalization.

2. Adaptive Learning: Develop algorithms that can continuously adapt to changes in the user's brain signals over time.

3. Multimodal Integration: Consider incorporating additional sensory information to enhance control accuracy.

**Data Description [9][10]:**

This is the description of standard dataset that we took for the training of our model. Each recording was recorded in a CSV file format, the values of each electrode are in microvolts (uV). In total, each subject generates 124 CSV files in each experiment (run). Some subjects perform two experiments, one executing the motor tasks and the other imagining doing them. The tasks are described below:

- Recording a Baseline with Eyes Open (BEO) without any task command: only once at the beginning of each run.
- Closing Left Hand (CLH): five times per run.
- Closing Right Hand (CRH): five times per run.
- Dorsal flexion of Left Foot (DLF): five times per run.
- Plantar flexion of Left Foot (PLF): five times per run.
- Dorsal flexion of Right Foot (DRF): five times per run.
- Plantar flexion of Right Foot (PRF): five times per run.
- Resting in between tasks (Rest): after each task.

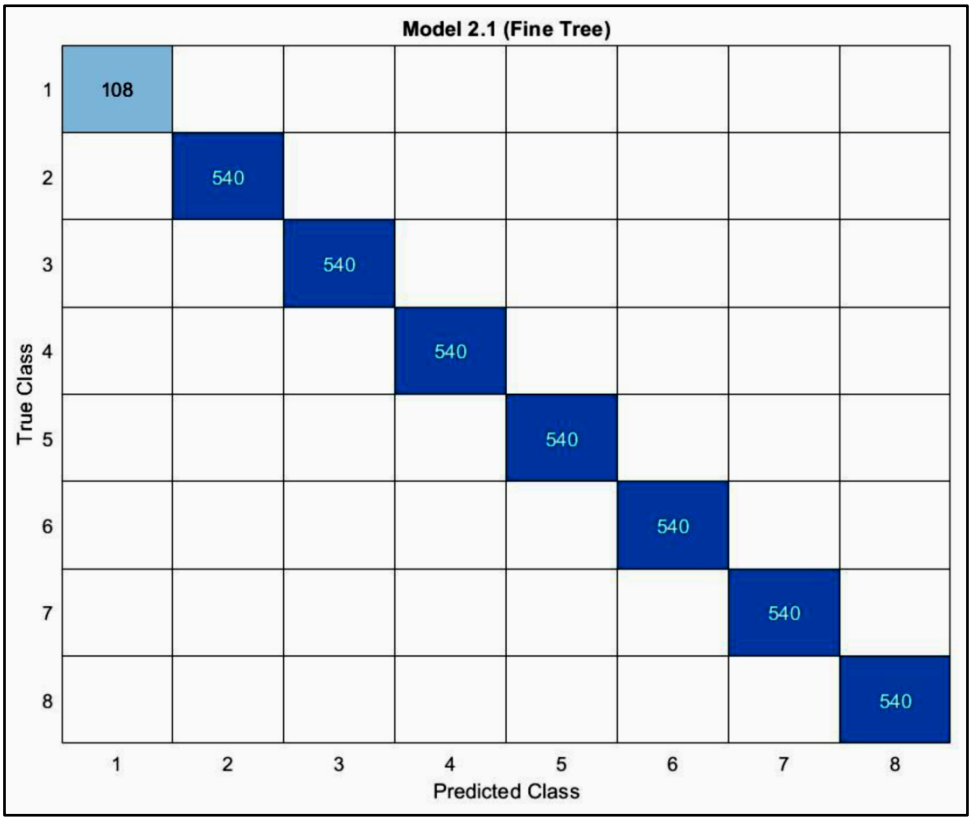


**Figure 1** Confusion Matrix for the Fine Tree preset model

**RESULTS**

Classification Learning was done to train the AI models for this project using the features of the brain signals like rms value, snr value, etc. The results were namely mapped to 8 different numeric classes from 1- 8 mapped by BEO, CLH, CRH, DLF, PLF, DRF, PRF, Rest classes respectively.

**Session: ClassificationLearnerSession**

- Observations: 3888
- Predictors: 28
- Predictor Names: Alpha, Theta, Delta, Beta, BEO, CLH, CRH, DLF, PLF, DRF, PRF, Rest, channel1Mean, channel1StandardDeviation, channel1RMS, channel1ShapeFactor, channel1CrestFactor, channel1PeakValue, channel1ImpulseFactor, channel1ClearanceFactor, channel1SNR, channel1SINAD, channel1THD, channel1MeanFrequency, channel1MedianFrequency, channel1BandPower, channel1OccupiedBandwidth, channel1PowerBandwidth
- Response Classes: 8
- Response Class Names: 1, 2, 3, 4, 5, 6, 7, 8
- Validation: 50-fold cross-validation
- Observations: 431

## CONCLUSION

The development of a mind-controlled bionic arm represents a significant advancement in the field of prosthetics. By harnessing the power of brain-computer interfaces (BCIs), individuals with upper limb amputations can potentially regain a degree of independence and functionality. While significant progress has been made, there are still challenges to overcome, such as improving the accuracy and reliability of BCI systems, addressing ethical considerations, and ensuring long-term usability. Continued research and development are essential to unlock the full potential of mind-controlled bionic arms and improve the quality of life for individuals with disabilities.

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338_IEC12385

# Silent Speech Recognition using Cascaded Classifier with sEMG Measurements from Facial Muscles

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***Abstract**: Silent speech recognition (SSR) leverages non-audible cues to interpret speech, offering significant potential for aiding individuals with speech impairments and enhancing silent communication interfaces. In this study, an attempt is made to explore the use of surface electromyography (sEMG) for silent speech recognition (SSR), specifically targeting facial muscles such as the mentalis, buccinator, hyoid muscles, and the Infraorbital Region (IOR), which includes the zygomatic major. Six healthy participants were recruited to silently utter arithmetic-related words, with the resulting sEMG signals being recorded, pre-processed, and analysed for features including Simple Square Integral (SSI), Root Mean Square (RMS), Variance (VAR), and Shannon entropy. The classification of these features was performed using Random Forest (RF), Support Vector Machine (SVM), and cascaded classifiers where RF preceded SVM, and vice versa. The results demonstrated that the RF classifier achieved an accuracy of 77%, the SVM attained 74%, the RF+SVM cascade reached 75.32%, and the SVM+RF cascade achieved the highest accuracy at 79.22%. These findings highlight the potential of SSR using sEMG for reliable silent communication, especially in scenarios where traditional acoustic methods are infeasible. This research paves the way for developing more sophisticated SSR systems, with practical applications in assistive technology and human-computer interaction, offering a silent yet effective communication channel.*

***Keywords**: Speech Recognition (SSR); Surface Electromyography (sEMG); IOR Region Muscles; Random Forest (RF); Support Vector Machine (SVM); Cascaded Classifiers*

## INTRODUCTION

Speech impairments are a major communication disorder in India, with 7.45% of the disabled population affected, according to the National Sample Survey Organization (NSSO). Rural studies show varying prevalence rates, with some areas reporting up to 41.54% of communication disorders related to speech and language issues. Human speech is a rich and intuitive medium for conveying emotions and intentions. Automatic Speech Recognition (ASR) technology processes speech signals, converting them into text or other formats, and plays a critical role in advancing Brain-Computer Interface (BCI) technologies [1]. Conventional ASR systems convert vocalized speech into text using microphones, but this approach is unsuitable for individuals with severe speech disorders or laryngectomy. To support them, alternative methods like speech synthesizers and sEMG signals, which encode speech-related information, offer a promising non-vocal alternative for ASR systems [2].

In 1985, speech recognition using surface Electromyography (sEMG) was first proposed, where sEMG signals were collected from muscles near the lips to classify five Japanese vowels [3]. During the same period, researchers used various features of Myoelectric Signals (MES) from the vocal tract to identify ten English words, achieving a 60% recognition accuracy [4]. Despite the lack of audible acoustic signals, the technology showed impressive performance in communication, suggesting that sEMG-based systems are feasible for silent interaction [5]. A multi-expert system (MES) combining five facial sEMG channels with acoustic recognition achieved 85% to 87% accuracy for classifying the English words "zero" through "nine" in two subjects. [6]. Utilizing eleven sEMG electrodes placed on the face and neck, a study captured data in a mouthed mode, achieving an 86.70% recognition accuracy for a set of 65 words [7]. The Silent-Speech-Interface, developed for individuals with speech disorders, enables silent communication of English letters, achieving 90.1% accuracy using an SVM algorithm [8].

An experiment using sEMG signals from the Orbicularis oris, Triangularis, and Platysma muscles of 20 subjects for voiceless Arabic vowel recognition achieved 77% accuracy with a random forest classifier, as evaluated by 10-fold cross-validation [9]. A proof-of-concept study achieved sEMG-based alaryngeal speech recognition in eight

laryngectomy subjects using data from four neck and face muscles with a 2500-word vocabulary [10]. A silent speech recognition system for Mandarin using sEMG signals, hybrid features, and a GRU model achieved 88.01% accuracy in multi-subject classification and 97.19% in single-subject classification [11].

In this study, an attempt is made to explore the SSR by analyzing facial muscles, including the mentalis, buccinator, hyoid muscles, and the Infraorbital Region (IOR) with the zygomatic major. The research evaluates feature classification using Simple Square Integral (SSI), Root Mean Square (RMS), Variance (VAR), and Shannon Entropy (SE), employing Random Forest (RF), Support Vector Machine (SVM), and cascaded classifiers (RF+SVM and SVM+RF). The goal is to assess the effectiveness and accuracy of these methods in advancing silent communication interfaces for individuals with speech impairments.

## METHODS

### A. Experimental Protocol and Signal Acquisition

The time-limited silent speech recording procedure was designed for a multi-session experiment using beep sounds to regulate timing. sEMG signals were collected from four facial muscles near the mouth—Buccinator, Mentalis, Hyoid and Infraorbital Region (IOR) which includes the zygomatic major —to capture subvocalization. A beep sound was generated every six seconds by a Python script running on a computer. The experiment involved four specific words related to arithmetic operations: ‘add,’ ‘multiply,’ ‘subtract,’ and ‘divide,’ which participants were required to silently utter in response to the beep. Each word was uttered twenty times per volunteer, with a beep sound marking the start of each trial. Six healthy volunteers (aged 18-21, 6 males) participated in the study. Prior to the experiment, all procedures were thoroughly explained, and consent was obtained from each participant. The local institutional ethics committee approved the study. Volunteers were trained to utter each word silently in sync with the beep.

The recording sites were cleaned with surgical spirit before electrode placement. Four Ag-AgCl surface electrode pairs were positioned bilaterally on the muscles—Buccinator, Mentalis, Hyoid and Infraorbital Region (IOR) which includes the zygomatic major —with 2 cm spacing in a bipolar configuration [12]. Each electrode measured 3 cm × 1.5 cm and was pre-loaded with conduction gel in a central circle (0.5 cm radius). A reference electrode was placed at the posterior auricular area to ensure measurement consistency. The electrode placements are illustrated in **Figure 1**. To optimize signal isolation, volunteers were seated on a wooden chair. sEMG signals were recorded using a BIOPAC BN-TX Smart Wireless BioNomadix Transmitters system, with a fixed sampling rate of 2000 Hz. Volunteers uttered the words silently upon hearing the beep, with each session consisting of twenty trials. A two-minute break was allowed between sessions for relaxation. sEMG data from all four selected muscles, recorded across four sessions, were pre-processed using a fourth-order Butterworth bandpass filter of band 10-500 Hz and a 50 Hz notch filter to remove noise and power line interference [13]. All signals are processed in MATLAB, starting with the removal of extraneous portions. The initial segments are trimmed, and the signals are then segmented into fixed lengths of 12,000 samples, corresponding to the 6-second interval between beep sounds (6 × 2,000 = 12,000). The segmented signals are further divided within the indices ranging from 1,600 to 4,600, based on the muscle activity.

**Figure 1** Electrode placement on the selected muscles

**B. Feature Extraction**

The EMG signals for each word were transformed into feature vectors that optimize the classifier's ability to correctly associate the raw data with its corresponding class. In this paper, temporal features such as Simple Square Integral (SSI), Root Mean Square (RMS), and Variance (VAR) were extracted from the sEMG signals [14]. Shannon entropy was also calculated to quantify the complexity and unpredictability of the EMG signal by measuring the uncertainty in its amplitude distribution [15]. RMS calculates the square root of the mean of squared EMG values, reflecting the signal's amplitude and overall level of muscle activity. VAR measures the dispersion of EMG signal values around the mean, indicating the variability in muscle activity. SSI represents the integral of the squared EMG signal over a specific time window, capturing the total energy or muscle activation during that period. These features are defined as follows:

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2} \quad (1)$$

$$VAR = \frac{1}{N-1}\sum_{i=1}^{N} x_i^2 \quad (2)$$

$$SSI = \sum_{i=1}^{N} x_i^2 \quad (3)$$

$$H(x) = \sum_{i=1}^{N} P(x_i)\log_2 P(x_i) \quad (4)$$

where $x_i$ represents denotes the EMG signal value at the $i^{th}$ segment, $P(x_i)$ represents the probability of the signal amplitude falling within the $i^{th}$ bin and N refers to the total length of the EMG signal.

**CLASSIFICATION MODELS**

In supervised learning, the model is trained using a labelled dataset, where each example is linked to its correct output label. The model's goal is to learn how to map inputs to the corresponding output labels, allowing it to accurately predict labels for new, unseen data.

**A. Random Forest (RF)**

Random Forest (RF) is an ensemble learning technique that excels at handling complex, high-dimensional data, making it essential for silent speech recognition using EMG signals [16]. In RF, for each decision tree, a feature's importance is assessed by summing the gain, weighted by the sample count at each node.

$$fi_i = \sum_{j:nodes\ j\ splits\ on\ feature\ i} s_j C_j \quad (5)$$

To compute the final feature importance in a Random Forest, the feature importance from each individual tree is first normalized with respect to the tree.

$$normfi_i = \frac{fi_i}{\sum_{j\in All\ Features, k\in all\ trees} normfi_i} \quad (6)$$

Subsequently, the feature importance values from all trees are aggregated and normalized [17].

$$RFfi_i = \frac{\sum_j normfi_{ij}}{\sum_{j\in All\ Features, k\in All\ trees} normfi_{ij}} \quad (7)$$

where $fi_i$ is $i^{th}$ feature importance, $s_j$ is the count of samples arriving at node j, $C_j$ is the impurity score of node j , $normfi_i$ is normalized $i^{th}$ feature importance, $normfi_{ij}$ is normalized $i^{th}$ feature importance for $j^{th}$ tree and $RFfi_{ij}$ is $i^{th}$ feature importance computed for all trees in RF.

**B. Support Vector Machine (SVM)**

SVM is a powerful classifier, particularly effective for handling the non-linear characteristics of EMG signals in SSR [18]. The SVM, which utilizes its RBF kernel to create precise decision boundaries. The equation that the SVM algorithm solves after applying the Lagrange multiplier is given by [19]:

$$\begin{cases} \min \frac{1}{2}\|W\|^2 + C\sum_{i=1}^{N}\xi_i \\ s.t.\, y_k(W \cdot X_k + b) \geq 1 - \xi_i, k = 1, \ldots, N \end{cases} \quad (8)$$

The radial basis kernel function is formulated as follows:

$$k(X_i, X_j) = exp\left\{\frac{\|X_i - X_j\|^2}{2\delta^2}\right\} \quad (9)$$

where $(X_k,y_k)$ denotes the training data for the $k^{th}$ sample, C denotes penalty factor, δ denotes kernel function parameter and $\xi_i$ is a slack variable representing the extent of the classification error.

**C. Cascaded Classifier**

In a cascaded classifier for sEMG signal processing, features are processed either by RF first and then SVM, or vice versa. The RF-to-SVM approach uses RF to handle complex data and filter features, which SVM then refines with its RBF kernel for precise classification. The SVM-to-RF approach applies SVM for initial non-linear separation, with RF further enhancing accuracy and robustness. This integration combines RF's robustness with SVM's precision, optimizing silent speech recognition.

**RESULT AND DISCUSSION**

The raw sEMG signals captured from four key facial muscles—Buccinator, Mentalis, Hyoid and Infraorbital Region (IOR) which includes the zygomatic major during the SSR task, recorded over approximately 165 seconds. The x-axis denotes time in seconds, while the y-axis reflects amplitude in millivolts (mV). Around, 480 epochs are recorded and one epoch of 1.5 of all four muscles during the utterances of each arithmetic words is presented in **Figure 2**. Overall, the amplitude ranges from -0.7 mV to 0.7 approximately. The periodic peaks in the EMG signals correspond to muscle activations associated with the silent articulation of four arithmetic words namely, 'add', 'subtract', 'multiply' and 'divide'. The distinct amplitude patterns observed across the facial muscles emphasize their different roles in silent speech production.

The classification model performance analysis provides significant insights into the efficacy of various approaches for silent speech recognition using sEMG signals. The signals were sampled at 2000 Hz, with features such as SSI, RMS, VAR, and Shannon entropy extracted. Eighty percent of the features were allocated for training, while the remaining twenty percent were reserved for testing. In silent speech recognition, the Matthews Correlation Coefficient (MCC) offers a balanced measure of classifier performance, essential for accurately differentiating subtle muscle activities. The F1-Score, combining precision and recall, ensures both accuracy and thorough detection of relevant muscle signals [20]. These are defined as follow:

$$MCC = \frac{TP\ X\ TN - FP\ X\ FN}{\sqrt{(TP + FP)(TP + FN)(TN + FP)(TN + FN)}} \quad (10)$$

$$F1\ Score = \frac{2 \cdot TP}{2 \cdot TP + FP + FN} \quad (11)$$

where TP is Ture Positive, TN is True Negative, FP is False Positive and FN is False Negative values.

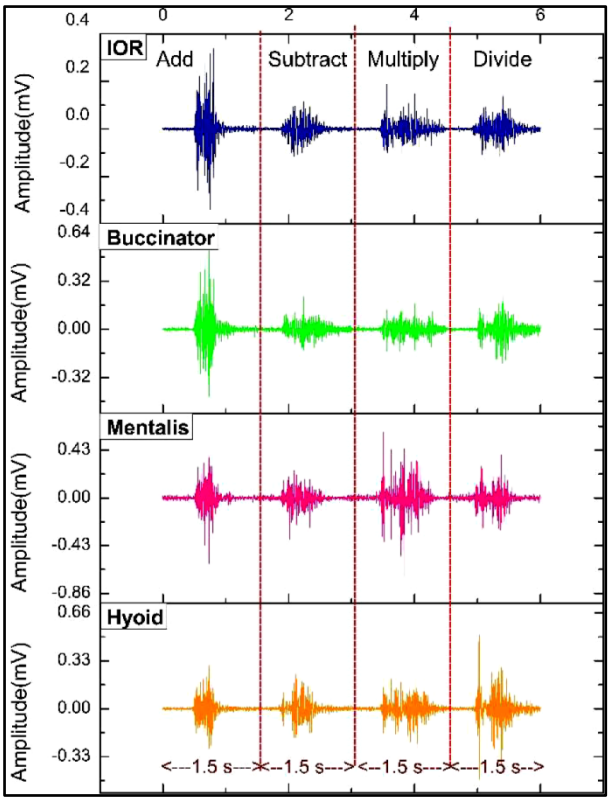


**Figure 2** Representative sEMG signals during utterance of ADD, SUBTRACT, MULTIPLY and DIVIDE words for the Volunteer 1

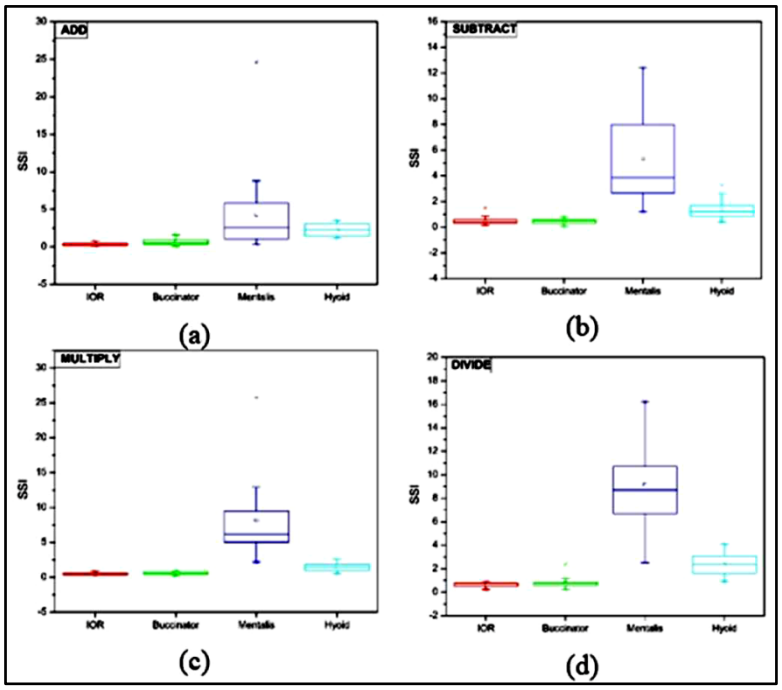


**Figure 3** Box Plots to the SSI feature during utterance of (a) ADD, (b) SUBTRACT, (c) MULTIPLY and (d) DIVIDE words for the volunteer 1

Among the models, the SVM+RF cascaded classifier stands out with an accuracy of 79.22%, precision of 0.80, sensitivity of 0.79, MCC of 0.72, and an F1-Score of 0.79, indicating superior performance in capturing and classifying the subtle muscle activations involved in silent speech. These metrics underscore its reliability in differentiating between silent utterances, as presented in **Table 1**.

**Table 1** Classification parameters of the various models

| Model | MCC | F1-Score | Accuracy (%) |
|---|---|---|---|
| RF | 0.69 | 0.77 | 77.00 |
| SVM | 0.66 | 0.74 | 74.00 |
| RF+SVM | 0.67 | 0.75 | 75.32 |
| SVM+RF | 0.72 | 0.79 | 79.22 |

In comparison, the RF+SVM cascaded classifier, with an accuracy of 75.32%, precision of 0.76, sensitivity of 0.75, MCC of 0.67, and an F1-Score of 0.75, demonstrates that the sequence of classifiers significantly influences the outcome. The standalone RF and SVM models, with accuracies of 77% and 74% respectively, alongside slightly lower MCC and F1-Scores, show adequate but less robust performance. **Figure 3** visualizing the distribution of SSI features for all muscles for one volunteer. The mentalis muscle, reflected by its notable variance and SSI, plays a crucial role in enhancing differentiation, especially in the RF model, where it aids in distinguishing between similar utterances. The hyoid muscle, with moderate RMS and lower SSI values, contributes to refining classification, particularly in cascaded models where combining its data with other muscles leads to improved performance. Shannon entropy reveals that the Mentalis muscle exhibits higher complexity in its activation patterns, indicating a more intricate role in silent speech. In contrast, the Hyoid muscle's lower entropy suggests more stable and consistent activity. This analysis underscores the importance of selecting specific muscle signals and considering entropy measures to enhance the accuracy and reliability of silent speech recognition systems.

## CONCLUSIONS

This research highlights the potential of using cascaded Random Forest and SVM classifiers for silent speech recognition with sEMG signals from facial muscles. The best performance, with 79.22% accuracy, was obtained using the SVM followed by RF, suggesting the value of cascading models for improved classification. Future work will focus on expanding the dataset to include more words and participants, exploring deep learning approaches, and enhancing real-time processing capabilities to improve the system's applicability in practical, assistive communication devices. Additionally, further refinement of signal processing and feature extraction methods will be explored to enhance classification accuracy and robustness.

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340_IEC12280

# Structural Connectivity Analysis in ASD: A DTI-based Machine Learning Classification

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***Abstract:*** *Autism spectrum disorder (ASD) refers to a range of neurodevelopmental conditions characterized by challenges in social interaction, communication, and the presence of repetitive, stereotyped behaviors. In this study, we explored the potential of diffusion tensor imaging (DTI) analysis for distinguishing between ASD and typically developing (TD) brains by examining structural connectivity (SC) and applying machine learning algorithms. Initially, the DTI images available at Barrow Neurological Institute (BNI) and Institute Pasteur and Robert Debré Hospital sites of the Autism Brain Imaging Data Exchange (ABIDE-II) database were preprocessed using a standard pipeline. Further, the white matter diffusion metrics such as fractional anisotropy, radial diffusivity, axial diffusivity, and mean diffusivity were extracted for different regions using the Johns Hopkins University atlas. SC features were calculated using Euclidean distance and, significant features were extracted using recursive feature elimination with cross-validation to construct a diagnostic classification model with a logistic regression and support vector machine (SVM) classifier. The SVM classifier achieved the highest performance, reaching a peak accuracy of 84.69% for the BNI dataset using 40 features. The top three SC features are Posterior limb of internal capsule R to Fornix (cres) / Stria terminalis R, Corticospinal tract L to Inferior fronto-occipital fasciculus R and Pontine crossing tract (a part of middle cerebellar peduncle) to Body of corpus callosum contributing to diagnose ASD and TD.*

***Keywords****: Autism Spectrum Disorder; Diffusion Tensor Imaging; Structural Connectivity; Feature Ranking; Machine Learning*

## INTRODUCTION

Autism Spectrum Disorder (ASD) is a complex neurodevelopmental condition, characterized by difficulties in social communication and interaction, along with restricted interests and repetitive behaviors. Often, it co-occurs with other developmental disorders [1]. The severity of ASD symptoms can vary widely, ranging from mild to severe. In 2020, it was estimated that 1 in 36 children aged 8 years (about 4% of boys and 1% of girls) were diagnosed with ASD, and the prevalence continues to rise. Traditional methods for diagnosing ASD rely on observational screening tools such as the DSM-5, M-CHAT, ICD-10, ADOS, and ADI-R [2]. However, these tools are often time-consuming, challenging, and have limitations in accuracy.

Diffusion Tensor Imaging (DTI) is a promising non-invasive magnetic resonance imaging (MRI) technique for identifying microstructural changes associated with neuropathological conditions and monitoring treatment response [3]. DTI measures the diffusion of water molecules, allowing for the characterization of properties such as anisotropy, diffusion magnitude, and directionality. Key metrics derived from DTI include mean diffusivity (MD), fractional anisotropy (FA), radial diffusivity (RD), and axial diffusivity (AD) [4]. These anisotropy and diffusivity measures of the brain's structural network capture individual differences and provide valuable discriminative power for diagnosing various brain disorders. Studies have shown that modeling structural connectivity (SC) by tracking neural fibers between different brain regions offers the potential for diagnosing ASD.

In this study, we calculated the SC from DTI derived parameters using Euclidean distance correlation metric. Machine learning (ML) classification models, combined with feature elimination and hyperparameter tuning, were employed to accurately identify and characterize brain microstructural connectivity in individuals with ASD and typically developing (TD) [5],[6].

## METHODOLOGY

**Figure 1** outlines the process pipeline adopted in this study, including DTI data having bvals, bvecs files from Barrow Neurological Institute (BNI) and Institute Pasteur and Robert Debré Hospital (IP) in Autism Brain Imaging

Data Exchange (ABIDE-II) database [7], preprocessing steps, followed by DTI reconstruction and computation of DTI derived parameters. Features are derived using a white matter (WM) atlas, and these features are subjected to correlation analysis. Significant features identified through this analysis are fed into the classifier to differentiate between individuals with ASD and TD.

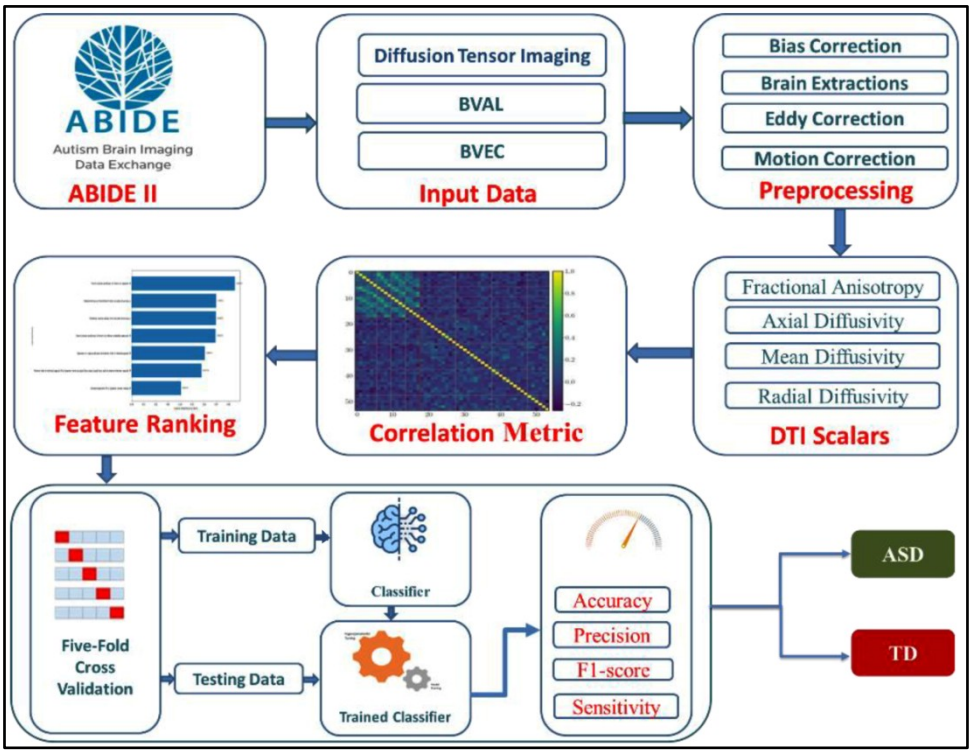


**Figure 1** Process pipeline of the study

The preprocessing steps for the DTI images in NIfTI format began with correcting motion artifacts and eddy current distortions using FSL's eddy tool [8]. Affine transformations were then applied to align each volume and rotate the gradient vectors. Non-brain structures were removed by extracting the first b0 volume from each subject and performing skull stripping, followed by the creation and application of a mask to the remaining volumes. Tensor fitting was subsequently performed using the DTIFIT tool from the FDT toolbox, where each voxel was fitted with a diffusion tensor defined by its three principal eigenvectors ($\lambda1$, $\lambda2$, $\lambda3$). The resulting tensor maps were then used to calculate scalar maps for fractional anisotropy (FA), mean diffusivity (MD), radial diffusivity (RD), and axial diffusivity (AD). Subsequently, the scalar maps underwent registration to the FMRIB58_FA_1mm.nii.gz template, involving affine transformation followed by non-linear registration using the advanced normalization tools (ANTs) software. Lastly, brain regions were segmented using the WM atlas ICBM-DTI-81 from Johns Hopkins University, which is based on ICBM coordinates and delineates the brain into 50 distinct WM regions [9]. For each WM region, we computed FA, AD, MD, and RD values resulting in a vector consisting of these values. Further, we calculated Euclidean distance between these vectors from different regions and generated a matrix of size 50×50 for each subject. We extracted either the upper or lower triangular matrix, resulting in 1225 (50×49/2) SC features [5]. Our study employed the recursive feature elimination with cross-validation (RFE-CV) technique to pinpoint the significant SC features. We built classification models using LR and SVM and tested on selected top significant 5, 10, 20, 40, 50, 75, 100, 150, and 200 features to classify the ASD and TD. The performance of classification models was evaluated based on accuracy, sensitivity, specificity, precision, F1-score, and area under the curve (AUC) [10].

## RESULTS

**Figure 2(a)** shows the performance of the LR classifier for the BNI and IP sites from ABIDE II. For BNI, accuracy starts at 70.45% with 5 features, peaks at 81.06% with 50 features, and declines to 53.33% at 200 features. For IP, it

begins at 72.18% with 5 features, peaks at 83.45% with 40 features, and drops to 70.18% with 200 features. Both sites perform best with 40-50 features, but performance declines with more features. In **Figure 2(b)**, the SVM classifier shows similar trends. BNI peaks at 84.69% with 40 features, while IP starts at 73.82% and gradually declines to 62.91% with 200 features, without a significant peak. The SVM classifier achieved the highest accuracy of 84.69%, with a sensitivity of 84.69%, specificity of 89.33%, precision of 85.87%, F1-score of 84.43%, and AUC of 86%.

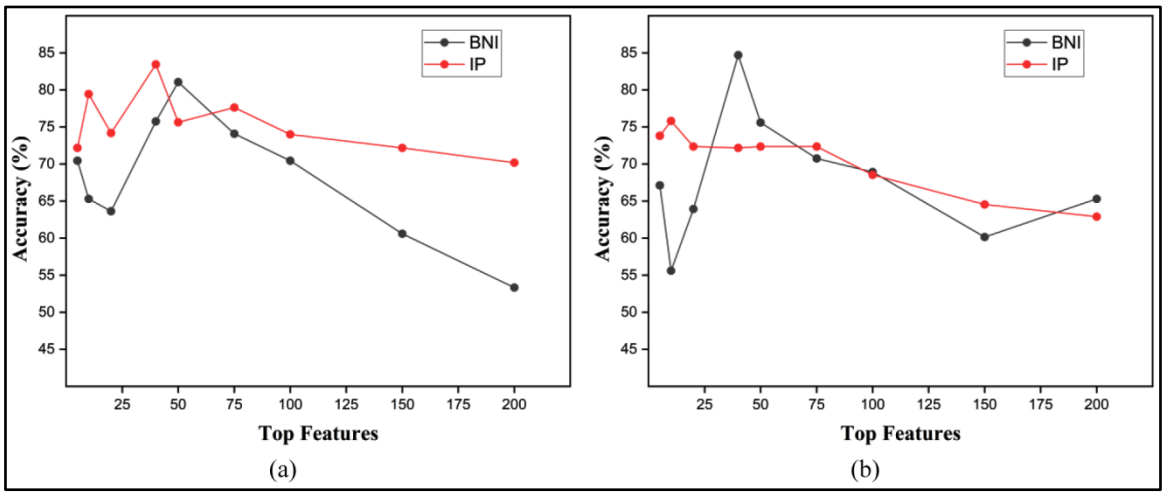


**Figure 2** Performance of classifier (a) LR and (b) SVM on the different number of SC features

## CONCLUSION

This study demonstrates the potential of DTI combined with ML algorithms for distinguishing between ASD and TD brains. Significant features were extracted using RFE-CV by analyzing SC through key diffusion metrics such as FA, MD, RD, and AD. The LR and SVM classifiers performed well in classifying ASD and TD, with optimal results achieved using 40 to 50 features. Beyond this range, performance tended to decline, indicating that excess features could lead to overfitting and reduced accuracy. Both classifiers demonstrated good discriminative power, with the LR peaking at 83.45% for the IP dataset with 40 features and 81.06% for the BNI dataset with 50 features. The SVM classifier performed similarly well, peaking at 84.69% for the BNI dataset with 40 features. However, performance generally declined as more features were included in the model. The top three SC features are the Posterior limb of internal capsule R to Fornix (cres) / Stria terminalis R, Corticospinal tract L to Inferior fronto-occipital fasciculus R and Pontine crossing tract (a part of middle cerebellar peduncle) to Body of corpus callosum. These findings suggest that careful feature selection is crucial for optimizing classification accuracy and avoiding model degradation. The results highlight the promise of using DTI-derived metrics and ML for developing diagnostic tools that can support the early and accurate identification of ASD. However, further research is needed to refine the model and validate its efficacy across larger and more diverse datasets.

## ACKNOWLEDGEMENT

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# Identification of Optimal Features for EEG-based Authentication in Response to Emotional State

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***Abstract***: *EEG-based authentication demonstrates strong potential in biometrics, but its performance is often hindered by the complexity of feature computation and its sensitivity to variations in emotional states. This study attempts to identify the features of EEG signals for biometric authentication, specifically focusing on the high arousal, high valence emotional state. Initially, the signals were preprocessed and 76 features from different domains were computed. These features were fed to the XGBoost to identify the significant features and to build a classification model. Our results found that the maximum value of the signal, Hjorth complexity, variance, kurtosis, and Higuchi's fractal dimensions are crucial for EEG-based authentication. Further, our model achieved the highest accuracy, sensitivity, precision, and F1 score of 81.22%, 82%, 83%, and 80% respectively. In conclusion, the proposed pipeline highlights their potential to enhance the efficiency of EEG-based biometric systems, through critical features.*

***Keywords***: *Biometric; Electroencephalography; Emotions; Optimal Features; Machine Learning*

## INTRODUCTION

Biometric authentication employs unique biological traits for identity verification and is traditionally categorized into conventional and cognitive biometrics. Conventional biometrics rely on physiological features such as fingerprints [1], facial recognition [2], and iris patterns [3], but they face limitations in terms of susceptibility to forgery and performance variability in different conditions. Cognitive biometrics, on the other hand, leverage physiological signals like electrodermal activity (EDA), electrocardiography (ECG), and electroencephalography (EEG), which offer a higher level of security due to their complexity and resistance to replication [4]. Among these, EEG signals stand out as they reflect unique brain activity patterns that are challenging to duplicate or manipulate, making them a promising tool for secure biometric systems.

Various elicitation protocols are commonly used in EEG-based biometrics, including motor imagery [5] and mental computation [6]. However, an individual's emotional state can significantly influence the brain's response to these stimuli. Incorporating emotional stimuli into EEG-based biometric systems introduces additional complexity, but it also enhances system robustness against potential fraud [7]. Since different emotional states evoke distinct brainwave patterns, leveraging these variations presents an opportunity to improve the accuracy and reliability of biometric authentication systems.

Feature extraction plays a crucial role in identifying key metrics from EEG signals that represent individual identity [8]. Despite advancements in EEG-based biometric authentication, challenges remain in extracting subject-specific features due to the non-stationary nature of EEG signals [9]. While past studies have used statistical [10], time, frequency [11], spectral [12], fractal [13], and entropy [14] features, few approaches fully capture the complexity of EEG data. In this study, we incorporated a broad range of features across multiple domains to enhance authentication performance.

The optimization of EEG signal features is crucial for developing highly accurate biometric systems. Previous studies have applied methods such as the Fisher discriminant ratio, recursive feature elimination [15], mutual information [16], principal component analysis, linear discriminant analysis [17], genetic algorithms, correlation maps, ANOVA F-test, logistic regression weights [8], maximum information coefficient, and quantum particle swarm optimization [18] to identify ideal features. However, there has been limited exploration of machine learning algorithms specifically for identifying optimal features in EEG-based biometric authentication. In our study, we addressed this gap by utilizing the XGBoost model to identify significant features.

In this study, we aim to address the challenges of EEG-based biometric authentication by leveraging the XGBoost model for optimal feature identification. By incorporating a wide range of features from multiple domains, including statistical, spectral, fractal, and entropy measures, we enhance the system's ability to capture the complex, non-stationary nature of EEG signals. This approach aims to improve the accuracy and reliability of biometric authentication by using emotional stimuli to elicit distinct brainwave patterns.

## METHODOLOGY

**Figure 1** outlines the process pipeline adopted in this study, which includes (1) EEG signal segregation based on annotations, (2) preprocessing, (3) feature extraction, (4) classifier training, and (5) performance evaluation. We utilized the publicly available Database for Emotion Analysis using Physiological Signals (DEAP) [17], which comprises EEG recordings from 32 participants exposed to 40 videos designed to elicit various emotional responses. However, we focused solely on the High Arousal and High Valence (HAHV) emotional state for our analysis. The dataset includes recordings from 32 EEG channels, with each participant having an 8064-point data matrix, along with ratings from 1 to 9 for valence, liking, arousal, and dominance. For our analysis, we considered the HAHV data, selecting instances where both the valence and arousal ratings were greater than 5. The raw EEG signals were recorded at 512 Hz and then down-sampled to 128 Hz. We applied common average referencing to the signals and removed electro-oculographic artifacts using blind source separation [18]. A bandpass filter (0.4–45 Hz) was utilized, and the signals were segmented into 60-second trials, excluding a 3-second pre-trial baseline. A total of 76 features per channel were extracted, covering statistical, time-domain, frequency-domain, entropy, fractal, spectral, and shape characteristics. These features were structured into a dataset with records of channel, clip number, and subject ID. For classification, we utilized the XGBoost algorithm, known for its ability to handle high-dimensional data and deliver robust performance through its boosting mechanism. Hyperparameter tuning was conducted to optimize model performance. XGBoost was used to identify the most significant features through feature importance analysis, aiding in the reduction of computational complexity. The key features identified by XGBoost offer valuable insights for improving the performance and efficiency of EEG-based biometric systems.

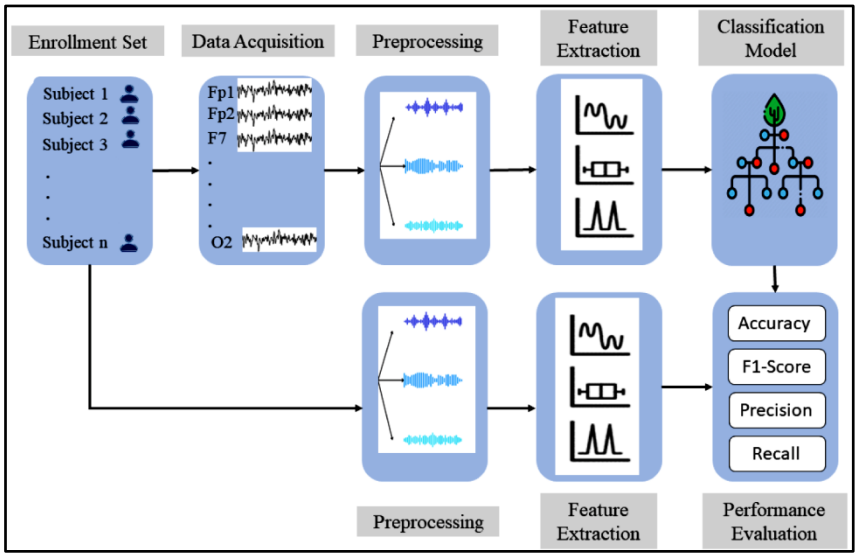


**Figure 1** Process pipeline of the study

## RESULT

We analyzed EEG data across 32 channels, and channel P7 demonstrated the highest accuracy of 81.22% using the XGBoost model. The performance metrics for channel P7, including sensitivity, precision, and F1 score, were 82%, 83%, and 80%, respectively, demonstrating strong effectiveness in classifying emotional states for biometric authentication. The top 20 features identified from channel 11, along with their importance scores, are shown in **Figure 2**. The most significant feature identified was the Maximum value of the signal (Max), indicating its critical role in the classification process. Hjorth Complexity (HC) and Variance (Var) also emerged as essential features. These statistical measures contribute substantially to understanding the underlying EEG signal dynamics. Kurtosis and Higuchi's Fractal Dimension (HFD) were also found to be significant. This suggests that the shape of the signal distribution and its complexity are crucial for accurate EEG-based biometrics.

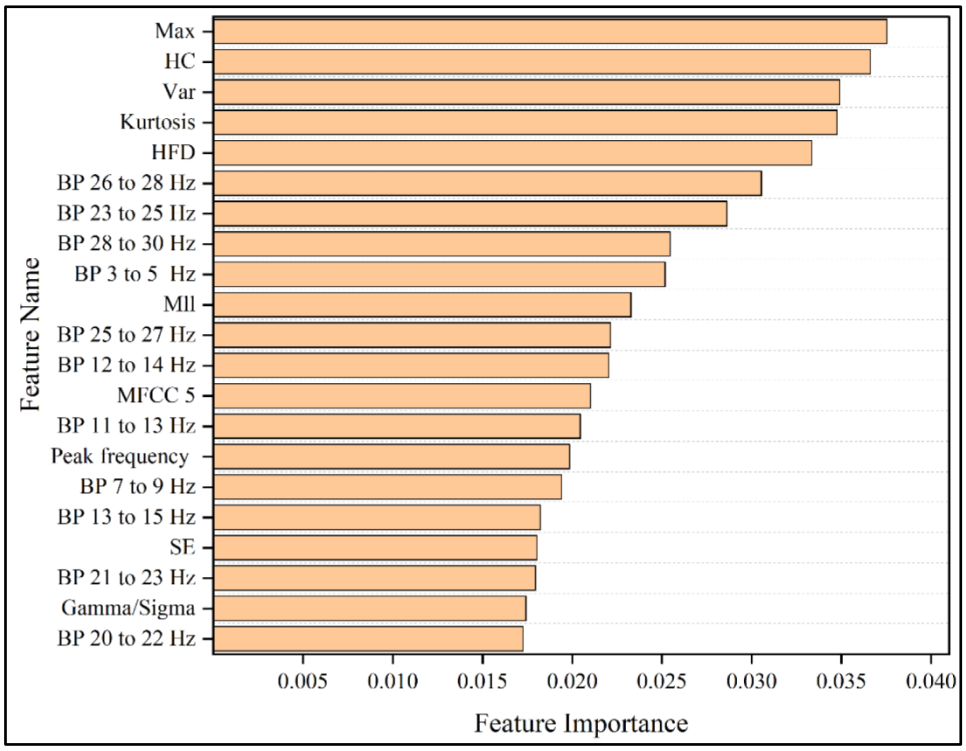


**Figure 2** Top 20 features for HAHV emotion stimuli (*MLL- Mean line length, *BP- Band Power, *MFCC- Mel-frequency cepstral coefficients *SE- sample entropy)

## CONCLUSION

This study demonstrates the potential of EEG signals as a viable alternative for biometric authentication, particularly emphasizing the impact of emotional states on classification performance. Utilizing the XGBoost model, we achieved an accuracy of 81.22% in classifying emotional states. The analysis revealed critical features, such as Max, HC, and Variance, significantly contributing to the model's performance. These findings underscore the importance of feature selection in optimizing EEG-based biometric systems. By addressing the complexities of EEG data, our research lays the groundwork for developing more efficient and accurate biometric authentication methods that leverage emotional state variations. Future work may focus on expanding the feature set, exploring additional emotional conditions, and validating these findings across larger and more diverse populations to enhance the robustness of EEG-based biometrics.

## ACKNOWLEDGMENT

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360_IEC71472

# Revolutionizing Cancer Drug Development with Artificial Intelligence: Navigating Patent and Licensing Challenges

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***Abstract***: *Cancer, a global health challenge, presents unique treatment complexities due to its heterogeneous nature, leading to varied patient responses. This paper explores the transformative role of Artificial Intelligence (AI) in revolutionizing cancer drug development, focusing on its applications in drug discovery, target identification, and patient response prediction. AI algorithms, particularly machine learning (ML) and deep learning models, enable the analysis of vast, complex datasets to enhance drug efficacy and toxicity predictions, identifying patterns beyond traditional methodologies. By integrating chemical and gene expression features, AI fosters precision medicine, tailoring therapies to individual profiles. Additionally, computational drug repurposing leverages deep learning to discover new applications for approved drugs, expediting treatment development.*

*However, the deployment of AI faces challenges, including data diversity, model interpretability, and compliance with regulatory standards. Ethical and legal issues surrounding AI-generated inventions, such as the absence of patent recognition, complicate intellectual property rights. While AI offers promising accuracy in drug interaction predictions, its contributions remain limited to specific stages of drug development. This paper highlights AI's potential to revolutionize cancer therapeutics while addressing its limitations and the need for robust frameworks to maximize its impact.*

***Keywords***: *Cancer Drug Development; Artificial Intelligence; Precision medicine; Intellectual Property Rights; Drug Discovery*

## INTRODUCTION

Cancer is an international medical concern. Owing to its great heterogeneity, patients with the same tumour may respond differently to the same medications or surgical techniques, necessitating the development of more precise tumour treatment techniques and patient-specific personalised treatments. To design focused treatment options for patients, it is imperative to have a thorough understanding of the changes that tumours experience, including changes in their genes, proteins, and cancer cell morphologies. Precise therapy of tumours is fundamental.

The era of Artificial Intelligence (AI) is transforming cancer drug development through enhanced efficiency in drug discovery, target identification, and patient response prediction. AI algorithms are capable of analyzing huge datasets and thereby can predict drug efficacy and toxicity. This can improve the drug design process significantly [1,2].

However, the "black box" nature of the AI systems, challenges that are found would include data diversity, model interpretability, and regulatory compliance [3,5]. Moreover, it is very crucial to ensure that AI applications are ethically sound and they have been validated through clinical trials for their successful integration into different cancer research strategies [4,6].

AI enhances drug efficacy and toxicity prediction by leveraging machine learning (ML) algorithms to analyze extensive datasets, identifying patterns that traditional methods may overlook. These algorithms can integrate diverse data types, such as genetic profiles and chemical structures, leading to more accurate predictions of how individual patients will respond to treatments and the potential side effects [7,8]. For instance, deep learning models can predict drug activity based on historical data, while classifiers combining chemical and gene expression features improve the accuracy of toxicity predictions [9,10]. This integration fosters personalized medicine by tailoring therapies to individual patient profiles [11,12].

## METHODOLOGY

Precision medicine (PM) strategy, which considers a person's lifestyle, environment, and genetic composition, is a promising approach. It also takes into consideration the diagnosis, explanation, and therapy. Patients through the use of multi-omics or multi-mode data will be able to receive a personalised treatment plan [13]. Another effective method is the adoption of computational drug repurposing which discovers new applications for already approved drugs available in the market [14]. The first step of drug repurposing involves a computer screening of previously developed compounds by employing various computational techniques including ligand similarity analysis, molecular docking, and machine learning. One particularly sophisticated approach for drug development has been put forth by Al deep learning technology [15]. This method could incorporate a significant quantity of relevant data to forecast treatment interactions [16]. AI driven Drug discovery raises two legal questions firstly, is AI given a legal personality? Secondly, what are the proprietary rights relating to the intellectual properties of AI-driven drugs?

## RESULTS

The debate over whether Al should be granted legal personhood is often surrounded at the center of the ethical and legal considerations. Critics argue that AI lacks the fundamental characteristics of humans and cannot be held legally liable, while proponents of Al point to its decision-making ability and its impact over society [17]. The intracity over its decision-making process and potential ethical dilemma make it a challenge to establish a legal status for AI [18].

However, recognizing AI as a legal person would help the pharma companies to discover drugs easily. Moreover, it should fall in the public domain where digital assistance will be out of the purview of IPR.

The current legal framework does not recognize patents for Al-generated inventions, making ownership of Al-assisted inventions a legal challenge. Trade secrets or confidential know-how may offer alternative protections, but this may not be suitable for pharmaceutical industries. The issue of AI being trained with copyrighted or licensed material raises questions about dataset owners' rights. Additionally, potential royalty obligations may arise due to ownership and licensing issues, and patent holders may be entitled to royalties on discoveries made using AI systems. as demonstrated in Bayer AG v. Housey Pharm., Inc., [228 F. Supp. 2d 467, 470-71 (D. Del. 2005)] The patent holder may be entitled to royalties on discoveries made using the AI system if the system itself is patented. Careful negotiation between biopharmaceutical companies and AI providers is essential.

## CONCLUSION

AI has the potential to revolutionise drug research and development, especially through machine learning and generative capabilities. However, with all the promise and potential in drug development, AI tools have limitations. For example, the tools can, at best, provide up to 80% accuracy in predicting interactions (the accuracy comes down drastically for protein-RNA interaction predictions). Second, the tools can only aid a single phase of drug development, target discovery, and drug-target interaction. It will still have to go through the pre-clinical and clinical development phases, and there is no guarantee that the AI-derived molecules will result in success in those phases. Finding a balance between utilising AI's potential and adhering to patent restrictions needs considerable thought. Identifying what constitutes patent-eligible subject matter, addressing ownership and licensing rights, and distinguishing between human creativity and AI contributions are important concerns. Furthermore, continuing legal interpretations are required due to the developing notion of a person of ordinary skill in the art (POSA) in the context of artificial intelligence and the ramifications of public disclosures. The convergence of innovation and legal foresight will play a crucial role in determining the trajectory of this revolutionary journey as AI continues to alter medication development.

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**Biomedical Science & Technology**

# Biomaterials, Tissue Engineering, and Regenerative Medicine

42_IEC32451

# Study on Structure and Properties of Bioactive Bioceramic Biomaterial obtained from Marine Shell Species Magallana Cuttackensis

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***Abstract**: Calcium is an important element in our body having multiple roles in bone building, Blood clotting pathways, muscular activities, nervous transmission, Hormonal regulation etc. This study reports on the preparation, characterisation and structural analysis of calcium rich Marine shell bioceramic biomaterial from a marine shell species Magallana Cuttackensis. The heat treated shells were converted to a bioactive bioceramic biomaterial by using a wet chemical precipitation synthesis technique Phase analysis from XRD data revealed the presence of hydroxyapatite phases Bonding analysis by FTIR shows the functional group for $OH^-$, $PO4^{2-}$, $CO3^{2-}$. Morphological features are noted from scanning electron microscopy (SEM) data that execute pore formation while the mechanical properties like hardness data of the developed pellets are observed to be similar to the reported research studies. Conventional antibacterial studies, bioresorption analysis hemocompatibility cell toxicity and Clotting Time (CT) proved that the developed material is biocompatible with potential utilization as a bone healing agent or as an accelerator for blood clotting.*

***Keywords**: Marine Shell; HAP; Bioresorption; Bonegraft; Biocompatibility*

## INTRODUCTION

The necessity of bone grafting surgeries because of various bone related defects has reached a very high number, which is about 2 million worldwide, in the last decade [1]. Along with bone related diseases, the increasing number of sports injuries and accidents have accelerated the requirement for bone tissue replacement [2]. In this regard, autografting or allograf ting is ideal but has many limitations [3]. To overcome these issues many synthetic and natural materials have gained significant interest because of their biocompatibility, osteoconductivity and chemical resemblance with the inorganic component of bone. Over the years, various synthesis techniques have been developed to prepare synthetic hydroxyapatite (HAP). However, natural sourced HAP is gaining huge importance today due to the presence of different trace elements [4,5]. The present study emphasises the development of a probable idealistic bone graft material from a marine shell of Magallana Cuttackensis.

## MATERIALS & METHODS

### Development of Powder from Marine Shell

A Marine shell of the species Magallana Cuttackensis were collected from the Mangrove area of West Bengal, (India). Collected shells were cleaned & washed thoroughly and treated with diluted sodium hydroxide solution (97% minimum assay, procured from Fisher Scientific Pvt. Ltd, Mumbai, India) for 24hrs followed by washing with deionized water. The cleaned shell s were heated at a temperature of 900°C for 2 h, crushed, and ball milled for 20 hrs followed by sieving to get homogeneous fine powder.

### Preparation of Marine Shell Derived Hydroxyapatite (MS HAP)

The Marine shell powder (a specified quantity) was thoroughly mixed for about 30 minutes in boiled water at 80°C in a beaker. A stoichiometric amount of laboratory-grade orthophosphoric acid (0.6 M) was added to the beaker

dropwise. The precipitate thus formed was taken in petridishes and dried at 45°C for 3 days followed by calcination at 800°C.

**Preparation of Sintered Block and Porosity Study**

The calcined powders were pressed at a pressure of 150 MPa in a Hydraulic machine to form cylindrical pellets with a radius of 10 ± 0.05 mm and thickness of 6± 0.05 mm. The pellets were sintered at 900°C with a soaking time of 2 h and a heating rate of 5°/min in an air atmosphere. Apparent Porosity was measured by the following formula, Apparent porosity = (Ww - Wd) / (Ww- Ws) *100 Where, Ww: Weight of the pellet after removing from water Wd: Dry weight of the pellet Ws: Weight of the pellet when in suspended condition.

**XRD, FTIR, SEM Analysis**

Material phase and lattice parameters of the developed bioceramic material (MS-HAP) was evaluated by using XRD (Model-BRUKER D8, Japan ). It was done in the 2θ range of 20°-60° with a scan speed of 1° per minute. Lattice parameters (a and c) were calculated from peaks using the standard HCP unit cell plane spacing relationship [6].

$$\frac{1}{d^2}=\frac{4}{3}\left(\frac{h^2+hk+l^2}{a^2}\right)+\frac{l^2}{c^2}$$

Where d is the distance between the adjacent place, (h,k,l) is Miller indices. Unit cell volume had been calculated by using the formula $V=0.866\ a^2c$.[7].

The FTIR study was performed through Perkin-Elmer, Model No- 1615 (USA) by using KBr pallets in the IR region (5000-400 $cm^{-1}$). In this work, the surface morphology, microstructure of the dense samples was observed by using a scanning electron microscope (JEOL SEM, Model No-JSM, 5200, Tokyo, Japan).

**Hardness Study**

The synthesized sample (pellet form) was measured for hardness by a Vickers hardness machine (Model-VM 50,Fuel Instr.&Engg. India) using diamond indenter forming square bases having the angles 136°C between the opposite faces with 60 Kgf load applied for 15secs. Sloping surface area demarcated on the sample by indenter was measured while Vickers hardness value was calculated by dividing the load force by Kgf/square millimeter area.

**Bactericidal Study & MTT assay Hemolysis Study**

For the Bactericidal study nutrient agar media was taken in a conical flask and autoclaved at 121°C temperature for 20 mins. The media was cooled at 40-45°C temperature and inoculated with the culture of Staphylococcus aureus and poured in petridishes. Porcelain bits were dripped into the sample solution and placed in the petridishes. Two bits of 3 mg/10 ml and 5 mg/10 ml samples were taken. The petridishes were incubated at 35°C temperature for 24 hours and noted for the zone of inhibition.

MTT assay was done by Peripheral blood mono nuclear cells (PBMC) cells (NCCS, Pune). The cells were seeded in 24 well plates at a density of $5 \times 10^4$ cells/$cm^2$. The cells were treated with prepared calcined bioceramic powder samples and incubated for 24 hours. Then MTT was added, shaken for 15 mins and incubated for 4 hours. After removing the media DMSO was added for dissolving the crystals. A purple-coloured solution was formed. OD was taken at 545 nm against a blank. The experiment was performed in duplicate and the mean data was recorded. The haemolysis study was done by following the ASTM guidelines [8].

**Bioresorption Study (Stimulated Body Fluid Study)**

Simulated Body Fluid was prepared in the laboratory by maintaining all the composition levels and conditions as described by Kokubo et al [9]. Sintered pellets were immersed in the prepared SBF solution. The solution was

changed on three alternate days during a one-month study. The surface texture of the pellets was observed through a scanning electron microscope after a 1-month time point.

**Clotting Time**

For the CT test, 10mg calcined MS-HAP powder was added directly to the 340µl of human blood in an Eppendorf tube. Then the tube was placed into a water bath at 37°C for 15min. 20µl 0.2M $CaCl_2$ was added to the tube. Then the tube was turned up and down with a 1 sec interval. After that, the clotting time was measured with no movement of blood in the Eppendorf tube.

**RESULTS AND DISCUSSION**

**Physical Properties**

The physical characteristics of porous specimens (sintered at 900°C) of dimension (10 × 6 $mm^2$) are presented below in **Table 1**.

**Table 1** Data of physical properties

| Sample | Hardness(GPa) | Avg.Sintered Density(g/cc) | Apparent porosity (%) | pore size distribution(µm) |
|---|---|---|---|---|
| MS -HAP | 3.64±0.41 | 3.03 | 24.35±1.28 | 12-180 |

The sintered density of the developed ceramic is quite similar to the other hydroxyapatite derived from synthetic or biogenic sources like Eggshells. The result is very much conforming to the other literature values [10-11]. The porosity values show the presence of plenty of void spaces within the matrix which is very much essential for bone integration. The hardness values are quite confirming to the findings of Timothy P. Hoefner et al. [12], and P Bhattacharjee et al.[13].

**XRD & FTIR Analysis**

The XRD of raw marine shells showed the presence of calcium carbonate peaks. The phase analysis of the calcined MS HAP powder was examined through X-ray diffractometry in the 2θ range of 200-600, as no other prominent peaks are observed beyond this range. The samples showed several high-intensity peaks corresponding to various planes i.e. (0 0 2), (2 1 1), (3 0 0), (2 0 2), (2 1 2), (2 2 2), (2 1 3) that's matches with the standard card no JCPDS (09-0432) for Hydroxyapatite. The sharpest peak is observed at 2θ range of ~32.06 corresponding to the (2 11) plane proving the presence of hydroxyapatite crystals, as confirmed by other literature [14-15].

The lattice parameters as calculated are expressed in below **Table 2**.

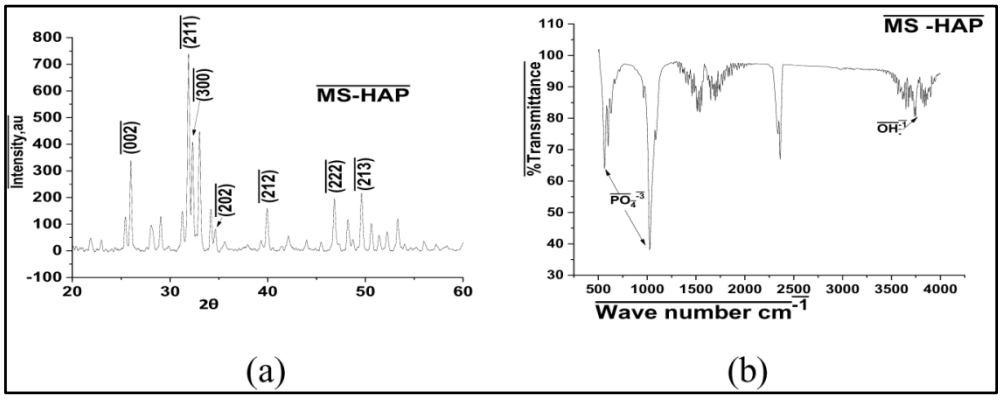


**Figure 1** (a) XRD of MS-HAP (b) FTIR curve of MS-HAP

**Table 2** Data of lattice parameters and unit cell volume

| Sl no | composition | a axis (Å) | c axis (Å) | Unit cell volume(Å3) |
|---|---|---|---|---|
| 1 | MS- HAP | 9.5230±.0.086 | 6.941 ±0.140 | 533.93±22.02 |

The FTIR curve shows the presence of peaks at 567 $cm^{-1}$ & 1022 $cm^{-1}$ signifies the presence of phosphate ions. The peak at 3750 $cm^{-1}$ and a long stretching band due to hydroxyl ions are also very clear. A sharp peak at 2357 $cm^{-1}$ is also noted which is due to the presence of some unreacted carbonate ion.

**Bioresorption Study (Stimulated Body Fluid Study)**

A huge amount of apatite layer is observed under the scanning electron microscope. This is due to the favourable interaction of the pellets in the SBF solution The dissolved pellets lost their weight at the beginning due to absorption and interaction with different ions present in them. The % of weight degradation is expressed in below **Figure 2**. The rate of degradation is faster up to 12-15 days after that the rate becomes slower probably because of the apatite layer appearance (**Figure 3**) above the pellets.

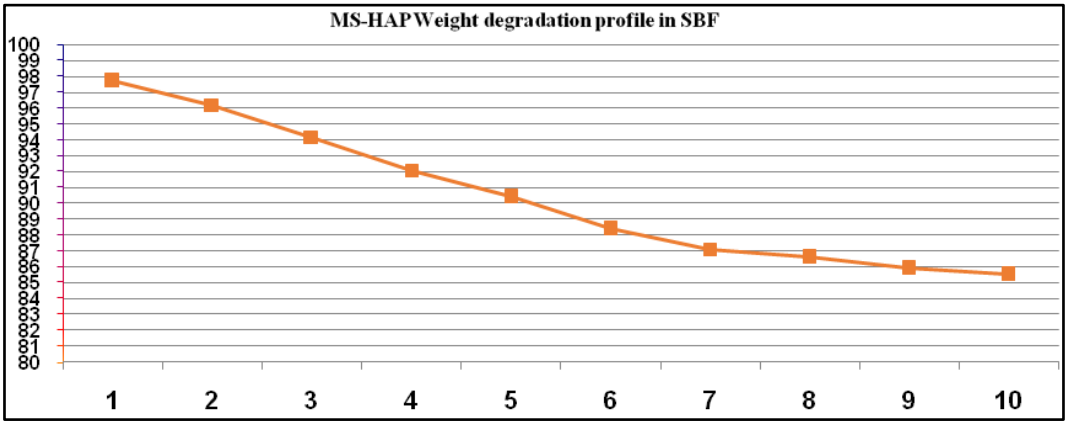


**Figure 2** Percentage weight degradation profile of MS HAP in SBF A 30 day record has been plotted

**Scanning Electron Microscopy**

Highly clustered HAP particles are revealed (**Figure 3**) under the Scanning Electron Microscope (SEM). The image expressed a highly perforated pellet matrix with almost the same kind of particles having a basic globular structure. The pore dimensions are of varying dimensions. The wide range of pore size distribution may be attributed to the cluster formation of the matrix or due to the evaporation of trapped water inside the matrix.

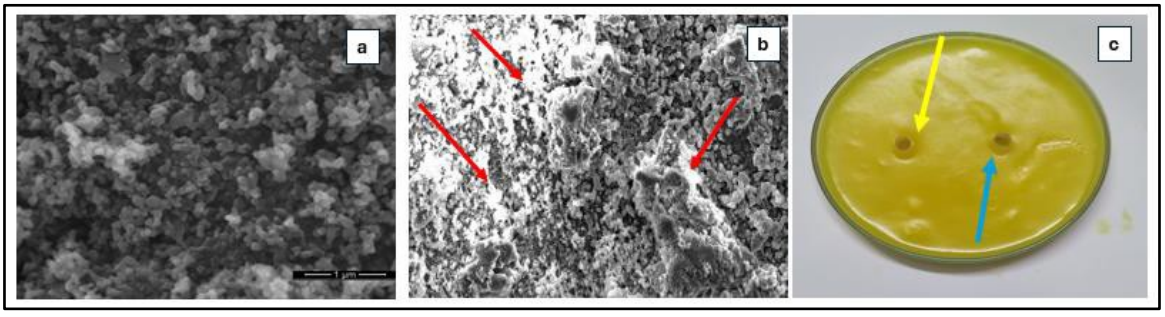


**Figure 3** (a) Depicting the SEM of developed MS-HAP,(b) SEM of Pellets after 30 days of study, the white region (red arrow point) is the apatite layers, (c) A petridish under the study, showing no zone of inhibition, the yellow arrow and blue arrow represents 3mg/10ml and 5mg/10ml samples respectively.

**Bactericidal, MTT Assay Hemolysis Study and Clotting Time**

The petridish showed nearly no zone of inhibition as examined under the microscope, suggesting that the material possesses no antibacterial properties. The MTT study data showed that more than 80% of cells are viable. The whole blood clotting time (CT) was only 108±4sec and the hemolysis result revealed that the material caused less than 3% haemolysis in study blood. The haemolysis study result is given in **Table 3**.

**Table 3** Haemolysis Study Data

| Composition | Wavelength (nm) | Avg. O.D. of Test sample | O.D. (+) ve control | O.D. (-) ve control | %Haemolysis |
|---|---|---|---|---|---|
| MS-HAP | 545 | 0.071 | 0.46 | 0.061 | 2.50 |

## CONCLUSION

The present study reported the development and description of a highly biocompatible bio-sourced hydroxyapatite from a marine shell. The density is very close to the theoretical density of synthetic HAP. The pellets showed a hardness value good enough to be used as an implant body capable of withstanding the required stress or strain. The phase analysis and FTIR study conclude the presence of a hexagonal HAP lattice and some unreacted carbonates in the final products. The SBF study indicated a favourable interaction with a good amount of apatite formation, suggesting ideal bone graft material properties. Hemolysis, bactericidal and MTT assay concluded the absolute biocompatibility nature of the material. The clotting time result showed an aggravated response which confirms the effect of the MS-HAP blood clotting pathways. Therefore, we conclude that the developed marine shell-derived bioceramic biomaterial can be used as a haemostatic agent or as an ideal bone graft material for faster bone healing.

## ACKNOWLEDGMENT

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147_IEC29315

# Wound Healing with the Controlled Degradation of Biomaterial

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***Abstract***: *Importance of wound healing in context of scaffold degradation cannot be overstated, as timing and manner of scaffold degradation directly influence healing process. In present study, a bio-composite scaffold (Chitosan: Polyvinyl alcohol, polyvinyl alcohol: Centella Asiatica, Centella Asiatica: Chitosan, Silk Fibroin: Chitosan, silk fibroin: Centella Asiatica) and explicit scaffold were considered for different hemocompatibility, anticoagulant assay and characterization study. In addition to this for scaffold degradation, explicit scaffolds as well as poly electrolyte complex (chitosan: Gelatin and chitosan: Alginate) scaffolds were fabricated. In the current study, scaffold deterioration was evaluated in presence of perfused media. Study found that the maximum degradation of chitosan: alginate (20:80) PEC based scaffold occurred at flow rates of 2 ml/min and 0.5 ml/min. Alginate-based scaffolds degraded almost 80% from their original weight, with slower degradation at 2 ml/min. FTIR analysis reveals different functional groups amide I, amide II and amide III for silk fibroin. Likewise for Centella Asiatica extract are phenolic groups and alkyl halides. Silk-I (alpha form) and Silk II (beta form) found at diffraction peaks 20–21° and 28° respectively according to XRD analysis. PVA/silk fibroin has the highest swelling ratio (77.5%) and Silk fibroin /Centella Asiatica have shown maximum serum adsorption capacity.*

***Keywords***: *Anticoagulant; Bio-composite; Degradation; Hemocompatibility; Perfused Media*

## INTRODUCTION

In both acute and chronic wounds, wound matrix materials are employed to promote dermal and epidermal layer regeneration. Modern wound matrices are mostly made of biologic materials, which include tissues that have been treated from allogeneic and xenogeneic sources. Regrettably, current biologic wound matrices have a number of drawbacks, such as inadequate strength, durability, longevity, and enzymatic resistance, all of which are necessary for providing long-term support for the creation of new tissue [1]. Three essential elements are needed to successfully restore living tissue: scaffolds, growth-stimulating signals, and cells [2]. Scaffolds serve as a framework for cells to grow, differentiate, and form tissues. They help maintain the shape and structure of the tissue being engineered. Scaffold degrade in vivo through a complex process of physio-chemical degradation that includes enzymatic breakdown, chain scission and material dissolution in a wet environment, as well as cellular metabolite-driven degradation like inflammation and cytokine response [3]. Normally, biomaterials degrade within the body to allow for the regeneration of new tissue. As scaffolds degrade, the by-products should be non-toxic and capable of being absorbed or eliminated by the body. Nevertheless, their deterioration might not coincide with the pace at which tissue grows, which could result in partial scaffolding material breakdown. The use of scaffolds as biomaterials provides numerous benefits, however there are various challenges associated with the interaction between implanted biomaterials and surrounding host tissue. It ranges from incomplete degradation to toxicity and mechanical failure [4]. Such incomplete degradation leaves residual elements that causes inflammation and fibrosis among other adverse effect. In addition to this scaffold that do not degrade properly can create a physical barrier that restricts the diffusion of nutrients and oxygen, both of which are essential for cellular metabolism and tissue regeneration. Biocompatibility of blood contacting devices relates mainly to the thrombotic response induced by the materials. Blood coagulation and thrombosis brought on by platelet adhesion and activation on material surfaces can result in functional failure and potentially catastrophic consequences, hence sufficient and persistent anti-thrombogenicity is crucial for materials that come into contact with blood [5]. However thrombotic and bleeding risks associated with necessary anticoagulant therapy remain serious concern with respect to wound healing and treatment [6]. To address these issues, the scaffold material, design, and degrading qualities must be carefully considered. It is critical to select biocompatible, non-toxic materials with proper degradation rates.

In the current study bio-composite as well as polyelectrolyte scaffold were fabricated. The four biomaterials silk Fibroin (SF), polyvinyl alcohol (PVA) Chitosan (CS) and Centella Asiatica (CA) were used for bio-composite and bio-film preparation in the ratio of 50:50 concentrations. In this study, we have utilized polyvinyl alcohol (PVA), a water-soluble, nontoxic, biocompatible and biodegradable polymer which is widely used for scaffold fabrication in tissue engineering. Additionally PVA can absorb a significant amount of water, which helps maintain a moist environment for cells and promotes cell adhesion and proliferation. Among various materials scaffolds-based chitosan and its derivatives have gained considerable attention. Chitosan is an cationic polymer is composed of N-acetylglucosamine (GlcNAc) and glucosamine (GlcN) residues, which displays some favourable properties such as low-toxicity, good biocompatibility, biodegradability and mucoadhesive [7]. Silk fibroin which is extracted from silk worm is the most abundant natural polymer due to many desired physiochemical properties such as excellent biocompatibility, biodegradability, bio-resorbability, low immunogenicity, and tune-able mechanical properties is used for scaffold preparation [8]. Inspite of that silk fibroin has shown poor anti-coagulant property [9,10], to overcome this Centella asiatica (CA) commonly known as Indian pennywort or Gotu kola, is a herbaceous, frost-tender perennial plant is used in the treatment of wounds and ulcers and is incorporated with Silk fibroin to promote blood circulation and to remove blood stasis [11]. The degradation of scaffolds is a critical aspect in tissue engineering and regenerative medicine. Scaffolds can lose structural integrity and mechanical strength if they decay too rapidly or incompletely, which results in mechanical failure, including collapse or fracture [12]. To overcome this rate of scaffold degradation should be in a controlled way. The present work had conducted degradation study of polyelectrolyte complex (PEC) and explicit scaffold up of Chitosan/Alginate and Chitosan/Gelatine at ratio of 20:80, 50:50 and 80:20 concentration. The scaffold degradation studies in perfused media were performed at flow rate of 0.5 ml/min, 1 ml/min and 2 ml/min. Perfused media had caused scaffold degradation due to presence of mechanical shear stress.

## MATERIALS

Chitosan (CAS No: 9012-76-4), Gelatine (CAS No: 9000-70-8), Sodium alginate (CAS No: 9005-38-3), polyvinyl alcohol (CAS NO: 9002-89-5) were purchased from HIMEDIA Laboratories, India and LOBA chemicals pvt Ltd. Mumbai, India. Silk fibroin were procured from Chhattisgarh gram Udyog and centella asiatica leaves were purchased from local market. Blood samples were collected from poultry farms.

## METHODS

### Bio-Composite Fabrication

Suspensions containing desirable amount of selected materials will be prepared in first step. Isolation of silk fibroin from cocoons of silk worm and is cut into small pieces and boiled in an aqueous solution of 0.2 M $NaHCO_3$. To obtain silk solution it is dissolved in 1 M calcium nitrate, the degummed fibers will be dialyzed to remove debris and silk aggregates. Followed by preparation of Centella asiatica leaf extract, the dried and powdered aerial plant parts were macerated using 40 mL of 99% purity methanol as solvent is used at room temperature for 5 hrs. Similarly PVA and chitosan suspensions were prepared. To prepare Poly vinyl alcohol solution (PVA) it was dissolved in deionized water with varying concentration of 5% (w/v) until continuous stirring at 70°C. To prepare Chitosan (5% w/v) it was dissolved in 80% (w/v) acetic acid until continuous stirring at 80°C. Biofilms were prepared by solvent casting method. Characterization study such as Scanning Electron Microscopy (SEM), X-ray Diffraction crystallography (XRD) and Fourier transform infrared spectroscopy (FTIR) is performed. Evaluation of in-vitro hemo-compatability testing of polymeric films of various blends is conducted. 24 well microtiter plates with 100 µl of serum separated from whole blood, polymeric films were incubated at 37°C for 24 hrs. To measure the adsorption of serum protein onto polymeric films the absorbance was checked at 540 nm after incubation using microplate reader.

### Polyelectrolyte Scaffold Fabrication and their Degradation

Explicit scaffold and PEC scaffolds were fabricated form chitosan, alginate and gelatine at mixing ratio of 20:80, 50:50, and 80:20 concentration by solvent casting and etching. The degradation test was performed for continuous 6 days. To perform degradation in a 60 ml BD Plastipak syringe, a simulated Body Fluid (SBF) was placed. The

programable Shenchen syringe pump (Darwin microfluidics, France) was loaded with the filled 60 ml syringe and put into infusion mode. 0.5 ml/min,1 ml/min and 2ml/min flow rate of syringe pump flow were maintained consistently. The flow-driven system was assembled by linking a syringe pump to the microfluidic chamber in a series configuration utilizing microfluidic accessories. Scaffolds made of all PEC ratio were cut in such a way that their initial weight was 50 mg and they were placed inside the microwells. Eight of dried scaffold of discharge SBF were observed after one day interval until the initial wight of scaffold was degraded upto 80%. Degradation study in perfused media had been performed in triplicate form.

## RESULTS AND DISCUSSION

### Characterization And Hemocompatibility Study

FTIR studies reveal characteristic peaks of silk fibroin at 1590 cm-1 (amide I), 1622 $cm^{-1}$ (amide II) and 1230 $cm^{-1}$ (amide III). Similarly for CA extract the major functional groups present are alkyl halides at (500-600 cm-1) and phenolic groups at (3000-3380 $cm^{-1}$) are present. XRD reveal that silk-I (alpha form) is present at diffraction peak 20-21° and silk II (Beta form) at diffraction peak at 28°. The maximum swelling ratio was approximately highest (77.5%) for PVA/silk among all bio-composite scaffold. Since hydrophobicity plays an important role for biocompatibility of polymeric materials. PVA/silk exhibited lower contact angle (75.5°). Hence incorporation of silk fibroin into PVA can decrease the contact angle, making the surface more hydrophilic. For invitro hemocompatibility test silk fibroin /Centella Asiatica have the maximum serum adsorption capacity (as shown in **Table 1**). Since silk has poor hemocompatibility and thermogenic response, the incorporation of Centella asiatica improved the response towards hemocompatibility.

### Degradation Study

Results indicated that the maximum degradation occurred in chitosan: alginate (20:80) PEC based scaffold at flow rate 2 ml/min. In addition, the maximum degradation had occurred for the flow rate 2 ml/min among all scaffolds at day 1. Similarly, at day 2 the maximum degradation was reported for the chitosan-alginate (50:50) based scaffold for flow rate of 0.5 ml/ min (as shown in **Figure 1**). Also the maximum degradation rate were observed at flow rate of 0.5 ml/min for explicit chitosan and Chitosan: alginate (20:80) scaffold, respectively. Alginate based scaffold was degraded almost 80% from its original weight for all three types of flow rates. The degradation of scaffold at flow rate 2 ml/min was slower as compared to other flow rates in day 5 and day 6. Additionally, the scaffold fabricated from higher concentration of chitosan had revealed slower degradation as compared to others configuration. PEC scaffolds may experience faster degradation at 1 ml/min flow rates as compared to 2 ml/min flow rates due to a at 2 ml/min (higher) flow rate there was reduction in the exchange of nutrients and waste products.

(a)

| S.No | Samples | Concentration | Average Optical Density (in triplicate form) with standard deviation (SD) |
|---|---|---|---|
| 1 | PVA | 50:50 | 0.458 ±0.5 |
| 2 | SF +CS | 50:50 | 0.480 ±0.3 |
| 3 | PVA+CS | 50:50 | 0.440 ±0.1 |
| 4 | CA+CS | 50:50 | 0.697 ±0.2 |
| 5 | CA+SF | 50:50 | 0.802 ±0.1 |
| 6 | SF | 50:50 | 0.439 ±0.3 |
| 7 | CA+CS | 50:50 | 0.537 ±0.2 |

(b)

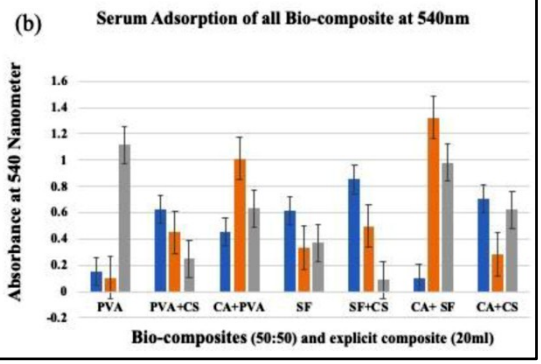


**Figure 1** (a) Serum adsorption of all Bio-composites with average optical density along with standard deviation (b) Serum adsorption of all bio-composites 540 nanometer

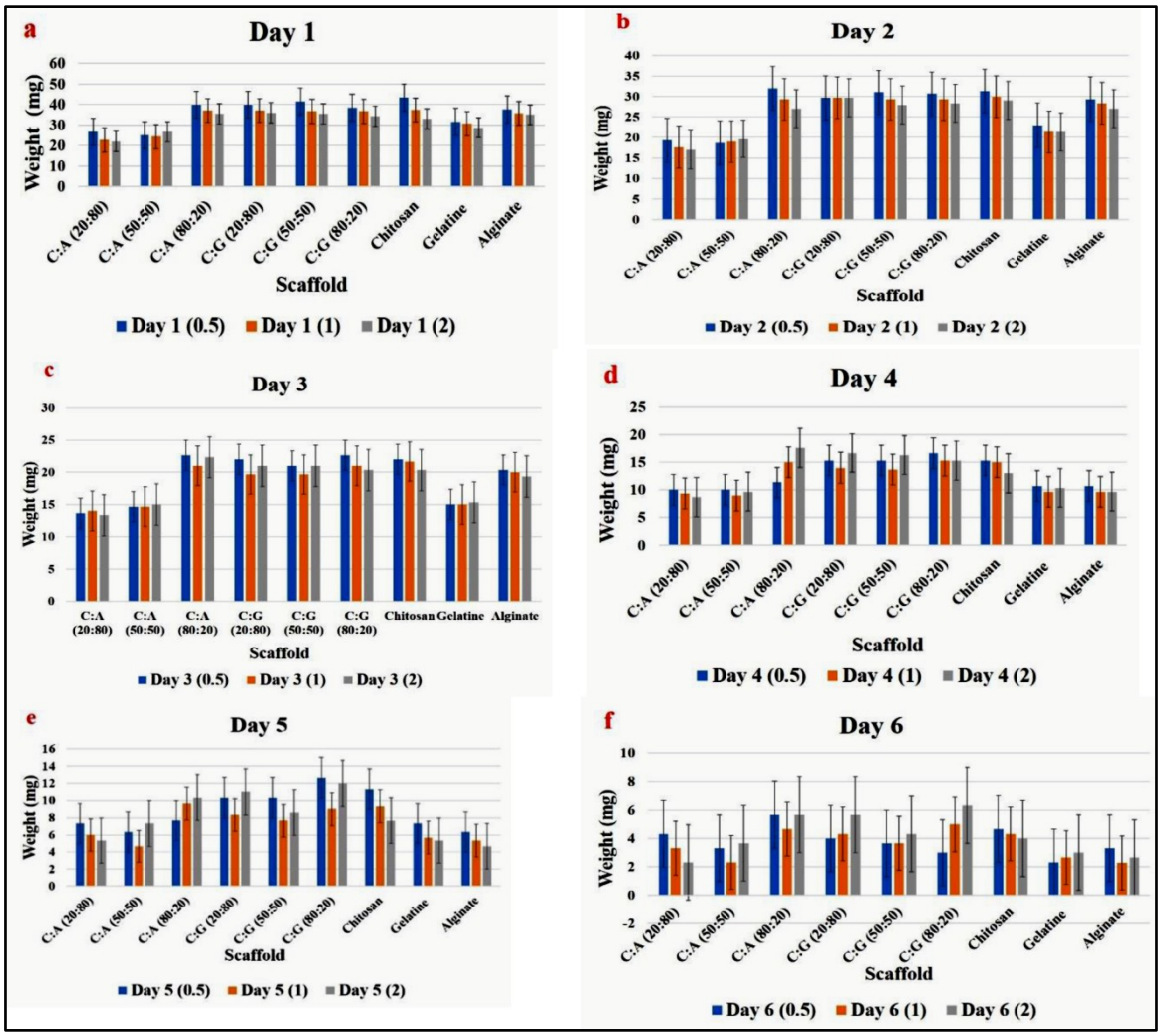


**Figure 2** Degradation of PEC scaffold at perfused media (a) Day 1, (b) Day 2, (c) Day 3, (d) Day 4, (e) Day 5, and (f) Day 6

## CONCLUSION

Thus the present study reveal the importance of correlation between controlled degradation and wound healing. The collapse and injury of the scaffold can be minimized with the incorporation of appropriate biomaterials that have good hemocompatibility and which prevents thrombosis and blood loss. The process of scaffold degradation in the presence of perfused media can improve nutrient supply and waste removal, but the mechanical stress imposed by the flowing media can cause the degradation of scaffold too. Enhancement of wound healing is dependent on the selection of the appropriate biomaterials and also the degradation of scaffold should be in a controlled way. The present study opens the new pathway to researcher to select the bio composite scaffold for wound healing and high mechanical properties for scaffold fabrication and degradation.

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# Degradable Microcarriers and their Role in Stem Cell Expansion and Hard Tissue Organoid Development

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***Abstract:*** *Microcarriers are extremely small particles that have been thoroughly studied for usage as medication carriers and in cell production. Their diameters range from 50 to 400 μm[1]. The biomedical industry has shown a great deal of interest in microcarriers with flexible designs, materials, and sizes for wider use in tissue fabrication, 3D bioprinting, and in vitro disease modeling platforms[2]. The use of microcarriers to scale up cells for use in cell therapy applications is growing in popularity. More simplified scale-up, process robustness, cost-effectiveness, and regulatory compliance are needed as cell therapies are employed in clinics more often[2]. One of the most thoroughly studied cell-based medicinal products, mesenchymal stem cells (MSCs) have been shown to have significant applications in tissue regeneration, immune-mediated regulation, and repair[3]. Owing to the constrained quantity of adult stem cells that can be extracted from patients, it is imperative to produce substantial quantities of stem cells extracellularly in a cost- effective way. An environment optimal for the large-scale generation of adherent cells may be created by combining stirred-tank bioreactors with the well-established technology of microcarriers in the biopharmaceutical sector[2]. The fabrication of in vitro tissue engineering models for drug screening and organ-on-a-chip platforms, as well as in situ tissue regeneration as a "one-size-fits-all" platform for minimizing highly invasive surgical procedures, have both been documented as intriguing uses for microparticles[4]. Presently, scaffold-free spheroid cellular aggregates are produced by 3D cell culture techniques, which hold great promise for supplanting traditional 2D cell culture methods. While they can more accurately and geographically reproduce the milieu of physiological tissues, they nevertheless have some drawbacks that may be resolved by incorporating biomaterials—such as micrometric particles—into the cellular constructions[5]. The development of biodegradable implants for bone tissue engineering has been impeded by the lack of biocompatible materials[2]. Therefore, optimizing bioactivity by altering the composite's surface is crucial for bone regeneration. The ratio of surface area to volume of microcarriers is their most important characteristic because it allows for the development of huge cell populations in a relatively small culture vessel while using less growth media[6]. For cell development and harvesting, the matrix materials utilized in the creation of microcarriers are essential. For instance, polylysine, poly(N-vinylguanidine), and poly(N-isopropylacrylamide) (PNIPAAm) surface coatings on microcarriers may promote MSC cell attachment, bead-to-bead cell transfer, nutrient perfusion, and differentiation into a range of target mature cells[2][7].*

*Furthermore, one of the most innovative areas of tissue engineering and regenerative medicine is the fabrication of engineered tissues, which has been made possible by microcarriers' bottom-up assembly. The current developments of biopolymer-based microcarriers—particularly polysaccharides like chitosan, chitin, cellulose, hyaluronic acid, alginate, and laminarin—for 3D cell culture and the creation of engineered tissues based on them are thoroughly examined in this study[8].*

***Keywords****: Microcarriers; Mesenchymal; 3-D Bioprinting; Fabrication; Tissue Engineering; Regenerative*

## RESULTS

Stem cells show great potential for drug discovery, cell therapy, regenerative medicine and many other biotechnical uses. They have the ability to renew themselves and differentiate into specialized tissue based on the requirement and source [4]. Even after having so many benefits the stem cells generation faces many challenges. To overcome these challenges microcarriers come into play. The cell adhesion capacity of microcarriers can promote cell expansion and differentiation. Cell aggregation which is a major problem to cell growth is also overcome with the help of microcarriers as it prevents cell aggregation and allows harvestation of concentrated cells by providing large surface area [5]. The attachment of stem cells to the microcarriers is facilitated by coating the microcarriers with a certain adhesive protein [6].

Although the conventional method was efficient, it possessed potential risk to the patient as the microparticles remained in the body. Hence the development of degradable microcarriers was a major step in overcoming the major challenges of conventional microcarriers [7]. The microcarriers were also successful in creating microtissue.

Nanofibrous microcarriers promoted cell proliferation, differentiation, and tissue recovery in an experiment on rats with knee cartilage defects, thus showing their potential for cartilage generation [8]. The surface modification of these biomaterials strengthen it thus becoming crucial for bone regeneration.

## CONCLUSION

Microcarrier technology offers benefits for tissue engineering, cell treatment, and large-scale production of functioning cells while preserving their unique phenotypes. Tissue engineering has a promising future thanks to advancements in microcarrier materials, particularly those made entirely of natural resources[9]. Biodegradable materials inspired by nature are also being investigated for use as microcarrier materials in the production of cells. Biodegradable microcarriers are less costly and more suited for in vivo use since they don't need to be removed from the body after implantation in order to heal tissue in a clinical environment. To promote tissue regeneration in some applications involving tissue repair and regeneration, cells may need to be seeded or implanted in a substrate that can act as a temporary matrix [10].

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358_IEC24648

# Electrophoretic Deposition of Alumina-Zirconia-CNT Composite Coating for Improved Tribological and Corrosion Properties of Magnesium Alloys

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## INTRODUCTION

Magnesium alloys are renowned for their lightweight nature and high strength-to-weight ratio, making them ideal for aerospace, automotive, and biomedical applications. However, their poor corrosion and wear resistance limit their extensive use. Protective coatings comprising alumina, zirconia, and carbon nanotubes (CNTs) have shown promise in enhancing these properties. Alumina provides wear resistance and improves surface hardness and durability. Zirconia enhances thermal and chemical stability, reducing porosity and improving corrosion resistance. CNTs boost tensile strength and toughness, integrating uniformly with ceramic matrices like alumina and zirconia. This study focuses on using electrophoretic deposition (EPD) to apply composite coatings on magnesium substrates to improve their corrosion resistance, wear properties, and overall performance. By combining alumina, zirconia, and CNTs, the composite coatings deliver synergistic advantages, with EPD enabling the co-deposition of these materials into a uniform and coherent layer.

***Keywords***: *Magnesium Alloys; Electrophoretic Deposition; Alumina, Zirconia; Carbon Nanotubes (CNTs); Wear Resistance*

## METHODOLOGY

Magnesium samples (15 mm × 15 mm) were prepared by polishing with emery papers of grades 120 to 1200. A suspension containing 80% alumina ($Al_2O_3$), 10% zirconia($ZrO_2$), and 10% CNTs was made using ethanol and ball milling for 24 hours. The prepared suspension was subjected to ultrasonic and electromagnetic stirring to ensure homogeneity. EPD was carried out using DC power, followed by sintering at 250°C in a muffle furnace to densify the coatings. Characterizations, including scanning electron microscopy, fretting wear testing, and frictional property assessments, were conducted to analyze the coatings.

## RESULTS

**Figure 1** shows the SEM image of coated magnesium samples exhibited uniform morphology and microstructural integrity. The absence of any significant pores and cracks in the coated samples causes an increase in corrosion and wear resistance of the materials as compared to the bare magnesium substrate. Coated samples demonstrated significantly lower wear rates and reduced material loss compared to uncoated samples. The coefficient of friction was also reduced, indicating smoother surfaces and enhanced performance. The composite coating increased resistance to wear such as adhesive and abrasive wear, crucial for biomedical applications. The wear behaviour of uncoated and coated magnesium alloys are shown in **Figure 2(a)** and **Figure 2(b)** respectively.

The graph in **Figure 1(a)** shows a faster progression in wear depth, reaching 60 μm compared to 30 μm in the **Figure 1(b)**, with no clear stabilization phase. In contrast, the graph in **Figure 2(b)** stabilizes after 800 seconds with significant periodic variations. Finally, the curve in **Figure 2(b)** plateaus, suggesting stabilization of the wear process. This reflects typical fretting wear behaviour with initial asperity removal, steady degradation, and eventual steady-state conditions. This suggests that uncoated magnesium alloy undergoes more aggressive wear while the graph of coated magnesium alloy indicates better wear resistance and steady-state conditions.

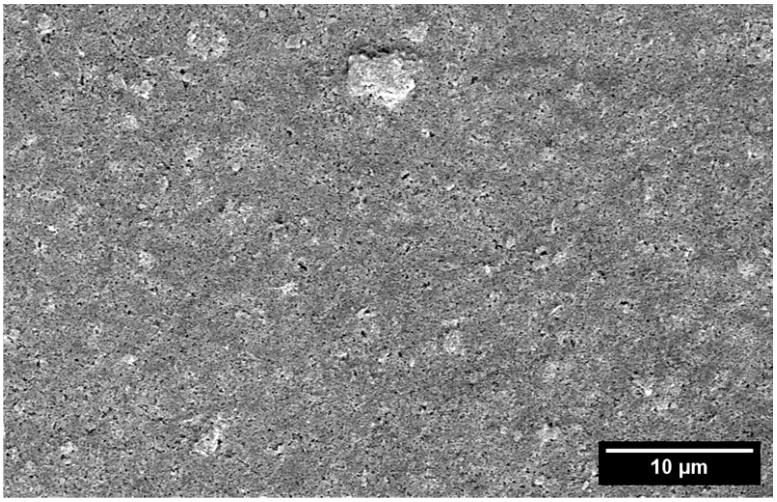


**Figure 1** SEM micrograph of $Al_2O_3$-$ZrO_2$-CNT coated Mg alloy

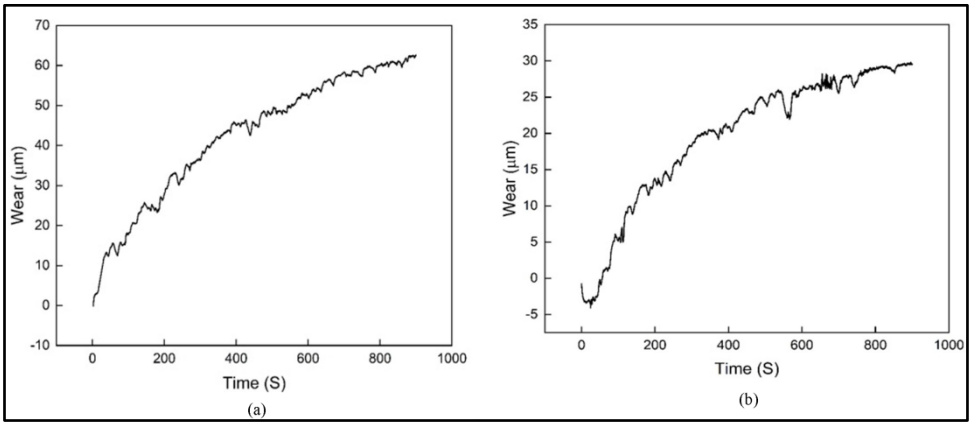


**Figure 2** A plot of wear depth against time for (a) bare Mg alloy (b) $Al_2O_3$-$ZrO_2$-CNT coated Mg alloy

## CONCLUSION

The study successfully developed wear-resistant composite coating incorporating $Al_2O_3$, $ZrO_2$ and CNT on magnesium alloys using EPD. The coated samples demonstrated superior wear behaviour compared to uncoated ones, highlighting the effectiveness of composite coatings in enhancing the durability and functionality of magnesium alloys for potential industrial and biomedical applications. Despite challenges such as scalability and long-term stability, these coatings hold potential for advanced applications in biomedical implants, aerospace, and automotive industries. Future research should focus on optimizing coating compositions and testing their in-vivo performance.

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**Biomedical Science & Technology**

# Biomedical Imaging-Sensing and Instrumentation

18_IEC82925

# Cancer Detection by Integrated Optic Devices: A Digital Signal Processing Approach

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***Abstract**: Digital signal processing and optical communication have an important spin-off in the form of biosensor at improving human health by relaying real-time biometric data. Proposed label-free integrated optic single ring resonator (SRR) with high-Q is designed and analysed to exhibit high sensitivity and high selectivity against five different common cancer cells. The Q- factor in this study varies around 5600. Distinct resonant peaks for different affected blood samples with respect to normal blood sample give an insight on the affected cells. This integrated optic device can seamlessly be integrated with the CMOS ecosystem with distinct advantages in terms of size, weight, power consumption, and cost.*

***Keywords**: Single Ring Resonator; Mason's Rule; Delay Line Signal Processing; Q-Factor; FWHM; Sensitivity*

## INTRODUCTION

Diagnosis, prognosis, and treatment of disease in time may greatly help in reducing human suffering and curing cancer. Death and devastation can greatly be reduced if it is detected at an early stage[1]. Early detection, pretherapeutic responsiveness prediction, and postoperative micrometastasis monitoring are the hallmarks for successful treatment[2]. Integrated photonic devices offer clear advantages in system miniaturisation, reducing weight and power cost in bio-sensing by leveraging the established CMOS manufacturing infrastructure. Photonic structures used for sensing include Fabry-Parot interferometers based ring resonators, photonic crystals are the enabling technologies today. Split ring resonator devices showed sensitivity to the bio-sensing parameters of transmission coefficient magnitude, resonant frequency and loaded Q values, due to the coupling of nano-size biomaterials [3]. The influence of dielectric nanoparticles on the conventional 4-port micro resonator configuration shows great potential to utilize this device as bio-sensor for detecting cancer.

Optical ring resonators based on evanescent field are versatile wavelength-selective passive elements without gain, play a vital role in integrated optics. It can be viewed as an optical transmission system incorporating feedback. The frequency selectivity of an optical resonator makes it useful as an optical filter or a sensor. These kinds of devices are generally characterized by their frequency response which describe the variation of magnitude and phase angles with frequency. Delay line signal processing using z-transform method coupled with linear system theory has been used in this work for analysis of ring resonator based devices.

The proposed bio-sensing platform exhibits high sensitivity(S) and high quality factor (Q). Label free optical bio-sensors provide an easy way of sensing by eliminating the need of the fluorescent levels on analyte molecules, Two sensing mechanisms can be used at output end i.e. the resonant wavelength or frequency shift monitoring or the variation in intensity at a selected wavelength or frequency [4].

In general, the light of a tuneable laser or a super-luminescence diode (SLD) is coupled to the waveguide via grating coupler or by butt coupling. The light is then partly coupled to the ring resonator. If the resonance condition is fulfilled, resonance peaks at the output spectrum results, as illustrated in **Figure 3**. At the output, the light is coupled to a photodetector (PD) or an optical spectrum analyser depending (OSA) depending on the light source used. Current advances in heterogeneous as well as monolithically integration give rise to implement laser and Photodiodes on the same chip together with the photonic sensors [5].

## ON-CHIP MICRO RING RESONATOR DEVICE STRUCTURE AND MATHEMATICAL FORMULATION

The optical ring resonator identifies the intended molecules or biochemical molecules by assessing the change in light behaviour. This change in light behaviour occurs due to the interactivity of evanescent field of the resonating light with bio-samples such as blood, serum, saliva, bacteria, protein or DNA traits present on the surface of the ring resonator. In response to that interactivity; the medium changes the combined or effective refractive index of the bounded bio sample, which leads to a change in the resonance wavelength of the resonator.

Human tissue contains a blend of water and organic compounds. Cancer cells have higher refractive indices than normal cells due to more protein in their cytoplasm. Therefore, detecting the normal and cancer cells is essential enough to make a passable diagnosis sensor. The difference between the refractive index of the normal and cancerous tissues leads to the resonance frequency shift at the optical transmission spectrum of the biosensor [6]. A high quality factor (Q), leads to a significant difference in the transmission diagram due to a small change in the refractive index.

These sensors must be capable of recognizing a small refractive index change of ($\Delta n$) < 0.01% that will shift the resonance wavelength or frequency to recognize cancer cells from normal cells.

(a) **Optical directional couplers and transfer matrix formalism**

Coupling occurs because of overlapping of the evanescent field of one wave guide with the core of another waveguide placed at close proximity as shown in **Figure1(a)**. The lines in **Figure 1(a)** indicate waveguides of finite dimensions. **Figure 1(b)** represents its z-transform equivalent. Here $E^i_1$, $E^i_2$ represent coupler input, $E_1{}^o$, $E_2{}^o$ represent coupler output, $C = \sqrt{1-\kappa}$ is the through port transmission coefficient, $-jS = -j\sqrt{\kappa}$ is the cross-port transmission coefficient and $\kappa$, the power coupling ratio of the optical directional coupler. The interesting relation between these two coefficients is as follows:

$$S^2 + C^2 = 1 \qquad (1)$$

Throughout the analysis it has been assumed that the effective group index is constant and does not vary from its nominal value. It is assumed that no loss occurred at the coupling region and the waveguides are perfectly matched i.e., the propagation constants of coupled waveguides are equal, also the coupling ratio is assumed to be wavelength independent. So the matrix elements are constants.

For an optical directional coupler as shown in **Figure 1**, the relationship between inputs and the outputs can be expressed by 2 × 2 transfer matrix formulation[7]. The transfer matrix of such configuration can be expressed as follows:

$$\begin{pmatrix} E_1^0 \\ E_2^0 \end{pmatrix} = q \begin{pmatrix} C & -jS \\ -jS & C \end{pmatrix} \begin{pmatrix} E_1^i \\ E_2^i \end{pmatrix} \qquad (2)$$

The coupler matrix in (2) has been approximated [4] by the product of an overall amplitude transmission coefficient, q ($0.9 < q < 1$) of the coupler and a unitary matrix.

(b) **Single ring resonator architecture**

This section focuses primarily on 4-port single ring resonator (SRR) architecture. As a single standing wave resonator side coupled to a single waveguide can only pick up half of the signal power at resonance. So, a second straight waveguide, called mirror waveguide is side coupled as shown in **Figure 2(a)** and its z-transform equivalent is shown in **Figure 2(b)**.

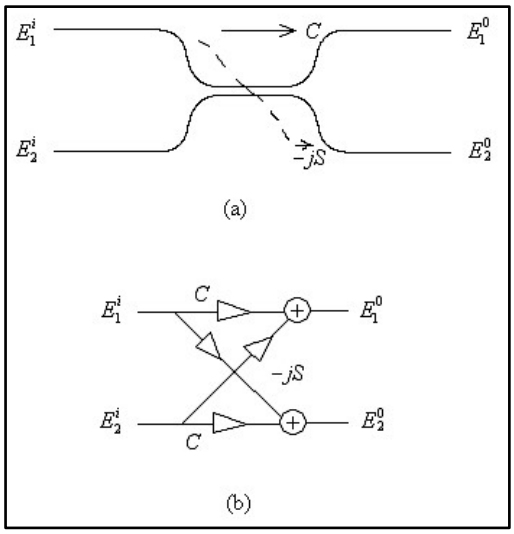


**Figure 1** (a) Schematic of a directional optical coupler, (b) Block diagram model of directional optical coupler

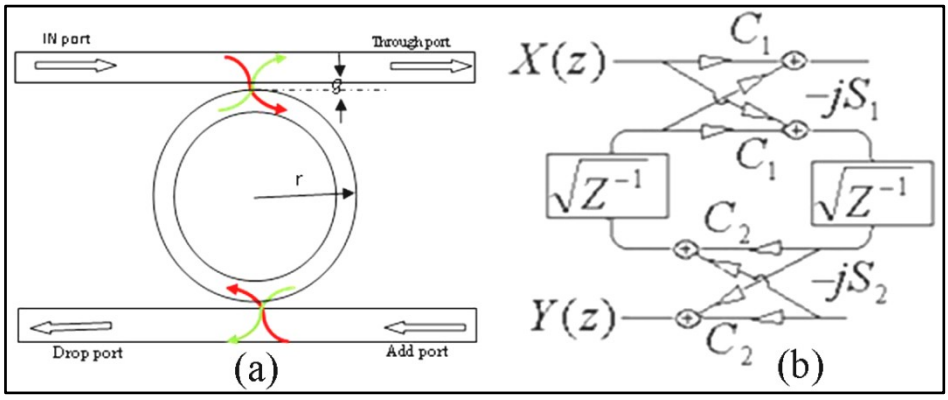


**Figure 2** (a) Configuration of single ring resonator (SRR) with different ports; (b) Signal flow graph (Z-transform equivalent) of SRR

Fiber lengths are capable of providing precise time delays that can be employed to perform the time-delay function. In delay line signal processing technique $z^{-1}$ represent unit delay. Moreover z-transform of the unit delay introduces periodicity over the frequency response and one such period is called free spectral range (FSR). This FSR is the reciprocal of unit delay time (T), so,

$$FSR = 1/T = c / nL_U = c / 2\pi nr \qquad (3)$$

where r is ring radius, c is velocity of light, n is the refractive index (RI) of medium and LU is the unit delay length. Following **Figure 2(b)**, the overall transmittance of the signal flow graph is as follows [8]

$$T_{f1}(z) = -\frac{S_1 S_2 \sqrt{\gamma} z^{-1}}{1 - C_1 C_2 \gamma z^{-1}} \qquad (4)$$

In the expression (4) the round-trip loss γ=exp (-αL), where α is average ring loss per unit length and L is the ring perimeter. $z^{-1}$ is generally known as unit delay in z-domain.

**(c) Single Ring Resonator as Bio-Sensor**

Propagation velocity of light varies inversely with refractive index (RI) of the medium. Accordingly, when light passes through analytes having higher refractive indices than that of air and water it's velocity decreases. Different

blood samples have different permittivity (ε) and according to the relation $\varepsilon = n^2$, where n is the effective refractive index of the medium. Accordingly, transmittance of light wave will be different for different samples attached to the ring resonator assuming that the refractive index of the mass covering the surface of ring resonator is varied according to blood samples. This change at the output in transmission spectra is observed by simulation on MATLAB platform for five different cancer cell lines along with healthy person's blood sample (with n= 1.35) as shown in **Figure 3**.

## SIMULATION RESULTS

The ring perimeter for the proposed device has been assumed as 4 μm, with coupling coefficients $\kappa_1 = \kappa_2 = \kappa = 0.01$. Transmission characteristics were obtained by simulation on MATLAB platform. Obtainable parameters for different blood samples are given the **Table I**.

**Table I** Performance metrics of the proposed device

| Name of cell | Disease | RI (*n*) | FSR= (THz) | FWHM (GHz) | Q- Factor | Sensitivity= S=Δf/Δn THz/RIU | FOM= S/FWHM |
|---|---|---|---|---|---|---|---|
| Normal | Normal | 1.35 | 8.84 | 36 | Reference | Reference | Reference |
| Jurkat | Leukemia | 1.39 | 8.584 | 36 | 5402.36 | 74.75 | 2076.39 |
| HeLa | Cervical Cancer | 1.392 | 8.571 | 35 | 5485.42 | 64.45 | 1790.34 |
| PC-12 | Brain | 1.395 | 8.556 | 35 | 5634.06 | 50.69 | 1448.25 |
| MDA-MB - 231 | Breast Cancer | 1.399 | 8.53 | 35 | 5621.88 | 35.08 | 1002.33 |
| MCF-7 | Breast Cancer 1 | 1.401 | 8.519 | 35 | 5605.83 | 28.20 | 805.60 |

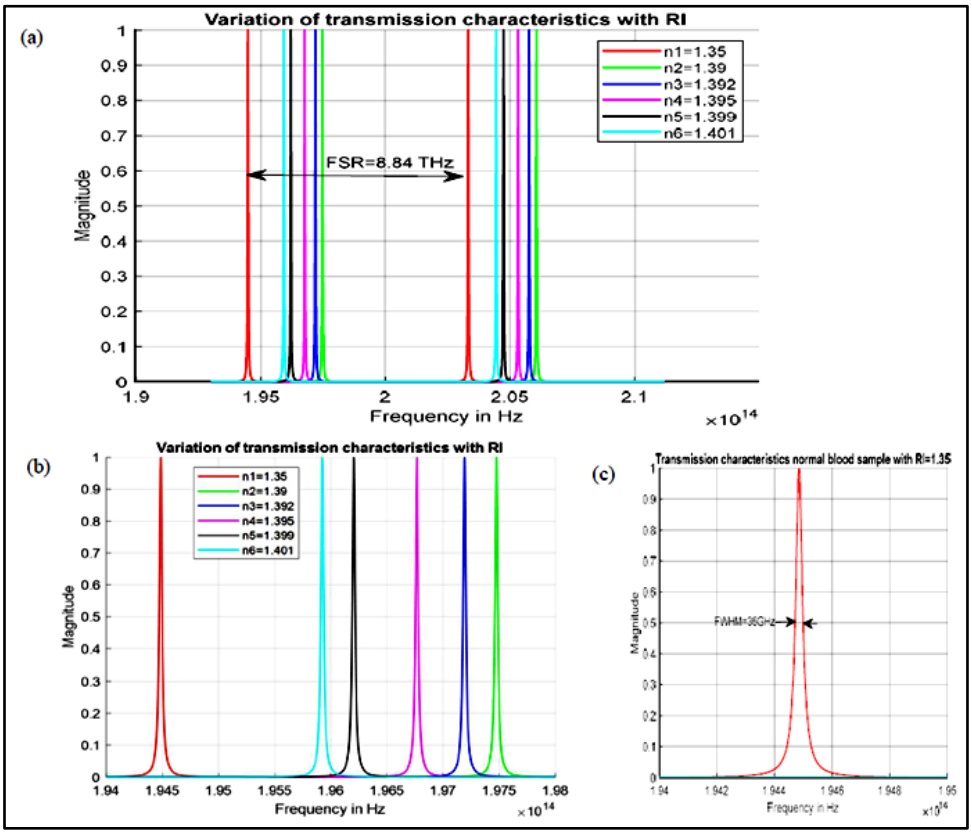


**Figure 3** (a) Repetitive nature of Transmission characteristics of the SRR for finding different parameters, (b) Once cycle of transmission characteristics for showing distinct shift in resonance frequency with different samples of different RI(n) ; (c) Highlighted single peak due to normal blood sample (n=1.35).

## CONCLUSION

From **Figure 3(a)** it is observed that even for a minute change in the refractive indices(Δn) of affected blood samples, the conventional 4-port micro-ring resonator-based bio-sensor provides a distinct change in the resonant frequency (Δf) which means it gives very sensitive results. And this is possible when the quality factor is high. The quality factor in this work is around 5600 depending on the samples being tested. FWHM for all the samples are around 35GHz. Sensitivity is high enough ranging between 400 to 1000 μm/RIU. All these results are comparable to that of [9]. This method of mathematical modelling and simulation is simple and straight forward. Detailed design parameters can be set using FDTD method for optimum results.

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173_IEC50993

# Graphene FET Biochips on PCB for Exosome based Early Screening of Cancerous Cells

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***Abstract***: *Tumor-derived exosomes (TEXs) are particularly significant in cancer, potentially serving as cancer prognostic markers. In recent years, several sensor technologies have been developed for exosome detection, including potentiometric sensors, electrochemical methods, capacitive sensors, fluorescence methods, and surface-enhanced Raman scattering. However, most of them lack the capability to detect at early stage. In this context, field effect transistor (FET) biosensor enables rapid, sensitive and label-free detection approaches. However, most of the FET based devices require sophisticated fabrication facilities which are often not economical. Herein, the work demonstrates a robust, custom-built scalable FET biosensor employing thermally reduced graphene oxide as sensing material designed on affordable PCB platform to achieve sensitive and reliable early detection of exosomes from lung cancer cells. The proposed device has the ability to detect 104 exosomes/ml which is comparable to the detection limit reported by other FET biosensors deploying cost intensive fabrication procedures. This unfolds the potential for effortless translation of graphene FET biochips on PCB platforms which additionally promises clinical translation capability as pre-screening device.*

***Keywords***: *Graphene FET; PCB Biochips; Exosomes; Thermally Reduced Graphene Oxide; Scalable*

## INTRODUCTION

Extracellular vesicles (EVs) are crucial mediators in intercellular communication wherein these membrane-bound vesicles form heterogeneous group, based on size, density and cellular origin. Exosomes are subset of EVs, ranging from 40 to 160 nanometers in diameter. Initially thought to be cellular waste, exosomes are now scientifically recognized as key players influencing various biological processes in health and disease, including cancer. Increasing research shows that tumor-derived exosomes (TEXs) are particularly significant in cancer, potentially serving as cancer prognostic markers [1,2].

Lately, liquid biopsy has emerged as a promising approach for non-invasive cancer detection [3]. The cancer-specific exosomal biomarkers (proteins, microRNA), offers unique opportunity for early detection [4] due to its presence in bodily fluids (blood, urine and saliva) makes them ideal candidates for developing non-invasive liquid biopsy platforms. Integration of such platforms with sensor-on-chip technology presents promising avenue for rapid, sensitive and cost-effective cancer screening tools [5,6] which can quantify and analyze exosomes from small volumes of biological fluids, enabling point-of-care diagnostics. Subtle changes in electrical measurements caused by the interaction of exosomes can potentially distinguish between exosomes derived from cancerous and non-cancerous cells based on their unique biophysical properties, such as size distribution and surface charge.

In recent years, several sensor technologies have been developed to lower detection limits (LOD) for exosome detection, like potentiometric, electrochemical, capacitive, fluorescence and surface-enhanced Raman scattering [7-9]. However, existing methods lack the capability to detect an early stage of cancer. Therefore, a direct, accurate and highly sensitive diagnosis platform with the capability for detection in clinical samples at an early stage is urgently needed. In this context, field effect transistor (FET) biosensor enables rapid, direct and label-free detection approaches besides notable advantages of real-time, ultra-high sensitivity, low power consumption and integrable with other on-chip components [10,11]. Recent research has evolved around several 2D materials like graphene, transition-metal dichalcogenides (TMDs), Mxenes and others [12] with graphene being the pioneer in biosensing application due to its stability towards environmental parameters. Graphene channels, typically achieved by transfer method of chemical vapor deposition (CVD) due to its conformality, are recently investigated for early diagnosis of

cancer based on exosome detection. Apart from being expensive, CVD suffers from surface contamination while its transfer process induces structural defects [13]. To address these setbacks, CVD can be superseded with competitive thermal reduction approach of graphene deposition. Since the thermal reduction method requires modestly high temperature for its deposition, plastics or polymers as substrates are not suitable. Consequently, printed circuit board (PCB) being economical is a promising candidate. Thus, as a point-of-care technology, it is desirable to develop a scalable approach of graphene fabrication which can be batch-produced on an affordable substrate.

Herein, the work demonstrates sensitive and scalable graphene FET biochips for exosome based early diagnosis of lung cancer. Thermally reduced graphene oxide was deposited on PCB by drop-casting graphene oxide solution enabling conformal deposition of graphene. Its only lately that lab-on-chip applications on PCB is gaining significance as the substrate of choice for biosensing applications [14,15]. Recent reports state the design of drain, source and reference electrodes in Ag-plated format or alternatively with a coverage of gold layer. To facilitate immaculate integration with electronics, unmodified copper on PCB is directly utilized as the source and drain electrodes. To combat the impact of Debye screening, exosomes has been extracted in low molar strength of 0.1X PBS buffer. Summarizing, this work demonstrates a robust, custom-built scalable graphene field-effect transistor (FET) biosensor designed on PCB to achieve sensitive and reliable early diagnosis and classification of exosomes derived from lung cancer and healthy cells. This unfolds the potential for effortless translation of FET biosensors into Lab-on-PCB platforms which additionally promises clinical translation capability as pre-screening device.

## MATERIALS AND METHODS

### A. Device Fabrication

A custom PCB design was created using Eagle CAD (Autodesk Inc., USA, v-9.6.2) and was fabricated using commercial PCB etcher (LpkfProtomat S64). The drain-source electrodes are spaced 100 µm apart, and the coplanar gate electrode is positioned 500 µm away from the channel, orthogonally. The substrates were cleaned with acetone and DI water. The gate electrode was modified by applying 1 µL of Ag/AgCl paste (Sigma Aldrich) and dried at 60°C for 1 hour. To obtain reduced graphene oxide (rGO), 10 µL of GO solution (Terracarb Ltd.) was drop-cast onto the channel and annealed at 300°C. For selective detection of lung cancer exosomes, CD91 antibody was immobilized on graphene surface using 5 mM of 1-pyrenebutanoic acid succinimidyl ester (PBASE) (Sigma Aldrich) in dimethyl sulfoxide (DMSO) as linker which was drop-casted onto the channel and incubated for 1 hour, followed by a rinse with phosphate-buffered saline (PBS, Sigma Aldrich). Thereafter it was treated with 10 µL of antibody in PBS for 2 hours, then rinsed with PBS to remove any non-immobilized probes.

### B. Exosome Extraction

A549 cells (human lung adenocarcinoma cell line) were obtained from CNCI, Kolkata, India and cultured in RPMI 1640 medium (Gibco, Thermo Fisher Scientific) supplemented with 10% fetal bovine serum (Gibco) and 1% penicillin-streptomycin (Gibco) at 37°C. Cells were passaged using 0.25% trypsin-EDTA (Gibco) till it reached 80-90% confluence. For exosome extraction, A549 cells were grown in T175 flasks till they reached 70-80% confluence. The medium was then replaced with serum-free RPMI 1640. After 48 hours of incubation, the conditioned medium was subjected to differential centrifugation to isolate exosomes. First, the medium was centrifuged at 300 × g for 10 minutes to remove cells. The supernatant was then filtered through 0.22 µm filter (Millipore) to remove larger vesicles. Exosomes were pelleted by ultracentrifugation at 150,000 × g for 70 minutes at 4°C then washed with PBS and re-pelleted by ultracentrifugation. The final exosome pellet was suspended in PBS and stored at -80°C for future.

### C. Characterization Techniques

Raman spectrum was recorded with 100X objective lens (WITEC UHTS 300) at 785 nm wavelength. Scanning electron microscopy (SEM) (Model No: ZEISS EVO 18) was used to evaluate conformal deposition of rGO on PCB. Successful immobilization of antibodies on graphene was confirmed by measuring fluorescence (Nikon Eclipse Ti U, Japan) of fluorescein isothiocyanate (FITC)-labelled CD91 antibodies with excitation wavelength of 495 nm. The size distribution and Zeta potential of exosomes with 50µg/ml concentration of exosomes diluted in ultrapure water

[16] was analyzed using dynamic light scattering (DLS) with Litesizer 500 Particle Size Analyzer (Anton Paar, GmBH, Austria). FTIR spectroscopy was conducted to analyse the chemical composition of isolated exosomes, recorded using Shimadzu IR FTIR spectrometer (Japan) in the range of 4000-400 $cm^{-1}$ with a resolution of 4 $cm^{-1}$.

### D. Electrical Measurements and Testing Protocol

For achieving reliable and repeatable electrical measurements of the devices, PDMS well was placed around the channel to accommodate the electrolyte and to avoid possibility of any unwanted interaction between the electrodes and analyte. Immediately following functionalization and immobilization of the sensor, electrical measurements were performed in 0.1X PBS to record the rms values of drain-source current as a function of gate voltage. This is followed by extraction of Dirac point. Samples have then been pipetted with exosomes extracted from patient's saliva samples for healthy and infected patients. After 15 minutes of incubation, sensor surface was washed with PBS and tested in the same buffer. Subsequently, the rms value of the drain-source current at the operating point and Dirac voltages have been computed. Total testing time is 30 min that includes the 15 min incubation, and multiple rinsing.

## RESULTS AND DISCUSSION

### A. Structural Characterization

The PCB substrate encompassing the channel region within the source-drain electrodes as obtained from bright field optical microscopy (**Figure 1(a)**) ensures complete removal of copper. The microscopic image of conformal graphene deposition in the sensing region is depicted in **Figure 1(b)** which has also been validated by SEM characterization (**Figure 1(c)**). The graphene quality after deposition was inferred from Raman spectroscopy analysis (**Figure 1(d)**). The ID/IG intensity ratio being greater than 1, bespeaks that reduction from GO to rGO resulted in high D intensity. In addition, the I2D/IG intensity ratio was observed to be of the order of ~0.28, corresponding to 3-4 layers thickness of the graphene layer.

### B. Characterization of A549 Exosomes

The hydrodynamic diameter graph in **Figure 2** shows two prominent peaks at 180 nm and at 650 nm. The 180 nm peak corresponds to typical size of exosomes, while 650 nm diameter is unusually large and indicates the formation of oncosomes (nano-vesicular bodies) or aggregation of exosomes. Zeta potential of -9.5 mV suggests overall colloidal stability, indicating that exosomes are likely to remain dispersed under physiological conditions, minimizing risk of spontaneous aggregation. The FTIR peaks of exosomes correspond to nucleotides (686, 731, 1104 $cm^{-1}$, representing DNA and RNA bases and phosphodiester stretching), lipoproteins (1231-1776 $cm^{-1}$, associated with Amide I, II, and III bonding) and carbohydrates (1004 $cm^{-1}$, linked to C-H bonding). These distinct FTIR signature of exosomes point to their potential use in therapeutic monitoring, particularly in lung cancer diagnostics and treatment.

### C. Electrical Characterization

The variation of drain current (Ids) with gate-source voltage (VGS) has been obtained by establishing VDS at +0.5 V. The characteristics in **Figure 3(a)** for 15 representative devices, reveals a p-doped rGO with mean Dirac point centred around 0.3 V. The fluorescence image shows that significant number of CD91 antibody molecules have been bound to graphene's surface (**Figure 3(b)**). **Figure 3(c)** is a representative of Ids-VGS characteristics for varying A549 lung adenocarcinoma cell line concentration where the molecules being negatively charged affect the local electrostatic field, resulting in rightward shift of Dirac point. **Figure 3(d)** indicates the Dirac point shift and percentage change in Ids at -0.5V VGS for healthy and cancerous cell line concentrations spiked in buffer. It is observed that the standard deviation of both the percentage change in Ids and Dirac point shift in buffer is moderate enough to distinguish 104 particles/ml. It is further observed from real time transient response of **Figure 3(e)** that Ids significantly increases for cancerous cells (without intermediate washing) which act as the proof of distinguishability. Comparison of analytical performance amongst other existing exosomes sensors has been represented in **Figure 3(f)** [17-20].

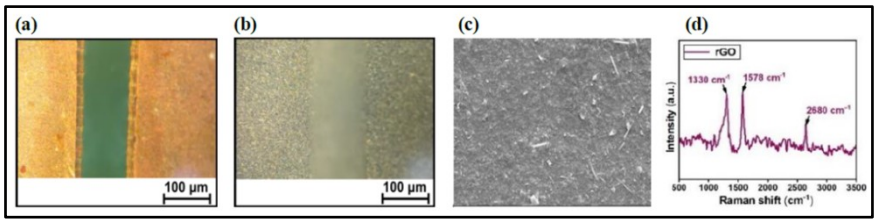


**Figure 1** Bright field optical microscopy of (a) PCB substrate, (b) graphene deposited PCB, (c) SEM image of rGO deposition on PCB, (d) Raman spectra of rGO

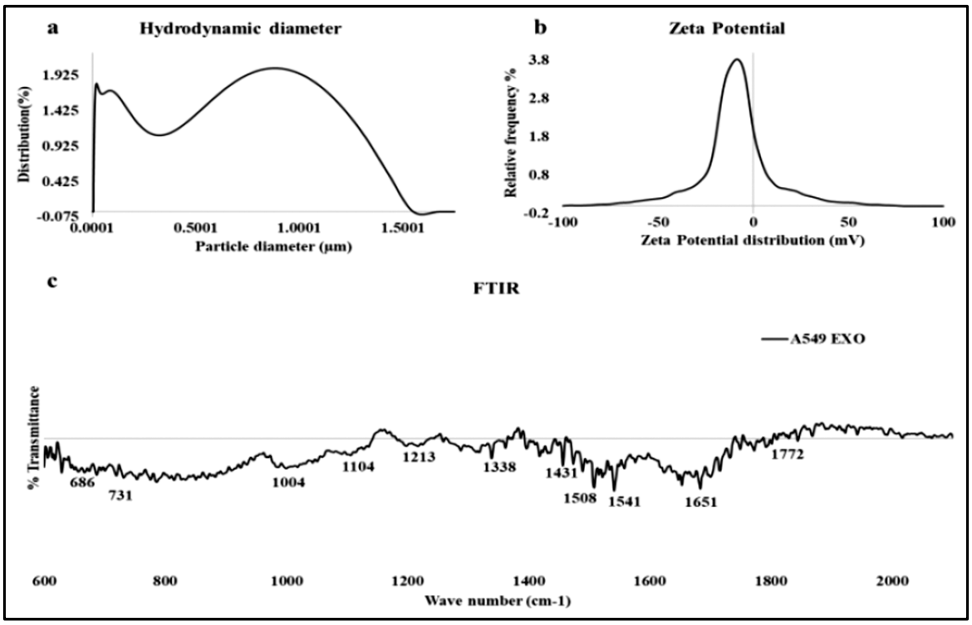


**Figure 2** Characterization of A549 exosomes conducted via (a) hydrodynamic diameter, (b) Zeta potential, (c) FTIR spectroscopy of A549 exosomes

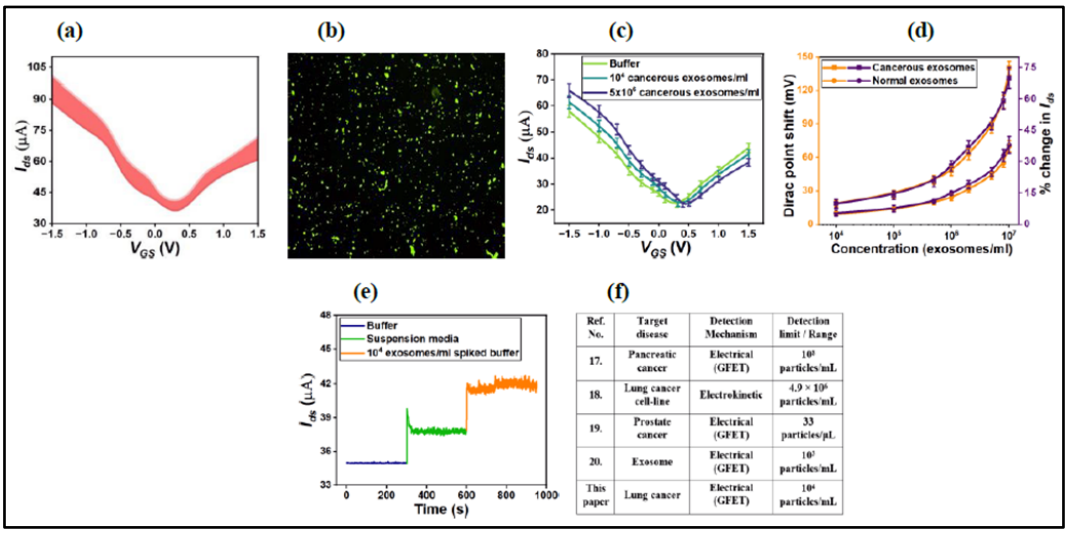


**Figure 3** Characteristics of 15 representative graphene devices, (b) fluorescence image after antibody immobilization, (c) Ids-VGS characteristics for varying A549 lung adenocarcinoma cell line concentration, (d) Dirac point shift and variation of percentage change in Ids with different cell line concentrations spiked in buffer, (e) Transient response of Ids, (f) Comparison with existing literature

## CONCLUSION

In summary, we demonstrate a graphene FET biochip system on PCB for classification of exosomes derived from lung cancer and healthy cells by drop-casting commercially available GO solution on copper plated PCB. To combat the impact of Debye screening, exosomes has been extracted in low molar strength of 0.1X PBS buffer, thereby enabling 104 exosomes/ml which is comparable to the detection limit reported by other FET biosensors deploying cost intensive fabrication procedures. Thus, a point-of-care technology, has been developed in a scalable approach of which can be batch produced on an affordable substrate.

## ACKNOWLEDGMENT

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177_IEC5681

# A Comprehensive Review of Sensors in Medical Application

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***Abstract***: *The healthcare industry is experiencing paradigm shift from conventional healthcare system to healthcare 5.0 standard to provide patent centric service. The healthcare 5.0 standard integrates various technologies such as IOT, Artificial intelligence, Machine learning and cloud computing. One of the requirements of such a healthcare system is reliable sensing solution to accurately measure and transmit the measured data by using IOT technology. The different types of sensors are available for measurement of healthcare parameters. The electronic sensors have proven their usefulness in biomedical applications, but they have limitations to support healthcare 5.0 standard. The electronic sensors are not suitable in radio frequency and electromagnetic based environment which affects the accuracy of measurement. Implanting the electronic sensors with radiating signals is not advisable for continuous monitoring of patients' healthcare parameters. In recent years, remarkable progress has been noticed in development of sensors for clinical diagnosis and treatment. The development of optical fiber sensors have proven the most promising solution for rapidly changing healthcare standard. The optical fiber sensors have compact size, immunity to electromagnetic interference and high sensitivity. The optical fiber sensors are also useful for wearable sensor technology due to its compact size and light weight. The optical fibre sensors have ability to support multiplexed and distributed sensing solution to meet the rapidly changing healthcare standard. This paper reviews the different types of sensors, their working principle, limitations and medical applications.*

***Keywords***: *Healthcare Parameters; Electronic Sensors; Optical Fiber Sensors; Wearable Sensors*

The historical development of different types of sensors used in biomedical application is shown in **Figure 1**. It shows the progress of wearable sensors used for measurement of different parameters such as blood pressure, oxygen level, heart rate and temperature.

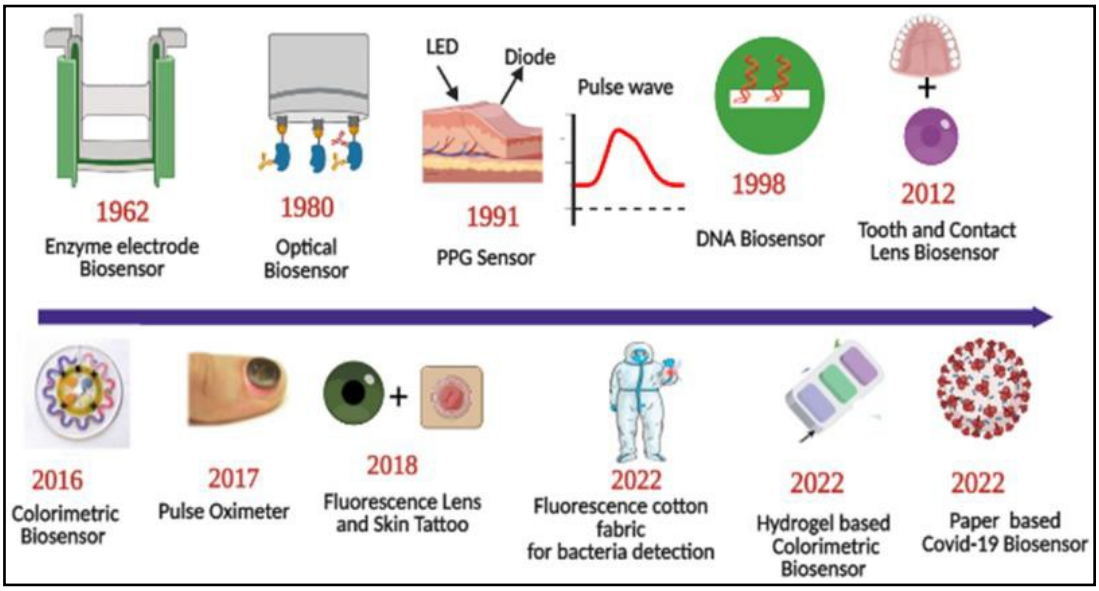


**Figure 1** Advancement in Sensor Technology [3]

The fiber Bragg Garting is type of optical fiber sensor which provides high sensitivity and is useful for precise monitoring of healthcare parameters. It's typical structure is shown in **Figure 2**.

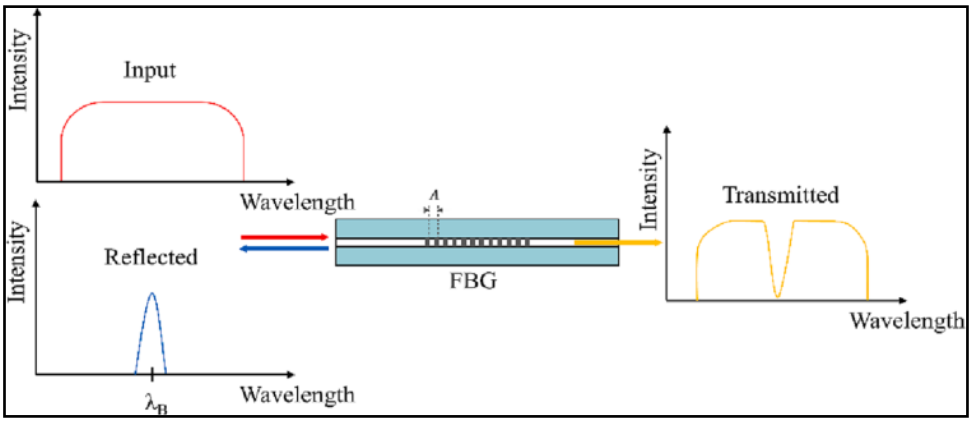


**Figure 2** Fiber Bragg Grating Sensor [4]

## CONCLUSION

The sensor technology plays vital role in development of rapidly changing healthcare systems. The review of different sensors shows that optical fiber sensors are more promising due to its inherent advantages over the conventional electronic sensors. Fiber sensors offer high sensitivity and precision in measurement which is needed for accurate clinical diagnosis. Their compact size and interface capability with existing fiber networks makes them suitable for optical fiber based IOT infrastructure.

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209_IEC3920

# Microwave Imaging: Using Gradient Method and Biconjugate Gradient Methods for Breast Cancer Detection

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***Abstract***: *The reconstruction problem for microwave imaging (using Tomographic method) is investigated in this work using gradient-based optimization and Biconjugate gradient-based optimization. For high-dimensional linear systems design, the incident fields can be resolved for each assessment of the cost function and its gradient, with a significant number of computations. Here we used Biconjugate gradient algorithm, with effective implementations unique to the microwave imaging context. To compare with the conventional gradient method, Biconjugate method computational time savings and get the better resolution, according to numerical experiments conducted on synthetic data set (collected from HFSS) observations. Breast models with cancerous area and without cancerous area (dielectric properties of tissues) are compared with Gradient method and Biconjugate gradient method, the results are quite similar but for Biconjugate methods the accuracy and resolution of images are high.*

***Keywords***: *Microwave Imaging; Gradient Method; Biconjugate Gradient Method; Microwave Tomography; Breast Cancer Detection*

## INTRODUCTION

Cancer is the disease where some cell of the body grows uncontrollably and spreads over to the other parts of the body. These cells form lumps of tissues which are known as “TUMOR” and it is maybe cancerous or not. The woman is affected by breast cancer which has the highest mortality rate. But early detection of cancer can reduce the mortality rate. Every year the affected case is increasing [1,2].

Microwave imaging for breast cancer detection is an emerging technology due to its non-invasiveness and potentially more appropriate alternative for traditional methods like mammogram, ultrasound etc. The technique used with microwave signals to generate images for breast tissues. Low power microwave signals are transmitted into breast tissue. These signals interact differently with various types of breast tissues. The healthy tissues, benign tumour and malignant tumor have different dielectric properties [3-5] and their interactions are different with the microwave signals. The signals that are reflected, scattered, and absorbed by the breast tissue are detected by the antenna system. Then the computed algorithm processes the collected data to reconstruct images. For microwave tomographic processes using different algorithms. For microwave imaging different advantages are there, like non ionizing radiation, non-compressing, and sensitiveness. Microwave imaging systems are still under development and some technical complexities are there. For microwave imaging purposes further research and development are necessary to establish the technology and its clinical utility.

Due to recent developments in computational techniques, numbers of researchers [6,8-14] are currently exploring microwave imaging as a potential low-cost breast cancer screening option. The capacity to both rebuilds and evaluate images using the gathered data is a crucial part of microwave imaging. In this paper data are collected from high frequency simulation software.

The reconstruction problem for microwave imaging is examined with gradient based optimization [6]and many high-dimensional linear systems as there are incident fields that must be resolved for each assessment of the cost function and its gradient, which entails a significant number of computations. Here the biconjugate gradient [7,8] stabilized technique, with effective implementations tailored to the microwave imaging environment, since all such systems require the same matrix. In this paper discuss about these two methods, gradient method and Bi conjugate gradient method and discuss about the results.

## METHODOLOGY

### Reconstruction of Software Dataset

The data set of breast models generated by high frequency simulation software (HFSS). The dipole antenna array is used to scan the breast model at different points. The antenna operating frequency range 1-4 GHz is utilized for scanning. An overview of the model-reconstruction's outcomes shown in Fig1. In this research, the linear antenna array system progressively covered the circular path and it covered one eighty-degree rotation on each side, covered a total three sixty degrees shown in **Figure 1(a)** and **Figure 1(b)** and two sets of data were received. For design purposes we used 36 sources placed on a circle. Each data set made up of 36 measurement points. Then accumulates all the sets of data and computational work is done by two reconstruction algorithms.

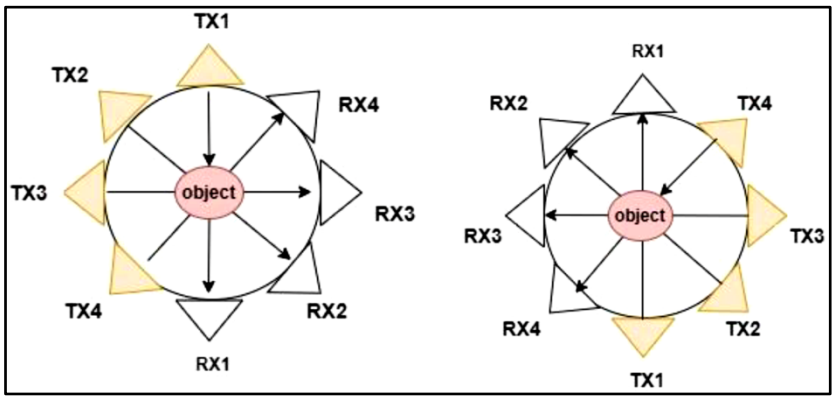


**Figure 1** Schematic diagram of rotating scanning object for receiving and transmitting devices

### Formulation of Reconstruction Algorithm

Different methods are using for tomographic image reconstruction purpose. In this paper using two methods for discussion. The basic flow chart of image formation is given in **Figure 2**.

### Gradient Method

The scaler approximation has been used in two-dimensional microwave tomographic problems. The scattered field

$$\nabla^2 E_{sn} + k^2 E_{sn} = \left(k_0{}^2 - k^2\right) E_{0n} \qquad 1)$$

The incident field $E_{0n}$ is produced by the transmitter number n. Where $k^2 = \left(\frac{2\pi}{\lambda}\right)^2 \varepsilon$ and λ is the wavelength of free space, ε is the complex permittivity of the system, $k_0$ is the wave number without object. $E_n$ is the total field and scattered field $E_{sn} = E_n - E_{0n}$. For computational experiments assume that the transmitters are point sources. The incident field $E_{0n}$ produced by the transmitter is located in the point. For receiver position m, the scattering field is,

$$E_{sm} = \int G_0\left(|r - r_m|\right)\left(k_0{}^2 - k^2\right) E_{0n}(r)\,dr \qquad 2)$$

Where $G_0$ is Green's function for homogeneous space.

Gradient = |Theoratical prediction|−|Experimental prediction| = > min

Here we used Gradient methods for minimizing the values. To solve the problems the first to calculate the value of gradient then go for an iterative process with Equation (2).

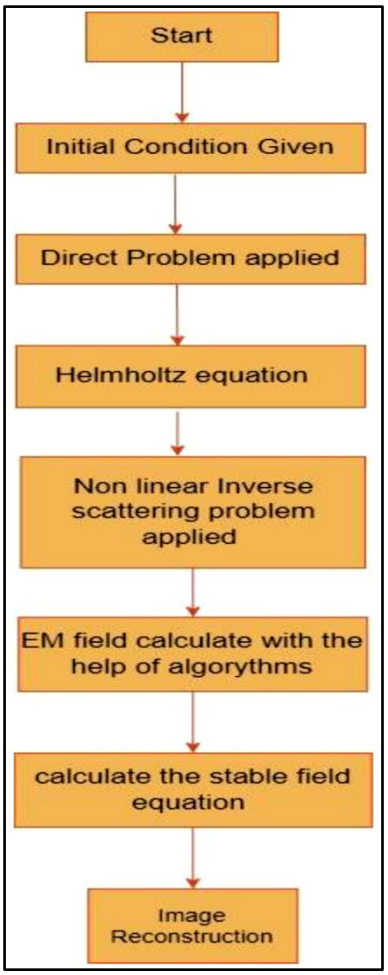


**Figure 2** The Reconstruction process for image formation

**Biconjugate Gradient method**

Microwave imaging using microwave radiation for generating images such as medical imaging, remote sensing, etc. Due to computational complexity one of the challenges in microwave imaging is achieving high resolution images. Biconjugate and block biconjugate reconstruction algorithms are a technique used to address this challenge.

For forward scattering problem at point r,

$$E_{tot}(r) = E_{inc}(r) + k^2 \int G_0(r).\chi(r)E_{tot}(r)dr \qquad 3)$$

Here $E_{tot}$ and $E_{inc}$ are the total electric field and incident electric field respectively and these values are known. k is the wave number for background medium and $G_0$ is the Green's function and $\chi$ is the contrast function depends upon the permittivity of the medium. The observation model is formed with the help of Equation (3).

The scattered field equation at any point r

$$E_{Scat}(r) = k^2 \int G_0(r - r').\chi(r')E_{tot}(r')dr' \qquad 4)$$

**RESULTS**

Microwave imaging technique used tomography process for predication on the distinction of an object's dielectric characteristics. The dielectric characteristics of -biological tissues have great medical importance. Biomedical imaging is very complicated and challenging for data receiving and image processing point of view. In this paper, two

different kinds of algorithms are used in these computational studies. In **Figure 1** shows the schematic structure of receiving-transmitting device for the tomographic imaging experiment with a 2-D breast model. It was operating at 2.4 GHz. The tomographic images are displayed in **Figure 3**, at sagittal position, supine position of the breast model is shown. The immersion medium and the breast are modelled as low-loss media with a conductivity of 0.68 S/m and a dielectric constant of 4.821. The skin layer has a conductivity of 0.68 S/m and a dielectric constant of 37[4,5]. Finite element method simulates each phantom using a distinct source illumination, and measurable fields are obtained.

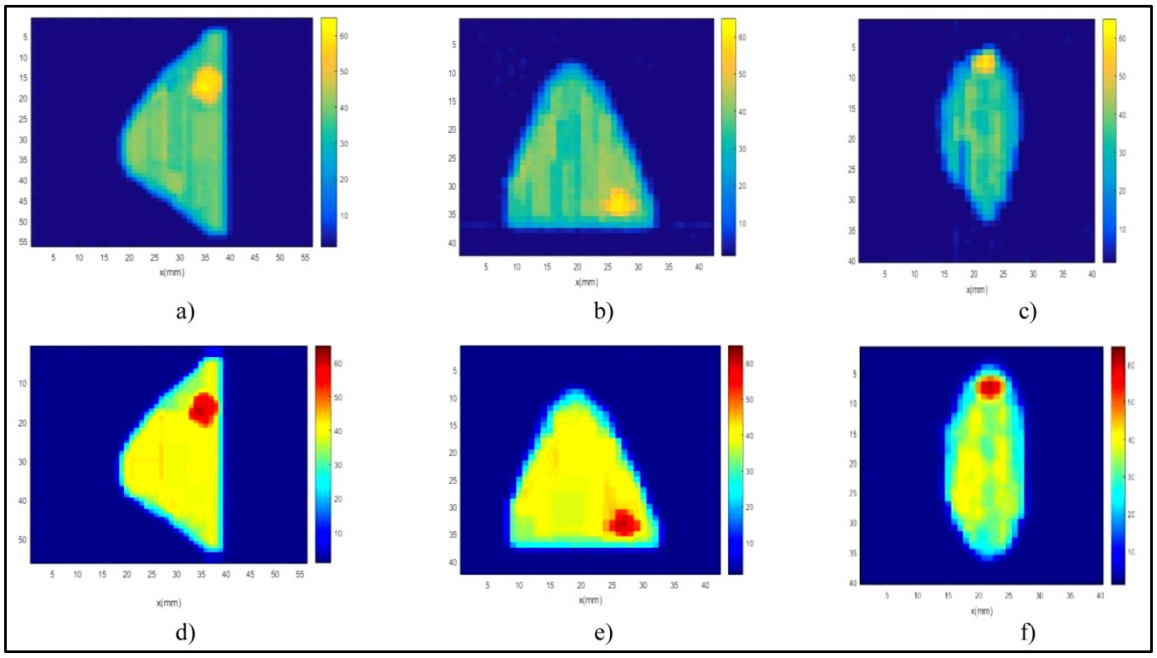


**Figure 3** The Tomographic model of breast with tumour in Gradient method for a) sagittal position, b) supine position, c) top view and the tomographic model of breast with tumour in Bi-Conjugate method for d) sagittal position, e) supine position, f) top view

The cancerous tumor and the different breast tissues also detected in **Figure 3**. For sagittal position in **Figure 3(a)** and **Figure 3(d)** tumour is detected in same location. For supine position infected areas are detected. **Figure 3**(e) in **Figure 3(b)** but more accurately detected by in **Figure 3(**e). **Figure 3**(c) and **Figure 3**(f) represent the results of image reconstruction using position.

## CONCLUSION

The outcomes of our studies on microwave tomography of objects with great similarities are reported in this study. Two-dimensional inverse issues for the Helmholtz equation have been solved using the gradient approach. A variety of two-dimensional microwave tomography geometric configurations were taken into consideration. It has been demonstrated that microwave images of two-dimensional objects can be obtained with just one row of transmitters and it consumes less computational effort. We used dielectric breast models, which are grounded in experimental evidence pertaining to biological tissues. The results displayed here demonstrate that the computational techniques and the research may produce three-dimensional images of intricate objects, including the phantom model.

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229_IEC34826

# An IoT-based Smart Health Monitoring Wheelchair System for Physically Challenged People

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***Abstract**: The research work presents a comprehensive study on an Internet of Things (IoT)-based smart wheelchair that offers complete mobility support in addition to real-time health monitoring, AI (Artificial Intelligence)-driven illness prediction, and a facial expression detection system. In contrast to traditional wheelchairs, our technology incorporates cutting-edge biomedical sensors to continuously track vital signs like blood pressure, oxygen saturation, heart rate, body temperature, and ECG (Electrocardiogram) monitoring. Furthermore, the wheelchair integrates fall detection capabilities and tracks the user's movement patterns to improve safety.*

*The wheelchair has Internet of Things (IoT) capability to enable seamless and smooth data transfer to a cloud-based platform, enabling caregivers and medical professionals to connect with their patients and also to monitor them remotely. It also enables them to create customized care plans, and have virtual consultations. Early diagnosis and predictive analysis are made possible by the AI-powered system used to gathered data to identify possible health problems. With the Internet of Things (IoT) technology installed in this cutting-edge wheelchair, users may have their entire health status tracked in real-time. The goal of this research is to develop assistive gadgets into all-encompassing health management systems rather than just basic mobility aids. This paper covers the creation, testing, and design of the smart wheelchair.*

***Keywords**: IoT; Smart Wheelchair; Predictive Analytic; Assistive Technology; Biomedical Engineering; Preventive Healthcare*

## INTRODUCTION

In today's world of critical technology, the need for a sophisticated healthcare solution on a global scale, particularly for people with mobility limitations, has propelled notable advancements in assistive technology. Conventional wheelchairs have historically helped people to assist in their movements, but they lack integrated health monitoring elements that are essential for people with complicated medical needs[3]. To tackle these difficulties, a more comprehensive approach and robust system is intended to be developed that offers proactive healthcare management, early disease identification, and real-time health monitoring.

To address these vital needs, this research paper presents an IoT-based Smart Wheelchair with Integrated Health-Monitoring Capabilities. It combines IoT connectivity, biomedical sensors, and AI-powered predictive health analytics into a single, all-integrated system. Various embedded sensors have been used and incorporated in the wheelchair to continuously monitors the vital physiological parameters like body temperature, heart rate, blood pressure, and oxygen saturation. It also has advanced system of measuring ECG data with the patients comfortably sitting on the wheelchair. Remote monitoring by caregivers and healthcare providers is made possible by the real-time transmission of these health data to a secured cloud platform via an IoT framework. This makes it possible to take prompt, proactive action to stop serious health events before they get worse.

Our smart wheelchair's AI-driven predictive analytics system is a significant innovation. This AI drive system analyzes the user's health information based on the data collected by our bio-sensors. The system is then trained to look for unusual patterns and anticipate possible illnesses before they become life-threatening, like cardiac arrests or breathing problems. Incorporating machine learning algorithms, the system provides individualized health insights that help preventive care and lower the risk of emergencies. Further on enhancing user safety, the wheelchair also has fall detection technology installed, which guarantees that caregivers receive instant alerts in the event of an accident[7].

## METHODOLOGY

The studied IoT based smart wheelchair has been integrated with various hardware sensors systems, AI driven predictive analysis system and IoT based Communication system. All of it has been methodically combined with its hardware design, software integration, data processing, and networking for efficient performance. The approach is broken down into multiple crucial phases to guarantee that the system functions properly and satisfies the needs of both mobility and healthcare.

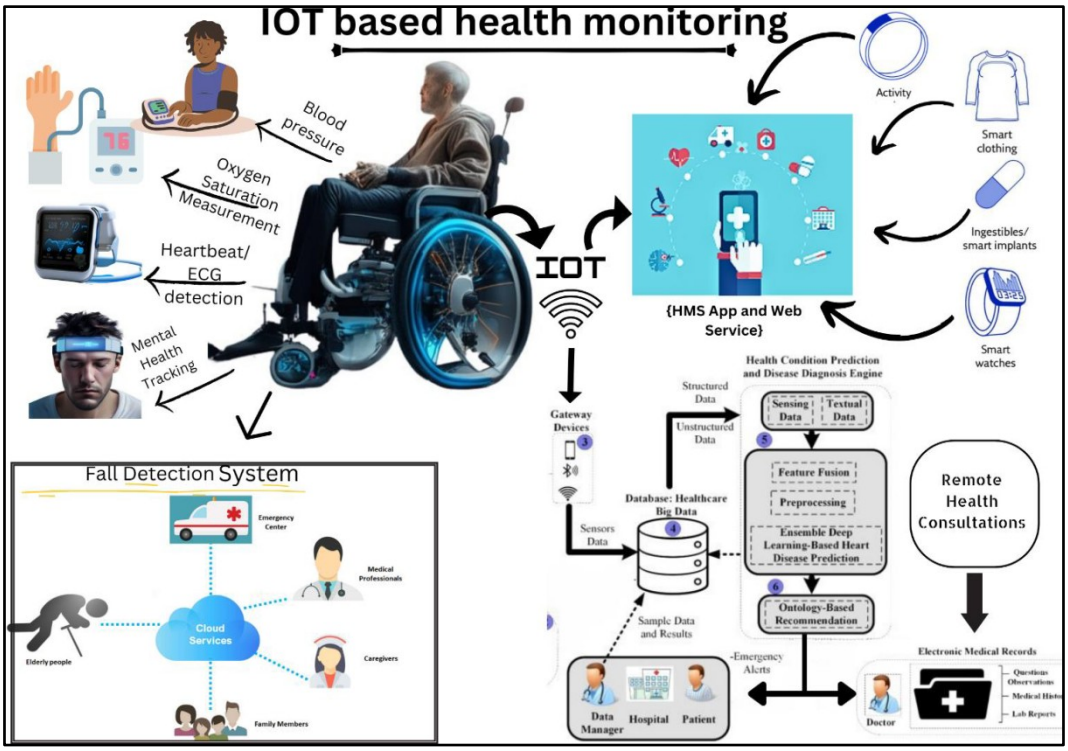


**Figure 1** Schematic block diagram of the proposed model

### System Architecture Design

• The smart wheelchair is powered by a host of sensors, heartbeat pulse sensor, pulse-oximeter ($SPO_2$) as an framework architecture of the smart wheelchair is made to seamlessly integrate with variety of parts, such as power management systems, motor control units, micro controllers, biomedical sensors, and communication modules.

To continuously monitor the user's health metrics, key sensors like blood pressure, oxygen saturation ($SpO_2$), heart rate, body temperature, ECG sensor, saline-bottle monitoring system, and accelerometers (for fall detection) are strategically placed [1][2] but the comfort of the user has been taken care of.

• A central processing unit collects data from sensors and makes sure that different modules communicate with each other smoothly. This can be a micro-controller Arduino Development Board or a single- board computer like the Raspberry Pi [3].

### Sensor Integration and Data Collection

• Real-time physiological data collection is done with the use of biomedical sensors. The selection of these sensors is predicated on their accuracy, dependability, and appropriateness for non-invasive health monitoring.

• The wheelchair is also equipped with gyroscopes and accelerometers to track the movement for mobility tracking, and accelerometers pick up on any unusual shifts that might point to a fall [4]. These sensors continuously gather data, which the micro controller processes locally.

**IoT Connectivity and Cloud Integration**

• The wheelchair is equipped with IoT communication modules, such as Wi-Fi or Bluetooth, to transmit health and mobility data to a cloud-based healthcare platform.

• The communication protocols incorporated is through secures transmission protocols. Which can be connected to the internet facility so that the family members or the medical attendee of the users can be updated with regular health-status.

**AI-Based Predictive Analytics**

• Predictive health analysis in the cloud platform is enabled by an AI-driven system. The gathered health data is analysed by machine learning algorithms, especially those that concentrate on time-series data and anomaly detection, to forecast possible health risks.

• The AI model can recognize early warning signs for conditions like cardiovascular diseases, respiratory problems, and other chronic health issues because it was trained using historical data on a variety of health conditions.

• When anomalous patterns are detected, the system sounds an alarm to guarantee early intervention.

**Fall Detection and Emergency Alerts**

•The accelerometer-based fall detection system continuously monitors the wheelchair user's movements. In case of abnormal patterns indicating a potential fall, an alert is sent to the cloud platform, triggering notifications for care givers and emergency services [5].

• It is equipped with an GSM/GPS module that is used to send accurate location coordinate of the user and also could send an SOS to the family members once the sensors are triggered.

is block diagram represents several modules, IoT interconnection and also AI system analysis for our smart Wheelchair[6].

**RESULTS AND DISCUSSIONS**

The proposed IoT-based smart wheelchair was designed, implemented, and tested in both simulated and real- world environments to evaluate its performance in terms of mobility assistance, health monitoring, and predictive healthcare mentioned in **Table 1**. The results demonstrate the system's effectiveness across several key parameters, including real-time health data acquisition, transmission reliability, AI-based prediction accuracy, and energy efficiency. We have also taken care of the potential implications for user health and safety. A detailed analysis of these results is provided below. Our model prototype has been shown in **Figure 2** and **Figure 3**. On conducting trials with 50 users over four months, we have demonstrated real-time data on wheelchair performance and health metrics. This trial gave us an idea about the effectiveness of our system and also its capabilities to serve several users in real time. Evaluation of the accuracy of the health metric data has been surveyed by calibrating it with present medical-graded devices such as a market-available Pulse-Oximeter, Blood-Pressure machine, temperature monitoring system and also Pulse-rate measuring devices. On conducting several trials over 100 times we have concluded with the findings of our system accuracy of about 93% with a 12% deviation.

Our systems AI prediction systems has also been analyzed with a dataset from the MIT BIH data bank [8]. On analysis of the digitized recorded data, we have achieved an accuracy pattern of prediction rate of 92%. Primarily tested on ECG Arrhythmia detection consisting of 360 samples per second per channel with 11-bit resolution over a

10-mV range. We have also tested with PPG (Photo plethysmography) data [9] to validated the sample prediction of SPO2, pulse level and other vital factors.

**Figure 2** and **Figure 3** both give the real pictorial representation of our prototype. **Figure 2** also represents the portability and the compact size of our prototype which can be installed and can be fitted very easily in a wheelchair. It's easy to use and compact size is also a key differentiating factor among other existing health monitoring systems. **Figure 2**. demonstrates an application user interface (UI) of our Customized application for user use, to give a visual representation of the health analysis.

**Table 1** Result Summary Analysis

| Parameter | Result | Analysis |
|---|---|---|
| Real-time health monitoring accuracy | ±12% deviation from medical-grade devices | Highly reliable for continuous health tracking |
| IoT data transmission delay | <1.5 seconds | Ensures real-time data access and minimal latency |
| AI prediction accuracy | 92% | Effective in early detection of health risks |
| Fall detection sensitivity | 90% | High accuracy in detecting falls and triggering alerts |
| User feedback | Positive usability, intuitive interface | User-friendly and practical for everyday use |

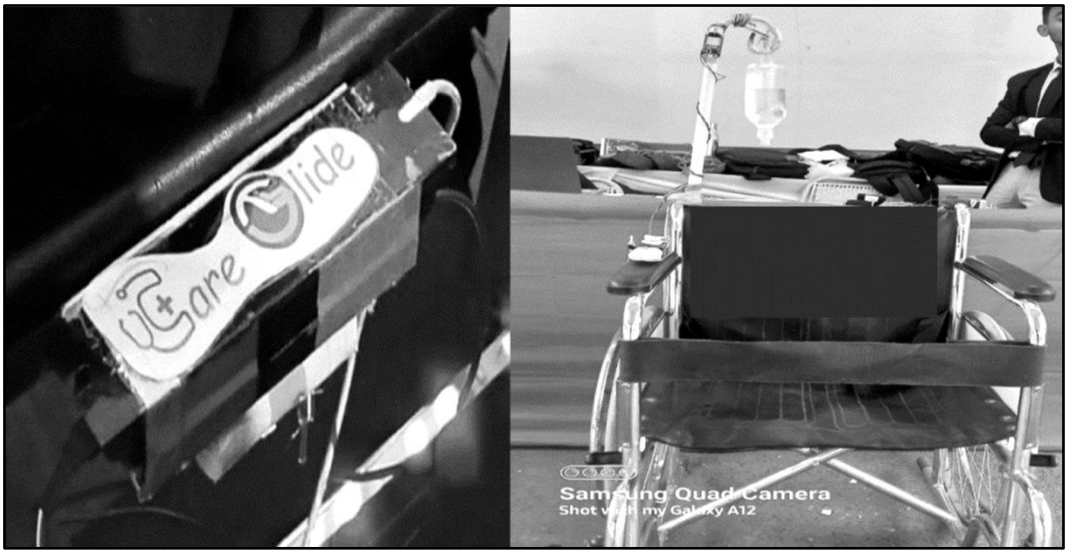


**Figure 2** Proposed Prototype

## CONCLUSIONS

This work has been successfully designed, and tested in a real-time environment. This work aims to develop a device that can be a reliable assistance to Wheelchair Dependent Patients. IoT and sensors accomplished the project.

The product solves the problem of the absence of a regulated personal health monitoring system for patients. The use of sensor technology makes it an innovative solution for patients and their family members.

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322_IEC2424

# Container Filling System for Radioactive Materials

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***Abstract:*** *The present paper relates to systems for filling containers with radioactive and/or other types of potentially hazardous materials. The systems include a shielding material that substantially defines a chamber that substantially blocks radioactivity, a conduit extending from outside to into the chamber, and a unit that is disposed in the chamber proximal to the conduit and is adapted to receive a capsule through the conduit.*

*The container filling system specifically comprises: a. a dispensing chamber that is made of a shielding material, and having:*

*(i) a first side opening;*
*(ii) a second side opening;*
*(iii) at least one rod inside the dispensing chamber that vertically extends outside and above the dispensing chamber for manipulating the position of a syringe that is located inside;*
*(iv) a chute manipulator extending vertically inside and outside the dispensing chamber for sliding a capsule inside the dispensing chamber;*
*(v) a capsule securing unit having at least one receptacle has a size adapted to tightly receive a capsule that has slid inside the dispensing chamber; and*
*(vi) (a) shielded window for allowing a user of the system to see the syringe and capsule securing unit;*
*(b) a loading chamber that is made of a shielding material, and having a first side opening and second side opening, the second side opening is in communication with the first side opening of the dispensing chamber, the first side opening provides access to a user hand for introducing a material;*
*(c) a sliding door for alternatively closing and opening the first side opening of the dispensing chamber and therefore closing communication with the loading chamber;*
*(d) a door for alternatively closing and opening the second opening of the dispensing chamber;*
*(e) a syringe controller for controlling the syringe;*
*(f) a computer that activates the syringe controller; and*
*(g) a waste container located at a level within the system that is lower than a level at which the dispensing chamber or the loading chamber are located within the system, wherein the waste container is made of or surrounded by a shielded material and comprises a first waste chute interconnecting the dispensing chamber or the loading chamber to the waste container and allowing waste material to slide into the waste container.*

***Keywords***: *Radiopharmaceuticals; Radiochemistry; Syringe; Shielded Cells; Diagnostic Equipment*

## INTRODUCTION

A number of scientific uses require relatively small aliquots of radioactive materials. For example, nuclear medicine employs solutions of radioisotopes, such as Technetium-99m, Iodine-123, Iodine-125, Iodine-131, Phosphorous-32, Indium-111, Cobalt-57, and Chromium-51, as radiopharmaceuticals or as radioactive tracers. These radioisotopes typically are measured and dispensed for use. However, for safety reasons, it is highly desirable that the technician responsible for measuring and dispensing radioisotopes be exposed to minimal radioactivity. It is also desirable in some instances that the actual radioisotope doses be empirically determined in terms of radioactivity.

## METHODOLOGY

The methodology used in this disclosure provides systems for filling containers with radioactive and/or other types of potentially hazardous materials. Preferred systems are those that deposit one or more radioactive materials in relatively small containers such as capsules or small vials. Such systems typically comprise a shielding material that substantially defines a chamber and substantially blocks radioactivity, a conduit extending from outside to into the

chamber, and a unit that is disposed in the chamber proximal to the conduit and is adapted to receive a capsule through the conduit. The systems comprise a syringe, a syringe controller that is disposed in the dispensing chamber and adapted to meter an aliquot from a radioactive stock solution and inject the aliquot into the capsule or a vial; a computer for receiving user's inputs and having a memory that activates the controller. The systems further comprise a tapered guide lid that is positioned over the radioactive stock solution to guide the needle of a syringe.

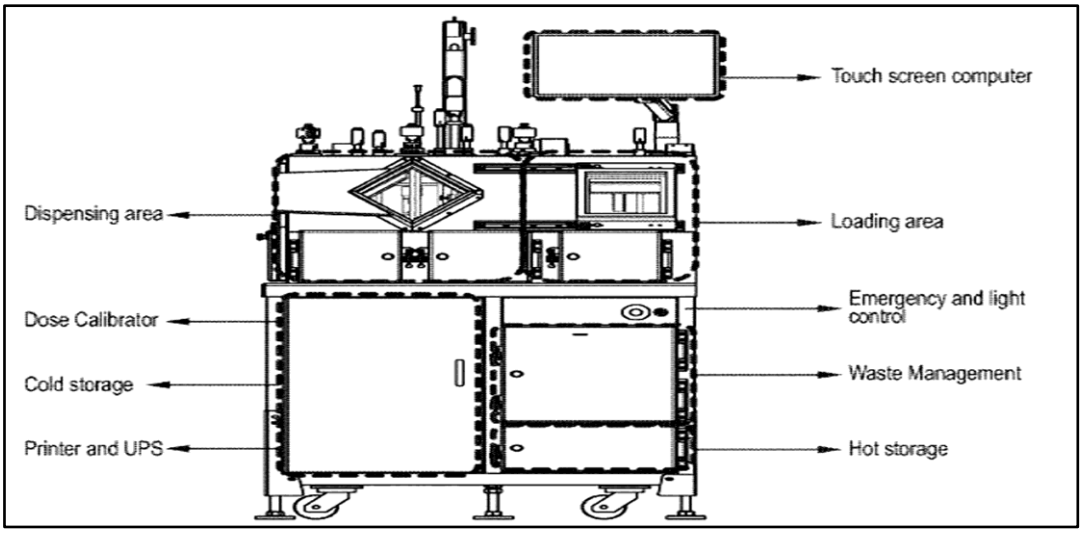


**Figure 1** Perspective view of the container filling system

**RESULTS**

As a result of methodology and container filling system devised, the present disclosure provides systems for filling containers with radioactive and/or other types of potentially hazardous materials. The materials may include chemicals and biological agents but of particular interest are those that emit one or more radioactive species. Radioactive solution that can be dispensed by the system of the present disclosure, includes Technetium-99m, Iodine-123, Iodine-125, Iodine-131, Phosphorous-32, Indium-111, Cobalt-57, and/or Chromium-51.

The devised container filling system comprises a dispensing chamber that is made of a shielding material, and that has a first side opening, a second side opening, at least one rod inside the dispensing chamber that vertically extends outside and above the dispensing chamber for manipulating the position of a syringe that is located inside, a chute manipulator extending vertically inside and outside the dispensing chamber for sliding a capsule inside the dispensing chamber, a capsule securing unit having at least one receptacle has a size adapted to tightly receive a capsule that has slid inside the dispensing chamber, and a shielded window for allowing a user of the system to see the syringe and capsule securing unit; a loading chamber that is made of a shielding material, and having a first side opening and second side opening, the second side opening is in communication with the first side opening of the dispensing chamber, the first side opening provides access to a user hand for introducing a material; a sliding door for alternatively closing and opening the first side opening of the dispensing chamber and therefore closing communication with the loading chamber; a door for alternatively closing and opening the second opening of the dispensing chamber; a syringe controller for controlling the syringe; a computer that activates the syringe controller; an entrance tray that moves between an internal position that is completely inside the dispensing chamber and an external position where at least one portion of the entrance tray is in the loading chamber; and an exit tray that moves between an internal position that is completely inside the dispensing chamber and an external position where at least one portion of the exit tray extends outside the second side opening of the dispensing chamber.

The system also provides a waste container that is surrounded by a shielded material and comprises a waste chute for sliding waste material in the waste container, said waste container comprises at least 2 compartments that are upwardly opened, and the waste container can pivot around a vertical axis in order to place one compartment vis-à-vis the duct for receiving the waste material. Preferably, the waste container has a controller for controlling the rotation

of the waste container around the axis, wherein a computer causes the controller to rotate the waste container so that one compartment is vis-à-vis the first duct or the first and second ducts during a pre-determined period, which is pre-determined such that, upon one full rotation, a compartment contains waste material that has completely decayed.

The system also contains a ventilation system for a container filling system that creates a negative pressure in all the chambers of the container filling system, wherein each door of said chambers does not hermitically close. When active, this ventilation system results in a continuous entrance of ambient air into the container filling system. The ventilation system preferably comprises replaceable filters.

The system also provides a container filling system that has a dispensing chamber equipped with a replaceable floor for ease of decontamination.

The system also provides a container filling system adapted to manage two different radioisotopes by providing two dispensing chambers, and two loading systems.

The systems of the disclosure include a chute manipulator extending vertically through the shield material into the dispensing chamber. Chute manipulators according to the disclosure are substantially hollow structures that supply a pathway for introducing containers to the chamber. Containers that pass through the chute manipulators are preferably capsules or part of capsules. The chute manipulator may be made from any suitable material such as, for example, lead, tungsten, and other metals and allows that provide an effective barrier to radioactive species. In cross-section, the chute manipulator may have any shape, provided that the shape allows the container to pass through the chute. Preferably, the shape of the chute manipulators substantially corresponds to the shape of the container. In certain embodiments of the disclosure, chute manipulators can be interchangeable such that each is adapted for use with specific containers. In certain embodiments, the chute manipulator is treated (as, for example, with a lubricant) to reduce friction. A rod that is adapted to pass through the chute manipulator and engage the capsule may be provided. This rod may be used to tamp on half of a capsule onto its other half located in the securing unit. Preferably, the capsule is composed of an external capsule and an internal capsule filled with a pharmaceutically absorbent material for adsorbing an aliquot of radioactive solution. The internal capsule is made of a material that can be punctured by the needle of the syringe without collapsing or changing its overall shape. When filling a capsule, a user preferably inserts a capsule that has its top half of the external capsule being removed; injects an aliquot of radioactive solution inside the internal capsule by means of the syringe and the syringe controller; inserts top half of the external capsule; and tamp said top half on the lower half of the capsule with the rod adapted to that effect.

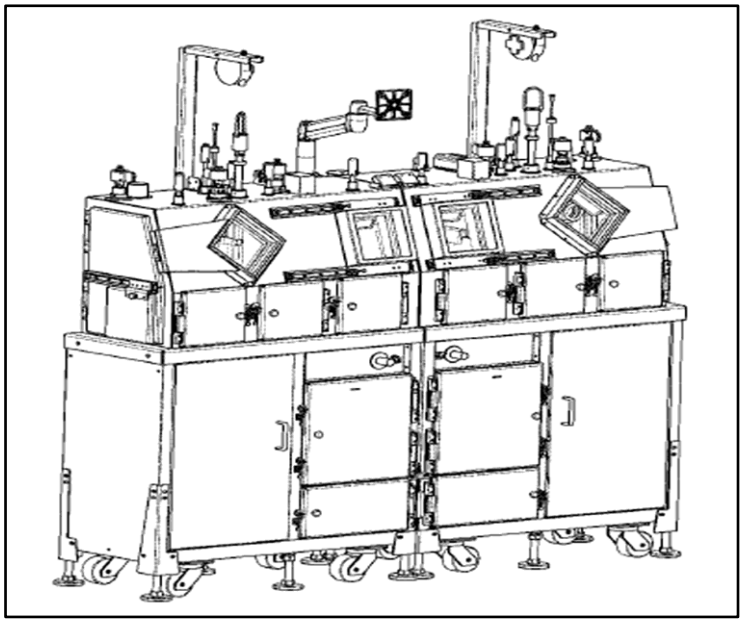

**Figure 2** is representative of container filling system

The systems of the present disclosure also include a securing unit that is disposed in the chamber underneath the chute manipulator and is adapted to receive a container through the chute. Securing units according to the disclosure generally are capable of receiving at least one container and, preferably, more than one container. The securing unit is preferably a carousel or a portion of a carousel that may rotate to receive several capsules, one after the other, after having rotated the carousel about a vertical axis and without moving the chute manipulator. The portion of the securing unit that receives the container preferably has a shape that corresponds to the shape of the container. Metering of the aliquot can be effected through operation of a controller. The computer may also be used to achieve a certain dosage. For example, if the concentration of stock solution is provided, the computer may calculate the volume required to attain a certain radioactive dose. Moreover, if a dosage of a certain radioactivity will be required for administration later, for example, two days later, the computer can account for the radioactive decay rate by dispensing an aliquot which has a radioactivity greater than the desired dosage by an amount representing the decay factors occurring over the time between dispensing and administration.

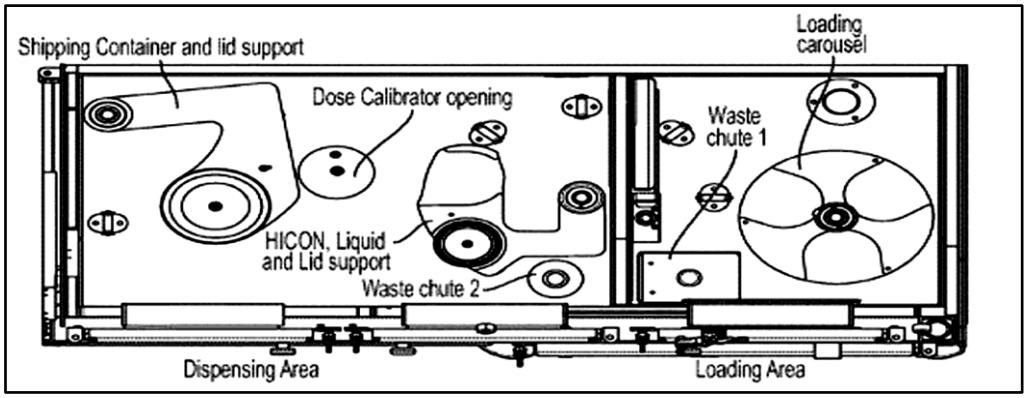


**Figure 3** presents top view of cross-section of a dispensing chamber and the loading chamber showing a rotary platform, an entrance tray, an exit tray and the floors of both chambers

## CONCLUSION

The container filling system significantly improves safety, efficiency, performance, or usability compared to existing solutions. Radioactive solution that can be dispensed by the system of the present disclosure Technetium-99m, Iodine-123, Iodine-125, Iodine-131, Phosphorous-32, Indium-111, Cobalt-57, and/or Chromium-51. The devised system is suitable for dispensing two different radioisotopes, for example I-131 and I-123, and preventing any contamination of one radioisotope when dispensing another radioisotope. This innovation is expected to have significant applications and benefits, potentially transforming industry practices.

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346_IEC99079

# Leveraging Force-Sensing Technology for Personalized LBP Care: A Scoping Review

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***Abstract***: *Low back pain (LBP) remains a significant global health burden. This review explores the potential of non-invasive force-sensing technology to revolutionize LBP diagnosis and treatment. By accurately measuring abdominal wall tension (AWT) and intra-abdominal pressure (IAP), force sensors offer a promising avenue for personalized rehabilitation strategies. Existing studies demonstrate the feasibility and reliability of force-sensing techniques in assessing core muscle activity and spinal stability. However, further research is needed to validate their clinical utility in LBP patients, establish standardized protocols, and address ethical considerations. Future directions include integrating force-sensing with biomechanical modeling and patient-reported outcomes to optimize personalized LBP care. The adoption of non-invasive force-sensing technology holds the potential to transform LBP management by providing objective, real-time data for tailored interventions and improved patient outcomes.*

***Keywords***: *Abdominal Wall Tension (AWT); Intra-abdominal Pressure (IAP); Force Sensor; Core; LBP*

## INTRODUCTION

### LBP and Precision

Low back pain (LBP), a widespread global health issue, significantly impacts individuals' lives and productivity [1-2]. With recurrent episodes often leading to chronic pain, LBP poses a formidable challenge for both individuals and healthcare systems [3]. Even after the initial pain fades, LBP frequently returns, creating a frustrating cycle of discomfort and disruption [4]. To tackle analgesic overuse and improve LBP treatment, technology must focus on non-drug therapies. The WHO's Rehabilitation 2030 initiative offers a path to better care for millions worldwide [5]. Sensing-based technology's unparalleled precision in data collection necessitates future research to identify optimal modalities and outcome measures, fully realizing its transformative potential [6-10]. Sensor-enabled personalized care for LBP can help reduce reliance on medications, leading to better patient outcomes.

### The Power of AWT and IAP for Spinal-Stabilization

The interplay between abdominal wall tension (AWT), and intra-abdominal pressure (IAP), is crucial for spinal stability. AWT, a force-generated component by the abdominal muscles, and IAP, created by the interaction between the abdominal wall and viscera, work synergistically to support and protect the spine [11-13]. This dynamic unit, influenced by the intricate anatomy and biomechanics of the abdominal wall as the core (abdominal muscles) and the myofascial connector [12], is pivotal in maintaining spinal health and preventing low back pain.

### Examining the Evidence: AWT and LBP

Non-invasive AWT force-sensing systems have the potential to revolutionize LBP rehabilitation. Sensor technology integrated with Laplace's law provides a deeper understanding of the valuable insights into the relationship between AWT, IAP, and the core's potential role in spinal stability. This approach offers a more practical alternative to invasive methods, which are often limited by their clinical use[11][12][14-16]. Unraveling the LBP enigma necessitates over-traditional, a novel approach using force-sensing to explore the AWT connection.

## METHODOLOGICAL APPROACH FOR SENSOR-BASED AWT AND LBP RESEARCH

A comprehensive literature review was conducted across multiple electronic databases (PubMed, CINAHL, Cochrane Library, Scopus, and Web of Science) to identify relevant research articles published in English between 2008 and 2023. These databases were selected for their extensive biomedical and health sciences literature coverage. To

enhance the search's comprehensiveness, reference lists of included studies were manually searched. A systematic search strategy was developed using a combination of MeSH (Medical Subject Headings) terms and keywords. The following keywords were employed: 'AWT,' 'IAP,' 'force sensor,' 'Core,' and 'LBP.' Logical operators (AND, OR, NOT) were used to refine the search results.

**RESULTS**

Van Ramshorst et al. [14] [15] conducted two studies investigating the relationship between AWT and IAP. The first study measured AWT in cadavers and found a strong correlation with IAP. The second study expanded on this by examining both cadavers and living subjects, further confirming the correlation and identifying specific measurement sites. These groundbreaking on intra-abdominal pressure (IAP) and low back pain (LBP) offer a promising non-invasive tool for clinical assessment. While initial cadaver studies laid the foundation, future research should focus on living subjects, considering the impact of muscle activity on IAP measurements. By combining biomechanical modeling, patient-reported outcomes, and clinical trials, we can validate the effectiveness of IAP assessment in LBP rehabilitation and develop more targeted treatment strategies. Chen et al. [17] introduced a novel technique for non-invasive monitoring of IAP by measuring AWT. The thrust-meter was positioned vertically against the abdomen, and the force required to displace the wall was recorded. The AWT was calculated as the force divided by the displacement. In **Figure 1** [17] the device was in contact with a specific anatomical landmark (C). The resulting vertical displacement of the abdominal wall sag (X) was recorded. AWT was calculated as the ratio of thrust to displacement (N/mm). The study demonstrated a strong correlation between these two variables, suggesting AWT is a reliable indicator of IAP. Sensor-based technologies offer non-invasive, real-time monitoring of physiological parameters, providing valuable insights for healthcare and research.


**Figure 1** Force-sensing used by muscle Chen et al. [17]

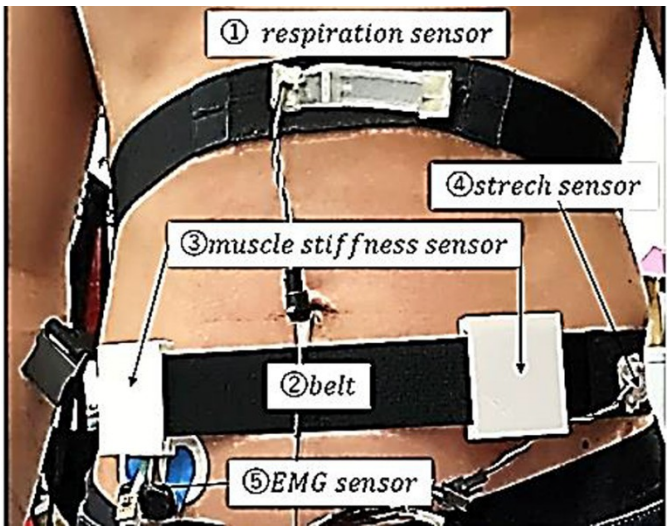


**Figure 2** The device has sensors for respiration, stiffness, stretch, and EMG [22]

In a study [18] the Ohm Belt, a non-invasive capacitive force sensor, was introduced to measure abdominal muscle activity. It revealed differences in upper and lower abdominal muscle activation and accurately captured changes under various loading scenarios and breathing patterns. Studies [19][20] have demonstrated a strong correlation between AWT measured by the DNS Brace and IAP measured by anorectal manometry. The DNS Brace shows promise as a non-invasive alternative to measuring IAP and subjective assessment in clinical settings. Another study [21] investigated the relationship between abdominal muscle activation by capacitive force sensors in different postures. Particularly the two postures show where core engagement was most prominent. AWT sensing shows potential for assessing abdominal muscle function in LBP. However, limitations in study design and focus on healthy individuals hinder its direct application to LBP patients. Future research should validate its clinical utility, explore its connection to LBP outcomes, and integrate it with other factors for comprehensive rehabilitation strategies. In **Figure 2** Nakamae et al.[22] introduced a novel method for accurately measuring Transversus Abdominis (TrA) muscle activity using a combination of muscle stiffness and stretch sensors. The new algorithm improves TrA activity estimation, accounting for respiration and belt tension. This innovative approach offers a promising alternative to invasive techniques like EMG, providing a convenient method for assessing core muscle function. Addressing respiratory and other factors, this method improves accuracy and offers valuable insights for rehabilitation and musculoskeletal disorder prevention. Another study[23] developed a sensing system for measuring abdominal stiffness the sensor technology is poised to make significant contributions to the field of abdominal muscle physiology. In one study[24] the MC (muscle contraction) sensor, initially developed for biceps brachii muscle tension measurement, demonstrates its adaptability for potential application in other anatomical regions. Further research is needed to validate its performance in abdominal-specific areas. Overall, all reviews collectively highlight significant advancements in non-invasive force-sensing methods for assessing IAP and abdominal muscle activity. The findings offer promising potential for improving the diagnosis, monitoring, and treatment of conditions related to abdominal wall mechanics.

## SUMMARY AND CONCLUSION

This comprehensive review investigated the efficacy of novel non-invasive force-sensing technology in assessing AWT for LBP. Findings provide strong evidence that force-sensing can significantly contribute to the evolution of tailored rehab strategies (**Table 1**). As illustrated in **Figure 3**, this innovative sensing approach will enable the measurement of core muscle-generated force for assessment and targeted treatment. Force sensors, or transducers, utilize a variety of physical principles to convert mechanical force into quantifiable electrical signals. Historically, precise physiological data measurements necessitated expensive equipment and were primarily confined to clinical settings. However, recent breakthroughs in sensing technology have ushered in a new era of affordable and accessible physiological sensors, driving heightened demand and facilitating applications in physical activity tracking, patient care, and health management. Force sensors translate mechanical stress into electrical signal output, enabling their use in physiological measurements. Ongoing research is refining their accuracy, sensitivity, and specificity, enhancing their value for diagnosis and prognosis in healthcare [25][26]. Force sensors employ various principles such as strain gauges, piezoelectric effects, capacitive sensing, and optical fibers. The selection of a particular principle depends on factors including application, sensitivity, range, and environmental conditions [27]. Force sensor design, materials, and calibration influence output variability. The choice of sensor and measurement technique affects data accuracy and precision. Force sensors have the potential to revolutionize healthcare through non-invasive, real-time quantification of physiological parameters. While advancements have expanded their applicability, sensor design, calibration, and data evaluation challenges remain. Overcoming these obstacles can pave the way for a paradigm shift toward personalized and preventative healthcare strategies enabled by advanced force sensor technology. This study highlights the significant advancements in non-invasive AWT and IAP assessment for LBP management. While existing methods show promise, limitations such as small sample sizes and focus on healthy populations persist. Future research should involve larger, diverse populations, consider muscle activity's impact, and conduct rigorous clinical trials. Integrating biomechanical modeling and patient-reported outcomes is crucial for comprehensively understanding AWT's role in LBP. Additionally, developing standardized protocols and addressing ethical considerations is essential for the widespread adoption of these non-invasive assessment techniques in clinical practice.

**Table 1** Potential for Force-sensing-based rehabilitation in personalized LBP care

| Study | Findings | Personalized LBP care and rehabilitation Strategies |
|---|---|---|
| Van Ramshorst et al., (2008) [14] | -Potential for measuring AWT, as a non-invasive way to estimate IAP. | -Improved IAP understanding aids LBP diagnosis and treatment. |
| Van Ramshorst et al.,(2011) [15] | -AWT reflects IAP. | -AWT measurement aids LBP diagnosis and treatment. |
| Chen et al., (2015) [17] | -Found a significant linear correlation between AWT and UBP (urinary bladder pressure). | -Targeted core-centric look can reduce LBP. |
| Novak, J., Busch, A., *et al.* (2021) [18] | -Distinct muscle patterns revealed unique responses to rest, weightlifting, and respiration. | -Core activity sensor aids LBP rehabilitation. |
| Novak et al., (2021) [19] | -The DNS brace sensor is a promising tool for evaluating postural control. | -Real-time data aids LBP treatment. |
| Jacisko et al., (2020) [20] | -DNS could be used for clinical decision-making. | -DNS brace enhances core awareness and treatment. |
| Madle et al., (2022) [21] | -AWT correlates with IAP in all exercises. | -Distinct position strengthens the core and aids LBP management. |
| Nakamae et al., (2023) [22] | -Transverse abdominis activation was satisfactory. | -Core activity monitoring is a promising alternative to EMG. |
| Wang et al., (2021) [23] | -Sensors measure the resulting indentation, which correlates with tissue stiffness. | -Sensor design aids LBP rehab; further research is needed. |
| Đorđević ei al., (2011) [24] | -Sensor system design might help to measure AWT in the abdomen area in the future. | -MC sensor potential for AWT measurement and LBP assessment. |

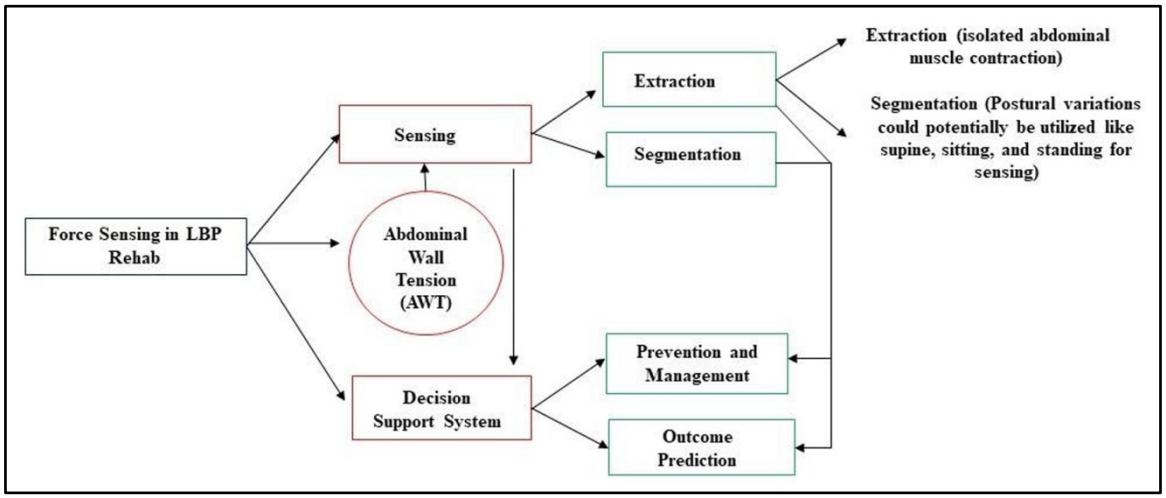


**Figure 3**

In conclusion, decoding the core, a non-invasive force-sensing-based precision medicine approach suggests a promising avenue for enhancing personalized LBP care. Standardized algorithms for data analysis, coupled with known reference values can facilitate comparisons across studies and clinical settings.

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347_IEC85073

# The use of Thermal Test, Electric Pulp Test and use of Modified Pulse Oximeter for Assessment of Pulpal Status of Permanenet Mature Teeth

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***Keywords***: *Pulse Oximeter; Pulpal Inflammation; Pulpal Oxygen Saturation; Dental Vitality Testing; Pulpal Diagnosis*

## INTRODUCTION

The sensory fibers in dental pulp are primarily nociceptors classified into A-delta (A∂) and C fibers. While A∂ fibers have a low threshold and are responsible for conducting pain in reversible inflammation, C fibers, with a higher excitation threshold, indicate irreversible pulpal inflammation when activated[1]. Traditional pulpal sensibility tests, such as heat, cold, and electric pulp tests, evaluate neural responses to these stimuli but often fail to provide accurate readings regarding pulp vitality, especially in cases with an open apex, recently traumatized teeth, or geriatric patients. These tests are subjective, relying heavily on patient responses, which may result in false positives or negatives [2].

The use of Pulse oximeter to assess the vitality of teeth was first assessed by Schnettler[3]. Setzer[4] et al. concluded "pulse oximeter can be used as valid measurements for the assessment of different stages of clinically diagnosed pulpal inflammation and may be a valuable adjunctive tool for clinical diagnosis". Bargrizan et al.[5] concluded "the pulse oximetry was effective in assessing oxygen saturation because it confirmed the avascularity of the root filled tooth". The use of a pulse oximeter, a non-invasive device traditionally used to monitor blood oxygen saturation, has been proposed as an objective alternative to evaluate pulpal vitality.

This study aims to design a modified pulse oximeter probe suitable for use on permanent adult teeth and measure the pulp oxygenation rates (%$SpO_2$) in teeth diagnosed with various pulpal conditions — irreversible pulpitis, and pulpal necrosis—and to establish whether $SpO_2$ values can be reliably used to assess the vitality of the pulp.

## METHODOLOGY

This study was conducted at the Department of Conservative Dentistry and Endodontics, involving 45 patients aged 18-60. Patients with at least one root canal treated molar tooth, one tooth clinically diagnosed as irreversible pulpitis and one healthy tooth free of any kind of pathology were included in the study. Also, the pulse oxygen saturation of all ten fingers were also measured. Ethical approval was obtained from the Institutional Ethics Committee (GNIDSR/IEC/22-23/41).

Pain history, clinical examination, and radiographic findings were used to confirm the diagnoses, followed by heat, cold, and electrical pulp tests. A modified pulse oximeter was used to measure oxygen saturation in the root canal treated tooth, tooth diagnosed as irreversible pulpitis and healthy tooth and ten fingers of the patients Statistical analysis of the collected data was performed using ANOVA and paired t-tests to compare oxygen saturation levels between groups.

## STATISTICAL ANALYSIS

The fata were collected, entered in Microsoft Excel 2007, and analyzed in SPSS version 27.0.1 (IBM, Armonk, USA). Categorical variables were expressed as frequencies and percentages, and continuous variables as means and standard deviations. Associations between categorical variables were tested using the Chi-square/Fisher exact test, while group means were compared using ANOVA. ROC curve analysis was used to assess predictive accuracy for

continuous variables, calculating cut-off points for sensitivity and specificity. For heat and cold tests, sensitivity, specificity, positive and negative predictive values were calculated. A p-value below 0.05 was considered significant.

Several intraoral probes were designed using a 3D printer

| Version | Modification | Limitations | Future Direction |
|---|---|---|---|
| V1 | | Not self-retaining probe housing | Modify housing for use in both right and left quadrants |
| | | Difficulty in placement on posterior teeth | Increase retention of probe housing |
| | | Interchangeable probes required for right quadrant placement | Modify probe for use on both anterior and posterior teeth |
| | | Inability to adapt on palatal surface of anterior teeth | Reduce size of probe |
| V2 | Smaller probe housing | Difficulty in placement on posterior teeth | Modify housing for use in both right and left quadrants |
| | | Interchangeable probes required for right quadrant placement | Increase retention of probe housing |
| | | Inability to adapt on palatal surface of anterior teeth | Modify probe for use on both anterior and posterior teeth |
| V3 | Smaller probe housing | Interchangeable probes required for right quadrant placement | Modify housing for use in both right and left quadrants |
| | | Inability to adapt on palatal surface of anterior teeth | Modify probe for use on both anterior and posterior teeth |

**RESULTS**

In this study the mean $SpO_2$ levels of healthy teeth was 92.42, of RCT treated teeth was 0 and teeth diagnosed as symptomatic irreversible pulpitis was 78.55.

Of the data obtained receiver operator characteristic curve analysis was done to determine the predictive value of heat, cold and electric pulp test.

**Table 1** -Distribution of $SpO_2$ (modified pulse oximetry) among the study participants according to the type of tooth

| $SpO_2$ | Mean | SD | P value |
|---|---|---|---|
| **Healthy** | 92.42 | 1.60 | <0.001 |
| **RCT** | 0 | - | |
| **SIP** | 78.55 | 2.51 | |

**Table 6** Receiver Operator Characteristic (ROC) curve analysis of EPT in determining the viability of the tooth

| ROC analysis | Result | 95% CI |
|---|---|---|
| **AUC** | 0.801 | 0.728 – 0.873 |
| **@ $SpO_2$ 17** | | |
| **Sensitivity** | 72.22% | 67.3% - 78.2% |
| **Specificity** | 80.0 % | 74.5% - 85.5% |

**Table 7** Predictive accuracy of heat test of the viability of the tooth

| ROC analysis | Result | 95% CI |
|---|---|---|
| Sensitivity | 86.54% | 80.7% - 92.30% |
| Specificity | 100% | 100% - 100% |
| PPV | 100% | 100% - 100% |
| NPV | 92.22% | 87.7% - 96.74% |

**Table 8** Predictive accuracy of cold test of the viability of the tooth

| ROC analysis | Result | 95% CI |
|---|---|---|
| Sensitivity | 86.54% | 80.7% - 92.30% |
| Specificity | 100% | 100% - 100% |
| PPV | 100% | 100% - 100% |
| NPV | 92.22% | 87.7% - 96.74% |

## CONCLUSION

The pulse oximeter has proven to be a reliable tool for assessing pulpal vitality and inflammation. This study demonstrated that a pulse oximeter can effectively determine pulpal status, and a successful design for a pulse oximeter probe was developed, making it a valuable addition to traditional diagnostic methods. However, limitations include challenges in sensor placement, the need for patient stillness, and determining the most suitable wavelength for use in teeth. Further studies are recommended to establish standardized $SpO_2$ ranges for clinical application. Despite these limitations, pulse oximetry holds promising potential in dental diagnostics.

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**Biomedical Science & Technology**

# Genomics, Bioinformatics, and Synthetic Biology

87_IEC2144

# Phase Response Synchronization using Fractional Kuramoto and Repressilator Models

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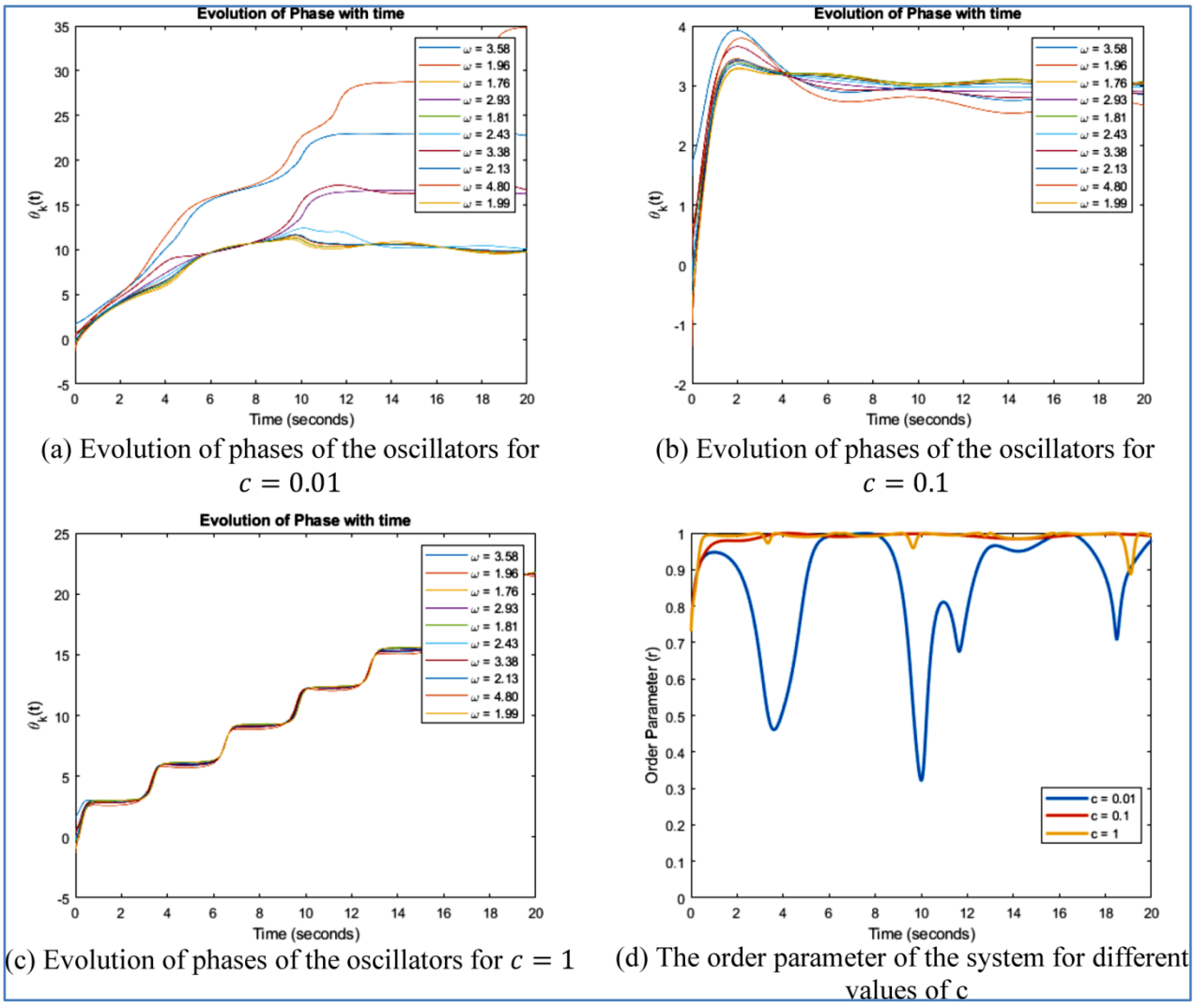
***Abstract:*** *Generating electrical oscillations through the synchronized activity of networks of neurons, is an intriguing feature of the brain, commonly termed as neuronal synchronization. Several researchers have employed the classical Kuramoto model with appropriate modifications to explain this phenomenon. However, the existing models have scope of improvements in terms of reducing the computational effort and making it more physics-based. In this paper, we first generalize the classical Kuramoto model by replacing the integer-order derivative by a derivative of fractional order. This is carried out to account for the deficiencies shown by integer-order models to explain the real physical systems. Simulation results show that the fractional dynamics can lead to the generation of chimera states for neurons, setting the coupling strength at a lower value than the critical coupling strength. Next, we make some revisions in the fractional Kuramoto model and study the effect of an external stimulus on phase response synchronization of a simple ten-oscillator system with time-varying coupling strength and time delay. Simulation results attached here with demonstrate the occurrence of chimera states for various combinations of stimulus intensity, stimulus frequency, and coupling schemes. Also, we show that for higher stimulus frequency, the oscillators get synchronized in both the cases of weak and strong coupling. However, the stimulus intensity has very little effect in case of strong coupling. A popular concept in Synthetic Biology deals with the generation of limit cycles in protein concentration using repressilator model. We have translated a new application of the repressilator model by synchronizing nine repressilator rings to study the synchronization characteristics. Generally, these models are used for emulating the protein synthesis system, wherein the output of three oscillators are synchronized through a Hill Function based model. By modifying the system output in terms of phase stabilization, we have shown interesting potential of the model for the synchronization of the oscillators. We have included the results of simulation of a three pairs of triplet oscillators and shown their convergence with time. Furthermore, this work opens a direction of research whereby studies might offer more insight into the phenomenon of neural synchronization by integration of fractional derivatives and repressilator models.*

***Keywords****: Electrical Oscillations; Neural Synchronization; Fractional Kuramoto Model; Chimera States; Phase Response Synchronization*




(a) Evolution of phases of the oscillators for $c = 0.01$

(b) Evolution of phases of the oscillators for $c = 0.1$

(c) Evolution of phases of the oscillators for $c = 1$

(d) The order parameter of the system for different values of c

**Figure 1** 10 oscillators system, $I = 1.5$, $\varepsilon = 0.8$, $\Omega = 0.8$, plots of phase evolution and order parameter of oscillators for different $c$ values

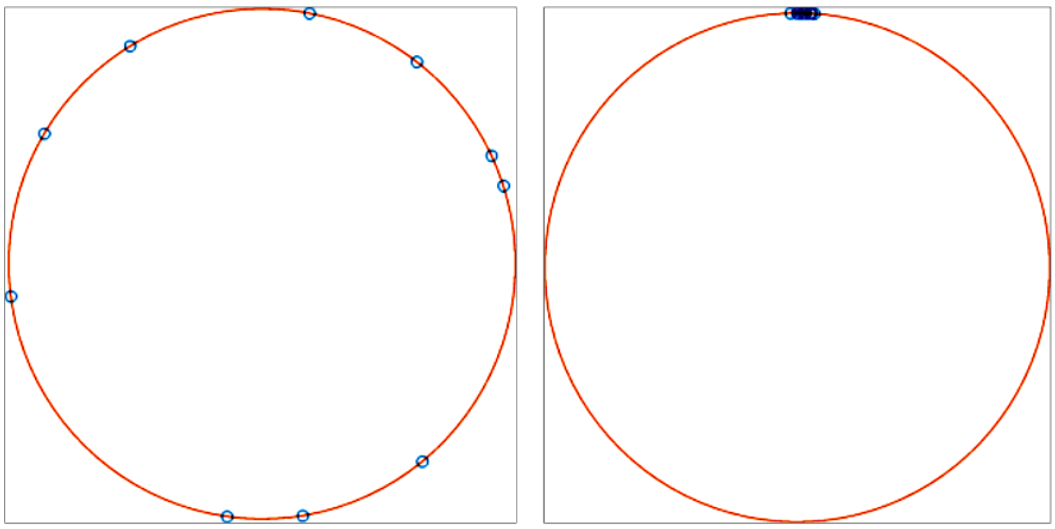


**Figure 2** (a) and (b) Kuramoto Order Parameter (R) characterizing coherence between oscillators ($N = 10$)) (a) $R = 0$ (Incoherence) (b) $R = 1$(Complete synchrony)

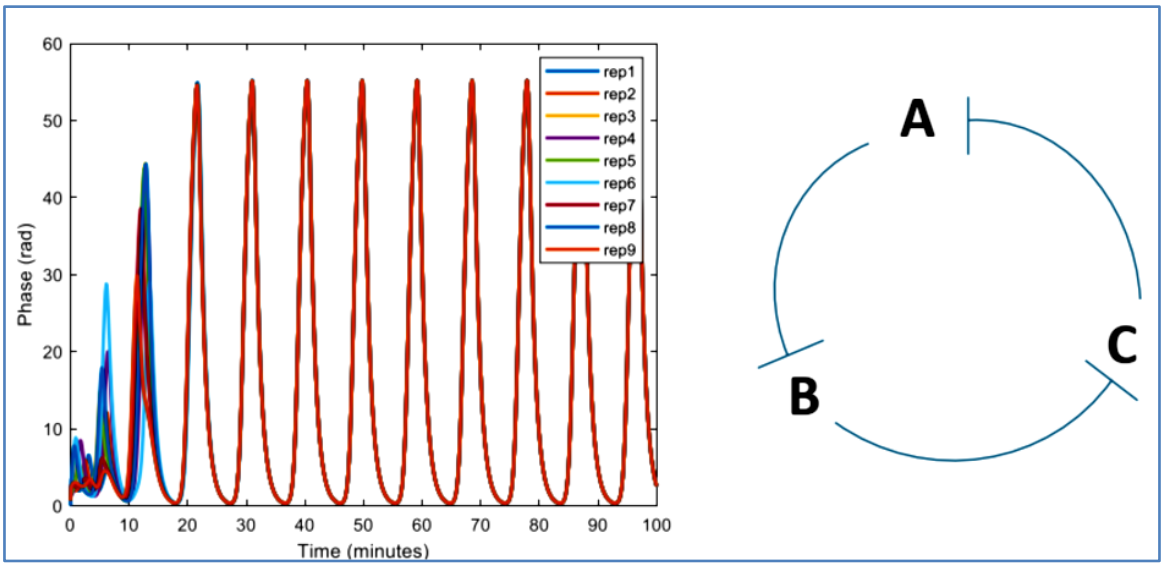



**Figure 3** (a) This shows the phase synchronization of 9 repressilator models with time. It can be shown that with increasing the coupling strength the synchronization time reduces; (b) The diagram shows the repressilator network. System A represses System B which in turn represses System C thereby producing an oscillatory response.

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# Farming the Future: Revolutionizing Agriculture with Gene Editing to Tackle Food Insecurity

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***Keywords***: *Gene Editing; Crop Production; Food Insecurity; CRISPR-CAS9; Disease Resistance; Biofortification; Agriculture*

## INTRODUCTION

The path to secure a country's future is through grains, not guns. This emphasizes the importance of addressing food security[1]. Currently, there are about 840 million people with constant starvation and 3 billion individuals facing nutritional deficiencies mostly seen in developing countries. To address this concern, strategists must focus on increasing agricultural productivity using various gene editing techniques to enhance crop tolerance to combat various challenges[2].

By combining traditional plant breeding methods with the modern plant breeding techniques is crucial for enhancing agricultural productivity and crop resistance[3]. Gene editing is a term that encompasses various molecular techniques[4]. Some of the techniques of gene editing are- CRISPR-CAS9, TALENS, ZFNS, etc., of which CRISPR-CAS9 is the most versatile and known technique for crop production and protection[3]. This technique allows researchers to modify gene function in plants and animals without using the foreign DNA. By introducing genetic variation within the crops, it increases productivity, disease resistance, and tolerance to various environmental stresses. By increasing crop resilience and productivity, CRISPR-CAS9 has been playing a vital role in addressing barriers like food security and supporting sustainable agricultural growth[5]. This article focuses on the application of gene editing technology for crop enhancement through CRISPR-CAS9 techniques.

## METHODOLOGY

Gene editing, particularly through the CRISPR-Cas9 tool, is revolutionizing agriculture with its ability to precisely modify plant genomes. Unlike traditional breeding methods, which can take years, CRISPR-Cas9 offers a faster, more accurate way to enhance crops. By editing genes that control key traits like growth, photosynthesis, and grain size, scientists can significantly boost crop productivity, creating larger and more efficient plants. CRISPR also plays a crucial role in improving disease and pest resistance. By modifying or introducing resistance genes, plants can better withstand infections, reducing the need for chemical pesticides, which is beneficial for both the environment and crop health.

In the face of climate change, gene editing offers a pathway to create crops more resilient to environmental stressors such as drought, extreme temperatures, and salinity. For example, by altering genes that control root growth, crops could access deeper soil layers, reducing their reliance on rainfall or irrigation. This is especially valuable in drought-prone areas where water scarcity is a growing concern.

CRISPR also holds promise for biofortification, the process of enhancing the nutritional content of crops. By modifying genes that influence nutrient production and storage, crops can be enriched with essential vitamins and minerals like Vitamin A and iron, helping combat malnutrition, particularly in food-insecure regions. Furthermore, gene editing can improve nitrogen use efficiency, reducing the reliance on chemical fertilizers and minimizing the environmental impact of farming.

Finally, CRISPR accelerates breeding cycles by enabling precise changes to genes that regulate growth and reproduction. This rapid breeding capability allows farmers to quickly develop new crop varieties that are better suited to changing conditions, ensuring food security and meeting market demands.

## RESULTS

Gene editing through CRISPR-Cas9 has made significant strides in enhancing crop yields and productivity. By precisely modifying genes involved in plant metabolism, crops like rice, wheat, and tomatoes have shown faster growth and higher yields. This advancement is crucial in addressing the growing food demand of a rapidly increasing global population, particularly in regions struggling with food insecurity.

CRISPR has also been instrumental in improving the nutritional quality of crops. Edited rice varieties now have higher levels of essential nutrients like iron and zinc, providing better nutrition for populations dependent on rice as a staple. Similarly, tomatoes have been enhanced with increased antioxidant content, improving their health benefits.

Climate resilience has been another major achievement. CRISPR-edited crops are showing increased tolerance to environmental stresses, such as drought and extreme temperatures, ensuring they can thrive even under adverse conditions. For example, CRISPR-modified rice has demonstrated resilience to these stresses, helping secure crop yields despite changing climates.

Moreover, CRISPR's ability to create pest and disease-resistant crops has reduced the need for chemical pesticides, minimizing environmental contamination. Crops like herbicide-resistant soybeans are a prime example of this, helping preserve soil and water quality.

## CONCLUSION

Gene editing, particularly through CRISPR-Cas9, is poised to transform agriculture by enabling the creation of high-yield, climate-resilient, pest-resistant crops with enhanced nutritional content. By addressing the challenges posed by climate change, pests, diseases, and malnutrition, CRISPR holds the potential to revolutionize food production and security. This technology could become a cornerstone in feeding a growing global population while also promoting sustainable farming practices.

However, to unlock its full potential, further research is needed to refine these technologies and ensure their safe, effective implementation in diverse agricultural systems. With continued advancements and a focus on solving key challenges, CRISPR-edited crops could soon play a central role in feeding the world and sustaining the future of agriculture.

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# Potential Mechanisms of Selected Intracellular Metabolites on HEWL Aggregation: Insights from Endpoint Assays, Aggregation Kinetics and Computational Studies

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***Abstract:*** *Proteins undergo misfolding due to changes in physiological conditions, mutation or cellular homeostasis, resulting in various neurodegenerative conditions. As disturbed homeostasis of nitrogenous bases and nucleotides are associated with neurodegenerative diseases, we wanted to investigate the effect of these molecules on protein amyloid formation/dissociation. In the current study, we have investigated the effect of these compounds on preformed amyloid as well as on specific steps of amyloid formation, including primary nucleation, secondary nucleation and elongation. Our results show that by adding these ligands, soluble aggregates/oligomers at physiological pH convert towards more matured fibrils as measured by Thioflavin T (ThT) binding and atomic force microscopy. Surprisingly, turbidity and UV scattering intensity of the preformed oligomers at physiological pH decrease, which may be due to an overall decrease in scattering due to the presence of large aggregates in the solution. Detailed investigation of ThT binding kinetics showed that these ligands at physiological pH modify key microscopic protein aggregation processes depending on the step of aggregation they are introduced in. While they promote oligomer to mature amyloid formation, fragmentation and elongation are inhibited. The study provides aspects for further investigations of these metabolites as protein aggregation modifiers and potential therapeutics in neurodegenerative diseases.*

***Keywords****: Lysozyme; Protein Aggregation; Neurodegenerative Diseases; Intracellular Metabolites; Aggregation Kinetics*

## INTRODUCTION

Protein misfolding diseases cause neuropathic and non-neuropathic pathological conditions in humans, mainly due to protein misfolding and the subsequent formation of amyloid or aggregates. Amyloid plaque, characteristic of various neurodegenerative conditions, is an ordered structure, mostly fibrous [1]. The acceleration in the rate of amyloid deposition is supposedly a primary event in the pathogenesis of Alzheimer's disease (AD). A wide array of endogenous factors could affect the rate of amyloid formation in vitro and play a role in the pathogenesis of AD [2]. Cellular systems have their quality control mechanism, which maintains a balance between protein production and degradation. Deregulating these systems could prove vital for being a causative factor in various diseases, primarily neurological disorders and systemic amyloidosis [3-5]. Nucleotide balance is an essential factor in both dividing and quiescent cells. The emphasis is more on neural tissues as there is a high rate of metabolism and, hence, a high requirement of ATP [6] for proper functioning. One exciting aspect of protein misfolding diseases that has come into being is the existence of intermediates during the formation of amyloid fibrils or complete protein unfolding. These oligomeric intermediates are potentially more cytotoxic and have also increased the scope of further research [7].

In the current study, we have tried to elucidate the effect of selected nitrogenous bases viz—cytosine, guanine, thymine and uracil, and nucleosides viz. adenosine and Guanosine on amyloid formation using HEWL amyloids as a model. We have also investigated the possible formation of intermediate states and monitored structural changes, morphology and shape of the possible oligomers and amyloid fibrils using extensive spectroscopic and imaging analysis. We have also studied the effects of these molecules on modulating the oligomeric state towards a more fibrillar state, potentially less toxic. We have extensively used spectroscopic and microscopic techniques and complemented Thioflavin T aggregation kinetics to gain valuable insights into establishing a potential mechanism that the ligands exhibit depending mainly on the dynamic behaviour of proteins based on pH. Lastly, we have utilised molecular simulation studies based on our previous molecular docking studies to gain more insights into the possible mechanism of the effect of metabolites on the model protein.

The data suggest the anti-amyloidogenic nature of these metabolites. Our results indicate that the metabolites can drive the hen egg-white lysozyme towards forming aggregates over 120 hours in near physiological pH. Further, when added to soluble aggregates/oligomers at near physiological pH, our results indicate these ligands convert them towards more matured fibrils as measured by Thioflavin T (ThT) binding and atomic force microscopy. Detailed investigation of ThT binding kinetics showed that these ligands at physiological pH modify key microscopic protein aggregation processes depending on the step of aggregation they are introduced in. We have also shown a significant decrease in the aggregation index of the protein solutions incubated with various selected metabolites. Surprisingly, turbidity and UV scattering intensity of the preformed oligomers at physiological pH decrease, which may be due to an overall decrease in scattering due to the presence of large aggregates in the solution. Moreover, the molecular simulation studies also indicate that these metabolites have stable binding at amyloidogenic sites of HEWL and possibly prevent amyloid by inhibiting intermolecular interactions. The study provides aspects for investigations of these metabolites as protein aggregation modifiers and potential therapeutics in neurodegenerative diseases.

## METHODOLOGY

We have utilized extensive computational methods like molecular docking and simulation to analyse the interactions of various nucleosides, nitrogenous bases and nucleotides with aggregation-prone zones of model amyloid protein, i.e. Hen egg White Lysozyme (HEWL). Based on our previous molecular docking studies [8], we have employed molecular dynamics using GROMACS v2018.8 of the chosen protein-ligand complexes. We have performed 100 ns molecular simulations of the chosen complexes utilising the GROMOS 54a7 forcefield. We generated topology files for the metabolites from the PRODRG server as described previously in our works and set up the simulation using a similar methodology [9-11]. As for the binding energy analysis post-simulation, we utilised the widely accepted MM/PBSA method. We also utilised the g_mmpbsa tool of GROMACS, calculating the per residue-free energy analysis [12-13].

Subsequently, we examined the effect of the best computationally identified compounds for anti-amyloid properties using HEWL amyloid as a model system. HEWL amyloid is well characterized at pH 12.2 and widely reported in the literature. We have also characterized HEWL amyloid at near physiological pH, i.e., 7.4. Our results showed that amyloid fibrillation is more pronounced at near physiological pH than at pH 12.2. Further, we also report a lower formation of oligomers and, subsequently, matured fibrils of HEWL in the presence of both nitrogenous bases (Cytosine, Guanine, Thymine and Uracil), nucleosides (Adenosine and Guanosine) in a time-dependent manner. We also validated the results using supporting data like aggregation index, dynamic light scattering (DLS) studies and atomic force microscopy (AFM) imaging.

We performed three different Thioflavin T kinetics assays in the current study. Firstly, we established the approximate model of HEWL aggregation using a range of concentrations of HEWL from 20µM, 50µM, 100µM, 150µM and 200µM 50mM Tris-100mM NaCl buffer at pH 7.4. For a mechanistic understanding of the behaviour of ligands and their impacts on various stages of protein aggregation, we measured ThT intensity as a function of time. We performed the experiments in two phases to understand the roles of the ligands in inhibiting key steps such as primary nucleation, secondary nucleation and fibrillation. The first Thioflavin T kinetics was studied by simultaneous incubation of HEWL at a specific concentration and ligands at a specific concentration. Secondly, we performed a separate experiment by adding a preformed seed in a 1:1 ratio to a freshly prepared HEWL monomer solution. We sonicated the seed solution for 15 minutes with a pulse of 5 seconds ON and 7 seconds OFF to break down the oligomers formed. We aimed to understand the impact of ligands on a possible inhibition of secondary nucleation. We normalised the Thioflavin T kinetics raw data using Amylofit– The Amyloid Aggregation Fitter (https://amylofit.com) server developed by Miesl and colleagues [14]. We also used the Boltzmann equation for calculating our lag times in seeded experiments.

## RESULTS

HEWL amyloid is well characterized at pH 12.2 and widely reported in the literature. We have also characterized HEWL amyloid at near physiological pH, i.e., 7.4. Our results showed that amyloid fibrillation is more pronounced at near physiological pH than at pH 12.2. Further, we also report a lower formation of oligomers and, subsequently,

matured fibrils of HEWL in the presence of both nitrogenous bases (Cytosine, Guanine, Thymine and Uracil), nucleosides (Adenosine and Guanosine) in a time-dependent manner. We concluded that the selected nucleosides and nitrogenous bases potentially suppress (slow down) primary nucleation processes under these experimental conditions.

Through the endpoint assay at pH-7.4, we obtained amyloid fibrils up to a length of 0.543µm in the control samples. The HEWL fibrils treated with various metabolites at this pH produced heights ranging from 0.33 to ~0.45µm. The results here show that the metabolites affect the overall length and morphology of the HEWL amyloid fibrils. We carried out our DLS studies after incubating the samples for five days with and without metabolites at both pHs. At near physiological pH, the peak intensity is higher in samples treated with metabolites. The Z-average hydrodynamic radii of control aggregates are 229.8 nm. Among nucleosides, adenosine lowers aggregate size with a hydrodynamic radius of 7.57 nm and Guanosine around 197.6 nm. Among the nitrogenous bases, uracil shows a vigorous intensity indicating a higher homogenous population in the solution with a radius of ~ 125 nm. In the presence of Guanine, Thymine and Cytosine, aggregates of lower hydrodynamic radii compared to control samples ranging between 145-200 nm. The polydispersity index of all the samples is within 0.7

We attempted to unravel the HEWL amyloid kinetics in near physiological pH and determine the critical microscopic stages of HEWL aggregation. The HEWL aggregation followed a Saturation Elongation and Fragmentation model. We report that upon adding ligands on preformed HEWL amyloids, there is a sharp increase in the Thioflavin T intensity of the samples indicating the rapid formation of matured fibrils upon adding the chosen ligands. The observation was repeated at three different time points. Our AFM analyses also supplemented this. On the contrary, our turbidity and UV scattering analyses showed a decreasing trend, which could be explained by the overall reduction of scattering intensity due to large aggregates. We further elucidated using the Thioflavin T kinetics assay that in the presence of the metabolites, the HEWL aggregation half-time is shortened compared to HEWL aggregation without metabolites. Further, there is an increase in combined nucleation and elongation rate. Considering these two factors, we concluded that the selected metabolites enhance and promote fibrillation processes at this stage. Although in seeded reactions where we had anticipated quickening up of the overall reaction and shortening of the lag phase, the addition of ligands along with preformed seeds to HEWL monomers showed varied results. Adenosine and Cytosine did not decrease lag time compared to control samples. On the contrary, Guanine, Guanosine and Thymine increased overall lag time. This important observation indicates that the metabolites modify the lag phase period in aggregation kinetics, depending much upon the stage of protein aggregation they encounter in solution.

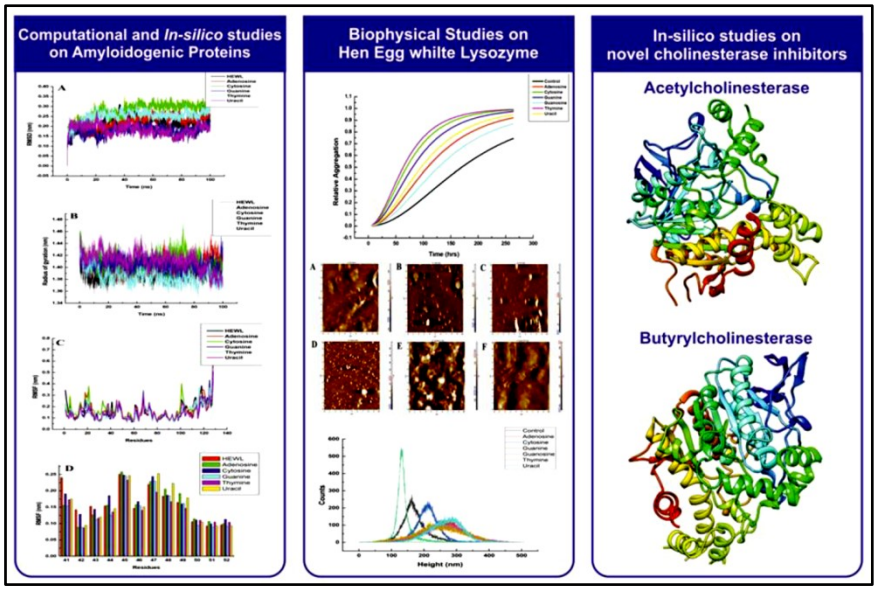


**Figure 1** Major thematics of the current study: Computational and Biophysical studies on Hen Egg White Lysozyme using selected metabolites supplemented with Cholinesterase inhibitor study

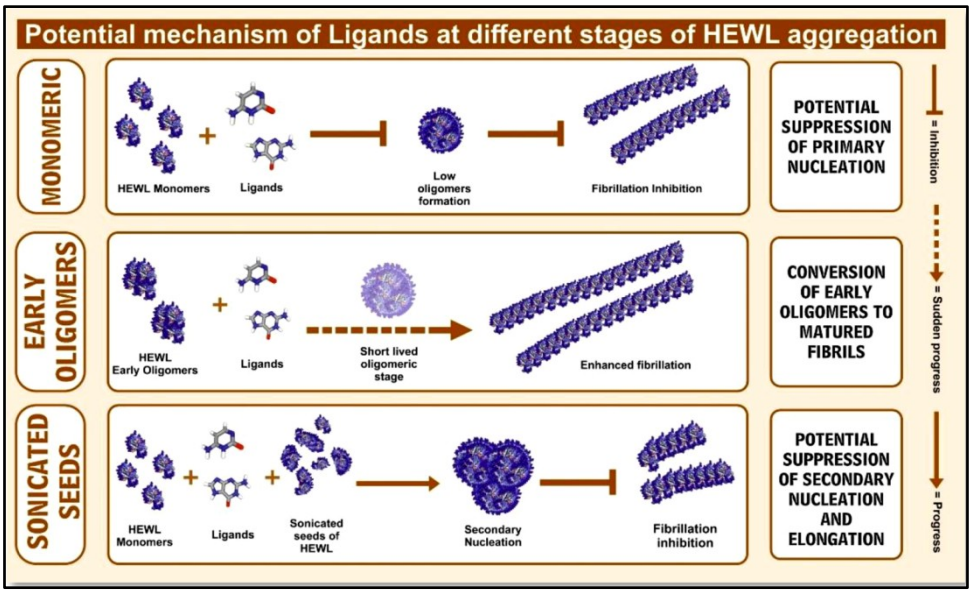


**Figure 2** Summary of the major mechanisms concluded from the study for the various molecules and their impact on the HEWL aggregation

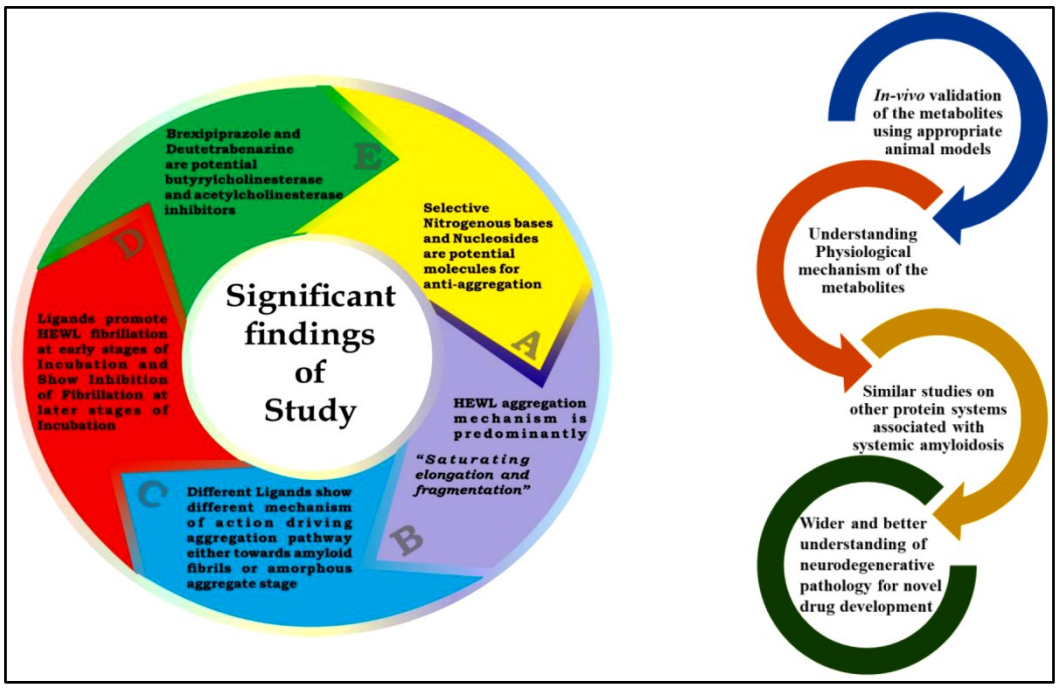


**Figure 3** Significant findings of the study (Left) and the potential areas of future work (right)

## CONCLUSION

The study focuses on the impact of selected intracellular metabolites on the primary nucleation step of protein aggregation. Since fibril-dependent processes are absent, primary nucleation is the driving force for protein aggregation under these conditions. Our results show that primary nucleation processes are suppressed in the presence of metabolites as there is a simultaneous loss of ThT and ANS intensity. Interaction of small molecules directly with aggregation-prone disordered zones within the full-length protein is also an exciting strategy for finding small molecules as protein aggregation modifiers. Much of the drugs discovered to treat various proteinopathies are based on targeting primary, and secondary nucleation or elongation of aggregated proteins.

In the current study, we have used prefibrillar oligomers as therapeutic targets. The challenge arises in understanding the exact kinetics of these micro-processes as no step here is ordered and timed. Small molecules like adenosine and guanosine show potential as drugs when tested upon Hen egg-white lysozyme. The overall processes were studied using established experimentation methods like Fluorescence Quenching which helped us conclude the binding affinity and binding sites of these molecules within the protein. The quenching result also indicates the capacity of the ligands to interact with the K peptide region of the protein consisting of key Trp residues. Interaction of key Trp residues with ligands suggests that the ligands possibly can stabilise hydrophobic residues, potentially blocking the oligomerisation process of the protein. ThT fluorescence revealed that both nucleosides and nitrogenous bases reduce the half-time and increase the overall fibrillation, which indicates the process is directed more towards shifting from cytotoxic oligomeric species to stable elongated fibrils. We also studied the overall effect of drugs in seeded reactions (secondary nucleation), in which all ligands except uracil were less effective. The increase in size was further validated using atomic force microscopy, in which it was visible that overall fibrillation increased in the presence of ligands. This study provides a robust platform for more rigorous future experiments based on these molecules.

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# Facial EMG based Approach for Investigating the Activation of Zygomaticus Major during the Articulation of Malayalam Phonemes

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***Abstract***: *The coordinated action of various facial and vocal muscles facilitates speech. Facial muscles show distinct levels of activation depending on the words being pronounced. Investigating muscle activation while articulating different words may contribute to developing speech-assistive devices. In this work, the activation of Zygomaticus major muscle during the articulation of fifteen Malayalam syllables is studied using surface electromyography (sEMG) signals. Signals are recorded from twenty-one healthy female subjects using standard protocols. Features namely root mean square (RMS) and mean frequency (MNF) are extracted from the recorded signals, and the syllables related to the minimum, and maximum activation of the Zygomaticus major are identified. Results indicates that the highest mean values of RMS equals to 1.1E-02 obtained for the phoneme ംം (am), indicating the maximum activation of the muscle during the articulation of this phoneme. The minimum activation is noticed while articulating the phoneme ാ (aa). However, MNF exhibited a maximum value of 83.22 Hz for the phoneme ൂ (uu). In addition, the syllables ാ (o), ാാ (oo), and ൗ (au) exhibited similar level of activation. Thus, the extracted sEMG features are found capable of reflecting the distinct activation of Zygomaticus major muscle for various Malayalam syllables. The proposed study may be used to identify the other facial muscles involved in the pronunciation of various syllables that contributes to human machine interfacing and developing speech aids for people suffering from speech disorders.*

***Keywords***: *Facial sEMG; Malayalam Language; Silent Speech Recognition; Swaraksharas; Zygomaticus Major*

## INTRODUCTION

Speech can be considered an efficient means of communication that eventually led to the development of many languages. It is the most natural and powerful way of communication for humans [1]. Speech enables the sharing of ideas, thoughts, and knowledge and is one of the primary ways of interacting with those around us. Effective speech requires the active coordination of facial and vocal muscles. Facial muscles are a group of about 20 flat skeletal muscles lying underneath the skin of the face and scalp. Neck muscles are the large groups of muscles in the cervical area that are responsible for the head movement in all directions, elevating the upper ribs for inhalation, and aiding in chewing, swallowing, and speaking. Together, these facial and neck muscles play an important role in the speech recognition process [2].

One of the most important muscles involved in speech generation is the Zygomaticus Major [3]. The coordinated action of this muscle with other facial and neck muscles helps in generating different facial expressions. The activation of these muscles are studied in developing human machine interfaces. They are known as laughing muscles due to their significant role in generating smiles. They are mainly activated during the articulation of words that require lip movement. It originates from the upper margin of the temporal process, part of the lateral surface of the zygomatic bone, and is inserted into the tissue at the corner of the mouth [3]. The importance of the zygomaticus major muscle extends to the development of assistive technologies for individuals who cannot produce audible speech. Studies have shown promising results in using facial muscle movements, including zygomaticus major, for the effective synthesis of speech [3]. Certain pathological conditions including muscular dystrophies, myalgia strains, Bell's palsy and myopathy can affect the Zygomaticus Major, leading to difficulty in generating speech [4]. Therefore, studying the activation of this muscle may help in developing speech aids for patients suffering from various muscle diseases. Conventional speech recognition systems, commonly employed for human-machine interaction and developing speech aids, are limited by their vulnerability to ambient noise. Silent speech recognition systems using surface electromyography (sEMG) signals are more robust against external noises and provide superior performance over conventional approaches [5].

sEMG can be measured by placing electrodes on the skin above the muscle of interest to detect the electrical potentials generated by muscle fibers during contraction [6][7]. It is widely used for analyzing muscle activation in speech signal processing [5]. Previous studies have utilized the reliability of sEMG features for the detection of syllables of various languages, including Thai and Spanish. Features such as root mean square (RMS), average amplitude, maximum amplitude, kurtosis, mean absolute value, zero crossing points, sum of all signal values, and sum of all rectified signal values are used for sEMG based syllable detection [8], [9]. In addition, studies have used sEMG signals for classifying the sub-vocal Hindi phonemes [10]. However, studies concerning syllable detection for Malayalam language have not yet been well investigated.

The analysis of muscle activation during the articulation of different Malayalam phonemes can contribute to developing speech aids for individuals with various speech disorders. However, the muscle activation of Zygomaticus Major during the pronunciation of various Malayalam syllables has not yet been studied. Hence, in this work, we focus primarily on studying muscle activation of Zygomaticus major muscles during the articulation of 15 Malayalam syllables using sEMG signals. RMS and MNF are extracted from recorded signals. Further, the syllables corresponding to the maximum and minimum activation of the muscles is identified using Wilcoxon signed rank test.

## METHODOLOGY

### Experimental Protocol

sEMG signals were collected from twenty-one healthy female volunteers aged ranging from 18 to 22 years old with no speech impediment or disorders and are natives of Kerala. Initially, the muscle is identified by palpation, and the skin surface is cleaned using an alcohol-dipped swab. Bipolar electrodes are placed at a distance of 1 cm, with the forehead as the location for the reference electrode. To reduce the posterior complexity of the system, electrodes are only placed on one side of the face [9]. **Figure 1** given below provides a visual representation of the final electrode placements.

**Figure 1** Electrode placement on Zygomaticus Major

Subjects were asked to articulate fifteen Malayalam syllables on a pitch scale. The swaraksharas are അ(a), ആ (aa) , ഇ (e), ഈ (ee), ഉ (u), ഊ (uu), ഋ (r̥), എ (eh), ഏ (ehh), ഐ (ai), ഒ (o), ഓ (oo), ഔ (au), അം (am), അഃ (ah). A timer is set and displayed in such a way that on the 5th second, the subject pronounces the 1st syllable, and on the 10th second the second one, and so on. A four-second break is given in between the pronunciation of the next syllable [5]. The protocol received ethical clearance from the Institutional Ethical Committee, District Hospital, Palakkad, Kerala, India (IEC Study Ref No: B4/499/18) [5][11].

### Instrumentation and Data Acquisition

sEMG signal acquisition is performed using BIOPAC MP160. It is a data acquisition system that provides a flexible tool for life science research. This can record at speeds up to 400 KHz. The Bionomadix system is a wireless multi-channel physiological recording platform. Bionomadix 2-channel EMG system is used for recording sEMG signals in

this study [12]. The sampling rate selected is 2000 Hz [11]. Acquired sEMG signals are filtered using a fourth-order Butterworth band pass filter with cutoff frequencies ranging from 30Hz to 300Hz. A notch filter of frequency 50Hz is further used to remove the power line interferences [5].

**Feature Extraction**

MNF is the average frequency of a signal weighted by its power spectral density. It provides a measure of the center of the power distribution in the frequency domain, often used in the analysis of biomedical signals to assess muscle activity. The mean frequency f' can be defined as,

$$f' = \frac{\sum_{i=1}^{N} f_i\, p(f_i)}{\sum_{i=1}^{N} p(f_i)} \qquad (1)$$

where $f_i$ is the ith frequency component, P($f_i$) is the power spectral density at $f_i$ and N is the total number of frequency components. RMS value is used in quantifying the amplitude of a signal. The RMS value of a continuous signal provides a measure of the signal's power and can be calculated as,

$$RMS = \sqrt{\left(\frac{1}{T}\int_0^T (x(t^2)dt)\right)} \qquad (2)$$

**RESULTS AND DISCUSSION**

The representative signal acquired from the Zygomaticus Major of a subject during the pronunciation of Malayalam syllables from അ (a) to അം (am) is shown in **Figure 2**. The duration of the signal is found to be 87s whereas the signal amplitude varies from -0.035mV to 0.025mV. The activation of the muscle during the articulation of various Malayalam syllables is identifiable from the distinct burst observed in **Figure 2**, where the highest amplitude is noted for the burst recorded during the pronunciation of ഉ (u) and ഊ (“uu”).

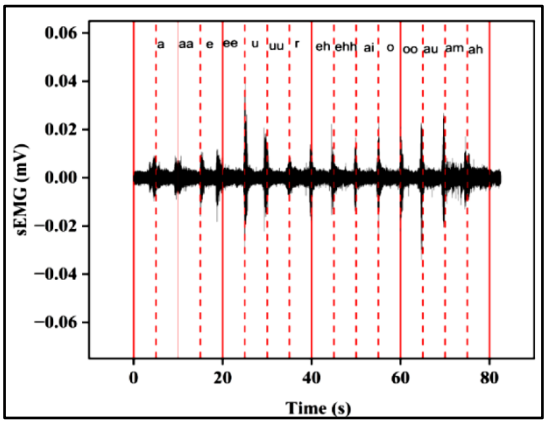


**Figure 2** Sample sEMG signal recorded from the Zygomaticus major muscle during the pronunciation of swaraksharas

**Figure 3** illustrates the RMS and MNF obtained for the representative signal during the articulation of Malayalam syllables. From Figure 3 (a), it is noticed that the highest RMS is obtained for the syllable അം (am), whereas the maximum MNF is noticed for the phoneme ഊ (uu). Further, the mean values of RMS and MNF is calculated for the entire signals and the results are tabulated in **Table 1**. From **Table 1**, it is evident that maximum activation of the muscle is observed during the articulation of the phoneme അം (am), and the corresponding mean value of RMS is 1.13E-02. However, the minimum activation is noticed while articulating the phoneme ആ (aa) with mean values of RMS and MNF equals to 5.19E-03 and 70.99 Hz. Highest MNF value of 83.22 Hz is noticed for ഊ (uu). In addition, the syllables ഒ (o) and ഓ (oo), exhibited a similar level of activation with RMS values equal to 8.40E-03.

The syllable ഊ (uu) demonstrated the second highest level of activation. Thus, the extracted features are found capable of exhibiting the distinct activation pattern of the muscle during the pronunciation of various Malayalam syllables.

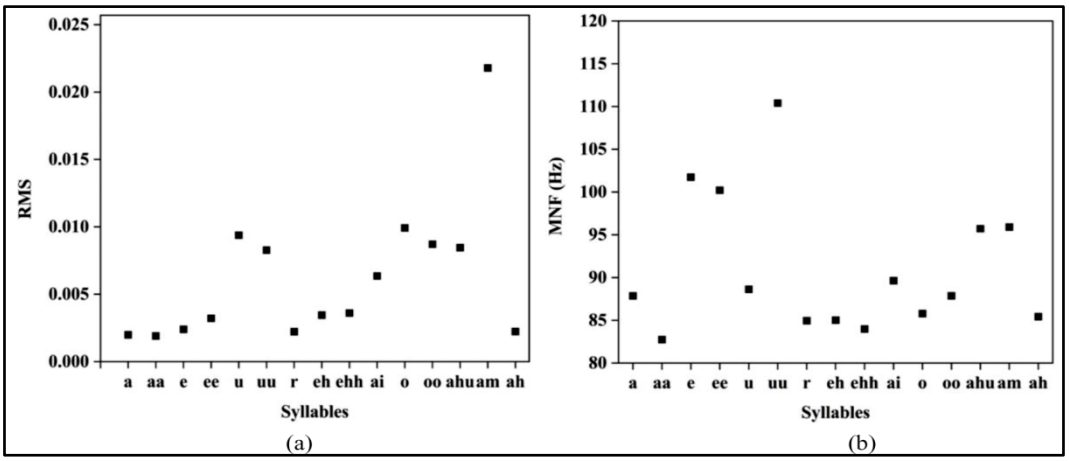


**Figure 3** RMS and MNF values obtained for the representative signals from Zygomaticus major muscle during the pronunciation of fifteen Malayalam syllables

**Table 1** Mean values of MNF& RMS during the articulation of 15 Malayalam syllables from 'അ' to അഃ (ah)

| Malayalam swaraksharas | RMS values | MNF values in Hz |
|---|---|---|
| അ(a) | 5.72E-03±4.1E-03 | 73.42 ±18.26 |
| ആ (aa) | 5.19E-03±3.1E-03 | 70.99 ± 13.55 |
| ഇ (e) | 5.85E-03±3.7E-03 | 73.16 ± 14.42 |
| ഈ (ee) | 6.20E-03±3.5E-03 | 73.65 ± 15.39 |
| ഉ (u) | 8.03E-03±6.4E-03 | 79.56 ± 15.17 |
| ഊ (uu) | 9.5E-03±1.02E 02 | **83.22 ± 17.99** |
| ഋ (ṛ) | 7.27E-03±5.7E-03 | 77.68 ± 17.56 |
| എ (eh) | 6.10E-03±6.1E-03 | 74.55 ± 18.89 |
| ഏ (ehh) | 7.36E-03±4.9E-03 | 73.17 ± 18.07 |
| ഐ (ai) | 7.40E-03±4.8E-03 | 74.94 ± 15.53 |
| ഒ (o) | 8.40E-03±5.2E-03 | 80.00 ± 19.22 |
| ഓ (oo) | 8.40E-03±5.2E-03 | 80.84 ± 19.51 |
| ഔ (au) | 9.79E-03±6.8E-03 | 80.85 ± 17.80 |
| അം (am) | **1.13E-02±5.6E-03** | 77.69 ± 15.58 |
| അഃ (ah) | 6.14E-03 ±4.0E-03 | 73.39 ± 15.13 |

## CONCLUSION

The proposed work aims to analyze the activation of Zygomaticus major muscles during the articulation of fifteen Malayalam syllables from 'അ' to അഃ (ah) using sEMG signals. In this study, sEMG signals from the muscles of twenty-one subjects are acquired using the standard protocol, and features such as RMS and MNF are extracted. Further, recorded signals and analyzed to identify the syllables corresponding to the minimum, and maximum activation of the Zygomaticus major. From the results, it is found that the maximum activation of the muscle is observed during the articulation of the syllable "അം (am)". The syllables ഒ (o) and ഓ (oo) exhibited similar level

of activation. The minimum activation is noticed while articulating the phoneme "ആ (aa)". Thus, the extracted features are suitable for studying the difference in the muscle activation of Zygomaticus Major for various Malayalam syllables. The proposed analysis may be employed for the syllable detection of other languages. This study can be extended to developing speed aids for speech-disabled persons by analyzing the activation of muscles for various Malayalam syllables.

## ACKNOWLEDGMENT

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# Bidirectional Gated Recurrent Unit based Recurrent Neural Network for the Real-Time Prediction of Epileptic Seizure Stroke

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***Abstract:*** *Epilepsy, a prevalent chronic neural disorder, affects millions worldwide, emphasizing the critical need for timely detection and treatment. This research explores the development and performance evaluation of four distinct model architectures for epileptic seizure detection cases using EEG signals. The dataset is strategically preprocessed, focusing on the detection of epileptic seizures. The proposed models, namely Recurrent Neural Network (RNN), Modified Recurrent Neural Network (Modified-RNN), Gated Recurrent Unit based RNN (GRU), and Bidirectional GRU-based RNN (Bi-GRU), are evaluated over the various metrics. Results demonstrate a notable progression in model performance, demonstrating significant advancements in accuracy, precision, and sensitivity. The bidirectional GRU-based model emerges as the most effective architecture, providing a promising solution for accurate epileptic seizure detection with more than 99% accuracy for all binary data clusters and almost more than 95.5% for all trinary data clusters. This was then used to deploy a web-based application that predicts epileptic activity in a patient's brain. These findings underscore the potential of advanced neural network architectures for enhancing diagnostic capabilities and improving patient outcomes in epilepsy management.*

***Keyword****: Epileptic Seizure Detection, Electroencephalogram, Deep Learning, Recurrent Neural Network (RNN), Gated Recurrent Unit (GRU)*

## INTRODUCTION-

Epilepsy is an increasingly prevalent neurological disorder marked by sudden seizures and is not contagious. Although it may occur at any age, newborns and the elderly are more likely to be diagnosed with epilepsy. The World Health Organization (WHO) estimates that 50 million individuals worldwide have epilepsy [1]. Seizures are swift and show an early abnormality in the electrical activity of the brain that disrupts its function, potentially affecting various bodily processes [2]. Numerous health issues, including memory loss, breathing difficulties, unconsciousness, body part stiffness, and many more, can result from this. Despite being prevalent worldwide, this illness is more severe in countries that are developing. Thus, it becomes imperative to develop a diagnostic technique of high accuracy and specificity in order to reduce the disability due to epilepsy [3].

The most frequent instrument used to investigate epilepsy and interpret brain electrical signals is the electroencephalogram (EEG) [4]. The voltage changes generated by the ionic current flowing through brain neurons are provided by the EEG and serve as a representation of the bioelectric activity of the brain [5]. Using EEG data for the identification of epilepsy is laborious and time-consuming, as it relies on the expertise of epileptologists and neurologists to meticulously analyze the voltage variations generated by neuronal activity while screening the EEG signals minutely. However, this approach is inherently susceptible to human error and lacks the scalability to address the global burden of epilepsy [6]. Thus, new methods for identifying epileptic seizures utilizing automated diagnosis systems have been created across the years. It aids in lowering the experts' clinical workload. In addition, this procedure is easier and more precise than conventional ones. [7]. Therefore, there is a critical need to design an automated diagnostic system to mitigate these issues.

Deep learning has demonstrated promising outcomes in audio and image recognition [8]. For epileptic seizure detection, researchers have built models using mainly time-frequency domain analysis [9]. Several research studies have proposed using artificial intelligence-based classification algorithms to detect epilepsy [10]. Results are somewhat compromised due to the challenges of filtering noise levels in the EEG signal and the proper selection of features [11]. But, by leveraging machine learning, such systems have the potential to automate the analysis of EEG signals for the detection of epileptic seizures, enhancing accuracy, efficiency, and accessibility.

The research work is organized as follows: Section 2 delves into an extensive literature review, presenting a thorough examination of various methodologies employed for early seizure detection. Moving on to Section 3, the methodology section elucidates the dataset used for the research, detailing its description and the preprocessing steps undertaken. Additionally, the section outlines the proposed model architectures, designed for accurate epileptic seizure detection. All the proposed model architectures with comprehensive details are described in section 4. The section 5 showcases the results obtained from the implemented models and draws insightful comparisons with previous research studies. Section 6 describes the deployed web-based application for predicting the chances of a patient experiencing seizures and taking appropriate actions to address them. Finally, Section 7 encapsulates the study's conclusions, synthesizing key findings and contributions to the field of epileptic seizure detection.

## LITERATURE REVIEW

This section examines the different approaches used for the early detection of epileptic seizures. While many machine learning and deep learning techniques are used for detection, the majority of this review section is devoted to various machine learning algorithms like SVM and RF, as well as RNN and ANN.

SVM, ANN, and KNN give significant performance in the analysis and processing of brain signal datasets. The hybrid model, which proposes a binary classification between epilepsy and non-epilepsy, was proposed by Dorai and Ponnambalam [12]. Birjandtalab et al. [13] have worked on the class imbalance issue. They have implemented the Gaussian mixture model (GMM) for the detection of epileptic seizures and achieved a satisfactory 85.1 F-measure. The authors [14] have shown an ANN classifier on the EEG activity dataset. The proposed model has achieved 95% accuracy in binary classification between non-seizure and seizure.

Two models—SVM and neural networks (black box approach)—were used in the Satapathy et al. [15] study to detect epileptic seizures on the dataset having 5 classes, A to E. SVM shows the best performance compared to all other models' networks. Hassan and Subasi [16] used genetic algorithms (GA), support vector machines (SVM), and particle swarm optimization (PSO) to achieve a satisfactory accuracy of 92.38%. The CHB-MIT dataset has been used by Shoeb and Guttag [17] to detect seizures. To attain 93.38% accuracy, they have used vector features and SVM classifiers. Four classifiers—SVM, MLP, KNN, and Naive Bayes—were employed by Amin et al. [18] for classification using the DWT method and relative features. According to the experiment's findings, they have a 92% accuracy rate. Zabihi et al. [19] processed a dataset containing frequency-domain and time-domain information using an SVM classifier, achieving 96.05% specificity and 93.78% sensitivity. Lahmiri and Shmuel [20] have classified non-seizures and seizures with an exceptional 97% accuracy rate utilizing the Hurst exponent (HE). For precise categorization, Raghu et al. [21] presented a hybrid architecture that was used on unprocessed EEG data. They used a hybrid KNN-SVM model, and the accuracy was 90%.

Golmohammadi et al. [22] have proposed two LSTM-based architectures, with the softmax classifier having 3 and 4 layers, and they get satisfactory results. Chen et al. [23] have proposed two architectures, one based upon LSTM and another based upon GRU. The first LSTM deep network [23] had three layers used for classification and feature extraction. The last layer has sigmoid activation, and they have achieved 96.83% accuracy. The second [23] 3-layer GRU-based deep network has sigmoid activation in the last layer and has 96.67% classification accuracy.

According to directed tests, two GRU and LSTM architectures were employed in [24]. The LSTM and GRU model architecture consisted of one layer of Fully Connected (FC) with a sigmoid activator, four layers of LSTM and GRU with the activator, and a layer of Reshape. A GRU-based detection method has been proposed by Talathi et al. [25]. They merged the 4-layer Gru network with the softmax FC layer in the classification step of the suggested approach, and 98% accuracy was attained. A GRU-based network with softmax activation in the final classifier layer was used by Roy et al. [26]. Five layers of GRU are used in the suggested design, which has produced remarkably accurate results.

In the landscape of epileptic seizure detection, previous researchers have worked on many different algorithms along with improvements in results. However, the advancements and improvements in past techniques in the field of epileptic seizure detection go hand-in-hand. In view of this, the present research has contributed to the further

enhancement of the research area in the following ways: (i) a comprehensive exploration of four different neural network architectures (RNN, Modified-RNN, GRU, and Bi-GRU) for detecting epileptic seizures using EEG signals; (ii) strategic preprocessing of a dataset from Bonn University, Germany, with a focus on seizure detection; (iii) the significance of advanced neural network architectures, particularly bidirectional GRU, in enhancing diagnostic capabilities for epileptic seizure detection; (iv) valuable insights for optimizing model architectures with potential implications for improved patient outcomes and diagnostic efficiency in epilepsy management; and (v) a light-weight app to continuously monitor and update the epileptic attack.

## METHODOLOGY

This section describes the dataset used for the proposed research, along with the various steps involved in the preprocessing of the data. The development of model architectures for the detection of epileptic seizures is also described in the next section.

### Dataset Description

The EEG time series signals created by Andrzejak et al. at Bonn University in Germany [27] comprise the dataset used for the study. As illustrated in **Figure 1**, the dataset consists of 5 classes. **Table 1** describes the representation of each class.

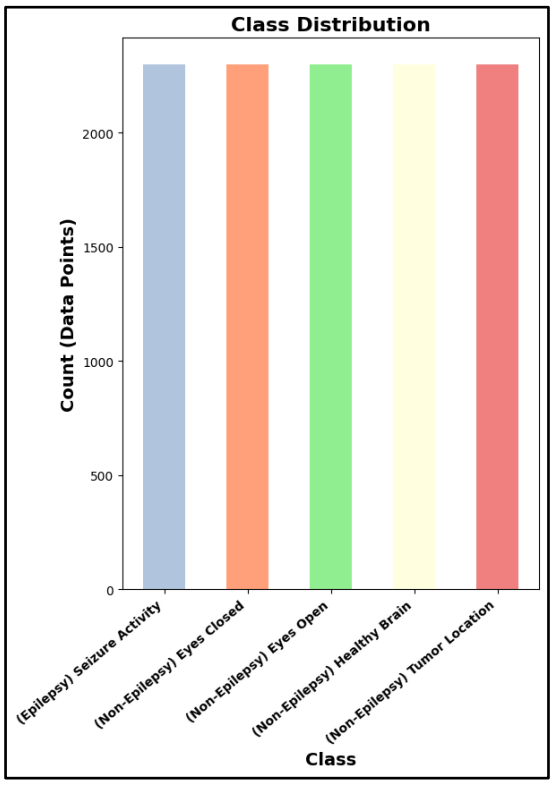


**Figure 1** Number of data points of each class

**Table 1** Class distribution

| Class | Represent | Epilepsy/Non-Epilepsy |
|---|---|---|
| 1 | Seizure Activity | Epilepsy |
| 2 | From the area where tumor was located | Non-Epilepsy |
| 3 | From the health brain area (where tumor was identified) | Non-Epilepsy |
| 4 | Eyes closed | Non-Epilepsy |
| 5 | Eyes open | Non-Epilepsy |

The dataset comprises a 23.6-second-long EEG recording with five classes. One recording has 4097 data points. These data points are divided into 23 chunks. Each chuck represents 1 second of EEG activity, which has 178 data points. This results in 11,500 rows, in which each row consists of 179 features representing the EEG values over time and a response variable, which denotes the class.

Class 1 specifically denotes epileptic seizure activity, while the other 2, 3, 4, and 5 classes represent the individual without seizure, as shown in **Table 2**. Our study focuses on the binary classification between epilepsy and non-epilepsy.

**Table 2** Result of Model 1 on various evaluation metrices

| Data Cluster | Accuracy | | Precision | | F1-Score | | Sensitivity | |
|---|---|---|---|---|---|---|---|---|
| | Train | Test | Train | Test | Train | Test | Train | Test |
| 1-2345 | 96.78 | 96.70 | 96.37 | 98.84 | 96.80 | 97.92 | 97.24 | 97.02 |
| 1-5 | 99.86 | 99.35 | 99.73 | 99.13 | 99.86 | 99.35 | 100.00 | 99.56 |
| 1-4 | 99.51 | 99.13 | 99.08 | 98.29 | 99.51 | 99.14 | 99.94 | 100.00 |
| 1-45 | 99.42 | 99.20 | 99.16 | 99.45 | 99.44 | 99.40 | 99.73 | 99.35 |
| 1-3 | 99.13 | 97.72 | 98.71 | 97.20 | 99.13 | 97.73 | 99.56 | 98.26 |
| 1-2 | 95.30 | 94.67 | 94.51 | 93.64 | 95.40 | 94.85 | 96.30 | 96.09 |
| 1-23 | 96.36 | 95.58 | 95.32 | 97.25 | 96.41 | 96.66 | 97.53 | 96.09 |
| 123-45 | 79.72 | 73.22 | 71.79 | 60.60 | 82.84 | 73.73 | 97.92 | 94.13 |
| 1-2-4 | 67.66 | 65.94 | 41.66 | 40.12 | 49.81 | 48.11 | 62.05 | 60.07 |
| 1-3-5 | 75.22 | 72.68 | 43.58 | 42.99 | 52.13 | 51.40 | 65.02 | 64.06 |
| 1-2-5 | 72.84 | 72.25 | 44.12 | 43.13 | 52.65 | 51.67 | 65.58 | 64.49 |

**Dataset Preprocessing**

The dataset preprocessing involved several key steps to optimize it for accurate model training and evaluation on various clusters. Mainly the data preprocessing consists of 4 stages as depicted in the **Figure 2**.

(i) Creating Required Clusters: The initial step involves segmenting the dataset into specific clusters relevant to the classification task. These clusters are designed to represent distinct categories or conditions related to epileptic seizure cases.

(ii) Train-Test Split: To train and evaluate the model, the dataset is then divided into training and testing sets. The training set is used for the training of the model, while the remaining amount is used to evaluate the model's performance.

(iii) Handling Imbalance with SMOTE: Addressing class imbalance is crucial for robust model training. In scenarios where certain clusters or classes are underrepresented, the Synthetic Minority Over-sampling Technique (SMOTE) algorithm is applied. SMOTE generates synthetic samples to balance class distribution, ensuring that the model is not biased towards the majority class.

(iv) One-Hot Encoding: To prepare categorical data for machine learning models, one-hot encoding is employed. This process converts categorical variables, such as cluster labels, into binary vectors, making them suitable for model input. Each category is represented by a binary feature, improving the model's ability to understand and utilize this information during training and prediction.

All these preprocessing steps collectively aim to enhance the quality of the dataset, address class imbalances, and transform categorical variables into a format suitable for effective machine learning model training and evaluation on different clusters.

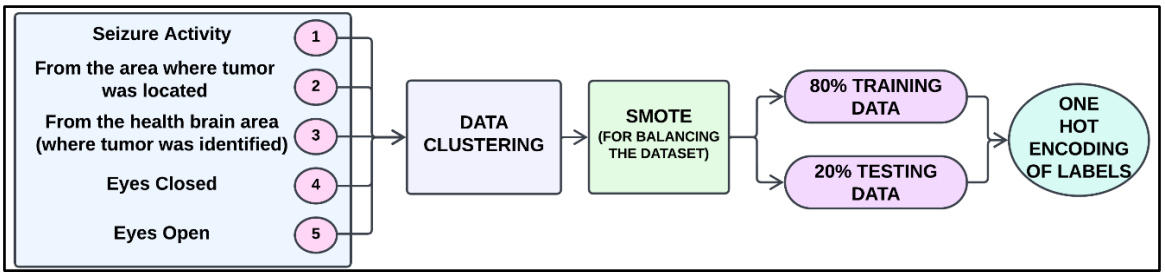


**Figure 2** Data Preprocessing Stages

## NEURAL NETWORK BASED MODEL FOR EPILEPTIC SERIES PREDICTION

This section gives insights into the different model architectures developed for the detection of epileptic seizures. We are proposing four models, namely Recurrent Neural Network (RNN), Modified Recurrent Neural Network (Modified-RNN), Gated Recurrent Unit based RNN (GRU), and Bidirectional GRU-based RNN (Bi-GRU). These models have been further evaluated using various evaluation metrics.

### Recurrent Neural Network Model (RNN)

The first proposed model is a Recurrent Neural Network (RNN) designed for detection of epilepsy using EEG time series signals. The proposed model architecture is shown in **Figure 3**.

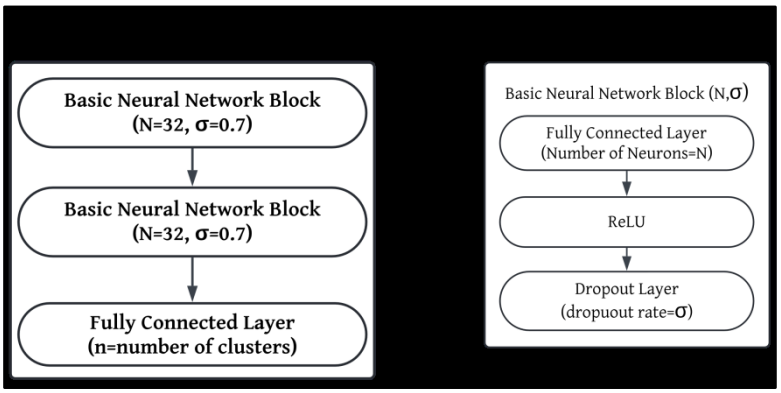


**Figure 3** Model summary of RNN

The proposed model comprises three layers. The first two layers consist of 32 neurons, each with rectified linear unit (ReLU) activation, and are followed by dropout layers with a 0.7 dropout rate to mitigate overfitting. The final layer, with a sigmoid activation function, gives the final classification output. The model architecture has 6850 model parameters. This RNN model leverages dense layers and dropout mechanisms to enhance generalization and prevent overfitting during the learning process. The use of ReLU activation and dropout layers aligns with common practices in building effective neural network architectures for binary classification tasks.

### Modified Recurrent Neural Network Model (Modified-RNN)

The Model 2 is a refined version of the previous architecture, showcasing an intricate Recurrent Neural Network (RNN) designed for the detection of epilepsy using EEG time series signals. The proposed model architecture is shown in **Figure 4**.

The model features a sequential stack of dense layers with increasing complexity; the first layer has 128 neurons utilizing the rectified linear unit (ReLU) activation function. After each dense layer, dropout regularization is applied with a reduced rate of 0.3, strategically implemented to mitigate overfitting during training. Subsequent layers follow a tiered structure with decreasing neuron counts (64, 32, 16, 8), each incorporating ReLU activation, and dropout

layers with the same rate. This hierarchical design aims to capture nuanced patterns within the EEG data. The final layer has a sigmoid activation function, resulting in a classification output. The model, with a total of 33,930 parameters, seeks to balance complexity and generalization, enhancing its ability to discern intricate temporal patterns in the EEG signals and improving overall classification accuracy. The architecture adheres to conventional feedforward neural networks, devoid of the recurrent connections typical of recurrent neural networks (RNNs).

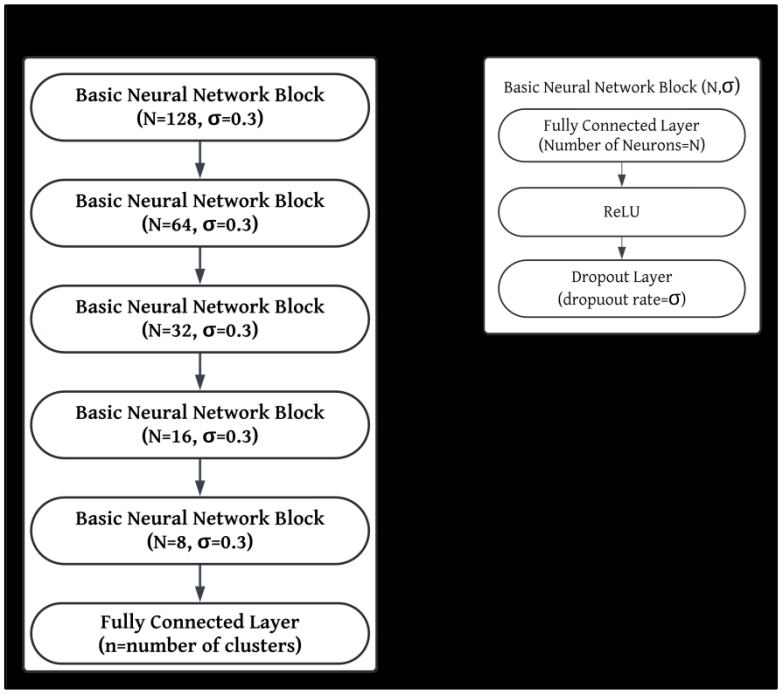


**Figure 4** Model summary of modified-RNN

**Gated Recurrent Unit based Recurrent Neural Network Model (GRU)**

The third proposed model architecture is an advanced version of RNN based on gated recurrent unit based RNN. The proposed model architecture is shown in **Figure 5**.

The model uses the gated recurrent unit GRU. The use of gated recurrent unit techniques is designed to address challenges associated with simple recurrent neural networks (RNNs). Gated Recurrent Units (GRUs), a variant of RNNs known for their ability to capture long-term dependencies while mitigating some of the vanishing gradient problems, The model starts with a GRU layer of 32 units, configured to return sequences, followed by dropout regularization and max-pooling to enhance generalization. Subsequent layers involve cascading GRUs with decreasing units, each accompanied by dropout and max-pooling, allowing the model to capture hierarchical features in the EEG time series data. The final layers are densely connected with ReLU activation and dropout, culminating in a classification output layer with a sigmoid activation function. The architecture, with a total of 6,644 parameters, reflects a thoughtful design aimed at leveraging the strengths of GRU for the detection of epileptic seizures while offering increased interpretability compared to traditional RNNs.

**Bidirectional Gated Recurrent Unit based Recurrent Neural Network Model (Bidirectional-GRU)**

The Model 4 represents a robust architecture designed to overcome challenges encountered in sequence data modeling, particularly in the context of EEG time series signals. The proposed model architecture is shown in **Figure 6**.

The Bidirectional Gated Recurrent Units (Bi-GRUs) model effectively captures both forward and backward temporal dependencies, addressing the limitations of traditional unidirectional recurrent networks. The model begins with a bidirectional GRU layer with 256 units, configured to return sequences. Subsequent layers involve cascading

bidirectional GRUs with decreasing units, each incorporating dropout and max-pooling to enhance generalization and prevent overfitting. The final layers consist of densely connected units with ReLU activation, providing the model with the capacity to learn intricate temporal patterns. The architecture culminates in a classification output layer with a sigmoid activation function. With a total of 1,159,754 parameters, this comprehensive design aims to eliminate challenges associated with modeling temporal dependencies in EEG signals, showcasing a sophisticated solution for accurate binary classification of epilepsy and non-epilepsy cases.

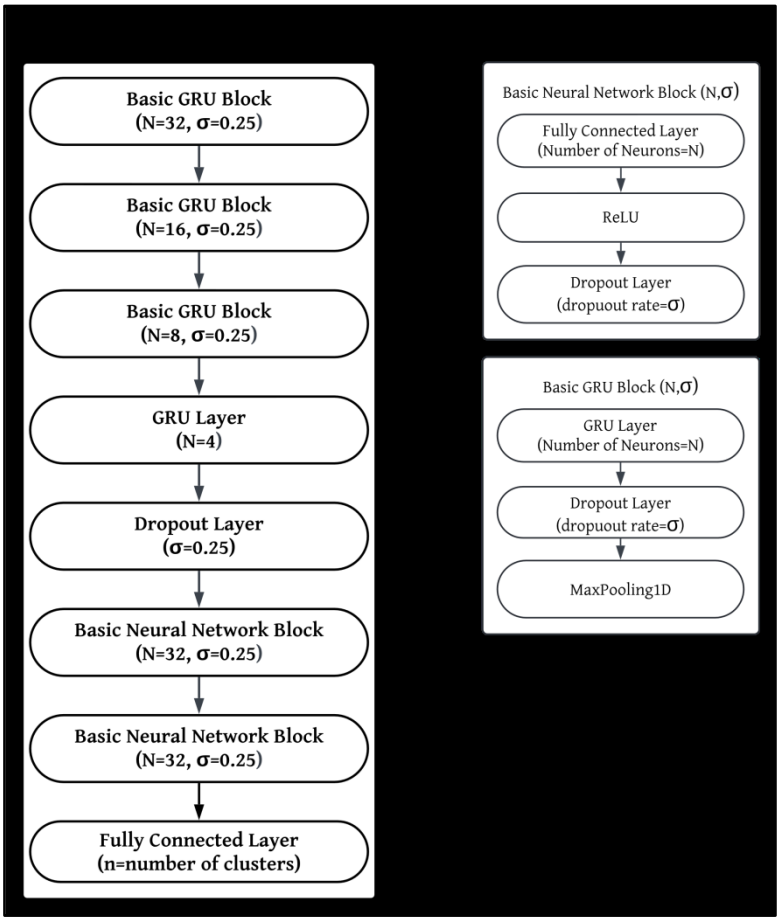


**Figure 5** Model Summary of GRU based RNN

## RESULT AND DISCUSSION

This section delves into the result of the various model architecture proposed for the research. We have used standard evaluation metrices for evaluating our model.

### Performance of Recurrent Neural Network Model (RNN)

The results of Model 1 performance showcase its effectiveness in detecting epileptic seizure cases across different data clusters. Notably, in the 1-2345 cluster, the model achieved high accuracy on both the training (96.78%) and test (96.70%) datasets, demonstrating robust generalization capabilities. Precision and F1-score metrics further reinforce its reliability, with values of 98.84% and 97.92% on the training set and 97.24% and 97.02% on the test set, respectively. This suggests that Model 1 is adept at minimizing false positives and false negatives, crucial for accurate seizure detection. In the 1-5 cluster, the model exhibited exceptional accuracy of 99.86% on the training set and 99.35% on the test set, coupled with perfect precision and sensitivity values. This outstanding performance extends to other clusters as well, with consistently high metrics observed in 1-4, 1-45, and 1-2 clusters. However, when faced with the 1-3 cluster, the model encountered challenges, resulting in lower accuracy and sensitivity values of 99.13% and 97.72% on the training set and 98.71% and 97.20% on the test set, respectively. This highlights a

potential limitation in the model's performance when dealing with three distinct classes, suggesting the need for further refinement or exploration of alternative approaches in such scenarios. In spite of this, the overall outcomes highlight the model's ability to reliably differentiate between different epileptic instances, highlighting its potential as a useful instrument for precise and automated seizure identification in a range of clinical circumstances.

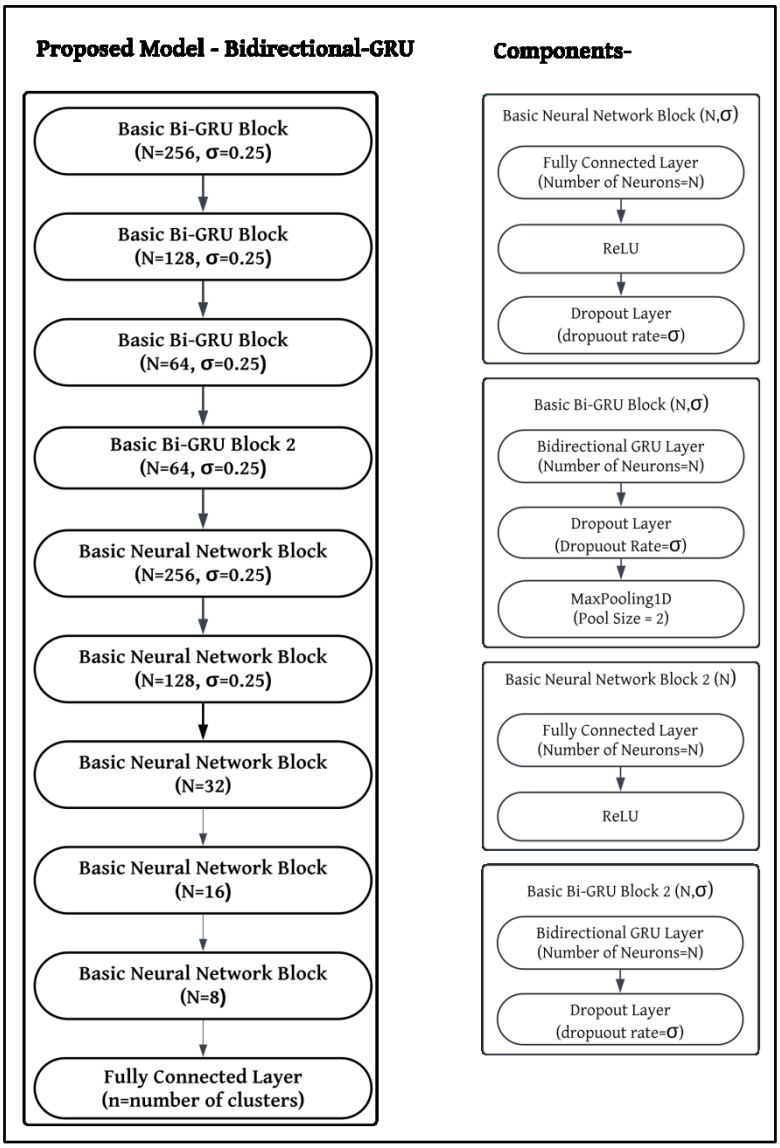


**Figure 6** Model Summary of Bidirectional-GRU based RNN

**Performance of Modified Recurrent Neural Network Model**

Model 2 exhibits exceptional performance across various data clusters, demonstrating its robustness in epileptic seizure detection. In the 1-2345 cluster, the model achieved impressive accuracy of 98.67% on the training set and 96.96% on the test set, coupled with high precision, F1-score, and sensitivity values. This indicates its proficiency in minimizing both false positives and false negatives, crucial for reliable seizure detection. Similarly, in the 1-5 cluster, Model 2 excelled with remarkable accuracy scores of 99.92% on the training set and 99.78% on the test set, along with near-perfect precision, F1-score, and sensitivity metrics. The model maintained its exceptional performance in other clusters, showcasing consistently high accuracy, precision, F1-score, and sensitivity values. However, it's noteworthy that in the 1-3 cluster, the model faced challenges, resulting in lower accuracy and sensitivity values, suggesting potential limitations in handling three distinct classes. Despite this, Model 2's overall performance

underscores its efficacy in distinguishing various epileptic cases, positioning it as a reliable tool for accurate and automated seizure detection in diverse clinical scenarios.

**Table 3** Result of Model 2 on various evaluation metrices

| Data Cluster | Accuracy | | Precision | | F1-Score | | Sensitivity | |
|---|---|---|---|---|---|---|---|---|
| | Train | Test | Train | Test | Train | Test | Train | Test |
| 1-2345 | 98.67 | 96.96 | 98.91 | 98.74 | 98.64 | 98.12 | 98.38 | 97.51 |
| 1-5 | 99.92 | 99.78 | 99.94 | 99.78 | 99.89 | 99.78 | 99.84 | 99.78 |
| 1-4 | 99.78 | 99.02 | 99.89 | 99.56 | 99.75 | 99.13 | 99.62 | 98.69 |
| 1-45 | 99.90 | 99.42 | 99.92 | 99.46 | 99.90 | 99.56 | 99.89 | 99.67 |
| 1-3 | 99.43 | 96.96 | 99.42 | 95.96 | 99.48 | 97.00 | 99.73 | 98.04 |
| 1-2 | 96.85 | 94.13 | 95.32 | 92.66 | 96.95 | 94.34 | 98.64 | 96.09 |
| 1-23 | 97.91 | 96.16 | 97.00 | 96.96 | 97.95 | 97.07 | 98.94 | 97.17 |
| 123-45 | 95.49 | 93.48 | 94.67 | 90.79 | 95.55 | 92.01 | 94.45 | 93.26 |
| 1-2-4 | 96.11 | 91.23 | 96.26 | 91.89 | 91.10 | 91.28 | 96.07 | 91.16 |
| 1-3-5 | 94.93 | 88.91 | 94.95 | 89.29 | 94.90 | 89.13 | 94.89 | 89.06 |
| 1-2-5 | 94.75 | 89.13 | 94.45 | 89.30 | 94.44 | 89.20 | 94.44 | 89.13 |

**Performance of Gated Recurrent Unit based Recurrent Neural Network Model**

Model 3 presents a varied performance across different data clusters, showcasing strengths in certain classifications while encountering challenges in others. In the 1-2345 cluster, the model achieved notable accuracy of 97.03% on the training set and 98.83% on the test set, with high precision and F1-score values. This highlights its proficiency in accurately identifying epileptic seizure cases in this particular cluster. Similarly, in the 1-5 and 1-4 clusters, the model demonstrated robust performance with accuracy scores exceeding 98%, along with perfect precision, F1-score, and sensitivity metrics, underlining its effectiveness in binary classifications.

However, in clusters involving three classes (1-3, 1-2, 1-23), the model encountered challenges, resulting in lower accuracy and sensitivity values. This indicates potential limitations in handling more complex classification scenarios, emphasizing the need for further refinement or exploration of alternative approaches in these cases. Notably, in clusters 1-2-4, 1-3-5, and 1-2-5, the model struggled significantly, yielding low accuracy, precision, and F1-score values, highlighting potential difficulties in accurately classifying instances when multiple classes are involved.

While Model 3 excels in certain binary classifications, its performance underscores the importance of considering the complexity of the classification task, especially when dealing with multiple classes. Further optimization and exploration of alternative model architectures may be necessary to enhance its efficacy in more intricate scenarios.

**Table 4** Result of Model 3 on various evaluation metrices

| Data Cluster | Accuracy | | Precision | | F1-Score | | Sensitivity | |
|---|---|---|---|---|---|---|---|---|
| | Train | Test | Train | Test | Train | Test | Train | Test |
| 1-2345 | 97.03 | 98.83 | 94.93 | 99.24 | 97.10 | 99.27 | 99.37 | 99.30 |
| 1-5 | 98.07 | 97.50 | 96.28 | 95.24 | 98.11 | 97.56 | 100.00 | 100.00 |
| 1-4 | 98.59 | 98.48 | 97.25 | 97.05 | 98.61 | 98.50 | 100.00 | 100.00 |
| 1-45 | 98.80 | 99.35 | 97.79 | 99.24 | 98.82 | 99.51 | 99.86 | 99.78 |
| 1-3 | 97.36 | 97.28 | 95.51 | 95.22 | 97.42 | 97.34 | 99.40 | 99.56 |
| 1-2 | 96.47 | 96.41 | 93.63 | 94.22 | 96.61 | 96.61 | 99.78 | 99.13 |
| 1-23 | 96.43 | 97.97 | 94.32 | 98.58 | 96.52 | 98.48 | 98.83 | 98.37 |
| 123-45 | 94.47 | 93.87 | 91.56 | 88.23 | 98.10 | 92.78 | 94.72 | 97.83 |
| 1-2-4 | 66.96 | 65.94 | 11.11 | 11.11 | 16.67 | 16.67 | 33.33 | 33.33 |
| 1-3-5 | 65.36 | 65.00 | 11.11 | 11.11 | 16.67 | 16.67 | 33.33 | 33.33 |
| 1-2-5 | 64.42 | 63.91 | 11.11 | 11.11 | 16.67 | 16.67 | 33.33 | 33.33 |

**Performance of Bidirectional Gated Recurrent Unit based Recurrent Neural Network Model**

Model 4 emerges as an exemplary performer across diverse data clusters, consistently achieving perfect or near-perfect scores in key metrics, showcasing its robustness and effectiveness in epileptic seizure detection. In the 1-2345 cluster, the model demonstrates flawless accuracy of 100.00% on both the training and test sets, along with perfect precision, F1-score, and sensitivity values. This remarkable performance extends across various other clusters, including 1-5, 1-4, 1-45, 1-3, and 1-2, where the model consistently achieves accuracy scores exceeding 99%, and often perfect scores, on both training and test sets.

Even in clusters involving more complex classifications, such as 1-23, 123-45, 1-2-4, 1-3-5, and 1-2-5, Model 4 maintains exceptional performance with accuracy scores ranging from 99.55% to 100.00% on the training set and 94.85% to 99.78% on the test set. These results highlight the model's versatility and reliability in handling scenarios with multiple classes.

Model 4's outstanding performance positions it as a superior choice for epileptic seizure detection, demonstrating its potential as a highly accurate and robust tool for automated diagnosis. The consistently high accuracy, precision, F1-score, and sensitivity values across various data clusters underscore the model's efficacy and underscore its potential clinical significance in enhancing diagnostic capabilities and improving patient outcomes in epilepsy management.

**Table 5** Result of Model 5 on various evaluation metrices

| Data Cluster | Accuracy | | Precision | | F1-Score | | Sensitivity | |
|---|---|---|---|---|---|---|---|---|
| | Train | Test | Train | Test | Train | Test | Train | Test |
| 1-2345 | 100.00 | 99.26 | 100.00 | 99.73 | 100.0 | 99.54 | 100.00 | 99.35 |
| 1-5 | 99.92 | 99.57 | 99.84 | 99.35 | 99.92 | 99.56 | 100.00 | 99.78 |
| 1-4 | 100.00 | 99.67 | 100.00 | 99.57 | 100.0 | 99.67 | 100.00 | 99.78 |
| 1-45 | 100.0 | 99.64 | 100.0 | 99.67 | 100.0 | 99.73 | 100.0 | 99.78 |
| 1-3 | 100.00 | 99.24 | 100.00 | 99.56 | 100.0 | 99.24 | 100.00 | 98.91 |
| 1-2 | 99.97 | 99.46 | 99.94 | 99.35 | 99.97 | 99.46 | 100.00 | 99.56 |
| 1-23 | 100.00 | 99.13 | 100.00 | 99.78 | 100.0 | 99.34 | 100.00 | 98.91 |
| 123-45 | 99.73 | 96.39 | 99.98 | 94.85 | 99.74 | 95.52 | 99.49 | 96.19 |
| 1-2-4 | 99.82 | 97.39 | 99.84 | 97.41 | 99.84 | 97.39 | 99.84 | 97.39 |
| 1-3-5 | 99.55 | 96.01 | 99.55 | 96.02 | 99.55 | 96.01 | 99.55 | 96.01 |
| 1-2-5 | 99.86 | 95.94 | 99.85 | 95.98 | 99.85 | 95.95 | 99.85 | 95.94 |

**Comparative Analysis with Existing Research**

**Table 6** presents a comparative analysis of findings from prior research endeavours, specifically focusing on studies that have utilized the same dataset. The comparison distinctly highlights that our proposed methodology surpasses the established results from previous studies.

In the research, each model underwent 45 epochs of training, with each epoch lasting around 10 seconds. Thus, the total training time for a single model was approximately 7 to 8 minutes. The computational setup utilized an 11th Gen Intel(R) Core(TM) i5-1135G7 processor with a base frequency of 2.40GHz and a turbo boost frequency of 2.42 GHz, alongside 16.0 GB of RAM. This efficient training protocol, balanced with computational resources, enhances the model's suitability for integration into portable and wearable devices, broadening its practical applications.

The research progression from Model 1 to Model 4 reflects a deliberate and systematic approach to enhancing the performance of epileptic seizure detection using EEG signals. Beginning with the foundational RNN architecture in Model 1, which established a baseline with dense layers and dropout mechanisms, the study gradually incorporated more sophisticated techniques in subsequent models. Model 2 introduced a more complex network with additional dense layers, capturing finer details in the EEG data. The transition to Model 3 marked a significant advancement with the integration of GRU layers, addressing the limitations of traditional RNNs by effectively capturing long-term dependencies. Finally, the introduction of bidirectional GRU layers in Model 4 culminated in the most robust

architecture, capable of analysing temporal data from both forward and backward perspectives. Each model iteration was designed to incrementally improve the system's ability to generalize and accurately classify epileptic seizures, with Model 4 emerging as the most effective solution, demonstrating superior accuracy and reliability in the detection process. This evolution underscores the importance of incremental architectural modifications in achieving optimal performance in complex neural network applications.

**Table 6** Comparative analysis with previous existing researches

| Reference | Classification Task | Methodology | Accuracy |
|---|---|---|---|
| 28 | 5-1 | Hermite transform and LS-SVM | 99.50 |
| **Proposed** | | **Bidirectional-GRU Network** | **99.57** |
| 29 | 4-1 | weighted horizontal visibility graph and KNN | 97 |
| 30 | | CNN+LR | 98.83 |
| **Proposed** | | **Bidirectional-GRU Network** | **99.67** |
| 31 | 45-1 | Weighted complex networks and SVM | 96.4s0 |
| 32 | | Matrix determinant and MLP | 97.10 |
| 28 | | Hermite transform and LS-SVM | 98.67 |
| 33 | | TQWT, entropy features, Hjorth parameter and HMM | 99.58 |
| **Proposed** | | **Bidirectional-GRU Network** | **99.64** |
| 34 | 3-1 | MT rational DSTFT and MLP | 98.50 |
| 28 | | Hermite transform and LS-SVM | 98.50 |
| 35 | | CEEMDAN and Adaboost | 99.00 |
| 30 | | CNN+LR | 99.17 |
| **Proposed** | | **Bidirectional-GRU Network** | **99.24** |
| 34 | 2-1 | MT rational DSTFT and MLP | 94.90 |
| 28 | | Hermite transform and LS-SVM | 97.50 |
| 36 | | DWT based WL, ZC, SSC and NB&SVM | 97.75 |
| 30 | | CNN+LR | 98.00 |
| **Proposed** | | **Bidirectional-GRU Network** | **99.46** |
| 31 | 32-1 | Weighted complex networks and SVM | 94.50 |
| 28 | | Hermite transform and LS-SVM | 98.00 |
| 37 | | GModPCA and SVM | 95.80 |
| 33 | | TQWT, entropy features, Hjorth parameter and HMM | 97.50 |
| 30 | | CNN+LR | 98.88 |
| **Proposed** | | **Bidirectional-GRU Network** | **99.13** |
| 34 | 1-2345 | MT rational DSTFT and MLP | 98.10 |
| 28 | | Hermite transform and LS-SVM | 97.60 |
| 33 | | TQWT, entropy features, Hjorth parameter and HMM | 97 |
| 36 | | DWT based WL, ZC, SSC and NB&SVM | 97.90 |
| 38 | | SEA based DNN | 97.17 |
| 30 | | CNN+LR | 98.47 |
| **Proposed** | | **Bidirectional-GRU Network** | **99.26** |

## WEB-BASED APPLICATION

The app utilizes Model 4, a bidirectional GRU-based RNN, to empower the users to make informed decisions about their health by predicting the likelihood of epilepsy based on EEG data. It seamlessly analyses EEG data in the same format as that of the Bonn Dataset and makes predictions for each individual in the CSV file, featuring 178 features, tailored to the patient's specific condition: "low probability of epilepsy" for less imminent concern and "high probability of epilepsy detected. Please seek medical attention." for urgent action. The working of the web application of depicted in **Figure 7**.

The application then informs the patient’s caretakers immediately in case action needs to be taken. This would prove to be helpful, especially in the case of elderly patients or children suffering from epilepsy. The predictions can be explored through informative bar charts and pie charts to grasp the overall distribution of patients with and without

epilepsy. The patient can also opt to donate their EEG data, securely stored without patient information, to advance research and improve future predictions, fostering collective progress. The user interface of the application is shown in **Figure 8**.

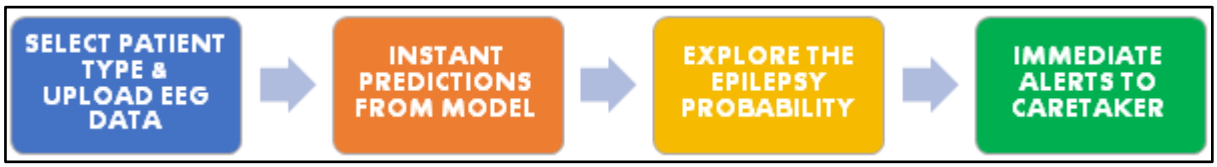


**Figure** 7 Working of the web application


**Figure 8** User Interface of developed web application

## CONCLUSION

The presented study examined and assessed four different proposed model architectures that are used in EEG data processing in an effort to identify epileptic seizures early and reliably. The models, namely Recurrent Neural Network (RNN), Modified Recurrent Neural Network (Modified-RNN), Gated Recurrent Unit based RNN (GRU), and Bidirectional GRU-based RNN (Bi-GRU), were systematically assessed across various data clusters derived from the Bonn University dataset. The results unequivocally establish Model 4 as the superior architecture, showcasing exceptional performance with flawless or near-flawless accuracy, precision, F1-score, and sensitivity across diverse scenarios, including both binary and three-class classifications. This promising outcome underscores the potential of advanced neural network architectures, particularly bidirectional GRU-based models, to revolutionize the landscape of epileptic seizure detection. The findings of this research contribute valuable insights to the field, emphasizing the significance of model selection and architecture in achieving accurate diagnostic outcomes. As the most effective model identified, Model 4 holds promise for advancing automated diagnosis systems, reducing clinical burden, and improving patient outcomes in epilepsy management. The model is then used to deploy a web-based application for the prediction of epileptic seizure activity in a patient's brain and to take appropriate actions if epilepsy is detected. Further research could explore optimization strategies and additional dataset considerations to enhance the generalizability and applicability of these models in real-world clinical settings.

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## DATA AVAILABILITY

**The dataset analyzed during the current study are available in the repository**

https://repositori.upf.edu/handle/10230/42894

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**Compliance with ethical standards**

**Conflict of interest**: The authors declare that they have no conflict of interest.

**Ethical approval**: This article does not contain any studies with human participants or animals performed by any of the authors.

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# A Numerical Investigation of Thermal Transport for Magnetic Fluid Hyperthermia in Breast Tissue with Lobular Carcinoma

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***Abstract***: *Conventional treatment methods for malignancy often face efficacy challenges specifically for advanced stage cancers or after prolonged treatment exposures. Magnetic Fluid Hyperthermia (MFH) treatment is found to offer promising outcomes in unison with the existing treatment methods like chemotherapy, surgery, radiotherapy, immunotherapy, etc. Rapid advancement in nano-science has led to the synthesis of super-paramagnetic nanoparticles (SPNs) which has gained confidence in MFH as a promising novel treatment therapy. The present numerical study explores the thermal transport phenomena due to infused surface modified super-paramagnetic iron oxide nanoparticles (SPIONs) of volume concentration 0.003, infused into a spherical tissue-tumour geometry of breast tissue and exposing to an alternative magnetic field of tolerable ranges with field strength (H0) of 5518 A/m and frequency (f) of 300 kHz which is within the Atkinson–Brezovich limit. The results presented includes the trajectory of spatial temperature distribution across the geometry, temperature contour representing temperature rise at the centre of the tumour and tissue tumour periphery when the treatment is carried out for 500 sec. Considerable damage at the tumour region with negligible baneful effect to the adjoining healthy tissue can be concluded. However further regulation of temperature to restrict the rise to hyperthermic levels of around 42-45℃ may be a future scope from this study.*

***Keywords***: *Magnetic Fluid Hyperthermia; Super Paramagnetic Iron Oxide Nano Particles; Alternating Magnetic Field; Cancer; Breast; Lobular-Carcinoma*

## INTRODUCTION

The concepts of magnetic fluid hyperthermia (MFH) were first proposed 1957 by Gilchrist et al [1] yet certain limitations have restricted the technique to be successfully translated into routine clinical application. The only clinical trial that received approval from the European Regulatory authority was carried out by the Magforce AG Company under its Nano-therm therapy program in 2013 for last stage glioblastoma which was later also approved by the FDA for intermediate-risk prostate cancer [2]. However, these trials were carried out for a small sample space for very specific type of tumours and were mostly inclusive.

However, in these 66 years considerable advancement in nanotechnology has led to the development of a number of SPMNPs which showed promising results when tested in in-vitro and in-vivo setups. However owning to the high cost, strict guidelines and approval procedures of regulatory bodies, conversion to clinical study is still far fetching. With the development of sophisticated Finite Element Analysis softwares, numerical simulations of developed mathematical models of biological tissues assisted in understanding the outcomes of the treatment procedure and regain confidence of the treatment. The challenging parts of MFH include determining the optimum safe magnetic field strength, frequency and exposure time for the targeted region; achieving sufficient concentrations of magnetic nanoparticles (MNPs) within the target tumour, developing a better understanding of the mechanism of MNP-mediated energy deposition and its effects on tissues in order to maximise the effectiveness of MFH with minimal harmful effects on healthy tissue and treatment temperature regulation. Magnetic fluid hyperthermia is a coupled multiphysics problem which is addressed by solving two partially independent equations for electromagnetic heat generation and biological heat transfer [3]. In the present study both of these solutions are carried out computationally using finite element analysis method-based solver. The exposed alternating magnetic field strength is assumed to be 5518 kA/m with a frequency of 300 kHz both of which are within the safe exposure limit. The treatment is carried out for a span of 500 seconds. The spatial distribution of temperature across the region of interest, the rate of temperature rise at the centre, tumour periphery and tissue periphery is also observed in this study by means of temperature contours. Assuming hyperthermic threshold to be around 45°C, the results obtained from the study will help in

assessing the damage caused to the tumour and healthy tissue and also comment what extent of thermal regulation is required for the treatment.

**PROBLEM DESCRIPTIONS AND MODELLING**

An axis-symmetric model is constructed with two concentric semi circles of radius 5 mm for the tumour and 10 mm for the surrounding health tissues. As major portion of the breast physiology consists of fat, the healthy tissue region is assumed to be breast fat and the lobular tumour is modelled as a breast muscle tumour [8]. The heat generation due to magnetic relaxation losses of bio compatible surface modified SPIONs is evaluated using the Rosensweig's Equation (4) as stated below Equation (1)

$$P = \pi \mu_0 H_0^2 f \chi_0 \frac{2\pi f \tau}{1+(2\pi f \tau)^2} \quad (1)$$

Also $\chi_0$ is the actual susceptibility of the SPIONs (at equilibrium) is a function of the Langevin parameter ($\zeta$) and initial magnetic susceptibility ($\chi_i$) both of which depends on the nanofluid's magneto-physical properties.

$$\chi_0 = \frac{3}{\zeta}(coth\ \zeta - \frac{1}{\zeta})\chi_i \quad (2)$$

$$\zeta = \frac{\mu_0 M_d H_0 V_M}{k_B T} \quad (3)$$

$$\chi_i = \frac{\mu_0 M_S M_d V_M}{3 k_B T} \quad (4)$$

Also the magnetic saturation, $M_S$, is correlated with the domain magnetization, $M_d$, of the MNPs by the relation $M_S = \phi_m M_d$, where $\phi_m$ is the magnetic volume fraction of MNPs in the suspended fluid, correlated with the volume fraction, $\phi$, by the relation $\frac{\phi_m}{\phi} = (1+\frac{\delta}{R_M})^{-3}$, where $\delta$(m) is the thickness of the surfactant layer over the MNPs. Also, in Equation (1), the effective relaxation time, $\tau$, can be expressed in terms of Neel ($\tau_N$) and Brownian ($\tau_B$) relaxation times as

$$\tau = \frac{\tau_N \tau_B}{\tau_N + \tau_B} \quad (5)$$

where $\tau_N = \tau_0 \exp\left(\frac{KV_M}{k_B T}\right)$, and $\tau_B = \frac{3\eta V_H}{k_B T}$ , K $(J/m^3)$ is the effective anisotropy constant of the MNPs, $\tau_0$ (secs) is the attempt time, which is a typical material characteristic and usually ranges between $10^{-9}$ to $10^{-12}$ seconds.

For the present study the dosage of nanoparticles is considered to be 10mg/gm of tumour which is a standard dosage reported in clinical trials [3]. The different magneto-physical parameters of SPIONs used in the numerical computation are listed in **Table 1** [5].

The heat transfer mechanism inside the tissue-tumour model is numerically computed using the Pennes bioheat transfer model [6] for MFH is expressed in the form of Pennes Bioheat equation as :

$$\rho_t c_t \frac{\delta T}{\delta t} = \nabla.(k_t \nabla T) + \rho_b \omega c_b (T - T_b) + Q_m + P \quad (6)$$

where, P (W/m3) is the heat added to the tissue system from an external source which in case of MFH is due to infused SPM-nanofluid that can be evaluated using Equation (1). In the present study the tissue-tumour region is

assumed to be homogeneous and the thermo-physical properties of the tissue enriched tumour region are approximated using the following expressions

Specific Heat Capacity: $(1-\phi)c_t + \phi c_f$

Thermal conductivity: $\frac{1}{k_c} = \frac{1-\phi}{k_t} + \frac{\phi}{k_f}$

Density: $(1-\phi)\rho_t + \phi\rho_f$

**Table 1** Magneto-physical parameters of super paramagnetic Iron oxide nano particle

| Parameters | Description | Unit | Magnitude |
|---|---|---|---|
| $\mu_0$ | Permeability of free space. | [Tm/A] | $4\pi\times10^{-7}$ |
| $H_0$ | Magnetic field strength | [A/m] | 5518 |
| $f$ | Frequency of AMF | [kHz] | 300 |
| $M_d$ | Domain Magnetization | [kA/m] | 446 |
| $V_M$ | Volume of SPMNP | [$m^3$] | $3.5914\times10^{-24}$ |
| $R_M$ | Radius of SPMNP | [m] | $9.5\times10^{-9}$ |
| $k_B$ | Boltzman Constant | [J/K] | $1.381\times10^{-23}$ |
| $\phi_v$ | SPMNP volume fraction | [1] | 0.003 |
| $\eta$ | Dynamic viscosity of fluid | [kg/m/s] | $1\times10^{-3}$ |
| $V_H$ | Hydrodynamic Volume of SPMNP | [$m^3$] | $5.0805\times10^{-22}$ |
| $\delta$ | Thickness of surfactant layer | [m] | $4\times10^{-8}$ |
| $\tau_0$ | Attempt time | [s] | $10^{-9}$ |
| K | Effective magnetic anisotrophy constant | [$J/m^3$] | $1\times10^{4}$ |

The thermo-physical properties of tissue, tumour, ferrofluid, composite region and blood used in this computational study is provided in **Table 2** [3,5,7]

**Table 2** Thermophysical properties of tissue, tumour, ferrofluid, composite region and blood used in computation

| Tissue | Specific Heat capacity (J/kg/K) | Thermal conductivity (W/m/K) | Density ($kg/m^3$) | Blood perfusion rate (mL/min-kg) | |
|---|---|---|---|---|---|
| | | | | Tissue | Tumour |
| Breast tumour | 3421 | 0.49 | 1090 | 13.17 | 291.74 |
| Breast tissue (fat) | 2348 | 0.21 | 911 | | |
| Ferro-fluid | 4000 | 40 | 5180 | - | - |
| Composite Region | 3422.7 | 0.49146 | 1102.3 | Same as tumour | |
| Blood | 4180 | 0.51 | 1050 | - | - |

The final temperature profile is evaluated computationally by conducting a time dependent study for time ranging from 0 to 500 seconds with time step of 0.001 seconds using COMSOL Multiphysics 6.0 which is a finite element-based solver. In respect of initial and boundary conditions, isothermal boundary is assumed and the tissue periphery temperature is kept constant at 37ºC. The initial temperature of tissue and tumour is set at 37ºC and that of blood is also considered to be 37ºC. Heat generation is assumed to be only due to magnetic relaxation of nanoparticles in this study. The present study is carried out with 2912 triangular elements for the geometry and the mesh size has been finalised after conducting mesh independence study. Finally, the present mathematical model has been validated extensively to ensure the efficacy of the present model. The validation results are not presented here for the brevity.

## RESULTS AND DISCUSSIONS

The temperature distribution in the tumour and surrounding healthy region is important to assess the effectiveness of the therapy. In **Figure 1(a)** the trajectory of the rise of temperature with respect to treatment time shows that a

hyperthermic temperature of 45ºC is reached at the centre of the tumour after 80 seconds. The spatial distribution of temperature in **Figure 1(b)**, shows a maximum temperature of 52.86ºC at the centre of the tumour, which gradually decreases towards the tissue periphery, ensuring minimal damage to the healthy tissue. **Figure 2**. Illustrates the temperature contours showing temperature distribution after 500 s for 2D-axis symmetric geometry and 3D-geometry of tissue-tumour model. There is no much difference between the two results. However, 3D-geometry of tissue-tumour model analysis is very important when the particle distribution are not homogeneous in the tissue.

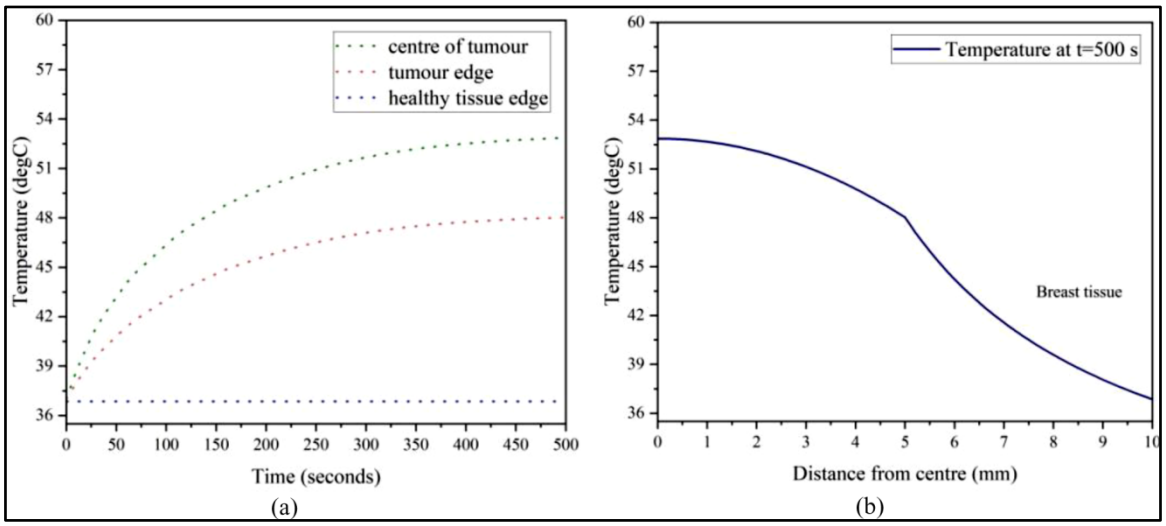


**Figure 1** (a) Temperature versus time trajectory at different locations, (b) spatial distribution of temperature across the geometry

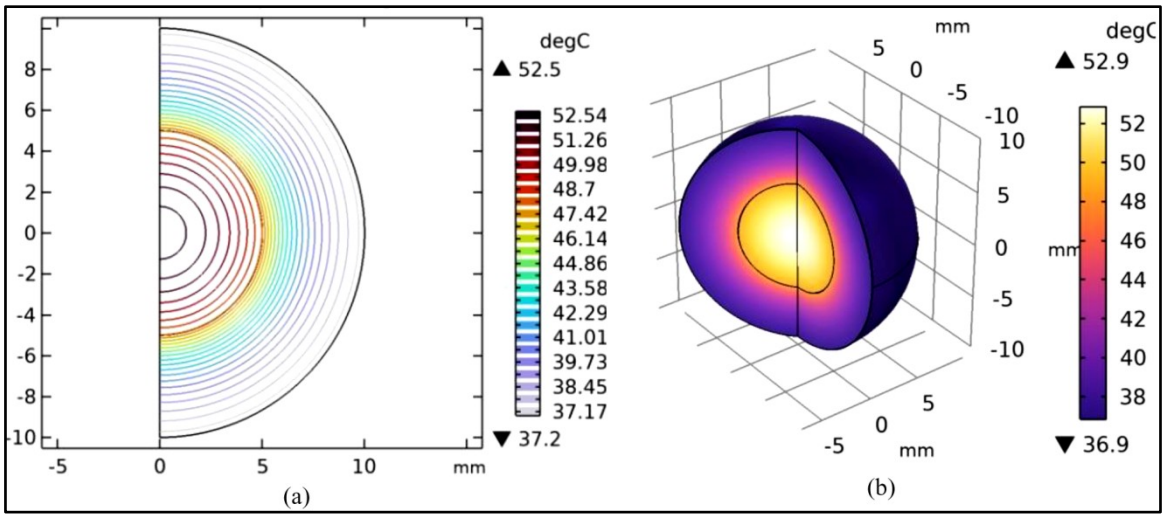


**Figure 2** Temperature contours showing temperature distribution after 500 s for (a) 2D-axis symmetric geometry, (b) 3D-geometry of tissue-tumour model

The finding of the study includes

- Higher thermal diffusivity of the tumour region resulted in greater temperature rise (53ºC) compared to the healthy tissue region (46ºC).
- The spatial temperature distribution of temperature is also observed to experience a sudden dip after the tumour periphery.
- The maximum temperature rise is beyond the hyperthermic levels concluding the need of thermoregulations, The hyperthermic threshold is reached after 80 seconds.

## CONCLUSION

The results of the study depict that using the SPIONs and AMF, maximum temperature achieved is 52.86ºC, which is more than the target temperature 45ºC. Also, the temperature profile of at the tissue-tumour edge is also required to be further scaled not in order to decrease the damage to the adjoining healthy tissue. Therefore, although considerable heating is achieved, thermoregulation is required to make the treatment process bearable for the patient. In one of the ways, this can be achieved is using SPION composites with Curie Temperature close to the hyperthermic range or conduct the treatment in step size of 80 s which can be a further extension of this study in future.

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# Interaction Dynamics of Pristine and Pt-decorated ZnO Nanosheet during Cytosine Adsorption: A Robust Electro-Chemical Analysis of Biosensor

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***Abstract:*** *The performance of pristine and platinum (Pt) decorated ZnO nanosheets in detecting cytosine (C) nucleobase was compared in the current study, using a first principle computational study with Gaussian 09W and Gauss View 6.0 package. Cytosine, a pyrimidine nitrogenous base, was selected as the adsorbed biomolecule for both nanosheets. Two systems were involved: cytosine-adsorbed pristine ZnO nanosheet (case-A) and cytosine-adsorbed Pt-doped ZnO nanosheet (case-B). The interaction between the sensed molecule and the sensing material was analyzed using various electronic parameters such as molecular electrostatic potential, the total density of states, the lowest unoccupied molecular orbital (LUMO), the highest occupied molecular orbital (HOMO), and Mulliken charge analysis. It was inferred that the Pt-doped ZnO nanosheet was a better sensing material, exhibiting strong adsorption energy (-1.421 eV) and a decreased binding distance (2.215 Å) compared to the pristine ZnO nanosheet, which had an adsorption energy of -0.377 eV and a binding distance of 2.707 Å. The importance of accurate detection and sensing of cytosine in our body was elucidated, helping in coding for proteins and regulating gene expression.*

***Keywords:*** *Cytosine; Pt-ZnO Nanosheet; Density of State (DOS); Mulliken Charge; Molecular Electrostatic Potential (MEP*)

## INTRODUCTION

Cytosine is a pyrimidine nitrogenous base encountered in DNA and RNA. It is paired with guanine through three hydrogen bonds, and a significant role is played in retaining the configuration of DNA and RNA and assuring the proper transmission of genetic information. Mutations can be induced by the improper pairing of cytosine in the body, potentially resulting in congenital disorders, cancer, or damaged cellular functions, hence becoming the epitome of research in recent times [1]. ZnO nanosheets are known to be semiconductors with a wide bandgap of about 3.37 eV. Hexagonal wurtzite structures are possessed by them, and they are used for UV photodetectors, sensors, and photo catalysis due to their strong excitonic emissions at room temperature. A high surface area, efficient biocompatibility, good conductivity, and enhanced photocatalytic activity are exhibited, making them ideal for use as biosensor materials [2].

The molecular structures of the nitrogenous bases (adenine, guanine, thymine, and cytosine) were examined using density functional theory (DFT) by Maity et al. to determine the stability and provide a detailed electronic perspective on the properties of four nitrogenous bases [3]. The electronic and the adsorption properties of the boron-carbon-nitride (BCN) nanosheet was investigated by Mir et.al. by analyzing the interaction of nitrogenous bases present in DNA or RNA for potential biological applications using density functional theory (DFT) demonstrating sheet's stability as a promising biocompatible sensing material [4]. The underlying importance behind incorporating ZnO based nanostructures as promising biosensors was critically analyzed by Tayebee et.al. with the help of computational study on the interaction of aliphatic aldehydes with ZnO based nanostructures [5]. The use of graphene and hexagonal boron nitride (hBN)-based nanostructures was thoroughly explored by Rani et. al. for the detection of all the nitrogenous bases present in DNA or RNA through demonstration of nanosensor's high sensitivity and selectivity towards biomolecules [6]. A density functional theory (DFT) based computational method was incorporated by Murti et. al. via molecular dynamics (MD) simulations to elucidate the electrochemical and vibrational properties of a nanostructured system composed of single strand DNA (ssDNA), dopamine and $TiO_2$ on an FTO substrate helping to detect damage of DNA [7].

In this research, extensive analysis had been performed to examine the performance of pristine ZnO nanosheet and Pt-doped ZnO nanosheet as a biosensing material in proper detection of cytosine biomolecule. The structure of cytosine and the nanosheets were geometrically optimized and the electronic characteristics such as density of state (DOS), molecular electrostatic potential (MEP), molecular orbital analysis, and Mulliken charge analysis were critically elucidated via first principle computational study. This research could be the considered as a novel electro-chemical technique in paving the way for ZnO nanostructure for becoming an effective biosensor.

## COMPUTATIONAL DETAILS

All the first-principle computations were executed using the Gaussian 09W and Gauss View 6.0 software. A semi-empirical method with a ZDO basis set was utilized to optimize the structures. Due to the presence of an even number of electrons in cytosine-adsorbed pristine and Pt-doped ZnO nanosheet systems, spin-restricted PM6 functional was employed for geometrical optimization and electronic structure approximation [3]. Additionally, GaussSum3.0 was used to plot the DOS spectrum.

The adsorption energy (Eadsorption) of both case-A and case-B was calculated by the following equation,

$$E_{adsorption} = E_{system} - E_{cytosine} - E_{nanosheet} \quad (1)$$

where $E_{system}$ was the total electronic energy of both systems after adsorption and $E_{nanosheet}$ was the individual electronic energy of nanosheets without adsorption [8]. Lastly, $E_{cytosine}$ was the electronic energy of cytosine.

## RESULT AND DISCUSSION

### Adsorption Energy and Binding Distance

The enhanced ability to detect cytosine was critically elucidated in case-A, resulting in robust adsorption energy of -1.421 eV and a reduced binding distance of 2.215 Å as compared to that of case-B with adsorption energy of -0.377 eV and a binding distance of 2.707 Å in **Figure 1(a)** and **Figure 1(d)**. The electronic characteristics of the pristine ZnO nanosheet were modified upon introducing a Pt atom over its surface, leading to enriched electron density towards platinum due to its lower electropositivity compared to zinc [9]. A more assertive charge transfer between the oxygen atom of the cytosine molecule and the platinum atom of the Pt-doped ZnO surface was facilitated as a result of the surface mutation introduced by the platinum doping. New reactive sites were developed due to the catalytic property of platinum, leading to increased surface reactions for better adsorption of cytosine on the Pt-doped ZnO surface.

### Interpretation of the Density of State (DOS)

The adsorption of cytosine was critically analyzed by examining the total density of states, which altered the electronic structure of both the nanosheets and enhanced the sensitivity of the nanosheet in detecting cytosine molecules [8]. The graph of the total density of states was plotted for both cases keeping the energy range from -15 eV to +15 eV, as mentioned in **Figure 1(b)** and **Figure 1(e)**. It was demonstrated that there was a significant gap between HOMO and LUMO.

### Molecular Electrostatic Potential (MEP) Map

The 3-dimensional MEP mapping of the cytosine adsorbed nanosheet in both cases was plotted with the SCF density matrix in the range of -4.741e0 eV (dark red colour) to -2.141e0 eV (dark blue colour) where the colour legend was arranged in an order of blue > green > yellow > orange > red. For both cases, the potential was observed to be more negative at the binding zone of cytosine and subsided towards the hydrogen-passivated perimeter as shown in **Figure 1(c)** and **Figure 1(f)**.

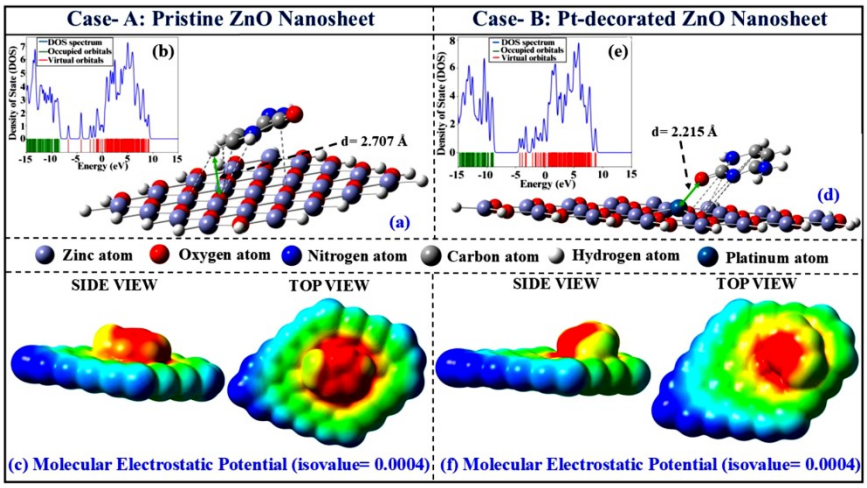


**Figure 1(a)**, **(d)** Optimized structure of pristine (case-A) and Pt-doped (case-B) ZnO nanosheet after adsorption of cytosine; **(b)**, **(e)** Total DOS graph for case-A and case-B; **(c)**, **(f)** MEP mapping for different two cases

**Analysis of Molecular Orbitals (MOs)**

The lowest unoccupied molecular orbital (LUMO) and the highest occupied molecular orbital (HOMO) of cytosine adsorbed pristine and Pt-doped ZnO nanosheet were generated. For both cases, the HOMO was present at a side of nanosheets, while the LUMO was spread all over the sheet. However, in the case of the Pt-doped ZnO nanosheet (case-B), there was no LUMO in cytosine, unlike in the pristine nanosheet (case-A) as framed in **Figure 2**. The electronic energy difference between HOMO and LUMO in case-A and case-B was 1.7837 eV and 4.5525 eV respectively. The larger energy gap in case-B was an evidence of reduction of background conductivity, resulting in better chemical stability of Pt-decorated towards cytosine [8].

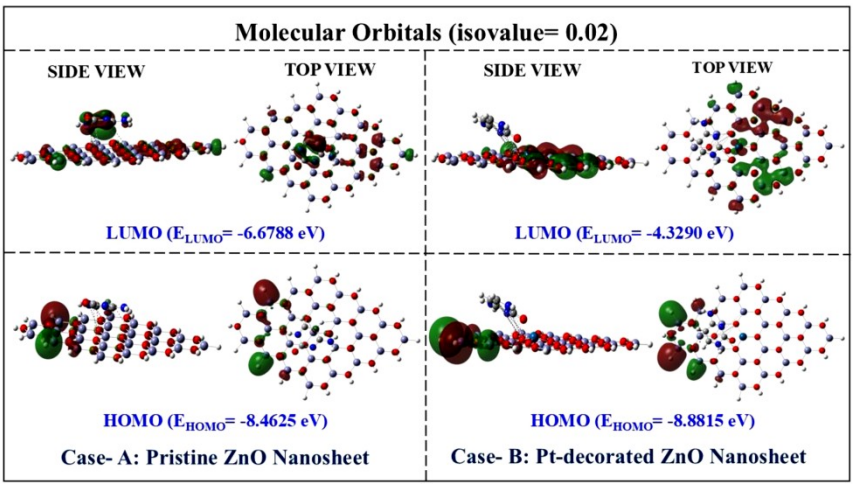


**Figure 2** Molecular orbital analysis of cytosine adsorbed pristine and Pt-decorated ZnO nanosheet

**Analysis of Mulliken Charge**

Mulliken charge analysis was utilized to monitor the transfer of electron density, with a negative sign indicating acceptance and a positive sign pointing to the donation of density [9]. In **Table 1**, the Mulliken charge population was noted for each atom of case-A and case-B. It was observed that the charge was accepted by three N atoms, one O atom, and a C atom of cytosine for both cases. Additionally, in case-B, the highest amount of charge was transferred from the Pt atom of the sensing material (nanosheet) to the nearest electronegative O atom which was clear evidence of better adsorption.

**Table 1** Mulliken charge transfer analysis of cytosine adsorbed pristine and Pt-decorated ZnO nanosheet

| Case-A: Cytosine adsorbed pristine ZnO nanosheet | | | | | | Case-B: Cytosine adsorbed Pt-doped ZnO nanosheet | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Atom** | ***Mu.C.** | **Atom** | ***Mu.C.** | **Atom** | ***Mu.C.** | **Atom** | ***Mu.C.** | **Atom** | ***Mu.C.** | **Atom** | ***Mu.C.** |
| O1 | -0.5 | Zn28 | -0.004 | H55 | 0.338 | O1 | -0.5164 | O28 | -0.431 | H55 | 0.333 |
| O2 | -0.524 | O29 | -0.413 | H56 | 0.337 | O2 | -0.5303 | O29 | -0.534 | H56 | 0.332 |
| O3 | -0.523 | O30 | -0.48 | H57 | 0.329 | O3 | -0.5171 | O30 | -0.412 | H57 | 0.218 |
| O4 | -0.513 | O31 | -0.456 | H58 | 0.218 | O4 | -0.5206 | O31 | -0.463 | H58 | 0.226 |
| Zn5 | -0.002 | O32 | -0.496 | H59 | 0.219 | Zn5 | 0.0056 | O32 | -0.521 | H59 | 0.21 |
| Zn6 | 0.4301 | O33 | -0.513 | H60 | 0.227 | Zn6 | 0.4635 | O33 | -0.435 | H60 | 0.178 |
| Zn7 | 0.4299 | O34 | -0.391 | H61 | 0.177 | Zn7 | 0.3794 | O34 | -0.522 | H61 | 0.325 |
| Zn8 | 0.4425 | O35 | -0.509 | H62 | 0.325 | Zn8 | 0.396 | O35 | -0.492 | H62 | 0.177 |
| Zn9 | 0.0386 | O36 | -0.488 | H63 | 0.177 | Zn9 | 0.0209 | O36 | -0.412 | H63 | 0.204 |
| Zn10 | -0.005 | O37 | -0.456 | H64 | 0.214 | Zn10 | -0.0225 | O37 | -0.517 | H64 | 0.223 |
| Zn11 | 0.4106 | O38 | -0.522 | H65 | 0.217 | Zn11 | 0.4056 | O38 | -0.469 | H65 | 0.218 |
| Zn12 | 0.373 | O39 | -0.435 | H66 | 0.218 | Zn12 | 0.3515 | O39 | -0.553 | Pt66 | 1.309 |
| Zn13 | 0.3863 | O40 | -0.506 | N67 | -0.54 | Zn13 | 0.3325 | O40 | -0.521 | N67 | -0.51 |
| Zn14 | 0.4426 | O41 | -0.503 | N68 | -0.364 | Zn14 | 0.396 | O41 | -0.532 | N68 | -0.39 |
| Zn15 | -0.007 | O42 | -0.492 | C69 | 0.678 | Zn15 | -0.0308 | O42 | -0.53 | C69 | 0.715 |
| Zn16 | 0.3848 | O43 | -0.524 | C70 | 0.185 | Zn16 | 0.3737 | O43 | -0.522 | C70 | 0.201 |
| Zn17 | 0.3798 | O44 | -0.522 | H71 | 0.214 | Zn17 | 0.3506 | O44 | -0.47 | H71 | 0.181 |
| Zn18 | 0.3803 | O45 | -0.429 | C72 | -0.31 | Zn18 | 0.379 | O45 | -0.462 | C72 | -0.47 |
| Zn19 | 0.4316 | O46 | -0.441 | H73 | 0.222 | Zn19 | -0.0426 | O46 | -0.43 | H73 | 0.22 |
| Zn20 | -0.038 | O47 | -0.437 | C74 | 0.448 | Zn20 | 0.3771 | O47 | -0.517 | C74 | 0.517 |
| Zn21 | 0.3798 | O48 | -0.501 | N75 | -0.438 | Zn21 | 0.3982 | H48 | 0.3324 | N75 | -0.39 |
| Zn22 | 0.3627 | H49 | 0.3287 | H76 | 0.28 | Zn22 | 0.4102 | H49 | 0.3331 | H76 | 0.28 |
| Zn23 | 0.3959 | H50 | 0.3375 | H77 | 0.283 | Zn23 | 0.4639 | H50 | 0.3258 | H77 | 0.313 |
| Zn24 | 0.4332 | H51 | 0.3377 | H78 | 0.319 | Zn24 | -0.0437 | H51 | 0.3369 | H78 | 0.317 |
| Zn25 | -0.038 | H52 | 0.343 | O79 | -0.362 | Zn25 | -0.0623 | H52 | 0.2242 | O79 | -0.59 |
| Zn26 | -0.018 | H53 | 0.2543 | | | Zn26 | -0.0405 | H53 | 0.337 | | |
| Zn27 | -0.011 | H54 | 0.3431 | | | Zn27 | 0.0057 | H54 | 0.3259 | | |

*Mu.C.: Mulliken charge

## CONCLUSION

The present research incorporated the first principle-based calculation and critically analysed the sensing ability of pristine ZnO nanosheet and Pt-doped ZnO nanosheet in cytosine detection. It was outlined that the sensitive behaviour in case-B was much improved compared to case-A, resulting in an increased adsorption energy (almost 3.8 times) and a reduced binding distance (nearly 1.2 times). The interaction between the adsorbed molecule and the nanosheets was further studied with the help of various electronic parameters such as molecular electrostatic potential (MEP), density of state (DOS), molecular orbital analysis including HOMO and LUMO, and Mulliken charge analysis. The HOMO-LUMO bandgap was calculated to be 1.7837 eV for case-A and 4.5525 eV for case-B, catering to better sensitivity of Pt-doped ZnO nanosheet in detecting cytosine thus paving its way for becoming an effective biosensor.

## ACKNOWLEDGMENT

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# Biomedical Science & Technology

## Microbiology, Virology, and Evidence-based Medicine

202_IEC34121

# Evaluation of Lactic Acid Bacteria from Chilli and Capsicum Stalks (Calyx) as a Starter Culture for Curd (Dahi) Preparation

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***Keywords:*** *Chilli; Capsicum; Starter Culture; Curd; Lactic Acid Bacteria; Capsaicin*

## INTRODUCTION

Chilli stalks (calyx) are a known source of lactic acid bacteria, namely Lactobacillus acidophilus and Streptococcus thermophilus. Recently the potential of chilli stalks as a starter culture for fermented milk products has gained attention owing to the mass media. However, use of chilli calyx to induce fermentation in milk is not a new practice; the root of the tradition lies in ancient South Indian and Mexican cuisines. Freeze-dried started cultures are reportedly expensive and unavailable in most market-places. Store-bought and packaged products often contain additives that make them unsuitable to be used as a starter culture. Another issue is the decrease in production potential of active starter cultures over time due to various environmental reasons. Hence, this practice of repurposing food waste promotes sustainability and accessibility of affordable food products. Although, a few studies have evaluated the quality of curd produced by chilli calyx, the microbial nature of the starter culture and the chemical aspect of the production have still been largely unexplored. In one study, capsaicin, the major chemical compound present in chilli, has been reported to increase the production of lactic acid in lactic acid bacteria. The role of capsaicin in curd production, however, has not been studied yet. In this study, lactic acid bacteria were isolated from green chilli, capsicum, and bell peppers and evaluated on their ability as a starter culture. The whole calyx as well as the isolated bacteria from the said calyx were evaluated based on their potential of fermentation mainly focusing on the followings: total time required for initiation of curdling, change in pH, titrable acidity (lactic acid), sugar (lactose) content, and syneresis of end product. The obtained data then were compared with the same from conventional method.

## METHODOLOGY

Pasteurized milk samples were collected from market. For chilli samples, mid-sized green fresh chillies were collected from market and washed under running water followed by cleaning with an 8% sodium hypochlorite solution and rinsing with distilled water before storage. Fresh green capsicum and yellow bell pepper samples were also cleaned and sterilized following the same method and stored. Calyx was detached from the fruit only at the time of inoculation. All glasswares used for the experiments were sterile to avoid contamination and observation bias. Milk samples set for fermentation and bacterial plates were all incubated at 37°C for entire length of experiment.

10 ml of milk samples with increasing number of calyx (from 1 to 4) were incubated at 37°C till fermentation occurs. As control, 200 ul of homemade and store-bought curd were added in two beakers with 10 ml milk samples. Observations were made every 1 hour.

The fermented product derived from chilli calyx–inoculated samples was plated both in MRS agar and nutrient agar; observed colonies were isolated and examined for distinguishing characters of lactic acid bacteria with help of gram staining, catalase testing, and motility test. The samples were also tested for presence of yeast or any other fungal strains with help of fungal stains. Bacteria that showed characteristics of lactic acid bacteria were then subcultured in both aerobic and anaerobic conditions (candle-jar method) to confirm anaerobic nature of isolated bacteria.

250 ml of milk samples were inoculated with isolated bacteria that showed characteristic of lactic acid bacteria. 11 ml of samples were taken out from the curd in 2, 4, 6, 8, and 12 hour intervals. After the pH value of obtained sample

was taken, 1 ml of the sample was used for lactose estimation by DNS method with help of UV-vis spectrophotometer, and the rest 10 ml was titrated against 0.1 N NaOH using phenolphthalein indicator. The values were noted and plotted in a graph. The rest of the sample was kept in a funnel laced with a filter paper with 125 mm pore size at 3°C for 2 hours to separate the liquid part. Sample was weighed before and after the procedure.

## RESULTS

Inoculation of 10 ml milk with one calyx was proven to be more effective, increasing the number of calyx (and in turn bacterial load) resulted in runnier consistency of sample, although the curdling time of the samples with higher number of calyx were lesser than that of single calyx. The conventional method resulted in formation of curd within 5-6 hours of inoculation, and calyx inoculation typically took 8-10 hours. After using the isolated lactic acid bacteria from the fruit samples the fermentation time reduced to 7-8 hours.

Eight bacterial colonies were isolated from MRS and nutrient agar culture, and 3 showed gram positive and catalase negative result after being subjected to gram staining and catalase testing. The 3 samples were also non-motile in nature. Under microscope the gram positive catalase negative bbacterial strains showed coccal and bacilli structure. Morphology structure of the said bacterial strains also showed satisfactory structure and 'glistening' colonies typical to lactic acid bacteria. Fungal staining of the curd sample showed no presence of fungi in the sample. Selected strains of possible lactic acid bacteria were isolated and subcultured in broth and agar plates separately for further experimentation. The selected strains also showed ability to grow in anaerobic condition (following the candle jar method), further confirming the nature of lactic acid bacteria.

The initial pH of the milk sample was 7.3 and the final fermented product at 12 hour mark had a pH of 5.8. The change in pH every 2 hours was recorded and plotted in a graph and later compared to that of conventional curd.

Lactose concentration decreased from 1.89% to 1.49% in 12 hours; the observation every 2 hour and plotted graphically. The lactic acid concentration increased from 0.2% to 0.81% in the span of 12 hours and the graphical demonstration showed sigmoidal growth.

Synereis showed a 56.47% dry weight after being separated for 2 hours; the value closely resembles good quality packaged curd (47-48%).

## CONCLUSION

The quality of the final product was identical to homemade curd, but lacked the structure of packaged product. The fermentation time required while using the calyx itself as a starter culture is longer than the time required in conventional method, and increasing the inoculation does not affect the time of fermentation. Instead, excess inoculation acts negatively on the texture of the curd. However, isolating the lactic acid producing bacteria can give a similar fermentation profile to that of conventional method. The final pH, lactic acid content, and lactose content were similar to conventional curd samples as well. But, if isolating the bacteria is an integral part of getting desired result, the process lacks accessibility to general population who lacks that knowledge or means. The role of capsaicin in this process also needs to be investigated.

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315_IEC95247

# Wastewater Testing for Surveillance of Covid-19 Outbreaks at a Ward Level: Emerging Insights from Bangalore City in India

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**Abstract:** The global COVID-19 outbreak highlighted the need for efficient, evidence-based methods to allocate limited public health resources, especially in resource-constrained settings. Wastewater-based surveillance emerged as a potential solution for monitoring SARS-CoV-2 transmission at the community level and early detection of outbreak hotspots, as SARS-CoV-2 RNA is excreted in feces and can be detected in sewage systems before clinical cases are identified. However, its implementation and utility in resource-constrained settings remain understudied. To implement and evaluate a city-wide wastewater surveillance system using mixed and untreated wastewater in Bangalore, India, for early detection of COVID-19 outbreaks at the ward level and to assess its effectiveness as a predictive tool for community transmission for use as an early warning system. The study monitored 45 highly populated wards in Bangalore, covering one-third of the city's population, through twice-weekly sampling of stormwater drains. Additionally, 28 sewage treatment plants were sampled every 10 days at both inlet and effluent pipes. Samples underwent qRT-PCR analysis for SARS-CoV-2 RNA quantification, with results displayed on a real-time dashboard. Environmental factors such as rainfall and temperature were tracked to account for their effects on viral RNA detection. The wastewater surveillance system successfully detected SARS-CoV-2 RNA in sewage samples. Viral load trends in wastewater correlated with community infection rates. Notably, increases in wastewater viral loads were observed approximately one week before corresponding spikes in community positivity rates. The study developed a color-coded dashboard system indicating viral load trends using Exponential Weighted Moving Average calculations for each municipal ward. This research, representing Asia's first comprehensive wastewater epidemiological surveillance program, demonstrated the effectiveness of sewage testing as a cost-efficient early warning system for COVID-19 outbreaks in an urban setting with limited resources. The color-coded dashboard system successfully tracked COVID-19 transmission patterns across the city, providing early warnings of potential outbreaks before clinical cases were reported. Despite challenges in viral RNA detection and environmental variables, the study established wastewater surveillance as a valuable complement to traditional clinical testing. The findings suggest potential applications beyond COVID-19, including monitoring drug use and antimicrobial resistance, but further research is needed to address data gaps and optimize methodologies for reliable, actionable insights.

**Keywords:** Wastewater based Epidemiology; Wastewater Surveillance; Sewage Monitoring; SARS CoV2 Covid-19 Surveillance; Pandemic Prediction

## INTRODUCTION

After the outbreak of COVID-19 all over the world, responses like lockdown, testing, tracing, and vaccination were executed commonly. However, when faced with limited resources, the efficient distribution of the available resources has proved to be a problem in the control of the pandemic in some places. Wastewater monitoring services can proactively find novel solutions, therefore, they can be used for timely detection of the hotspots and most importantly for the right resource distribution.

The first COVID-19 case was detected in India on January 30, 2020, and by the middle of May 2021, more than 25 million cases had been added during the second wave[1]. Limited testing and tracing resources[3,4] force the adoption of alternate pathways such as wastewater monitoring to act as the first signal. Along with the other coronaviruses, SARS-CoV-2 also excretes RNA through the feces[5], and by the sewage scrutiny, the viral RNA was traced out 4-10 days earlier than the actual clinical cases ever were[6,7,8], leading us to believe wastewater study a cost-effective mechanism for monitoring purposes[9].

Although there is a relationship between the levels of the sewage's RNA and the number of cases in a community[13,14], the problems including the existence and survival of the virus in wastewater, natural elements such as temperature, or how the different RNA readings are parallel to the thwarting the infectivity in a community have to be still figured out. These defects make it necessary that further research be made into this topic.

## METHODOLOGY

Bangalore City, the second-largest city in India with an area of 709 sq km, is divided into 198 wards for governance. For this study, 45 of the most populated wards, covering one-third of the city's population, were selected for longitudinal monitoring. Sampling was conducted twice a week at stormwater drains in these wards. Although stormwater drains are intended to carry only rainwater, they also frequently contain untreated sewage from slums, households without underground drainage connections, and overflowing sewage pipes. Additionally, each of the 28 functioning sewage treatment plants (STPs) was sampled once every 10 days at both the inlet and effluent pipes.

Before starting sampling, ward-wise data on the number of COVID-19 cases reported on the Bangalore municipality's website prior to the study were considered. Wards showing a consistent rise in cases over a period of more than 15 days and those with high populations were selected. For STPs, those connected to the selected wards were prioritized.

Rainfall and temperature data was obtained from Karnataka State Natural Disaster Management Center, and Indian Meteorological Society respectively. Samples were collected in plastic buckets from open drainage water in the morning and handled using personal protective equipment (masks, face shields, and gloves) and poured into separate pre-sterilized collection bottles. The bottles were marked with the ward name and date and transported under cold conditions to the laboratory testing facility within 1h of collection where they were QR-coded with records of the collection time and temperature. In the lab, the samples were heat-inactivated, filtered, and centrifuged after adding PEG-NaCl, to separate the liquid from the solid particles. The viral RNA was extracted from the waste-contaminated water specimen and quantified after amplification using Quantitaive Real Time Reverse Transcription Polymerase Chain Reaction (qRT-PCR).

Community positivity data is obtained from Bruhat Bengaluru Mahanagara Palike (BBMP) which conducts random testing of people in various primary healthcare centers and points of entry into the city. The longitudinal dataset obtainedis a representative of all the 8 zones of Bangalore city, consisting of the total number of tests conducted at each center, number of positive people and the positivity rate. BBMP on average has conducted 40750 tests daily with a standard deviation of 15065 tests during the study period from May 15, 2021, till January 30, 2022. There was a built-in time lag of 3 to 4 days before test results were reported.

## RESULTS

The city-wide sewage sampling study contributed data to a real-time dashboard (**Figures 1A**, **1B**, and **1C**). It includes sewage details and community spread rates, combining the EWMA for each ward in the city. The viral load data was calculated from the SARS CoV2 RNA measured in the wastewater samples and uploaded on a real-time dashboard indicating the wastewater surveillance trends based on the Exponential Weighted Moving Average (EWMA) of the actual viral load in each of the selected wards in Bangalore. Based on the viral load trends, the sites/wards were color-coded with Green for wards showing viral load decrease, Red for viral load increase, Yellow meant no change, and grey indicated no detectable viral load.

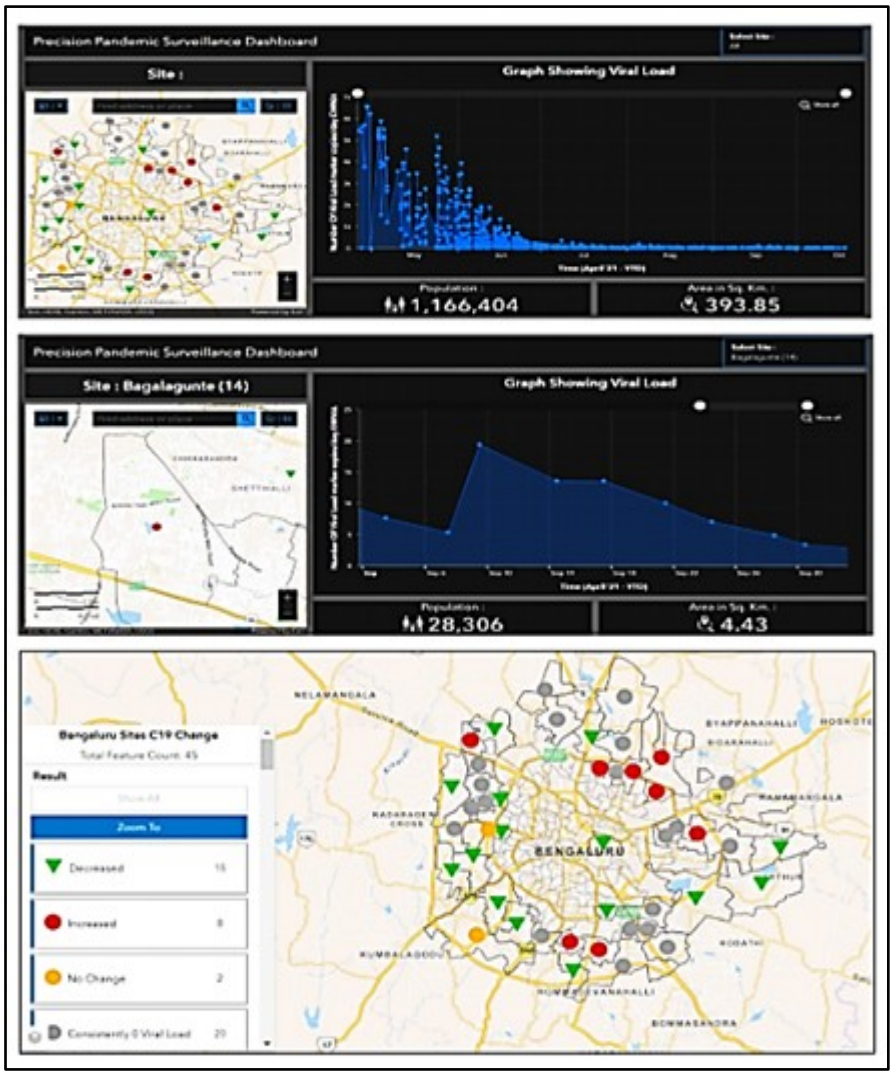


**Figure 1** The wastewater surveillance dashboard that displays the trends in ward-level and city-wide changes in viral load detected in sewage samples in Bangalore. (A) A Snapshot of sewage testing data from 45 sites across the selected wards over a 6-month period**; (B)** A snapshot of the data from Bagalgunte ward (BBMP ward number 14) from the month of September 2021 and **(C)** A snapshot of the wastewater trends for the 45 sampling sites based on calculation of EWMA of actual viral load for each site.

Analysis of the data on viral loads in wastewater was used to track and predict the transmission of COVID-19 in Bangalore to provide an early warning system. **Figure 2A** shows a snapshot of data from a week of sewage testing across 45 sites in May 03-11, 2021, covering about 30% of the population of Bangalore city. Each of these wards are expected to have a positivity rate of over 10% (over 2000 positive cases approx) based on data released in daily reports by the government (**Figure 2B**) which shows the positivity rates from the city's RTPCR testing program on a daily basis. If viral loads and positive sites rise while Ct values fall when positivity rates of the virus go up, it shows more threat of COVID-19. **Figure 2C** and **Figure 2D** shows the correlation between the city's infection positivity rate and the viral load quantified in sewage.

In addition, variables like rain, temperature and presence of effluent scan affect the quality of the data obtained. Rain may dilute the viral RNA concentration in sewage, while hot weather and chemical agents in industrial wastes may degrade the RNA, reducing the accuracy of viral load measurements. A snapshot of the rainfall and temperature data in Bangalore city is shown in Table 1 in order to account for the effect of rainfall and temperature on wastewater viral load data during 03 to 11 May 2021.

**Table 1** Average temperature and precipitation of Bangalore city over the period of May 3-11, 2021, corresponding to the period of wastewater sampling

| Date | Temperature (°C) | Temperature max. (°C) | Temperature min. (°C) | Precipitation/ Rainfall (mm) |
|---|---|---|---|---|
| May 03, 2021 | 27 °C | 33 °C | 21 °C | 3.2 mm \| 0.1 inch. |
| May 04, 2021 | 27 °C | 32 °C | 21 °C | 4.0 mm \| 0.2 inch. |
| May 05, 2021 | 26 °C | 32 °C | 21 °C | 2.6 mm \| 0.1 inch. |
| May 06, 2021 | 26 °C | 32 °C | 21 °C | 3.6 mm \| 0.1 inch. |
| May 07, 2021 | 26 °C | 31 °C | 21 °C | 4.3 mm \| 0.2 inch. |
| May 08, 2021 | 26 °C | 31 °C | 21 °C | 4.6 mm \| 0.2 inch. |
| May 09, 2021 | 26 °C | 31 °C | 21 °C | 4.5 mm \| 0.2 inch. |
| May 10, 2021 | 26 °C | 32 °C | 21 °C | 3.0 mm \| 0.1 inch. |
| May 11, 2021 | 26 °C | 32 °C | 21 °C | 3.0 mm \| 0.1 inch. |

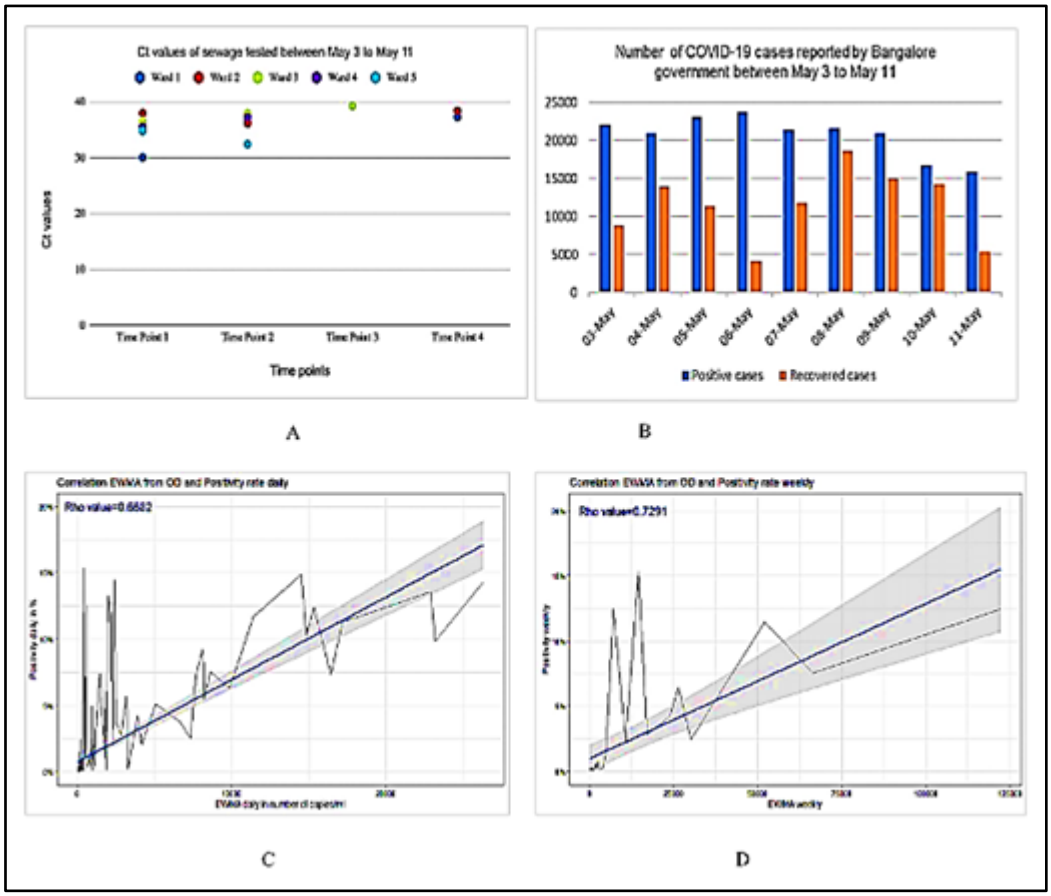


**Figure 2** (A) Sewage data from wards with over 10% positivity (1 week), **(B)** Data on positive cases, recoveries, and deaths over 10 days in BBMP zones, **(C)** Daily comparison of SARS-CoV-2 RNA levels in the community and storm drains and **(D)** Weekly comparison of SARS-CoV-2 RNA levels

The analysis of changes in the total city-wide viral load in wastewater obtained from all the selected STPs over time, compared to that of the city-wide total infection positivity rate based on recorded clinical cases of data also shows the spike in SARS CoV2 RNA in wastewater was found about one week before the spike in positivity rate from the city-wide community level clinical testing (**Figure 3**). Our data shows that wastewater viral load data have the potential to signal an upcoming spike in infection rates to provide an early warning about increase in Covid 19 infection in the community through wastewater surveillance.

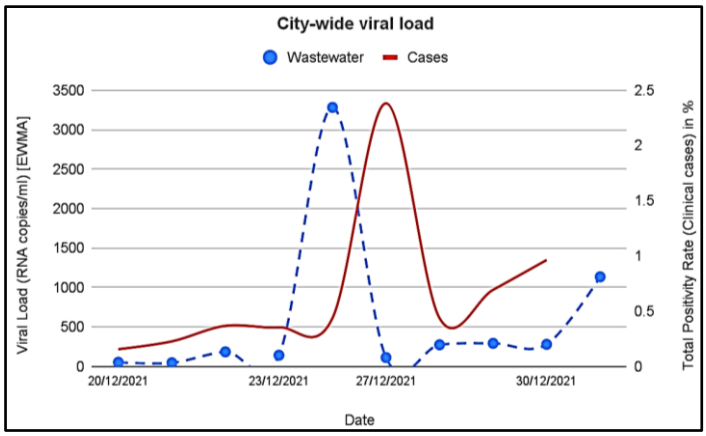


**Figure 3** The spike in SARS CoV2 RNA in wastewater was found about one week before the spike in positivity rate from the city-wide community RTPCR testing program

## CONCLUSION

This city-wide epidemiological surveillance program, the first in Asia, integrates sewage testing data with existing public health surveillance systems, offering a promising platform for tracking other public health issues, such as drug use and antimicrobial resistance. The study focused the detection and quantification of viral particles in wastewater and utilization of the data to enhance local-level surveillance by identifying emerging hotspots, and guide resource allocation for targeted clinical tests. Despite the barriers such as the semi-quantitative nature of viral RNA detection and the challenges of variability in virus excretions and the sewage system, this method can be an excellent tool for supplementing the standard surveillance methods for the early detection of an outbreak and for getting possession of the movement of the disease in the space where people agglomerate. The ongoing COVID-19 pandemic emphasizes the necessity for receiving funds for building wastewater treatment infrastructure, especially in the developing countries, and conducting more extensive research to find solutions for challenges occurring at the reference of environmental factors as a matter of RNA viability and a higher correlation of RNA levels with community infections for more effective public health interventions.

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356_IEC9568

# Analysis of Viral Proteins from Common Viruses of West Bengal using Bioinformatics Tools

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***Keywords***: *Virus; NCBI; PDB; West Bengal; Protein; Drug Target*

## INTRODUCTION

The analysis of viral proteins for potential drug targets plays a pivotal role in modern infectious disease research, especially for regions with recurring outbreaks. In West Bengal, several notable viruses, including Dengue, SARS-CoV-2, and Japanese encephalitis, continue to pose significant public health challenges. By leveraging bioinformatics tools, researchers can dissect the molecular makeup of these viral proteins, unveiling their structure, function, and interactions with host proteins[1].

Bioinformatics tools allow for sequence alignment, structural modelling, enabling researchers to predict the unique amino acid sequences present in viral proteins of different strains that are essential for viral replication and pathogenicity of that specific virus strain. The computational analysis further aids in understanding viral evolution[2]. Thus, the combination of bioinformatics and virology offers a strategic framework for understanding viral infections endemic to West Bengal, contributing to global efforts in controlling viral diseases.

## METHODOLOGY

### Data Collection

A comprehensive literature review was conducted to identify the most prevalent viral diseases affecting West Bengal. This review involved an extensive search of academic journals, epidemiological reports, government health publications, and databases such as PubMed and Google Scholar. All the name of the viruses and their different strains were identified and they were sorted according to their families, genus and different strains.

All the protein sequences of eukaryotic viruses were systematically collected using two major bioinformatics resources: the NCBI Virus Portal and the Protein Data Bank (PDB). The NCBI Virus Portal serves as a specialised resource within the National Center for Biotechnology Information (NCBI) platform, offering a comprehensive database of viral genomes, proteins, and related biological information. Through this portal, protein sequences of eukaryotic viruses were retrieved by selecting relevant taxonomic categories, including specific virus families, genera, and strains, ensuring that all available and annotated viral proteins were gathered for analysis. The search was tailored to include complete and high-quality sequences to facilitate subsequent bioinformatics analyses. Additionally, the Protein Data Bank (PDB), which focuses on the structural data of proteins, was utilised to collect viral protein sequences that had been experimentally determined using methods like X-ray crystallography, NMR spectroscopy, and cryo-electron microscopy. This provided not only sequence information but also structural data, which is crucial for understanding protein function and interactions with their host.

### Multiple Sequence Analysis

To identify unique sequences within viral proteins, a protein-protein multiple sequence alignment (MSA) was performed. This process involves aligning multiple viral protein sequences to one another in order to identify conserved and variable regions across different viral strains or species. The MSA method allows for a comparative analysis of protein sequences by aligning amino acid residues based on their similarity, thus revealing patterns of

conservation and divergence. During the alignment, conserved regions, which are likely crucial for viral structure and function, are identified, while variable regions or unique sequences that differ significantly between the viruses are highlighted. The unique sequences are of particular interest because they may represent novel epitopes, potential drug targets, or evolutionary adaptations that differentiate viral species or strains.

**Linear Regression**

To investigate the relationship between query and target sequences of viral protein sequences within the same family, we employed linear regression, focusing on sequence similarity metrics as predictive features. First, we prepared a dataset by aligning each query protein sequence with corresponding target sequences, sequence alignment scores, and alignment length, which capture structural and functional similarities between proteins. After data normalization, we split the dataset into training and testing sets and applied a linear regression model to predict similarity scores of unknown sequences based on these features. The model's performance was evaluated using R-squared and root mean square error (RMSE) metrics, assessing its ability to capture the linear relationship between query and target sequence attributes. This methodology provides insight into conserved regions and functional similarities within the viral family, potentially aiding in understanding viral evolution and protein function prediction.

**RESULTS**

With the help of the Basic Local Alignment Search Tool (BLAST), the MSA is conducted for several different viral strains under three different virus families – Coronaviridae, Flaviviridae, and Retroviridae.

**Figure 1** shows the resultant MSA from aligning the Spike Glycoprotein of SARS-CoV-2 (alpha variant) with the spike glycoproteins of SARS-CoV-2(beta, gamma and omicron variants). It showed >95% identity in all cases. However, an unique amino acid sequence of 14 amino acids was present towards the end of the amino acid sequence in the beta variant. Another unique amino acid sequence of 11 amino acids was found to be commonly found in both the gamma and omicron variants.

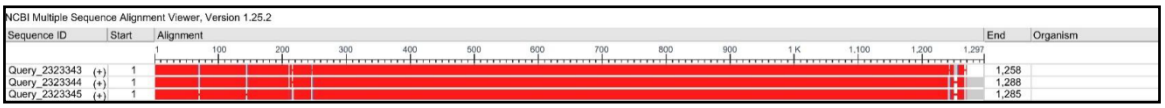


**Figure 1**

**Figure 2** outlines the conserved regions of the Envelope glycoprotein of Dengue virus (type 3) which have been sequence aligned with the envelope glycoproteins of Dengue virus (type 1,2, 2 Puerto Rico/PR159-S1/1969, and 4) along with Japanese Encephalitis Virus. A unique sequence of 13 amino acids was found to be present in Dengue virus type 4 while Dengue virus types 2 and 2 Puerto Rico/PR159-S1 possess the same unique sequence of 11 amino acids. No such sequences were found to be present in the case of Dengue virus type 1. However, the Japanese Encephalitis Virus contains two unique amino acid sequences of 10, which seem to be absent from Dengue virus type 3.

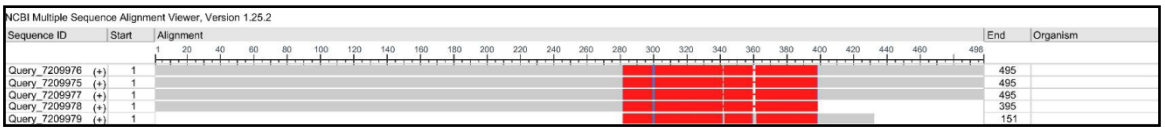


**Figure 2**

**Figure 3** encompasses the sequence alignment of capsid protein of Human Immunodeficiency Virus-1 with the capsid proteins p26 and p24 of Human Immunodeficiency Virus-2 and that of Human T-Lymphotrophic Virus-1. No notable unique sequences were captured for p26 and p24 proteins of HIV-2. However, a unique sequence of 25 amino acids was located in the capsid protein of HTLV-1.

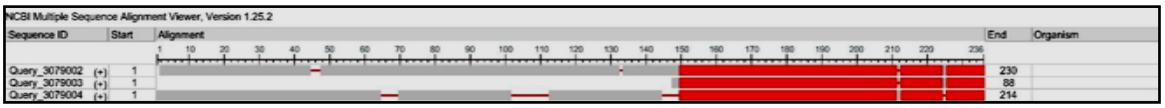


**Figure 3**

## CONCLUSION

With the help of bioinformatics tools, such as BLAST, we were able to pinpoint certain unique amino acid sequences in the studied proteins. Further analysis of these proteins, using homology modelling and ligand docking for evaluation of protein-protein interaction would help us move forward with this work. These amino acids represent some changes that have been undergone in the viral genome to facilitate the emergence of various new strains that are similar to the major viral structure but differ in certain key aspects.

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365_IEC93161

# Natural Synergy: Neem and Honey as a Biocompatible Oral Irrigant for Enhanced Dental Care

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***Abstract***: *This study evaluates the potential of a natural oral irrigant combining Neem (Azadirachta indica) and honey as an alternative to sodium hypochlorite, a conventional endodontic disinfectant known for its potent antimicrobial properties but also for drawbacks such as cytotoxicity, strong taste, and patient intolerance. Neem, with its broad-spectrum antibacterial, antifungal, and anti-inflammatory properties, offers a more biocompatible option, though its bitterness reduces patient acceptability. Honey, known for its antibacterial and wound-healing benefits, complements Neem's effects while making it more palatable. This research analyzed the antimicrobial effectiveness of Neem-honey extracts on bacterial cultures from infected root canal samples and compared them to sodium hypochlorite. The findings revealed that a 1:5 Neem-honey dilution demonstrated superior antibacterial efficacy without the harsh side effects associated with sodium hypochlorite, suggesting it as a viable alternative for endodontic irrigation.*

***Keywords***: *Oral Irrigant; Neem, Honey; Sodium Hypochlorite; Biocompatible*

## INTRODUCTION

Endodontic procedures require a sterile oral environment achieved through methods like interdental cleaning, antimicrobial treatment, and notably, oral irrigation. Oral irrigation, which clears debris and bacteria, improves gum health and prepares the oral cavity for further treatments like root canal therapy by reducing microbial presence. A key factor in successful root canal therapy is the complete removal of necrotic tissue, bacteria, and other harmful substances from the intricate root canal system, typically through a chemo-mechanical approach using both mechanical tools and chemical agents. Sodium hypochlorite is widely used for its potent antimicrobial activity and ability to dissolve soft tissue at higher concentrations, but its use comes with significant drawbacks. These include an unpleasant taste, cytotoxicity, the potential to compromise tooth structure, and the inability to remove the smear layer formed during canal preparation. These issues have led to interest in biocompatible alternatives like Neem (Azadirachta indica), which has natural antibacterial, antiviral, and antifungal properties. Although effective, Neem has a bitter taste, making it less appealing to patients. Honey is a promising adjunct to Neem, known for its antibacterial, anti-inflammatory, and wound-healing properties, which date back centuries in traditional medicine. Honey's role is to enhance the palatability of Neem, while potentially creating a synergistic antibacterial effect. Together, Neem and honey form a biocompatible combination that may match or exceed the efficacy of sodium hypochlorite without its harsh side effects. This approach exemplifies the blending of traditional remedies with modern dental science, pointing to a future in which natural agents like Neem and honey might replace chemical solutions, offering safer and more patient-friendly options in dental care.

## METHODOLOGY

The following is a brief protocol for the microbiological study of isolating and analyzing bacterial cultures of infected dental pulp or root canal samples. The key steps include the following:

Sample Collection, Preparation of Culture Medium, Bacterial Isolation, Testing Reagents Preparation, Antibiotic Resistance Profiling, Incubation in Culture Broth, Isolation of Genomic DNA, and Oral Irrigant Assay.

This work examines the bacterial diversity present in the infected dental tissues and evaluates various alternative oral irrigants that might be used in dental care according to their antimicrobial effectiveness.

## RESULTS

The study compared the activity of Penicillin P-10 against various bacterial strains; it is obvious from the graph that isolated strain #8 showed the greatest sensitivity, followed by strains #10, #5, and #2. A wider comparative study of Penicillin, Ampicillin, and Streptomycin against these four strains proved that all the strains were sensitive to the antibiotics, though to different extents. Except for antibiotics, a comparative evaluation of some suggested oral irrigant alternatives presented honey and a combination of neem and honey in a 1:5 ratio as the most striking. Fig. 8 represents the synergistic effect of both Neem and honey, outweighing sodium hypochlorite. The graph justifies the hypothesis that a combination of biocompatible Neem and honey is way more effective than sodium hypochlorite. This finding implies that the natural alternative will be safer and more effective for oral irrigation.

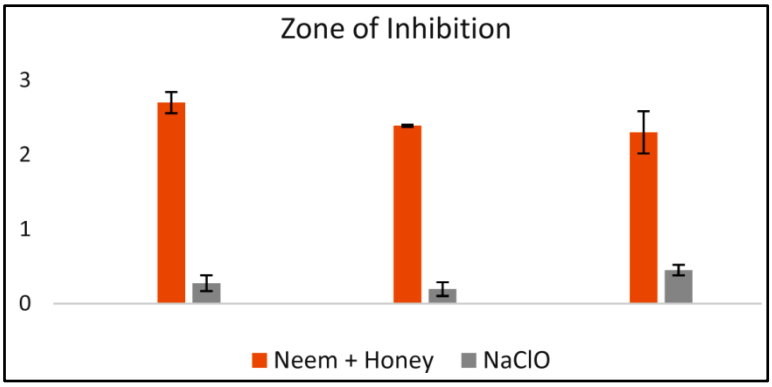


**Figure** Graph depicting the comparison between the activity of Neem + Honey and Sodium hypochlorite

## CONCLUSION

The study proved that a 1:5 diluted ethanolic extract of Neem and honey can be an immensely effective alternative to sodium hypochlorite solution as an oral irrigant. Oral microflora is heterogeneous, having varying resistive powers against antibiotics; some are highly resistant whereas others are sensitive. From the study, it was observed that Neem and honey possess strong antibacterial action. Hence, the concoction of Neem and Honey can be used effectively as a dental irrigating solution. This would probably be beneficial, especially for the people with sensitivities or concerns about the adverse side effects of conventional treatments. Further, in vivo research is on the way to testing this oral irrigant for acceptability by patients.

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# Biomedical Science & Technology

## Neural and Rehabilitation Engineering / Technology

179_IEC54384

# Need for Wearables in Generating EHRs for Physical Rehabilitation Sector, Pheezee® — A Case Study

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***Abstract**: In the era of digital health, electronic health records (EHRs) are becoming the norm for storing and analyzing patient data. Data not only aids in clinical decision-making but also has the potential to help in achieving better clinical outcomes during patient recovery. Recently, wearables are seen to play a crucial role in creating EHRs, especially in a home-based care setting where traditional bulky machines cannot be deployed for continuous monitoring of patients. Pheezee®, an USFDA-listed [510(k) exempt] novel prognostic app-based wearable device for the rehab sector, has established itself to have huge potential in generating patient-specific ailment records in a scientific manner, thereby establishing the concept of EHRs in a clinical rehab setting. It consists of range of motion (ROM) sensors and a surface electromyography (sEMG) bio-amplifier that can be used for assessment, monitoring, and tracking of the recovery of patients via shareable scientific reports. The objective is to integrate the multi-sensory information from the device into an EHR system through remote monitoring. Pheezee® acquires the movement and muscle contraction information in real-time and pushes the data to the cloud for postprocessing, thereby establishing a novel approach to introducing EHR in physiotherapy. The data is encrypted, stored in a secured format, and maintained through an effective database management system. This clinical data helps the healthcare providers track the patient's rehabilitation and propose patient-specific, tailor-made treatment protocols. In the future, this EHR data combined with AI/ML algorithms has the potential to be used not only for assessments but even for exact diagnoses. The AI/ML models can also open preventive and predictive clinical models for value-based insurance claims.*

***Keywords:** Rehabilitation; Wearable Sensor; Electronic Health Record; Evidence Based Practice; Patient Adherence; Recovery Tracking*

## INTRODUCTION

Wearable sensors, such as accelerometers and gyroscope-based devices, give real-time data on patient movements and can assist physiotherapists and physicians in the development of personalized treatment protocols and tracking of recovery [1]. Surface electromyography (sEMG) is effective in understanding muscle physiopathology, disease prevention, and planning intervention [2]. The World Health Organization's digital health plan underlines the necessity of patient engagement [4]. Digital technology has made it easier for patients and healthcare providers (HCPs) to communicate with each other periodically [3]. Electronic health records, essentially, represent longitudinal data that are gathered throughout routine healthcare delivery and are stored electronically [5]. Immediate transfer of the clinical data into the EHR is one critical element that was found missing in the design of the wearable sensor and its architecture [6]. Physical therapy (PT) is concerned with identifying and maximizing quality of life and movement potential within the spheres of promotion, prevention, treatment/intervention, habilitation, and rehabilitation [7]. With the rising requirement to keep clinical information systematically, physiotherapists too see the value of electronic record systems [8]. Big data is a new area in the field of physiotherapy with significant importance in research and clinical application. Data science can help in the value-based insurance claims and optimization of health insurance claims by prioritizing the outcomes and maintaining optimal documentation. EHR not only aids in improving the patient's end outcome but also reduces the likelihood of errors due to built-in decision support tools that aid in therapy planning [9]. Pheezee® can monitor performance, track adherence, and generate scientific patient reports with valuable clinical insights. The objective of the study is to integrate the data collected by Pheezee® into an EHR system in the field of physiotherapy to improve clinical decision-making and remote monitoring and thereby help establish better clinical outcomes for patient recovery.

## METHODOLOGY

### Data Source and Collection

Pheezee® is worn by the patient during physiotherapy sessions. It interacts wirelessly with an Android phone where range of motion [ROM] and muscle activity of the selected joint is acquired and displayed by the device [10]. A total of 826 users' data was acquired in a duration of four (4) years.

### Data Acquisition and Management

The data acquired by Pheezee® is shared with the Android app via Bluetooth protocol, which is then transferred to the cloud server where the data is encrypted, stored, processed, and eventually displayed in a report format [10]. **Figure 1** provides the overall data acquisition and storage methodology.

### Data Storage

Data storage refers to the process of storing the patient information in a system. This includes the use of the wearable sensor Pheezee for collecting an array of clinical data such as ROM, exercise adherence, and muscle physiology through sEMG sensors. The format used to store this data is .json (JavaScript Object Notation) is used due to its accessibility and compactness..

### Data Retrieval

Retrieving the data on time is essential for healthcare providers to make informed clinical decisions. This is made efficient by using a REST API (Representational State Transfer Application Programming Interface). This facilitates data retrieval by easy connection between Pheezee and the EHR. This helps the physiotherapist access the patient data whenever required and improves clinical decision-making and patient care.

### Data Security

Data security is critical in any healthcare application, particularly when it involves sensitive patient data.

Multiple security layers are used by the system to safeguard the privacy and security of data.

Storage technology and format

The system uses MongoDB, a NoSQL database, in addition to .json for data storage. MongoDB is especially useful for managing unstructured data that is common in clinical settings.

Security measures

(a) Server-Side Security: The implementation of a Security Hashing Algorithm, specifically Hash64, ensures that sensitive data is hashed before storage. This process transforms the original data into a fixed-length string, making it virtually impossible to reverse-engineer the original data from the hash.
(b) Hardware Security: To further enhance security, AES-CCM (Advanced Encryption Standard in Counter with CBC-MAC) is utilized. This encryption method ensures that data is securely transmitted and stored by encrypting it before it reaches the database. **Table 1** shows overall elements of data management.

### Data Visualization

Pheezee® dashboard is a comprehensive visualization tool that offers real-time updates and shows the EHRs. The data is visualized in a graphical format which shows patients' recovery from the baseline assessment. **Figure 2** shows the Pheezee® dashboard.

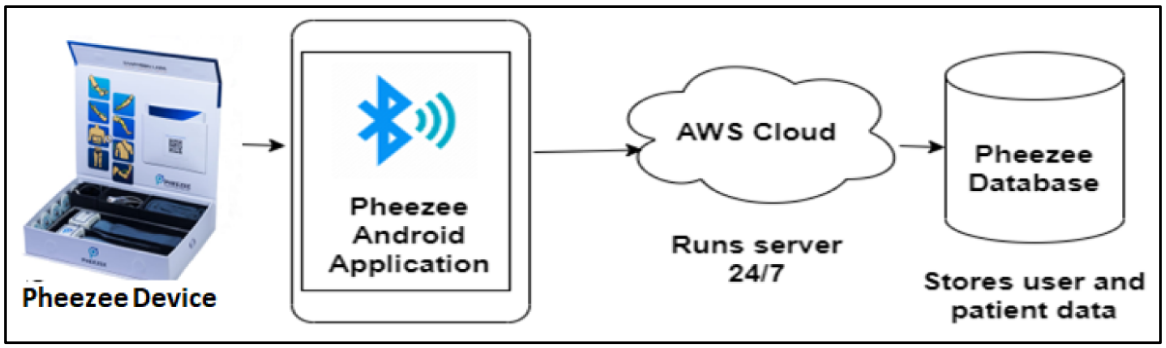


**Figure 1** Data transfer between device and cloud platform

**Table 1** Element of data management

| Storage | Retrieval | Security |
|---|---|---|
| **Format:** .json<br>**Tech:** MongoDB | **Format:** .json<br>**Tech:** REST API | **Server:** Hash64<br>**Hardware:** AES-CCM |

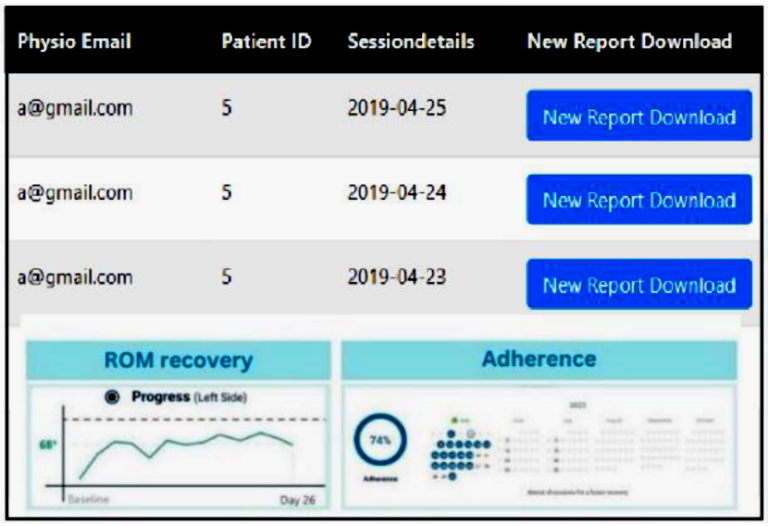


**Figure 2** Data visualization on the dashboard

## RESULTS

Data collected by Pheezee® was used to create patient specific EHR. Fig. 3 shows how Pheezee® EHR helps in clinical decision making and brings the physician, physiotherapist, and patient onto a common platform.

The custom-made software was designed to retrieve the EHR data when needed for the analytics. Pheezee® dashboard displays the patients' data and their corresponding clinical reports like physiotherapist's details, patient details, patient ID, session date, and number of sessions done etc. This extensive data set serves as a valuable resource for data-driven in-depth patient care and data-driven research. Pheezee® scientific reports give comprehensive information about the patient to the physician and the physiotherapist. For example, a male subject with an Anterior Cruciate Ligament (ACL) tear had undergone reconstruction surgery and was indicated for physiotherapy. The subject was assessed using Pheezee® every week for up to 10 weeks. This recovery process was remotely monitored and stored in the server as integral part of EHR. Post treatment, Pheezee® EHR showed 90% improvement in the primary knee muscles as compared to the baseline [11]. This process of monitoring and tracking using EHR, helped in timely intervention and helped in patient's recovery journey.

Additionally, Pheezee® EHR detects the overall adherence of the patient to the treatment protocol which ensures the treatment's success. Non-adherence in patients results in significant disease progression, mortality, and higher healthcare expenses [12].

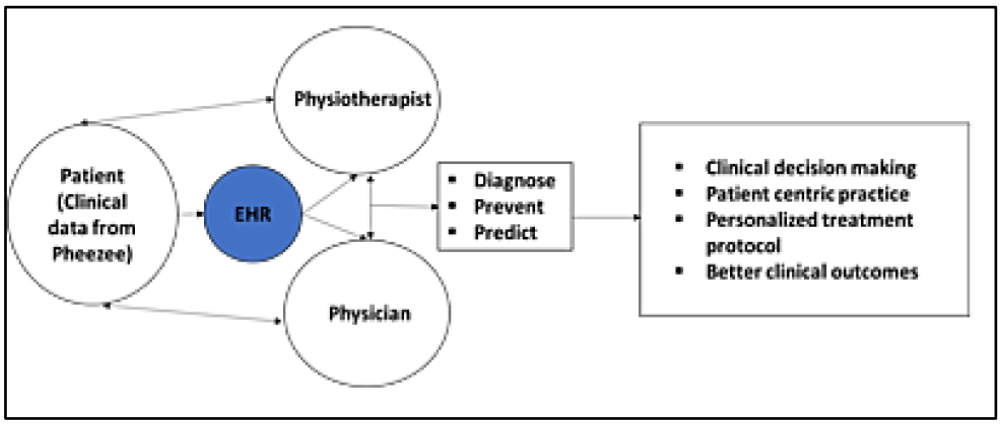


**Figure 3** Pheezee® EHR and clinical decision making

## DISCUSSION & CONCLUSIONS

This comprehensive data collected from the patient helped the physiotherapist in dynamic clinical decision-making for diagnosing and modifying the treatment. This process emphasizes patient-centric and personalized care. EHRs are increasingly being adopted instead of paper-based records due to their various advantages [13]. However, limited digital literacy of the user poses some challenge during the usage of the device. For neurological conditions, where prolonged monitoring is required this EHR-based analysis helps to secure the data for correlating with the period of recovery. EHR data in physiotherapy helps in applying value-based insurance plans for better patient experience and care. Physiotherapists benefit from the data for their day-to-day clinical decision-making process, tailor-made treatment protocol design, patient-informed and patient-centric care, and effective documentation. In future, this EHR system with big data analytics using state of the art AI/ML tools, has the potential to predict and prevent Musculo-skeletal & neurological ailments. Insights on data can assist policymakers in gaining a deeper knowledge of ailments to enhance the outcomes of policies implemented, boost the productivity of healthcare professionals. The principles outlined in the Helsinki Declaration of 1975 as revised in 2000 have been followed. This EHR data has the potential to enhance the value-based insurance coverage in the field of physiotherapy and rehabilitation.

### Clinical Relevance

Pheezee® has excellent accuracy in ROM and high correlation for sEMG assessments when compared with gold standards. The Pheezee® EHR helps to improve clinical decision-making and establish better clinical outcomes during patients' treatment and recovery period.

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302_IEC81438

# Determining the Efficacy of using EEG Signals in Post-Stroke Rehabilitation Engineering Applications through a Pilot Study

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***Abstract**: Stroke is one of the major cause of disability globally. Monitoring recovery after stroke is crucial for assessing rehabilitation progress. Electroencephalography (EEG) plays a key role in stroke diagnosis and helps track patient's recovery. To facilitate restoration of lost motor function, post-stroke patients are instructed in a range of physical activities designed for Activities of Daily Living (ADL). This study assesses the EEG data collected from patients in rehabilitation from Day 1 to Day 30, focusing on pre and post exercise EEG data. Parameters such as Mean, standard deviation, and Power spectral density (PSD) were extracted as features from healthy and stroke subjects as a pilot study. A positive mean and change of PSD was seen as the rehabilitation progress, which signifies changes in brain activity. The finding shows that monitoring neural changes through EEG data can provide valuable insights into post-stroke recovery.*

***Keywords:** Electroencephalography; Power Spectral Density; Stroke Rehabilitation*

## INTRODUCTION

Stroke occurs due to the interrupted and reduced blood supply to the brain, which is the main cause of several neurological deficits or impairments, such as cognitive disorders. It is vital to adapt to ordinary life for patients with symptoms of neurology who need rehabilitation. Impaired upper limb exercise ability is present in more than two-thirds of stroke survivors.

[1]. Post-stroke rehabilitation mainly focuses on motor skill rehabilitation, which engages the affected part of the brain. This promotes quicker recovery. Therapies focus on exercises that replicate daily life activities [2]. Electroencephalogram (EEG) is a valuable tool for monitoring the rehabilitation progress of patients [3][4]. EEG specifically investigates electrical activity in the brain at cortical and subcortical levels, enables the tracking of neuronal dynamics with significant temporal resolution for studying the structure of whole-brain neural networks [5]. In the past, EEG signal analysis has been applied to a variety of tasks to evaluate activation pathways and gain insight into the fundamental principles for motor abilities [6]. This resulted in subsequent research focused on neurorehabilitation to investigate the ways in which activity patterns change depending on the position of cortex areas and on rehabilitation treatment for stroke [7]. The objective of this study is to monitor and evaluate the neural recovery process in post-stroke patients as compared to control undergoing rehabilitation by analyzing pre and post exercise EEG data. his work highlights the potential of EEG as a reliable tool for monitoring and guiding post-stroke rehabilitation, offering a deeper understanding of neuroplasticity and recovery progress over time.

## METHODOLOGY

Two healthy participants and four post-stroke patients with upper limb disability in one hand were participated in the pilot study. The clinical study was carried out at Christian Medical College, Ludhiana, India with Ethics approval and consent from the subjects involved. The subjects were instructed to execute a various hand exercises under the guidance of a physiotherapist. The pre and post exercise EEG data was recorded on Days(1,2,7,30). **Figure 1** is the proposed workflow. With 64 gel-based monopolar electrodes placed EEG data was captured using a g.HIamp biosignal amplifier (g.tec) according to the 10/20 system. Each exercise was performed repeatedly with interval for 5 times. The sampling frequency of 256 Hz was used and filtered with a bandpass FIR filter with cut off frequencies of 0.1 Hz and 45 Hz. The baseline correction was performed by removing the mean of the baseline data which was recorded (from 1 s to 0 ms) for each channel. Independent Component Analysis (ICA) was used to eliminate any

artifacts in the obtained EEG data. The data was preprocessed using the EEGLAB 2019 toolbox, and MATLAB R2021a was used for feature extraction. Within the data set, mean ( $\bar{x}$ ) represents the anticipated value of a sample. The average of the features is ($x_i$) computed for each trial. The degree of variation of a data set from the mean is calculated per trial is termed as standard deviation (σ) [8]. Power Spectral Density (PSD) estimates the signal's frequency content. X(f) is the Fourier Transform of the signal x(t) at frequency f [9].

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N}(x_i)$$

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

$$PSD(f) = \frac{1}{T}|X(f)|^2$$

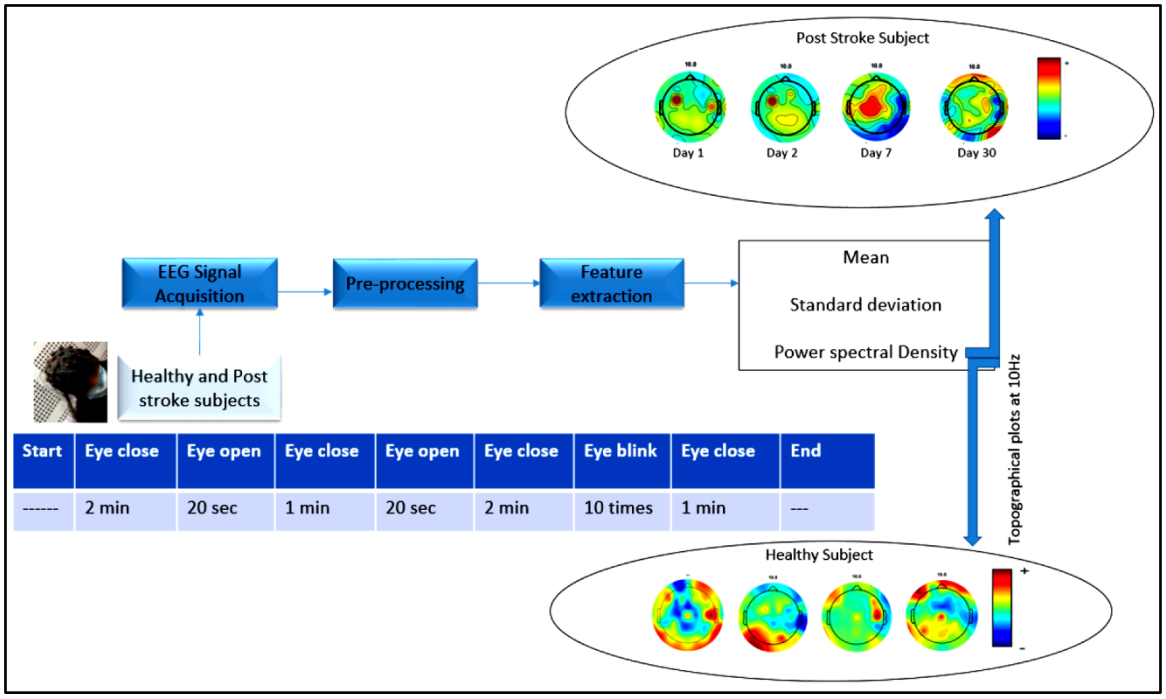


**Figure 1** Flow chart of the proposed work

## RESULTS

Standard Deviation and Mean was calculated to observe time domain properties and PSD was computed to analyze the frequency domain features. the PSD of every patient was individually compared, and the result for them was monitored. The analysis was done on occipital lobe because EEG signal of pre and post exercise was used here and this lobe shows maximum variation. The comparison of the time domain analysis parameters (mean and standard deviation) is shown for healthy and stroke patients in **Table 1**. The mean was initially negative for stroke patients compared to the healthy subjects, but as we progress with rehabilitation regime, a positive mean was observed at Day 30. No significant changes are observed for Standard deviation. There is a distinct variation of alpha band for healthy subjects and stroke patients is shown in the zoom out position of the proposed method in **Figure 1**. **Figure 2** shows the box plots of the healthy and stroke subjects of Days (1,2,7,30). In the box plot it can be seen that in day 1 the median of healthy and stroke subject quite differs but as the day increases the median is getting same for both the subjects which shows the progress of rehabilitation

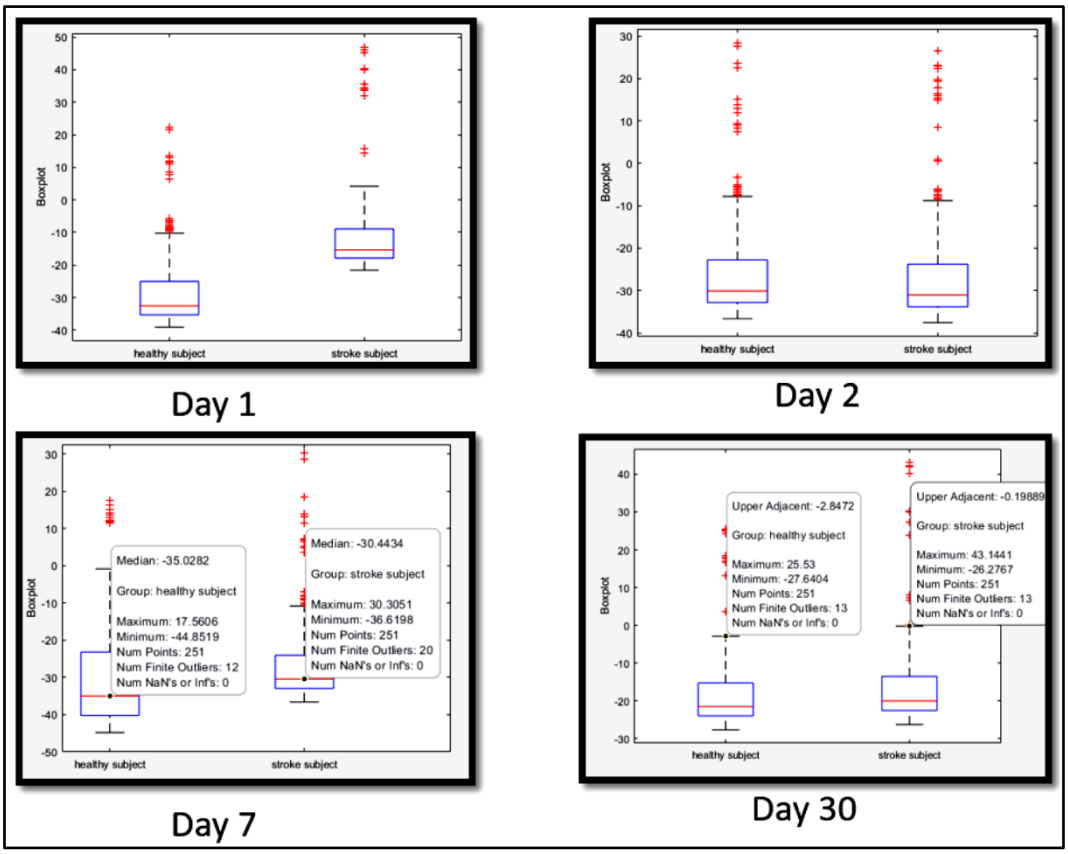


**Figure 2** Box plot of healthy and stroke subjects

**Table 1** Comparison of healthy and stroke subjects

| Days | Healthy subjects | | Stroke subjects | |
|---|---|---|---|---|
| | Mean | Standard deviation | Mean | Standard deviation |
| Day 1 | 4.8925 | 1526.5 | -0.0897 | 190.2671 |
| | 4.1427 | 1674.2 | -0.1852 | 190.6973 |
| | | | -0.6098 | 296.9182 |
| | | | -0.3699 | 293.4654 |
| Day 2 | 6.1491 | 1208.7 | -0.3525 | 374.8276 |
| | 1.8311 | 455.3378 | -0.4710 | 202.7561 |
| | | | -1.5265 | 338.4925 |
| | | | -0.5484 | 392.4575 |
| Day 7 | 2.1307 | 851.7815 | 0.6220 | 247.6184 |
| | 0.6247 | 438.5620 | 0.6775 | 262.8067 |
| | | | 1.8017 | 492.3260 |
| | | | 0.7737 | 301.9506 |
| Day 30 | 0.8344 | 1478.9 | 2.1297 | 444.1406 |
| | 0.0052 | 705.0056 | 2.1089 | 393.0792 |
| | | | 5.1946 | 604.0751 |
| | | | 2.4480 | 497.0863 |

## CONCLUSION

It was observed that the mean was negative for stroke patients initially but as we progress with the rehabilitation regime positive mean was observed. The PSD change can be seen very well with respect to frequency. As we are using pre and post-exercise data, the activity change in topo plot was observed for occipital region. The activity

change in the central region was seen from Day 1 to Day 30. It can be seen that motor recovery will be helpful if the patient continues to do exercise. This work underscores the efficacy of EEG as a dependable instrument for managing and directing post-stroke rehabilitation, providing enhanced insights into neuroplasticity and the progress of recovery over time. The study was done on a few subjects so a large scale study will be helpful to establish the rehabilitation progress further. Accordingly, schemes can planned to have persistent exercise regimes to ensure better recovery. This also opens up cases for robotics based exercise device development as a future rehabilitation engineering activity.

## ACKNOWLEDGMENT

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# Chemicals & Hydrocarbons

## Gas Processing

236_IEC44090

# Achieving Flowability for Enhancing Crude Oil Recovery using PIPESIM Software

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***Abstract:*** *This study outlines an effort to design and optimize a gas lift system utilizing Pipe SIM software. After depletion of primary pressure energy in an oil well, it is often installed the gas lift system to help extend oil recovery. The PIPESIM model analysis in this work considered gas lift design based on well completion data, reservoir fluid characteristics, and reservoir data. The temperature and pressure profile of the well system were taken into account for this analysis. The downhole condition of the well was replicated with an allotment of actual tubing and casing inside diameter, thicknesses, perforation details, and downhole completion information. Gas lift valve details, installation depths, and respective opening pressures were also incorporated into the model analysis. Finally, the work took into account sensitivity analysis, considering varying conditions to the gas lift system.*

***Keywords:*** *PIPESIM; Gas Lift; Optimum Gas Injection Rate; Well Data, Pressure-Temperature, Reservoir Pressure*

## INTRODUCTION

Artificial lift is the extension of the primary production phase, which, based on additional support provided to the oil system, helps produce crude oil from intake of the tubing to the wellhead [1]. Gas lift is a proven method that can multiply crude oil production rate by injection of compressed gas that helps push the reservoir fluids suffering from low reservoir pressure [2]. In the gas lift system, proper positioning of the valve setting depth, its numbers down the casing tubing annulus, and adequate yet optimum tubing sizes effectively reduce pressure losses, improving the flow rate of the well fluids into the well [3] [4]. Gas lift produces under two mechanisms: continuous and intermittent. Reasons for application of gas lift production also very well to well. The gas lift installation process facilitates well pressure to reduce beyond formation fluid pressure, thereby enabling well fluid to enter the well [5]. Pressure at the well bottom and at the top are the crucial information based on which well flow condition in the well system is established. Different measurement systems are in practice that eventually provide equivalent pressure data when it is measured with direct intervention with pressure measuring gauges. PIPESIM model analysis determines all these pressure data in the well and finds out the feasibility of the gas lift in any well condition to hence productivity [6]. The fundamental application of PIPESIM is to estimate the performance of the well in terms of its flow rate, how much optimum gas injection will help reduce water cut, and the adequate valve setting depth [7]. Administering the right amount of gas injection is a key to optimizing the management of gas distribution to wells of a field. Excess amount of gas injection may reach the formation or occasionally pressurize the well, preventing well influx to the well. However, optimum amounts help enhance production output from such wells [8]. Gas lifted wells also suffer from solid depositional issues; the issue is the byproduct of mismanaged distribution of either gas injection rate or sub-optimum gas injection. In such cases, coil tubing operations are needed to mobilize the solid deposition [9] [10].

The present study aims to examine the performance of a gas lift well in terms of its flow rate, pressure distribution, and how production can be improved. The details of the various stages that have been adopted in the analysis can be evidenced in the subsequent analysis.

## METHODOLOGY

In this analysis with PIPESIM flow profile was first designed incorporating diameter data of flow line, its operating pressure, and fluid properties. Following this, a well profile has been designed incorporating well data that include casing and tubing data, surface equipment, and pressure temperature data (P-T) for both transient and steady-state conditions. **Figures 1-6** represent the above.

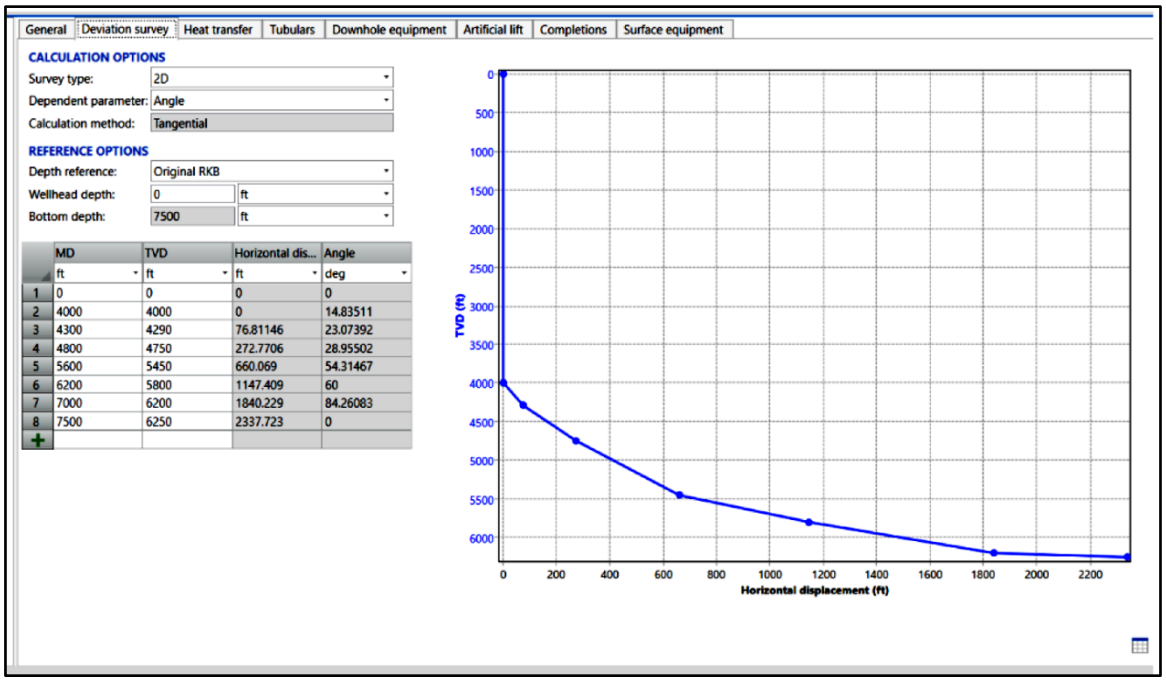


**Figure 1** Deviation survey

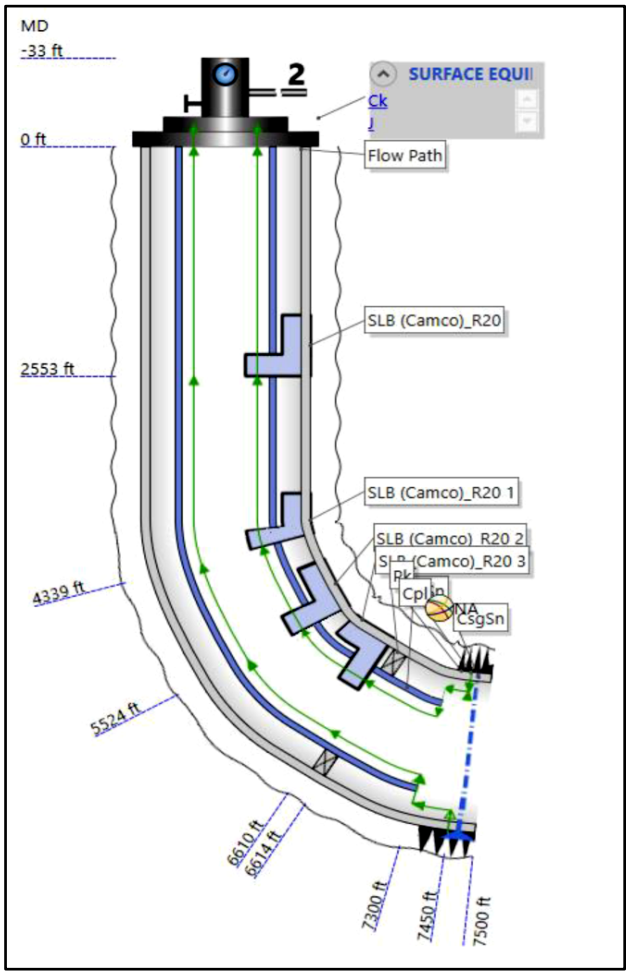


**Figure 2** Well Profile

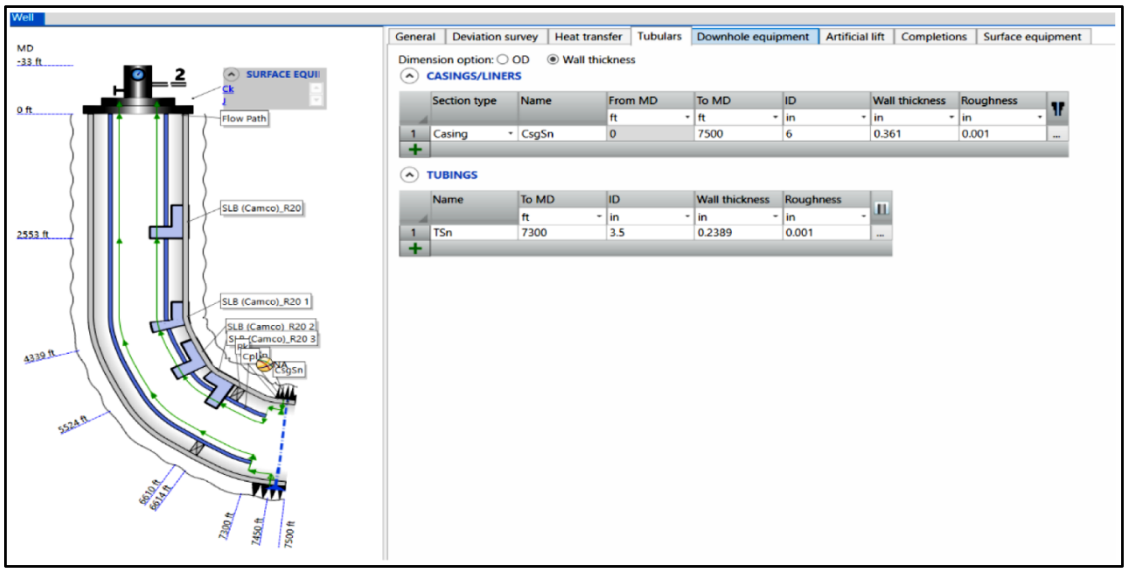


**Figure 3** Casing and tubular data (well profile)

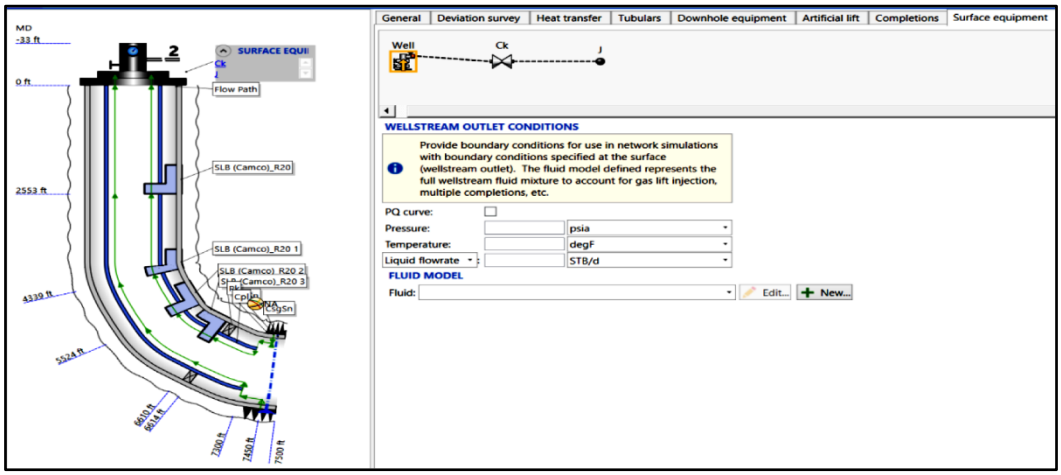


**Figure 4** Well Profile with surface equipment

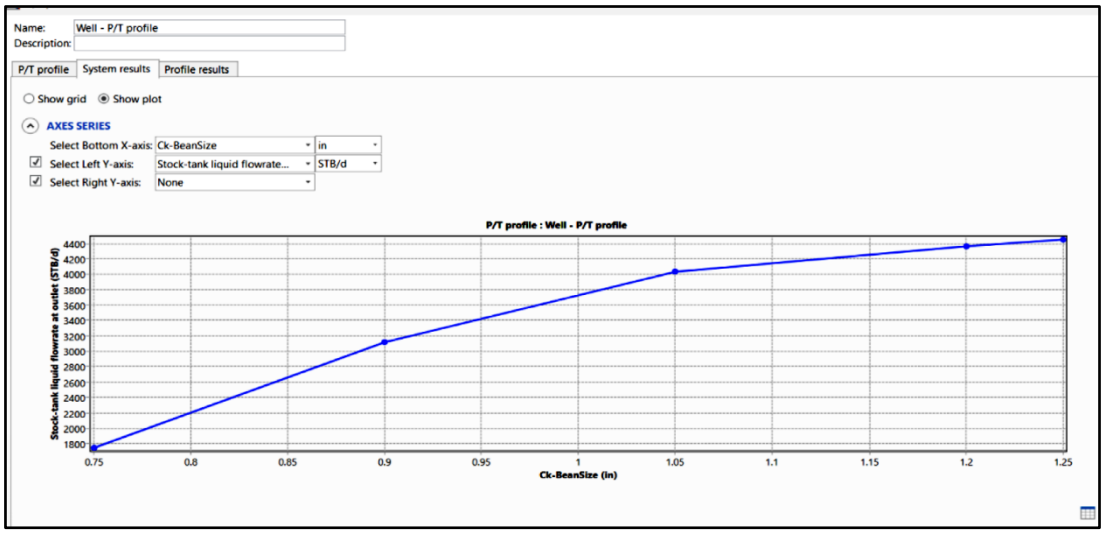


**Figure 5** PT-Profile system results steady state

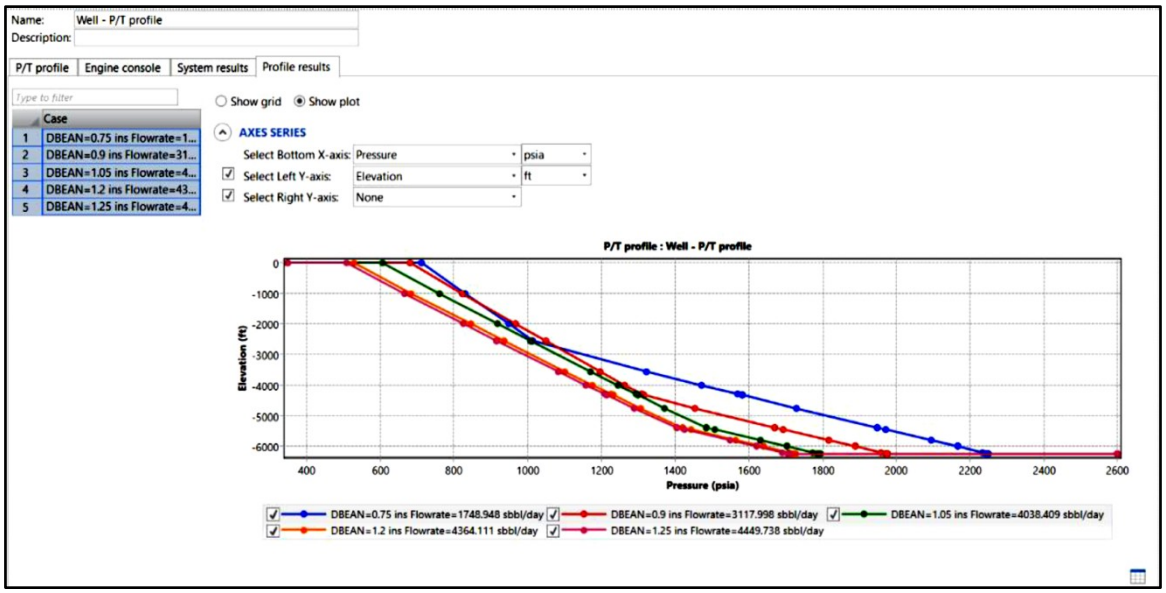


**Figure 6** PT-Profile result transient state

## RESULT DISCUSSION

The PIPESIM model analysis based on the above input data establishes the gas lift valve setting depths at 2553.464 ft, 4339.054 ft, 5524.073 ft, and 6609.975 ft, respectively (**Figure 7**). Under the flow condition and with respect to gas lift design, the valve size has been determined as 1.5 inches and the port size to be 0.25 inches (**Figure 8**). The P-T variation profile has been shown in **Figure 9**. This gas lift design identifies the optimum gas injection depth as 6006.094 depth (**Figure 10**). Under the scope of these calculations, the PIPESIM model study establishes that the well is establishing flow in the gas lift system (**Figure 11**).

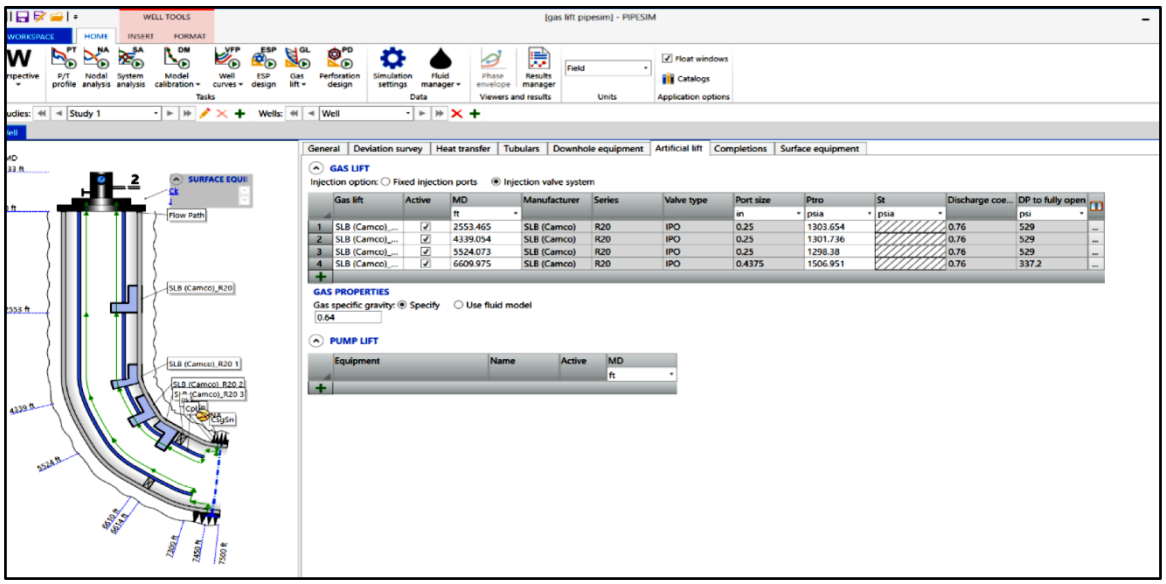


**Figure 7** Gas lift valve design

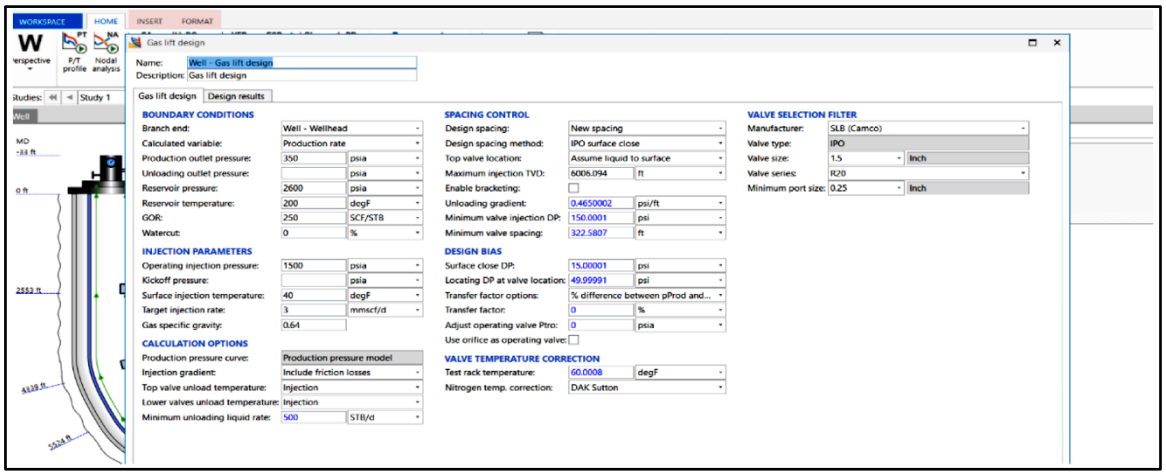


**Figure 8** Gas lift size determination

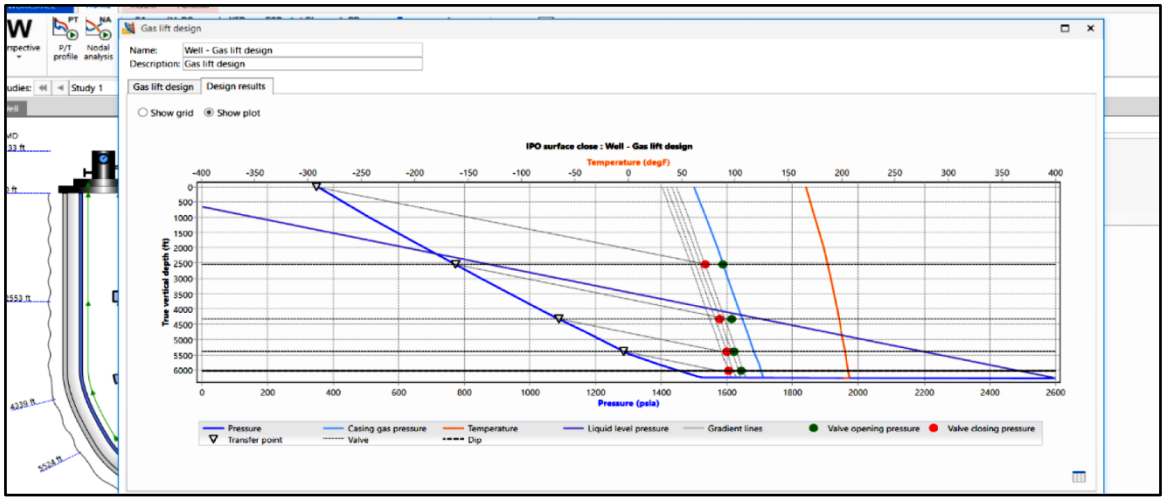


**Figure 9** Gas-lift P-T profile

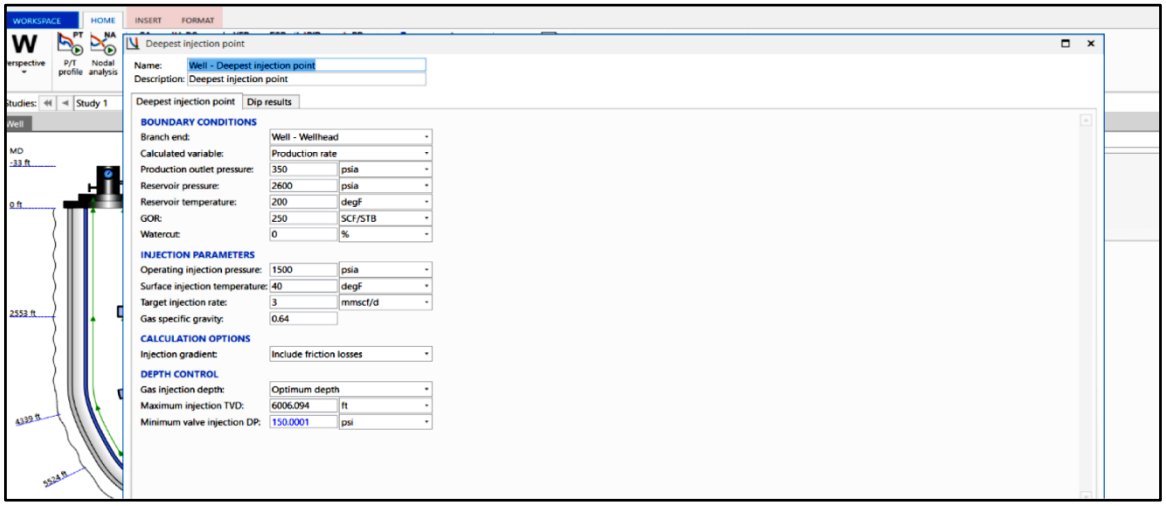


**Figure 10** Optimum gas injection depth determination

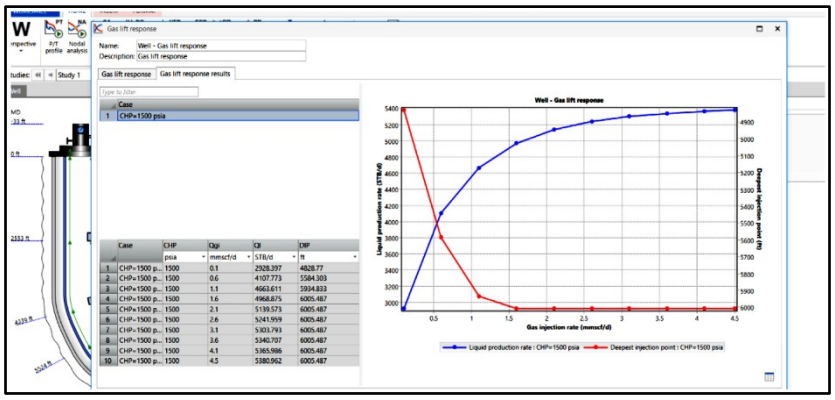


**Figure 11** Gas lift established flow condition

## CONCLUSION

Based on the above findings, the current study finds that PIPESIM software analysis based on well, reservoir, and surface condition data effectively determines the well performance of the well. This gas lift design establishes that the well can be produced provided optimal gas injection rate, valve setting depth, valve sizes, and flow components in the downhole are arranged as per the gas lift design.

## ACKNOWLEDGMENT

The authors wish to thank the department of Petroleum Technology, Dibrugarh University, and all persons who have directly or indirectly helped in carrying out the study. The work design is based on review papers and suggestions received from technocrats that shed light on the applicability of PIPESIM software to solve issues of oil well production systems.

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# Chemicals & Hydrocarbons

## Hydrogen Economy and Circular Economy

290_IEC23561

# Green Hydrogen: Engineering and Safety Challenges

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***Abstract:*** *In recent years, hydrogen has gained much attention as an energy carrier in the pursuit of sustainable and clean energy. Its ability to decarbonise various sectors, from transportation to industry, has increased the interest in the production and storage of hydrogen. But as the hydrogen economy continues to grow, concerns have been raised about the safety of green hydrogen. Green hydrogen production is at the forefront of the transition to a sustainable energy landscape. Green hydrogen refers to hydrogen produced using renewable energy sources such as wind, solar power, or hydropower, and is considered one of the cleanest forms of energy. One of the main advantages of green hydrogen production is the possibility of storing surplus renewable energy: during periods of low energy demand, surplus electricity can be used to electrolyze water, splitting it into hydrogen and oxygen. This hydrogen can be stored for later use in a variety of applications, such as fuel cells and industrial processes, and can effectively act as an energy carrier and grid balancing tool. This article provides a review of hydrogen safety, and highlights the safety challenges in the electrolytic production, storage and transportation of green hydrogen.*

***Keywords:*** *Climate Change; Renewable Energy; Hydrogen; Green Hydrogen*

## SAFETY IN GREEN HYDROGEN MANUFACTURE

Green hydrogen is produced through electrolysis, a process that separates water into hydrogen and oxygen, using electricity generated from renewable sources. Today it accounts for just 0.1% of global hydrogen production. At present, there are different types of electrolysers depending on their size and function. The most commonly used are polymer electrolyte membrane electrolyser, alkaline electrolyser, and solid oxide electrolysis cell (SOEC) [1].

### Polymer Electrolyte Membrane Electrolyser

The electrolyte in a polymer electrolyte membrane (PEM) electrolyser is a solid specialised plastic substance. At the anode, water reacts to produce positively charged hydrogen ions and oxygen. At the cathode, they mix with electrons from the external power source to create hydrogen gas, the hydrogen ions travel over the membrane.

At 70 to 90°C, PEM electrolysers normally operate. The main design/materials selection concerns with a PEM electrolyser are corrosion and the possibility of both external and internal hydrogen embrittlement, ignoring the electrodes and electrolyte, which should be regarded as consumables.

### Alkaline Electrolyte Membrane Electrolyser

At the cathode of an alkaline electrolyte membrane (AEM) electrolyser, hydrogen and hydroxide ions (OH-) are produced. The anode receives the hydroxide ions through the electrolyte, where they combine and surrender their excess electrons to create water and oxygen.

Compared to PEM electrolysers, AEM electrolysers provide a number of benefits [2]. Materials for the electrode (catalyst) are much less expensive. Anodic catalyst dissolves less readily. Because the electrolyte in AEM electrolysers may be changed, they are more robust. Due to the alkaline electrolyte's reduced gas diffusivity, the purity of the gases produced is higher. Corrosion and the potential for internal and external hydrogen embrittlement are the main design/materials selection concerns with an AEM electrolyser.

### Solid Oxide Electrolyser

The electrolyte in solid oxide electrolysers is a solid ceramic substance. Solid oxide electrolysers require a temperature range of 500–850°C to operate properly with the "electrolyte". Hydrogen gas and negatively charged

oxygen ions ($O_2$-) are produced when steam at the cathode interacts with electrons from the external power source. The solid ceramic membrane allows the oxygen ions to pass through, where they react with the anode to produce oxygen gas.

Solid oxide electrolysers must work at high temperatures; therefore, the main design/materials concerns are creep, loss of mechanical strength, and the potential for hydrogen reaction embrittlement.

**Safety Advantages of Alkaline Electrolysis**

When it comes to safety, alkaline electrolysis is superior to other techniques of producing hydrogen in various ways[3]:

Non-Flammable Electrolyte: Anon-flammable electrolyte called potassium hydroxide (KOH) is used in alkaline electrolysers. This removes the possibility of explosions that come with some other electrolysis techniques involving combustible materials.

Robust and Proven Technology: Alkaline electrolysis technique has been used successfully for a long time in a variety of industrial applications, proving its dependability and security.

Ease of Scaling: A wide range of applications can benefit from the easy scalability of alkaline electrolysers to satisfy changing demands for hydrogen production.

**CHALLENGES IN HYDROGEN STORAGE**

The advancement of hydrogen and fuel cell technology depends on hydrogen storage. Its low energy density necessitates the employment of innovative storage techniques that could raise its energy density [4]. Historically, hydrogen has been kept either as a liquid or a gas. Because it must be held at minus 253°C as a liquid, it is most frequently stored as a gas.

**Compressed Hydrogen**

Both hydrogen pipeline and compressed hydrogen tube trailer transportation employ compressed hydrogen. Most frequently, compressed hydrogen is kept in high-pressure gas cylinders at pressures of up to 200 bar [5]. Such cylinders should be made of a material with a high tensile strength, low density, and no hydrogen reactivity or hydrogen diffusion. Austenitic stainless steel, copper, and aluminium alloys have been the materials most frequently employed to date.

**Liquid Hydrogen**

Hydrogen needs to be cooled to its critical point of minus 240°C in order to become a liquid. However, it needs to be chilled to roughly - 253°C in order to be completely liquid under atmospheric pressure. By repeatedly compressing, cooling, and expanding the gas, such as with the Joule-Thompson cycle (Linde cycle), the gas is made to liquefy. The energy needed to liquefy the gas, which can be almost half as much as the energy needed to burn the hydrogen, is a disadvantage of liquid hydrogen storage, as was already mentioned.

**Ammonia**

Through synthesis and subsequent ammonia cracking (decomposition), ammonia can be utilised as a fuel or as a means of transporting hydrogen.

Ammonia ($NH_3$) has a higher hydrogen density than other hydrogen storage materials, is simple to catalyse, and can be produced and distributed using well-established processes. Ammonia has the potential to take the place of fuels that produce carbon dioxide in a number of transportation applications. Similar to hydrogen, it only releases water and nitrogen as byproducts of combustion when burnt in internal combustion engines, but this avoids the logistical and safety issues associated with using hydrogen fuels in motor vehicles.

At room temperature, ordinary carbon steel can be utilised as the material of construction, but specific steels are needed at low temperatures to prevent embrittlement.

**Metal Hydrides**

A different way to store hydrogen is as a metal hydride in the solid form, which is very useful for hydrogen-powered cars. Different metals and alloys can act as "carriers" because they can reversibly absorb hydrogen to generate metal hydrides [6]. An early transition metal (such as titanium or vanadium), a rare-earth metal, or magnesium are categorised as metal A, A2B, AB, AB2, and AB5 while aluminium, chromium, cobalt, iron, nickel, or manganese are classified as metal B. The ability of the "carrier" to absorb and release the hydrogen repeatedly without degrading is the most crucial aspect in connection to the actual use of metal hydrides [7].

## CHALLENGES IN THE TRANSPORTATION OF HYDROGEN

Currently, hydrogen is moved via land and sea from the point of production to the point of usage. On land, it is moved in cryogenic liquid tanks or compressed gas cylinders over road, rail and pipeline. Through the use of hydrogen "carriers" or cryogenic liquid tanks, it is carried by sea.

**Pipelines**

Pipelines are employed when there is a sizable demand for a product that is anticipated to last for a considerable amount of time. There are many parallels between the transportation of natural gas and hydrogen gas. To determine if natural gas pipes can be converted to hydrogen, a lot of study is now being done in this area. Liquid hydrogen 'carriers' like ammonia, cyclohexane, and methanol are also transported through pipes, although not in the same pipeline as hydrogen gas since the design specifications differ greatly.

Concerns about safety are particular to the transportation of hydrogen. Regarding pipelines, there are a number of extra issues. The pertinent codes and standards handle them

**Rail and Road**

In the case of hydrogen gas, compression is required before the hydrogen may be delivered. The starting pressure of the hydrogen that needs to be compressed plays a major role in the energy need for compression. 0.7 kWh/kg of hydrogen will be needed if it is expected that hydrogen must be compressed from 20 to 200 bar [8]. A reasonable estimate of the energy needed for the liquefaction process in the case of liquid hydrogen is 10 kWh/kg hydrogen. The energy needs for auxiliaries, flash gas control, losses, and boil-off during the liquefaction process are also taken into account in this number.

The option as to whether to transport hydrogen as a gas or a liquid comes down to cost and how the hydrogen is kept at the producing site. The design and material issues related to hydrogen storage and transportation by road and rail are fundamentally the same.

**Transport by Sea**

Transporting hydrogen by sea other than as a liquid is not economically feasible. Any kind of hydrogen delivery other than as liquid, by sea is not economically feasible. Under atmospheric pressure and minus 253°C, liquid hydrogen is transported; under these conditions, it takes up around 0.1% of the volume it did when it was a gas [9]. While many of the difficulties encountered while shipping liquid hydrogen at sea are comparable to those encountered when transporting LNG at minus 160°C, the transportation of liquid hydrogen also poses certain particular difficulties.

## CONCLUSIONS

The need for a continuous dedication to enhancing operational safety is underscored by the growing utilization of hydrogen across various industries in recent times. The crucial role of safety considerations in fostering public acceptance cannot be overstated. This analysis delves into the diverse landscape of hydrogen applications in the

transportation and energy sectors, with a specific focus on aspects like storage, transmission, and, notably, safety. Emphasis is placed on anticipating potential risks, establishing applicable standards to define permissible operational areas, and implementing reliable equipment and guidelines as fundamental elements for the secure utilization of hydrogen technology.

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# Chemicals & Hydrocarbons

## Net Zero, Sustainability

162_IEC83477

# Droplet Dynamics: A New Frontier in Energy Harvesting

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***Abstract:*** *Piezoelectric nanogenerators (PENGs) are a great option for developing renewable energy sources because of their adaptability, flexibility, and scalability. The kinetics of energy transmission and its implications for energy harvesting using piezoelectric mechanisms are emphasized in this research, which looks into the mechanics of droplet impact on a flexible cantilever-like surface. Surface wettability, droplet height, and impact speed are some of the characteristics that we simulate to find out how they influence surface deflection, force generation, and piezoelectric output. In order to better understand the intricate relationships between fluid dynamics and structural reactions, our research makes use of COMSOL Multiphysics. To optimize PENGs and make the most efficient use of the mechanical energy transferred by droplet collisions, it is essential to have a firm grasp of these interactions. Both the basic knowledge of energy harvesting systems and the creation of novel, environmentally friendly energy solutions with broad applicability are enhanced by this research.*

***Keywords****: Nanogenerators; Piezoelectricity; Energy Harvesting; COMSOL; Energy Materials; Fluid-Structure Interaction*

## INTRODUCTION

The term piezoelectricity, is derived from the Greek word “piezein”, which means to press. So, the term piezoelectricity refers to the phenomena in which specific materials with charge delocalization capabilities produce an electricity when exposed to mechanical stress. This concept governs the functionality of piezoelectric devices, which are progressively employed in applications including tunable and implantable devices, sensors, and self-sustaining electronics. With the increasing significance of energy gathering technologies, the adaptability and efficacy of piezoelectric nanogenerators render them essential for future advancements.

A standard piezoelectric device comprises three primary components: (a) a piezoelectric coating that produces electrical energy, (b) a substrate that supports the piezoelectric material, and (c) an electrode that conveys the created electrical energy to a storage system. Piezoelectric devices can be classified as unimorph or bimorph piezoelectric nanogenerators (PENG) based on the arrangement of their components.

Understanding the droplet impact dynamics on flexible substrates becomes a crucial point for enhancing piezoelectric devices when targeting grass leaf-like applications. In a recent study, by Chen et al. [1] (2016), they study the interaction behaviors of water droplets with both solid and flexible materials by varying the falling droplet's Weber numbers. Their results show that droplets striking soft surfaces with low Weber numbers tend to rebound, but larger Weber numbers lead to droplets dispersing before coming to rest. Analyzing such fluid structure interaction becomes essential when dealing with applications involving energy harvesting from vibrations or impacts, as it directly leads to the changes in net the mechanical stress and forces experienced by the piezoelectric material.

Similarly, Weisensee et al.[2] in 2016 in one of their research projects demonstrated that the modulus of elasticity of a soft surface affects droplet behavior, suggesting that softer materials can improve the efficacy of piezoelectric devices. Alizadeh et al. [3] (2013) observed that substrate flexibility can substantially influence droplet behavior upon impact, resulting in changes in the energy produced by piezoelectric coatings. The capacity of a flexible beam to efficiently distribute the net stress due to droplet impacts can directly influence the efficacy and dependability of energy harvesting.

This article aims to computationally explain the droplet impact dynamics on a thin, flexible cantilever beam in order to assess the net stress experienced by the structure ultimately leading to its capacity to generate energy via utilizing piezoelectricity. To better understand the fluid structure interaction behavior on a flexible beam, COMSOL Multiphysics 6.2 is utilized which supports the coupling three different physics modules: (a) laminar for fluid

dynamics, (b) phase field for interface tracking, and (c) structural mechanics for evaluating deformation and stress. Our simulations will concentrate on a droplet with a diameter of 4 mm descending freely from a height of 10 mm, maintaining a constant simulation duration of 0.02 seconds. Simulation results shows that the beam experiences a net average force of approx. 15 N/m$^2$ is applied over the spreading area of the droplet. If the beam is made up of polyvinylidene fluoride (PVDF) it can generate a maximum of 7V. Understanding the interaction between droplets and flexible beams helps improve the design and efficiency of piezoelectric devices, hence advancing energy harvesting technology.

## METHODOLOGY

A 2D domain of 70 mm × 40 mm is selected as a computational domain which is filled with air. A beam of length 50 mm × 0.1 mm is placed inside the domain, and droplet of radius 2 mm falling with the velocity of 1.4 m/s is placed just above the beam at a distance of 7 mm from the leading edge as shown in **Figure 1a**. The overall domain is divided into an extremely fine quadrilateral mesh with 2$^{nd}$ order of refinement and total 252704 number of elements. Defining droplet impact on a thin and flexible cantilever surface is a complex mechanism and requires several mathematical models to define it with accuracy. We have employed the following mathematical models: a) Laminar Flow: To define falling of the droplet, b) Solid Mechanics: To define mechanics of the beam, and c) Phase Field: To track the fluid-solid interface.

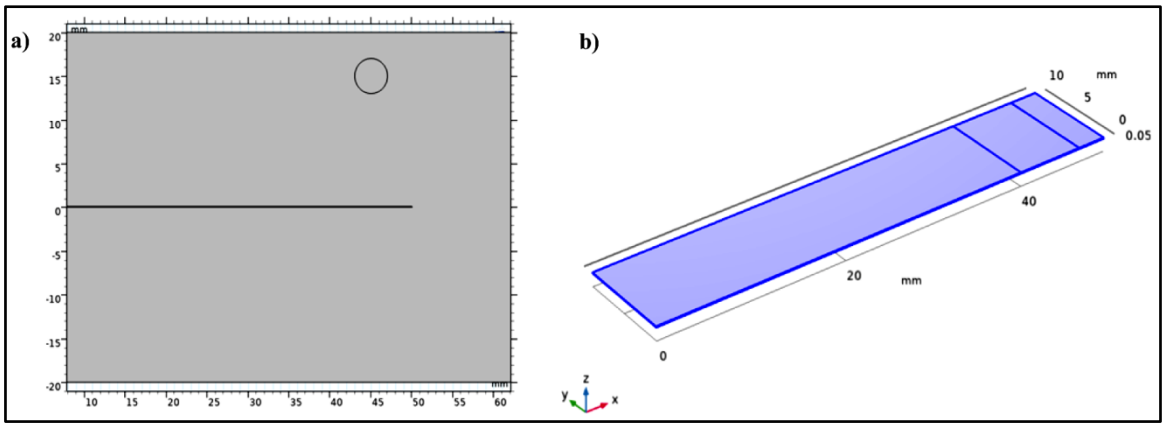


**Figure 1** Computational Domain for a) Fluid Structure Interaction, and b) Piezoelectric Energy Harvester

## RESULTS

Droplet is assumed to be in a laminar nature. A flow is said to be laminar as long as the Reynold's number stays below a certain critical limit. Two domains are defined under this model, which are droplet and air. This model solves the Navier Stokes and Continuity equation. Flow is incompressible and we have also included the effect of gravity. The equations used to define this model are:

$$\rho \nabla . u_{fluid} = 0 \quad (1)$$

$$\rho \frac{\partial u_{fluid}}{\partial t} + \rho (u_{fluid} . \nabla) u_{fluid} = \nabla . [-\rho I + K] + F + \rho g \quad (2)$$

Phase Field method is used for tracking of the interface. In the phase-field method the criteria are a function (phase field function) of [-1, +1], that in first phase area this function is +1 and in another one is -1. Using this function, the interface is where that this function is zero. This function has smooth variation, in a narrow area near the interface

$$\frac{\partial \emptyset}{\partial t} + u . \nabla \emptyset = \nabla . \frac{\gamma \lambda}{\epsilon_{pf}{}^2} \nabla \psi \quad (3)$$

$$\psi = -\nabla . \epsilon_{pf}^2 \nabla \emptyset + (\emptyset^2 - 1)\emptyset + \frac{\epsilon^2{}_{pf}}{\lambda} \frac{\partial f}{\partial \emptyset} \quad (4)$$

$$\lambda = \frac{3\epsilon_{pf}\sigma}{2.828}, \gamma = \lambda\, \epsilon_{pf}^2 \qquad (5)$$

The solid mechanics interface is used when we need to find stress, strain and displacement. It is based on equation of motions of a body. We have taken the default material which is Linear Elastic Material. The equations used to define this model are:

$$\nabla.\,(FS)^T + F_V = 0\,,\;\; F = I + \nabla u_{solid} \qquad (6)$$

Further the voltage output using PVDF based piezoelectric device is simulated by coupling Solid mechanics along with electrostatics. The equation used to define piezo electricity are:

$$D = dT + \varepsilon_0 \varepsilon_{rT} E\,,\; E = -\nabla V \qquad (7)$$

The impact dynamics analysis carries out over superhydrophobic beam shows dynamic behavior of Fluid structure interaction and its possible application in the field of piezoelectric based energy harvesting. A water droplet with a diameter of 4 mm falls from a height of 10 cm, converting potential energy into kinetic energy as it descends. The velocity ($v$) of the droplet upon impact can be calculated using:

$$v = \sqrt{2gh} \qquad (8)$$

where g is the acceleration due to gravity. Upon hitting the beam, the droplet makes contact in about 1 ms, leading to deformation and energy transfer. By 2 ms, the droplet transfers most of its energy to the piezoelectric beam and attains a pancake shape with bulged edges, indicating significant deformation. This shape change affects the contact angles with the surface, which can influence the behavior of the droplet. The cantilever beam experiences maximum deflection over time, with the maximum von Mises stress occurring at the fixed end, reaching 2.5 MN/m$^2$ as shown in **Figure 2b**. From **Figure 2c** it's clear that for a given simulation time the relationship between deflection and time is nearly linear, indicating a predictable response to the droplet's impact. The stress generated in the beam due to the droplet's impact creates a driving force for a piezoelectric (PVDF) beam, resulting in a peak electrical output of approximately 7 V as shown in **Figure 2d**. This interplay between mechanical deformation and electrical generation highlights the potential for using impact-driven systems for energy harvesting applications.

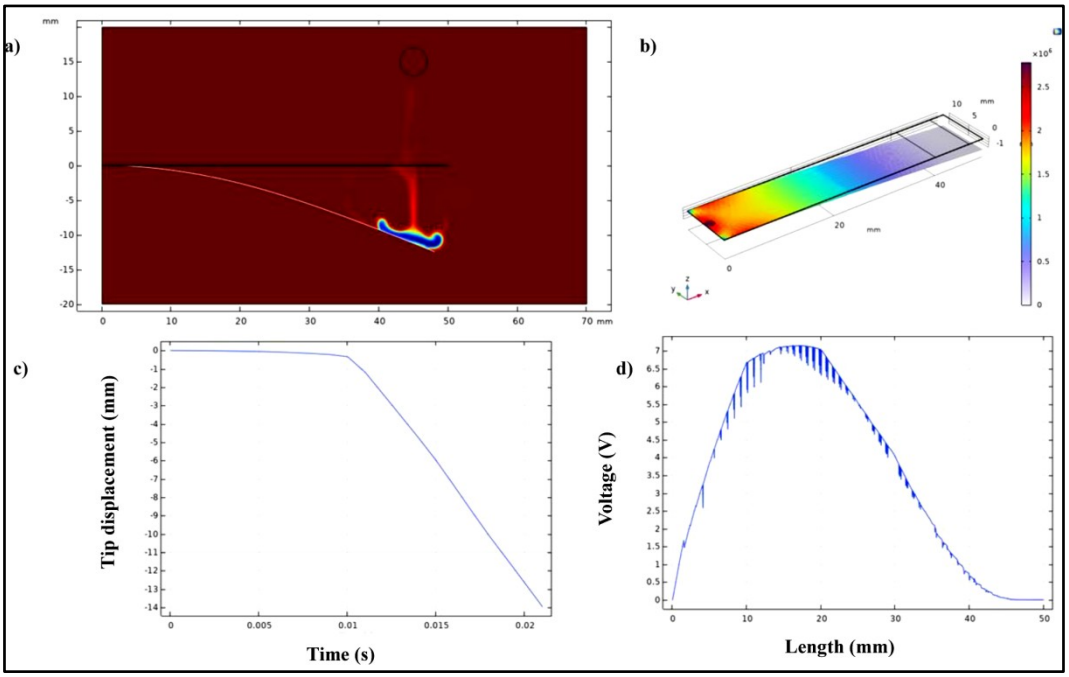


**Figure 2** a) Beam position and droplet deformation at t = tf, b) Max von Mises stress experienced by PENG, c) Time history of beam tip position, and d) Voltage generated by PENG throughout the length

## CONCLUSION

Piezoelectric nanogenerators (PENGs) are can be considered as a key to tap energy that is ultimately lost to environment to their versatility, flexibility, and scalability. The current article uses COMSOL Multiphysics to analyze the fluid-structure interaction dynamics of a flexible beam, with the objective of optimizing PENGs and maximizing the mechanical energy derived from droplet impacts. The study primarily focusses on the significance of comprehending the interaction between droplets and flexible beams to enhance the design and efficiency of piezoelectric devices, hence progressing energy harvesting technology. The article emphasizes on understanding the droplet impact behavior upon flexible cantilever type substrate. The research seeks to advance the fundamental understanding of energy harvesting systems and the development of innovative, sustainable energy solutions with wide-ranging applicability.

The research examines the potential of a single water droplet on a superhydrophobic piezoelectric beam as a source of energy and stress, ultimately investigating its behavior and possible applications in the fields of piezoelectric energy harvesting. With a 4 mm diameter, the droplet lowers from a height of 10 cm to convert potential energy into kinetic energy. Within 1 ms, the droplet makes contact with the beam producing deformation and energy transmission. The droplet distributes most of its energy to the piezoelectric beam within two milliseconds, producing a pancake shape with projecting edges. Over time, the cantilever beam experiences maximum deflection; peak von Mises stress results at the fixed end. The collision of the droplet creates a driving force for a piezoelectric (PVDF) beam, therefore producing a maximum electrical output of over 7 V from the stress applied in the beam. The coupling of mechanical deformation with electrical generation emphasizes the possibilities of impact-driven devices for energy collecting uses.

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195_IEC75237

# Amine Functionalized Activated Carbon Sourced from Wood Dust for $CO_2$ Capture

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***Abstract**: This study focuses on the production of wood dust-derived amine functionalized activated carbon for $CO_2$ capture applications. Wood dust has been employed as the carbon precursor. A quick and scalable one-step procedure is used to attach long-chain amine groups, (3-Aminopropyl) triethoxysilane (APTES) & tetraethylenepentamine (TEPA), to the surface of activated carbon (AC) obtained from the carbonization of wood dust to functionalize it. An in-house adsorption set-up has been utilized to test the $CO_2$ capture capability of the synthesized adsorbents. Under ambient conditions, the adsorbents have demonstrated adequate adsorption performance (~0.8 mmol/g at 32°C and 1 bar). Characterizations carried out on the samples indicate reversible physisorption of $CO_2$ on the adsorbents. The interaction of the long-chain amines and the naturally sourced reducing agent L-ascorbic acid has been observed to be a key factor in determining the $CO_2$ capture potential of the prepared capture materials. These adsorbents may be considered as a sustainable alternative for the capture of $CO_2$.*

***Keywords:** Activated Carbon; Wood Dust; $CO_2$ Capture; Sustainable; Adsorption*

## INTRODUCTION

Numerous mitigation strategies are being enforced to reduce the release of $CO_2$ into the atmosphere. Among such strategies, direct air capture (DAC) of $CO_2$ may be considered the most effective option[1]. Multiple plants have been set up and are being used to remove carbon dioxide from the atmosphere. However, these plans are mostly restricted geographically to developed countries[2]. Such measures must be implemented on a global scale to significantly reduce the amount of carbon dioxide in the atmosphere. This effort will require significant capital and land resource investment. A significant contributor to the cost is the mode of adsorption implemented and the adsorbent being used in the process[3]. Numerous adsorbents have been investigated with good potential for $CO_2$ capture. Adsorbents based on advanced materials like graphene, cellulose & metal-organic frameworks have shown very high $CO_2$ capture capability[4]. AC is a material which may be used as an alternative. AC may be produced relatively simply by pyrolysis of a precursor material and has been observed to possess a lot of characteristics similar to advanced materials, required to capture $CO_2$. Some investigations have highlighted the $CO_2$ capture potential of AC[5]. Techniques used to modify and improve adsorbent materials like graphene may be used to improve AC as well[6]. In this work AC has been produced by pyrolizing wood dust obtained from the waste of furniture industry with KOH activation for $CO_2$ capture capabilities.

## MATERIALS AND METHODS

### Preparation of Amine-Functionalized AC

Wood dust was collected from the local carpentry shop and use as a precursor material for AC preparation. The wood dust was carbonized under nitrogen protection inside a pyrolizer at a heating rate of 10°C $min^{-1}$ to 400°C for about 2 hours. The carbonized samples were blended with one molar KOH solution and activated by pyrolysis at 600°C with nitrogen gas protection. After activation, the samples were washed several times with one molar HCL to remove inorganic salts and washed with distilled water to attain a neutral pH. The samples were then dried in a hot air oven at 80°C for 24 hours[7]. This sample was denoted as NFAC (Non-functionalized activated carbon). 1g of the same sample was taken and mixed with 10 mL of water, to which 2.5 mL of glutaraldehyde and one gram of (3-Aminopropyl) triethoxysilane (APTES) was added and the preparation was freeze-dried for 24 hours[8], this was named as SET A. Similarly SET B was prepared by adding 1g of L-ascorbic acid to SET A to reduce the oxygen

functionalities before freeze-drying and it was named as SET B. In another set tetraethylenepentamine (TEPA) was used in place of APTES in SET A and SET B, to obtain SET C and SET D.

## CHARACTERIZATION OF MATERIALS

The distribution of surface functional groups was analyzed using conductometric titration making use of conductometric electrode Hanna instruments. FTIR spectroscopy (JASCO 4700LE) was used to identify functional groups on the functionalized AC in the range of 4000 to 400 $cm^{-1}$ and a resolution of 4 $cm^{-1}$.

## $CO_2$ ADSORPTION EXPERIMENTS

Direct Air Capture (DAC) adsorption/desorption experiments were performed using an in-house setup. Approximately 0.2-1 g of sorbent was placed in the adsorption chamber. $CO_2$ concentration at the reactor inlet and outlet was analyzed using an IR-based sensor, Thermoscientific 410i $CO_2$ analyzer. Each DAC sorption cycle consisted of an isothermal adsorption step at 30°C, followed by a desorption step in which temperature was raised up to 50°C at 2°C.$min^{-1}$. During the adsorption step, zero air was flown at 0.5 L.$min^{-1}$ with relative humidity fixed at 0%. The $CO_2$ concentration in the air flowing out of the sample was analyzed by the $CO_2$ analyzer. The amount of $CO_2$ adsorbed [mmol$CO_2$/g] is then calculated in the following way:

$$\Delta q^{ads} = \int_0^{t_{ads}} \frac{\dot{n}_{air}\left(c^{in}_{CO_2} - c^{out}_{CO_2}\right)}{m_s} dt \qquad (1)$$

Where $c^{out}_{CO_2}$ is the concentration of the $CO_2$ in the outlet air, $c^{in}_{CO_2}$ is the concentration of the $CO_2$ in the inlet air, with a mass flow rate $\dot{n}_{air}$, $m_s$ is the mass of the sample [9]. Which has been modified to

$$\Delta q^{ads} = \dot{n}_{air} \times \frac{\left(c^{out}_{CO_2(t_{ini})} - c^{out}_{CO_2(t_{ads})}\right)}{m_s} \times t_{ads} \qquad (2)$$

Where $c^{out}_{CO_2(t_{ads})}$ is the concentration of the $CO_2$ in the outlet air after adsorption time $t_{ads}$, and $c^{out}_{CO_2(t_{ini})}$ is the concentration of the $CO_2$ in the outlet air initially.

## RESULT AND DISCUSSION

### Conductometric Titration

Acid-base titration was employed to study grafting of amine groups to AC by conductometric titration for NFAC and functionalized derivatives SET A to D. 0.035 g of each prepared sample were suspended in 65 mL distilled water and 0.2 ml of 0.1M HCl solution was added in that suspension. The mixture was titrated against 0.01 M NaOH until a level of pH was reached. The degree of oxidation of each sample was calculated from the modified version of the formula written below[10]

$$DO = \frac{162 \times C \times (V_2 - V_1)}{m - 36 \times C \times (V_2 - V_1)} \times 100 \qquad (3)$$

Modified to

$$DO = \frac{12 \times C \times (V_2 - V_1)}{m - 36 \times C \times (V_2 - V_1)} \times 100 \qquad (4)$$

Here C is the NaOH concentration, V1 and V2 are the volume of NaOH and m is the weight of the dried sample. The percentage of surface functional groups have been evaluated from the titration curves, which are provided in **Table 1**.

**Table 1** Percentage of surface functional groups

| SET | DO (%) | Amount of –NH groups (%) | Amount of $–NH_2$ groups (%) |
|---|---|---|---|
| SET A | 0.31 | 0.84 | 5.70 |
| SET B | 0.27 | 1.80 | 2.94 |
| SET C | 0.17 | 1.31 | 0.91 |
| SET D | 0.29 | 1.39 | 1.88 |

Functionalized samples SET A and SET B show an increased DO as compared to NFAC, which may be due to reintroduction of oxygen functionalities during functionalization by APTES which has oxygen present in itself. However, the increased DO values observed for derivatives functionalized by TEPA which is without oxygen may be due to atmospheric oxygen bonding during functionalization. Comparing SET A and SET B indicates the introduction of L-ascorbic acid reduces the amount of $-NH_2$ groups and increases the amount of -NH groups in the presence of the APTES. Both $-NH_2$ and -NH group percentage is reduced upon introducing L-ascorbic acid during the functionalization of NFAC by TEPA. SET A has a greater percentage of $-NH_2$ groups than SET C, while a lesser percentage of -NH group on the surface.

**FTIR Analysis**

FTIR spectral characterization was carried out in the region of 450–4000 $cm^{-1}$ to understand and differentiate the molecular structure functionalized NFAC[11]. In **Figure 1**, the peak at 1402 $cm^{-1}$ due to the bending of the O-H bond in alcohol and carboxylic acid is retained after carbonization, indicating incomplete removal. Comparing the FTIR data of SET A, and B, in **Figure 1**, a broad peak is observed for SET A at 3455 $cm^{-1}$ indicating the reintroduction of oxygen functionalities during functionalization by APTES, and this peak subsequently deconvolutes to two smaller peaks in SET B, observed at 3455 $cm^{-1}$ and 3298 $cm^{-1}$, the latter is due to NH stretching of aliphatic primary amine and points towards a successful functionalization by APTES and reduction due to addition of L-ascorbic acid. A more pronounced peak is observed for SET B at 1597 $cm^{-1}$ due to N-H bending of amine groups, which may be indicative of better amine functionalization due to the presence of a reducing agent. Comparing SET C, and D, the broad peak observed at 3455 $cm^{-1}$ increases for SET D which may be indicative of ineffective removal of oxygen by L-ascorbic acid in the presence of TEPA yet the peak at 1597 $cm^{-1}$ is more refined and hence L-ascorbic acid is successful in facilitating greater functionalization by TEPA leading to increase in amine functionalities.

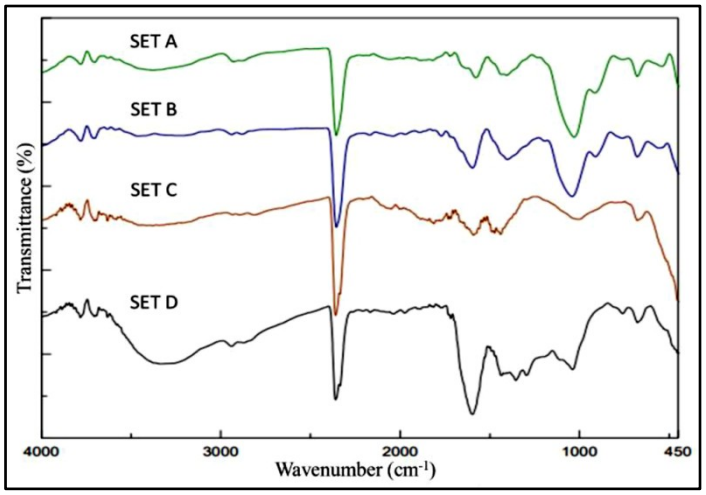


**Figure 1** FTIR analysis and comparison of SET A, SET B, SET C and SET D

The peak around 2881$cm^{-1}$ attributed to CH stretching of $–CH_2$ group is present in all the samples. There is $CH_2$ deformation at 1441 $cm^{-1}$, and $CH_3$ deformation at 1315 $cm^{-1}$, due to heat treatment causing rupture in carbon structure during liberation of oxygen groups. Many peaks were also observed for the functionalized samples in the

1500 $cm^{-1}$ region and beyond characteristic to –C-O stretching between 1200 $cm^{-1}$ and 1000 $cm^{-1}$ which is indicative of reintroduction of oxygen functionalities during amine grafting.

**$CO_2$ Adsorption Capacity**

From **Figure 2**, SET B has the highest DAC $CO_2$ adsorption as compared to NFAC and all other functionalized substrates. Comparing the adsorption capacity for NFAC with that of SET A the reduction in the functionalized derivative may be attributed to stearic hindrance introduced by APTES reducing uptake of $CO_2$. This inference is observed from **Table 1**, which shows a remarked increase in DO surface groups indicating stearic hindrance being the reason for reduced adsorption of $CO_2$ for SET A as compared to NFAC. It may be also noted from **Table 1**, that there is an increase in the percentage of surface -$NH_2$ groups and a decrease in surface -NH groups in SET A. Comparing NFAC with the highest performing $CO_2$ adsorbent SET B based on surface functional groups show an increase in oxygen-based surface functionality and -NH, and -$NH_2$ based surface functionality for SET B, which indicates that irrespective of stearic hindrance, surface -NH groups are likely the key factor in deciding the $CO_2$ adsorption capacity of prepared samples especially due to functionalization by APTES. This increase in -NH surface functional groups may also be interpreted from **Figure 1**, where the FTIR curve for SET B has a sharp peak at 1597 $cm^{-1}$ which is a result of N-H bending of the same -NH surface functionalities. This dependence on surface -NH group is reaffirmed upon comparing the surface functionalities of SET A and SET B from **Table 1**. This increase in surface -NH may be due to the presence of the reducing agent L-ascorbic acid. Such an effect is not observed when comparing TEPA functionalized derivates, where the presence of a reducing agent greatly reduces $CO_2$ adsorption capacity. The FTIR comparison indicates greater functionalization by amine for SET D, with more pronounced peaks at both 1597 $cm^{-1}$ and 3298 $cm^{-1}$.

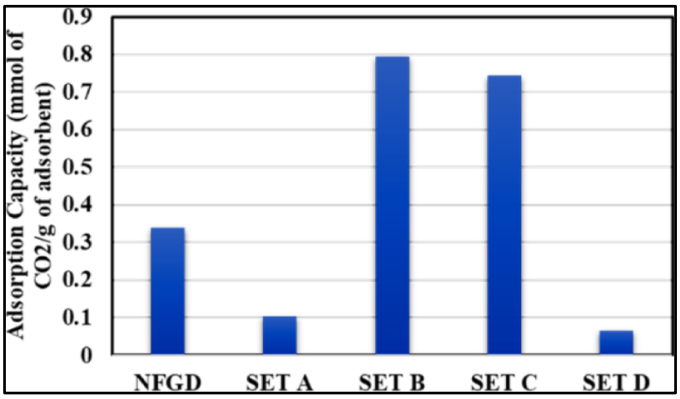


**Figure 2** Comparison of adsorption capacity for NFAC, SET A, SET B, SET C and SET D

However, these changes are mostly restricted inside the structure of the molecule and not at the surface observed from **Table 2** indicating a notable decrease in surface functionalities responsible for improving $CO_2$ capture capacity. Comparing SET A and SET C, APTES functionalized and TEPA functionalized AC without the reducing agent from data in **Table 1** establishes -NH surface functionality as a primary facilitator for $CO_2$ capture capability, also reduced oxygen functionality indicates to oxygen functionalities acting as an inhibitor towards $CO_2$ adsorption via stearic hindrance. This is evident from the general structure of APTES which consists of oxygen as compared to the absence of oxygen in TEPA. This oxygen-based hindrance is removed upon treatment by a reducing agent greatly improving $CO_2$ adsorption. So, two primary factors that decide the $CO_2$ uptake capacity of amine-functionalized activated carbon are the surface-NH functionality, which improves the $CO_2$ adsorption capacity the presence of reducing agents; and surface oxygen functionalities which hinder the $CO_2$ uptake via steric hindrance.

**CONCLUSION**

Amine functionalized AC have been prepared from wood dust precursor by using a mild carbonization technique providing an effective route to synthesize $CO_2$ capture devices. APTES functionalized AC with a reducing agent, L-ascorbic acid yields an adsorbent with a $CO_2$ capture capacity of 0.79 mmol/g at 32°C at 1 atm. Isotherms obtained

from BET study indicate, adsorption on a mesoporous solid, followed by capillary condensation. This work also sheds light on surface-based -NH functional groups and oxygen functionalities playing a major role in determining the $CO_2$ adsorption capacity and the influence of reducing agent, namely L-ascorbic acid during the functionalization process.

**FUNDING AGENCY**

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# Chemicals & Hydrocarbons

## Polymer and Nano Materials

333_IEC54788

# Integration of Advanced Multi-material Fibres in Electronic and Smart Textiles

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***Abstract**: The textile industry is in a new era where it has gradually evolved beyond conventional applications to integrating fibres composed of multi-materials to create newer functional and smart fabrics. These fibres may comprise various materials like metals, ceramics and various polymers. The combination of different materials enables a multitude of advanced applications like energy storage, health monitoring or wearable textiles. Fibres with core-sheath configuration are regarded as a notable development, offering multi-functionality that arises from incorporating different materials. With continued research in this direction, despite encountering problems in scalability, recent developments in fabrication methods have been shown to produce fibres with improved flexibility, durability, and conductivity. These developments make the fibres suitable for advanced operations.*

***Keywords**: Energy storage devices; Functional; Multi-material fibre; Smart textiles*

## INTRODUCTION

Traditionally known for producing garments, home furnishings, and industrial fabrics, the textile industry has undergone a paradigm shift by introducing advanced materials and technologies. As the world approaches sustainable energy solutions, there is increasing demand for flexible, wearable, and lightweight energy storage devices that seamlessly integrate with everyday objects. One emerging field is textile-based energy storage applications, where fibres with enhanced functionalities are incorporated into textiles to store and manage energy. Among the most exciting developments is the creation and application of multi-material fibres [1]. These fibres are composed of two or more materials engineered to exhibit enhanced or novel properties. By integrating multiple materials into a single fibre structure, researchers are opening up possibilities for textiles beyond basic functionality, paving the way for intelligent, interactive, and multifunctional fabrics.

Multi-material fibres can incorporate different polymers, metals, ceramics, and even biological materials, allowing for a wide range of physical, chemical, and mechanical properties. This versatility makes them suitable for various applications in sectors such as healthcare, energy storage, environmental monitoring, and wearable electronics. Integrating such fibres into textiles holds the potential to redefine what fabrics can do, extending their use beyond conventional applications and into the realm of intelligent textiles.

Traditionally, the textile industry relied on single-material fibres like cotton, wool, synthetic polymers such as polyester and nylon, or their blends. While these materials have served well in various applications, they offer limited scope for achieving advanced functionalities. The advent of multi-material fibres addresses these limitations by combining materials with complementary properties. For instance, a fibre might be composed of a conductive polymer for electrical conductivity, a thermoplastic material for flexibility, and a ceramic component for thermal resistance. This opens up new possibilities for creating textiles that can conduct electricity, regulate temperature, or even respond to external stimuli such as light, temperature, or pressure.

One key development in this area is the fabrication of core-sheath fibres, where one material forms the core and the other forms the outer layer [2]. These fibres allow for functional separation within a single fibre structure, such as a core made of a conductive material for electrical functionality, surrounded by a protective polymer sheath for mechanical durability and wear resistance. Coaxial extrusion, electrospinning, and thermal drawing techniques have been particularly useful in producing these multi-material fibres.

One of the primary advantages of multi-material fibres is their ability to offer multi-functionality in a compact and efficient form. Instead of using separate components to achieve different functions, such as sensors or energy storage

devices sewn onto fabrics, multi-material fibres allow these functions to be integrated directly into the fabric's structure. This leads to a more seamless and durable solution, making the final textile more comfortable, lightweight, and adaptable. For instance, multi-material fibres can incorporate sensing and energy harvesting capabilities, making them ideal for wearable technology. Fibres embedded with conductive materials and piezoelectric elements can harvest energy from movement or environmental stimuli.

In contrast, fibres containing sensors can monitor physiological parameters like heart rate, temperature, and blood pressure. This opens up a wide range of applications in medical textiles, where fabrics not only cover the body but also monitor health in real-time. Another advantage is the customisability of multi-material fibres. By carefully selecting the materials and their arrangement within the fibre, specific properties such as strength, flexibility, conductivity, and thermal resistance can be precisely tailored to meet the requirements of different applications. This makes multi-material fibres particularly attractive for industries like aerospace, where high-performance textiles are required to withstand extreme environments.

Energy storage is another field where multi-material fibres are making significant strides. By incorporating electrodes, electrolytes, and current collectors into the fibre structure, textiles can serve as flexible, lightweight energy storage devices. Such textiles could be used in portable electronics, allowing users to charge their devices on the go simply by wearing their clothes. In the future, smart textiles could harvest and store energy from the environment, making them ideal for applications in remote areas or during outdoor activities.

Energy storage is a key challenge in developing portable and wearable electronics, particularly in applications requiring flexibility and conformability such as smart textiles. Conventional batteries, though effective in terms of capacity and output, suffer from inherent limitations when integrated into textiles, such as weight, rigidity, and limited flexibility. Additionally, wearable devices often demand multifunctionality, such as the ability to stretch, bend, and flex without compromising energy storage capabilities. This is where multi-material fibres come into play. Their ability to integrate diverse functionalities in a single fibre structure makes them ideal candidates for the development of flexible, textile-based energy storage devices.

**RECENT DEVELOPMENT ON MULTI-MATERIAL FIBRES**

The development of multi-material fibres offers innovative solutions for next-generation flexible energy storage devices (FESDs) along with several advances in medical and smart textiles. By combining diverse materials at the fibre level, these structures enhance mechanical flexibility, conductivity, and energy efficiency, opening new avenues for wearable and portable energy systems. A great deal of research is currently being undertaken and some instances are mentioned below.

Dong's (2021) research focuses on the advancements and challenges in the field of electronic fibres, particularly thermally drawn multi-material fibres [3]. It discusses the various materials, processes, and functionalities that can be integrated into these fibres, highlighting their potential applications in electronics and textiles. The literature identifies two significant areas where the potential of electronic thermally drawn fibres has not been fully utilized:Capacitive-based microfluidic sensing; Triboelectric energy generation and self-powered monitoring. The paper discusses the promising application of capacitance in microfluidic sensing and extends this to energy harvesting through triboelectric effects. It notes that while fibres capable of harvesting mechanical energy are excellent for wearable electronics, their fabrication is complex, and their performance has not yet matched that of 2D planar configurations. The paper emphasizes the superior mechanical properties of the developed fibres, such as high stretchability (up to 560% fracture strain) and robustness, which are crucial for their integration into functional textiles that can withstand machine washing and long-term use. A deeper understanding of the rheological dynamics that govern the viscosities of materials used in fibre processing is also discussed. The literature also covers the integration of soft and stretchable materials into multi-material fibres, detailing both post-thermal drawing fabrication and direct multi-material drawing techniques. This integration is essential for developing advanced fibre electronic devices.

Yan et al.,(2019) particularly focused their research on their electronic and optoelectronic functionalities [4]. They emphasize the importance of combining different materials with varying electronic properties to create fibres that can

perform electronic and optoelectronic functions. This integration must occur at the sub-micrometre scale and within specific architectures to achieve desired functionalities. A significant challenge highlighted is the functionalization of fibres, which have unique geometries and aspect ratios compared to traditional planar substrates. The techniques developed for rigid substrates do not easily translate to long, thin, and curved fibre substrates, making this an area of active research. The authors also discuss recent scientific and technological breakthroughs that have enabled the development of fibre-integrated devices with complexities comparable to conventional 2D processing techniques. This includes advancements in materials science, fluid dynamics, and rheology that allow for better control over fibre architectures and functionalities. The study also mentions the rising industrial interest and funding in the field, exemplified by initiatives like the Advanced Functional Fabrics of America (AFFOA), which aims to develop the next generation of advanced fibres and textiles.

Tao & Abouraddy's(2012) paper also provides a comprehensive overview of the emerging field of multi-material fibres. Itbegins by acknowledging the transformative impact of optical fibres on telecommunications and various applications, including medical surgery and structural monitoring [5]. It sheds light on most optical fibres that are traditionally made from silica glass, which remains the dominant material despite the development of other materials. They also discuss the fabrication of multi-material fibres, which typically starts with a macroscopic preform. This method allows for complex cross-sections and the incorporation of various materials. The scalability of thermal fibre drawing enables the production of long fibres with consistent properties. Multi-material fibres have been developed with unique functionalities, such as fibres that can detect light, heat, or sound, and those that can produce electrical signals. These advancements suggest a shift towards integrating electronic and optoelectronic capabilities into fibre devices.

## CONCLUSION

The advent of multi-material fibres signifies a substantial progression within the textile sector, presenting a plethora of opportunities for the fabrication of intelligent, interactive, and multifunctional fabrics. Through the integration of heterogeneous materials into a singular fibre composition, researchers are capable of designing textiles with augmented characteristics such as electrical conductivity, thermal resistance, and sensing functionalities. Prominent applications of multi-material fibres encompass:

**Energy storage**: Textile-based energy storage devices can provide flexible, lightweight, and conformable power solutions for wearable electronics and other applications.

**Smart textiles**: Multi-material fibres may be incorporated into textiles to fabricate wearable sensors, actuators, and communication devices, thereby facilitating real-time surveillance of health indicators, environmental conditions, and additional data.

**Medical textiles**: Fabrics that incorporate multi-material fibres can provide sophisticated functionalities including wound healing, drug delivery, and patient monitoring.

**Environmental monitoring**: Textiles that are outfitted with multi-material fibres can be employed to assess air quality, water contamination, and other ecological parameters.

Recent research has demonstrated the potential of multi-material fibres in various applications, including electronic textiles, optoelectronic devices, and energy storage systems. While challenges remain in terms of scalability, cost, and performance, continued advancements in materials science, manufacturing techniques, and integration methods are expected to drive the adoption of multi-material fibres in a wide range of industries. Multi-material fibres offer a promising avenue for creating innovative and functional textiles that can address the growing demand for sustainable, intelligent, and wearable technologies. As research and development in this field continue to progress, we can expect to see even more exciting and innovative applications of multi-material fibres in the future.

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# Chemicals & Hydrocarbons

## Speciality Chemicals

94_IEC30297

# Turning Art into Design: Creating a Surface with a Discharging Effect

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***Abstract**: Discharge printing provides an additional surface embellishment by increasing the possibilities for artistic expression in textile substances. The discharging technique allows for the development of intricate patterns by eliminating ground colour from dark backgrounds. The study explores discharge printing on modal and crepe viscose fabrics to transform artistic concepts into functional designs and provide designers with a competitive edge. The study uses discharge chemicals like sodium hydrosulphite, stannous chloride, and sodium hypochlorite to obtain the desired effect. The findings explore the potentiality for reactive dyes to be used in innovative textile designs that are visually striking and commercially viable.*

***Keywords**: Art; Colourfastness; Design; Discharge; Textile*

## INTRODUCTION

Surface ornamentation on textiles has become essential to improve functional qualities and visual appeal. Manipulating texture is one of the most inventive ways to approach surface design. It helps designers play with the tactile and visual aspects of materials, adding dimension and depth that can turn an ordinary cloth into a unique piece of art. Discharge printing provides an additional adaptable technique for surface design in addition to texture; it allows for the development of complex patterns by eliminating colours from ground colour, particularly on dark backgrounds. This technique increases the possibilities for artistic expression in textiles.

In recent years, there has been a significant shift towards integrating more creative and unconventional printing techniques.

This study explores the use of innovative printing techniques that transform artistic concepts into functional designs by removing the dye from the ground colour, creating intricate patterns and unique effects. This technique pushes boundaries in fabric design, turning artistic visions into wearable art. The study assesses the impact of discharge printing on product versatility and marketability, providing designers with a competitive edge. Reactive dyes are widely used in the textile industry for several advantages, making them a preferred choice for dyeing cellulosic fibres like cotton, linen, and viscose. One of the primary reasons for their popularity is their ability to produce vibrant and diverse shades. It offers a broad colour palette, ranging from soft pastels to deep, intense hues, allowing designers to achieve precise colour matching and rich, eye-catching designs.

The effects of the colour discharge style of printing on cotton fabric using various sulphur, acid, natural, and pigment, focusing on reactive dyes as the ground colour have been reported in the literature [1] (Das et al., 2017). The controlled fading of soluble sulphur-dyed cotton fabric using oxidising agents has been reported in the literature [2] (Alam et al., 2018). A new eco-friendly reduction system has also been reported instead of the hazardous commercial chemicals used popularly in textiles [3] (Karthikeyan & Dhurai, 2011).

## TREND FORECAST 2024

An abstract print forecast for 2024 envisions a dynamic blend of organic forms, bold geometric patterns, and expressive textures that capture the spirit of creativity and innovation. Abstract prints will continue to dominate the fashion and interior design landscapes, showcasing fluidity, spontaneity, and a sense of freedom. This forecast reflects society's evolving focus on individual expression, sustainability, and the blending of the digital and physical worlds. Prints inspired by nature will take on a more abstract form, with flowing lines, gradients, and organic shapes mimicking water, clouds, and landscapes. Overall, abstract prints in 2024 will reflect a world in transition, blending organic and digital influences and offering limitless possibilities for personal expression.

## METHODOLOGY

In the present study, modal and crepe viscose fabrics procured from Burrabazar, Kolkata were used. Vinyl sulphone and triazinyl class of reactive dyes obtained from M/s Colourtex Industries Pvt. Ltd., Surat, Gujratwere used for painting purposes. Sodium alginate was used as a thickening agent to maintain the desired viscosity of the painting paste. Resist salt, sodium carbonate, and sodium bicarbonate were used in different proportions according to the colour composition. After painting, the fabrics were dried, followed by steaming at 102°C for 45 minutes to ensure proper fixation of the dye.

Different discharging agents like sodium hydrosulphite, stannous chloride, and Sodium hypochlorite (Rinala) were used to create different patterns on the fabric. Sodium hydrosulphite and stannous chloride were applied before the steaming process, whereas sodium hypochlorite was applied after steaming.

The fabric was treated with a cationic dye fixing agent (2 g/l) and acetic acid (5 g/l)at a pH of 4-5. The treatment was done at a temperature of 50°C for 20 minutes. After that the fabric was washed in cold water, followed by a hot wash using a soaping agent to eliminate any residual unfixed dye that could cause bleeding. Finally, the fabric was rinsed in warm water and dried in air. The final results are shown in **Figure 1**.

**Figure 1** Discharge effect on cellulosic fabric

## RESULTS AND DISCUSSIONS

Discharging with sodium hydrosulphite, stannous chloride, and sodium hypochlorite gave satisfactory results as they destroyed the dye chromophore and helped achieve the desired effect. The colourfastness to rubbing was evaluated and presented in **Table 1**. The results show that the colourfastness properties do not vary significantly when different discharging agents are used. Sodium hydrosulphite provides excellent rubbing fastness, rating 4-5 in dry and wet conditions. Stannous chloride and sodium hypochlorite (Rin ala) also show excellent rubbing fastness in dry conditions, with ratings of 4-5 and 4, respectively. However, their colourfastness to wet rubbing is slightly lower than their dry rubbing rating. This signifies proper washing and a mere deposition of unfixed dyes on the surface., with a rating of 4, which is half a grade lower than sodium hydrosulphite.

**Table 1** Colourfastness to rubbing

| Sl. No. | Discharging Agent | Colour fastness to rubbing (Dry) | Colour fastness to rubbing (Wet) |
|---|---|---|---|
| 1 | Sodium hydrosulphite | 4-5 | 4-5 |
| 2 | Stannous chloride | 4-5 | 3-4 |
| 3 | Sodium hypochlorite (*Rinala*) | 4 | 3-4 |

## CONCLUSION

This design project explored the artistic and technical possibilities of using reactive dyes in textile painting. Throughout the project, reactive dyes proved to be a versatile and effective medium for creating vibrant and durable designs on fabric. The project demonstrated the ability of reactive colour to produce a wide range of vivid colours with excellent rubbing fastness, which is one of the essential qualities for painted textiles. The process allowed for creative freedom, as reactive dyes bond chemically with the cellulose, enabling intricate patterns and designs with precision and clarity.

However, the project highlighted some challenges, such as the careful control required in the dyeing process to prevent unwanted colour bleeding and proper fixation and washing to ensure colour fastness. Overall, the project successfully demonstrated that reactive dyes are an excellent choice for textile painting, combining artistic expression with technical performance. The findings explore the potentiality for reactive dyes to be used in innovative textile designs that are visually striking and commercially viable.

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# Chemicals & Hydrocarbons

## Waste Management & Pollution Abatement

172_IEC77699

# Preparation of Activated Carbon-Alginate Beads for Adsorption of Methylene Blue

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***Abstract:*** *This study presents the development of activated carbon-embedded alginate beads for the efficient removal of Methylene blue (MB) dye from wastewater. The adsorbent was prepared by incorporating activated carbon into a sodium alginate matrix, followed by coating with calcium chloride. The effects of pH, adsorbent loading, and dye concentration on MB adsorption were investigated. The results demonstrated that the prepared beads exhibited optimal MB removal efficiency of ~66% at pH 4, an adsorbent loading of 1 g/L, and 100 ppm of dye concentration. The adsorption mechanism was influenced by the cationic nature of MB and the surface properties of the adsorbent. Overall, the developed activated carbon-embedded alginate beads offer a promising and sustainable solution for the treatment of dye-contaminated wastewater.*

***Keywords:*** *Activated Carbon; Alginate Beads; Dye Removal; Adsorption; Wastewater Treatment*

## INTRODUCTION

Freshwater scarcity is a rising issue that is a global concern at current times. Water bodies have been contaminated by a wide range of pollutants, including domestic waste, agricultural runoff, and industrial effluents, which have led to the degradation of aquatic habitats and the interruption of essential ecological processes[1]. Statistics show that in the last 20 years dye production has considerably reduced in USA and Europe whereas in Asian countries like China, South Korea, and India, production and consumption of dyes in various industrial sectors has constantly increased[2]. Synthetic dyes in effluents are particularly hard to remove because of their resistant nature and non-degradability[3]. Thus, the development of highly effective, commercially feasible, and ecologically friendly technology to handle the treatment of wastewater contaminated with dyes is imperative[1]. Methylene Blue (MB) is the most widely used dye in the textile and dyeing industry out of all the available dyes. It is poisonous to humans and can cause several illnesses, including vomiting, paralysis, and disorientation. Scientists are therefore drawn to developing novel methods that can effectively extract MB from polluted water[4]. Among various methods used in dye removal, adsorption is a widely known and widely used procedure. Using a highly adsorbent material like activated carbon for the removal of dye from wastewater has been explored in various studies before. In such a study nickel oxide nanoparticle and activated carbon composite was used inside alginate beads for catalytic reduction of Congo red dye. They observed 99.67% dye conversion at 80 ppm of dye concentration for catalyst dose 11 mg and NaBH4 concentration of 0.05 M[5]. Another similar study used activated carbon-alginate-polyaniline composite beads for the removal of Methylene blue dye. They observed 774.6 mg/g of adsorption capacity where the adsorption mechanism followed the Langmuir Model[1]. In one experiment novel adsorbent gel beads were synthesized by combining iron oxide, activated carbon, β-cyclodextrin, and sodium alginate. Their observed adsorption capacity was 5.882 mg/g from methyl violet and 2.283 mg/g for brilliant green[6]. Activated carbon-chitosan-alginate beads powder was used for absorbance of cationic dyes like Methylene blue and Methyl violet 2B in one such study. They observed a maximum adsorption capacity of 1.23 mmol/g for Methylene blue and 1.23 mmol/g for Methyl violet 2B[7]. 248.8 mg/g of maximum adsorption capacity was observed for Methyl red dye, where the hydrogel membrane used for adsorption had activated carbon and sodium dodecyl sulfate-modified montmorillonite clay embedded into sodium alginate[3].

In this study a novel iron-based carbon co-ordinate linker was used in preparation of the activated carbon, to interlink the carbon structure for enhanced adsorption properties. These activated carbon-embedded alginate beads were used to study the adsorption of Methylene blue dye in water.

## METHODOLOGY

**A) Beads Preparation:** To prepare activated carbon loaded alginate beads, at first sodium alginate and activated carbon (2:1) solution was prepared in 100 ml water. This solution was stirred for 30 minutes at 400 rpm. 10% calcium chloride solution was prepared and the sodium alginate-activated carbon solution was dropped in the calcium chloride solution from a height of 5 mm, one drop per second. The beads were kept in the solution overnight for hardening, washed thoroughly with distilled water after 24 hours, and stored at 4°C temperature. 500 ppm 1000 ml Methylene blue dye was prepared as a stock solution.

**B) pH Variation Study:** To study the effect of different pH of the dye solution on absorbance, a pH variation study was conducted. 100 ml of 50 ppm MB dye solution was prepared from the stock solution. Five different pH values 2,4,6,8 and 10 of 50 ppm MB dye solution were prepared using 0.1M HCl and 0.1M NaOH solution. Beads' loading was kept at 1g/l. The solutions were kept inside the incubator for 24 hours at 100 rpm and 25°C.

**C) Adsorbent Loading Variation Study:** To investigate the effect of different adsorbent loading on the absorbance of the dye, a loading variation study was carried out as well. Keeping the pH value with the highest absorbance rate from the pH variation study constant, adsorbent loading was varied as 0.25 g/l, 0.5 g/l, 1 g/l, and 2 g/l for 50 ppm MB dye solution. The solutions were kept incubated for 24 hours at 100 rpm and 25°C.

**D) Dye Concentration Variation Study:** Now that the optimum pH value and adsorbent loading for the highest absorbance rate were derived, keeping these values constant a concentration variation study was conducted to deduce the effect of different concentrations of MB dye solution on absorbance rate. From the stock solution of 500 ppm, different concentration solutions were prepared such as 50 ppm, 100 ppm, and 200 ppm. The solutions were kept under incubation at 100 rpm, 25°C temperature.

## RESULT

The adsorption of MB dye in the various studies was measured by UV-Vis at 665 nm wavelength.

**A) Effect of pH:** In the case of the pH variation study, the adsorption rate of MB against various pH is shown in **Figure 1**. It was noticed that from pH 6 to 10 through 8, the adsorption rate did not vary significantly. At slightly acidic pH 4, adsorption drastically increased at 66.22%, though at pH 2 it decreased once again. It can be derived that the adsorption works best in a slightly acidic environment. Methylene blue is a cationic dye in nature. From the observed results it can be said that in the acidic environment, cationic dye MB is not forming a stable suspension or not being well dispersed. Hence it is rather getting adsorbed inside the adsorbent and the tendency of desorption is low. The dye molecules are settling well inside the adsorbent rather than being part of an unstable environment outside. However, too acidic a solution is disrupting the whole adsorption mechanism altogether. Whereas in basic solution, the dye is stabilized which is affecting the adsorption process negatively and there is not much effect.

**B) Effect of Adsorbent Loading:** In the loading variation study, the pH of the dye solution was kept constant at 4, based on the results of the previously carried out pH test. The loading variation study result is shown in **Figure 2**. From the figure it can be clearly deduced that the adsorption percentage is quite high for 1g/l loading, compared to other adsorbent loading values. For 1g/l loading, the adsorption is at 66.22% which drastically decreased to 16.13% when the loading capacity was increased to 2 g/l. it can be said that higher loading of adsorbent was causing hindrance for a stable and increasing absorbance.

**C) Effect of Dye Concentrations:** The concentration variation study was carried out keeping pH 4 and loading 1 g/l constant, for dye concentrations 50 ppm, 100 ppm, and 200 ppm. The dye adsorption for 50 ppm solution was 38.3% and it was 44.29% for 100 ppm dye concentration. Following this trend, the adsorption should have increased to 200 ppm but from **Figure 3** it can be clearly deduced that the adsorption rate decreased to 41.55%. This decrease in adsorption percentage might be due to the increase in dye concentration where the presence of excessive dye molecules in the solution is affecting the adsorption mechanism and the percentage is decreasing.

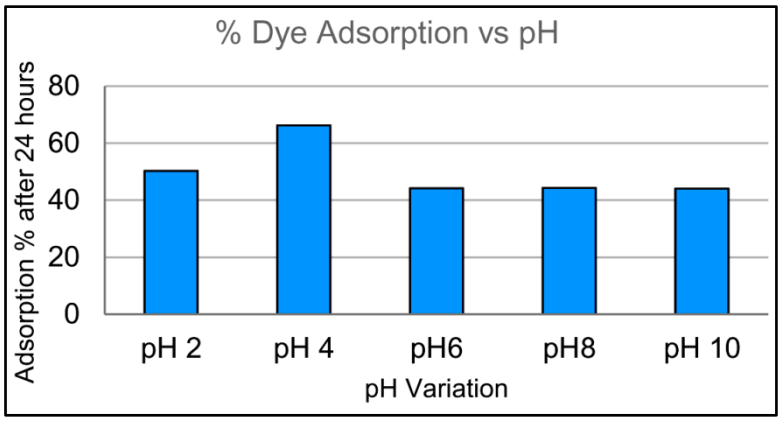


**Figure 1** Effect of pH on % dye adsorption after 24 hours

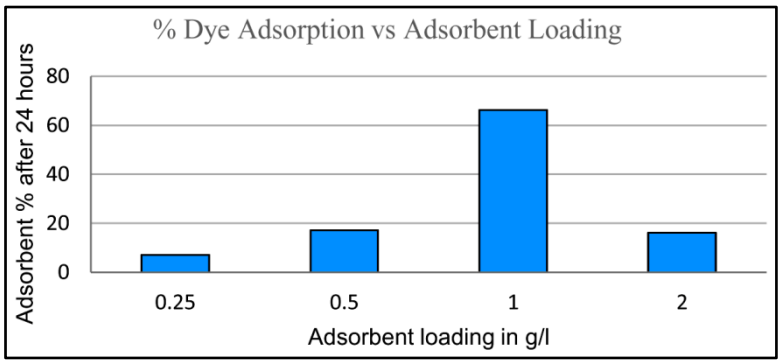


**Figure 2** Effect of adsorbent loading on % dye adsorption after 24 hours

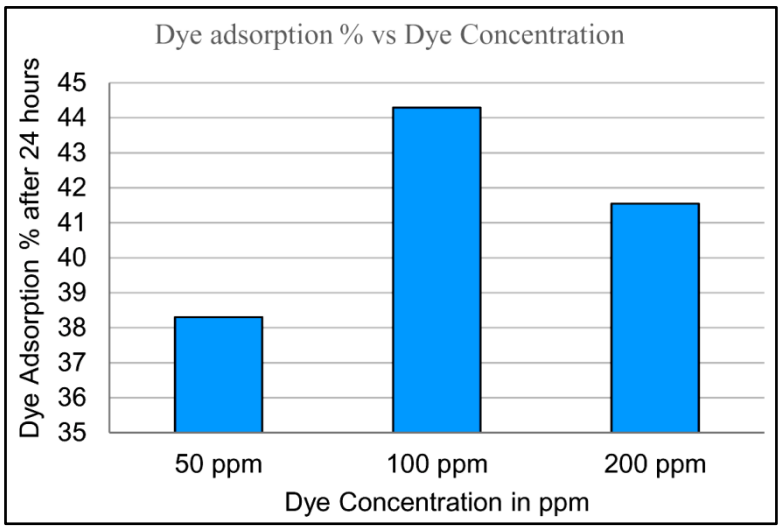


**Figure 3** Effect of dye concentration on % dye adsorption after 24 hours

## CONCLUSION

This study successfully developed and characterized activated carbon-embedded alginate beads for the removal of Methylene blue (MB) dye from wastewater. The results demonstrated that the prepared adsorbent exhibited effective adsorption capabilities under various conditions. The optimal pH for MB dye removal was found to be a slightly acidic pH of 4, indicating that the cationic nature of the dye and the acidic environment aided the adsorption. Additionally, an adsorbent loading of 1 g/L was determined to be most effective, ensuring efficient dye uptake of

~66%. The concentration variation study revealed that while increasing dye concentrations initially enhanced adsorption, further increases led to a decline in removal efficiency, likely due to saturation of the adsorption sites.

Overall, the findings of this research highlight the potential of activated carbon-embedded alginate beads as a promising adsorbent for the treatment of wastewater contaminated with Methylene blue dye. The developed material offers a sustainable and efficient solution for addressing the growing environmental concerns associated with water pollution. Future studies could explore the options to further optimize the adsorption performance of these beads as well as the application of these beads for the removal of other types of dyes and pollutants.

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192_IEC48857

# Effectiveness Study of Banana Peel Biochar (BPB) towards Adsorption of Fluoride Present in the Solution

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***Abstract:*** *Excessive Fluoride (> 1.5 mg/Lit) in drinking water is a smouldering problem worldwide. Fluorosis is a common health hazard caused by consuming fluoride contaminated water for long time. In india more than 20 states are effected by fluorosis pandemic. Weathering of rocks, geochemical reaction and waste effluents from industries are the main reason of ground water fluoride contamination. Different techniques like precipitation, ion exchange, electro coagulation, and adsorption have been successfully used to eliminate fluoride from water. In this work banana peel biochar (BPB) has been prepared for study the effectiveness of fluoride removal from solution. The BPB was characterized by using FESEM, FTIR and EDX. Point zero charge of the material was also examined. The effects of parameter were analysed for optimization. The experiment result shows that BPB has fluoride adsorption efficiency of 92 % in optimizing condition. In the batch study maximum fluoride adsorption was achieved at pH 4.0. This study shows that in room temperature at pH of 4, adsorbent dose of 2 gm/lit, contact time of 60 min and initial fluoride concentration of 10 mg/lit in the solution can be removed with efficiency of 92% by using BPB. The result shows good correlation with corresponding experimental data and well fitted with Langmuir isotherm. The results suggest that banana peel biochar (BPB) could be a commercial, eco-friendly adsorbent for removal of fluoride from aqueous solution.*

***Keywords:*** *Fluoride; Banana Peel; Adsorption; Batch Study; Optimization*

## INTRODUCTION

Due to rapid growth in urbanisation and population shortage of water and contamination of water are growing excessively. Presence of fluoride in ground water more than recommended value (> 1.5 mg/Lit) causes several health effects worldwide[1]. Major source of fluoride in human being is through drinking water and source of fluoride in ground water is formation of rock and industrial pollution [2]. Researcher has been developed various methods for fluoride adsorption such as ion exchange, electro coagulation and precipitation[3]. Literature shows various cost effective adsorbent and green materials for fluoride adsorption also. Among them fruits peel [4] are attracted concentration of researcher as it is easily available, biodegradable, economic and low cost. Using of BPB can enhance the waste management also.

## MATERIALS AND METHODS

All the chemicals used in this experiment are of analytical grade and Merck-Sigma Aldrich make. In laboratory the fluoride stock solution of 100 mg/lit was prepared by diluting 0.221 gm of sodium fluoride (NaF) in distilled water and dilute to 1 Liter in volumetric flask. For fluoride adsorption test sample were prepared by diluting the stock solution at different concentration of 2 mg/Lit, 5 mg/Lit, 10 mg/Lit, 15 mg/Lit and 20 mg/Lit. hydrochloric acid (HCL), sodium hydroxide (NaOH), ethanol, acetone and what-man filter paper (0.45 µm) were used for batch experiment. Adsorbent (BPB) were prepared from banana peel waste. Waste of Banana peel was collected from Jadavpur area fruit market. After collection the peel were washed by tap water several times followed by deionized water and cut into pieces. The pieces of banana peel then sun dried for 12 hrs followed by oven dried for 24 hrs in 60°C. After that using laboratory muffle furnace at 400°C for 1 hr banana peel biochar was prepared, grounded and store in air tight container. Characterization is done by FTIR spectroscopy (IR Prestige shimdzu), FESEM and EDX. The entire batch experiment was conducted varying the parameters as pH, initial fluoride concentration (mg/Lit), adsorbent (BPB) dose (gm/Lit), contact time (min) at room temperature. Batch experiments were carried out in a 250

ml conical flask containing fluoride solution (2.0–20.0 mg/Lit) with varying adsorbent (BPB) dose (0.5 gm/Lit – 5 gm/Lit). The pH of the respective solutions was maintained by using 0.1(N) HCl and 0.1(N) NaOH. The contact time was 15–60 min at room temperature. After adsorption, the residual fluoride concentration was calculated by the Hach Intellical ISEF121 combination fluoride ISE and the HQ40d portable multimeter. The percentage of fluoride adsorption was calculated by using the following equation as in (1).

Percentage Arsenic removal (%) = $(C_0 - C_i)/C_0 * 100$ (1)

where $C_0$ is initial fluoride concentration (mg/lit) in the solution, $C_i$ is the final fluoride concentration (mg/Lit).

The adsorption capacity (mg/g) of the experimental adsorbent was examined by using the following equation as in (2).

$q_e = (C_0 - C_e)V/m$ (2)

where $C_0$ is initial fluoride concentration (mg/lit) in the solution, $C_e$ is the equilibrium fluoride concentration (mg/Lit). V is the volume of the solution in liters, and m is the mass of the adsorbent used (gm).

**RESULTS AND DISCUSSION**

Structural study of the BPB has been done by FTIR, FESEM EDX and zero point charge. FESEM of BPB is state the surface morphology. Before and after fluoride adsorption by BPB has been shown in **Figure 1** which state that BPB has several micro pores structure and this is the area of fluoride loading during adsorption. This observation indicates that banana peel biochar has tremendous affinity towards fluoride adsorption.

EDX of banana peel biochar is shown in **Figure 2**. It shows that presence of nitrogen, magnesium, chlorine, iron, phosphorus, sodium and oxygen. Its energy peaks of EDX spectra before and after fluoride adsorption confirm the mechanism and clearly state that BPB can absorb fluoride in its surface area.

The FTIR spectra data confirms the presence of functional group in the surface the prepared banana peel biochar (BPB). Present adsorbent shows various sharp peaks such as 3900–3250 $cm^{-1}$ which indicate presence of OH stretching. Sharp peak around 1263 $cm^{-1}$, 1630 $cm^{-1}$ and 11100 $cm^{-1}$ confirmed presence of NH (amines) and C = O (carboxylic acid)[5]. After adsorption peak of OH slightly decrease which indicate fluoride adsorption on BPB surface.

Point zero charge $pH_{ZPC}$ of BPB was examined at 5.63 which indicates above this the surface of BPB is negatively charged and below this surface of BPB is positively charged [6]. This is the condition when the BPB surface can absorb negatively charged fluoride in the surface below the point zero charge[7].

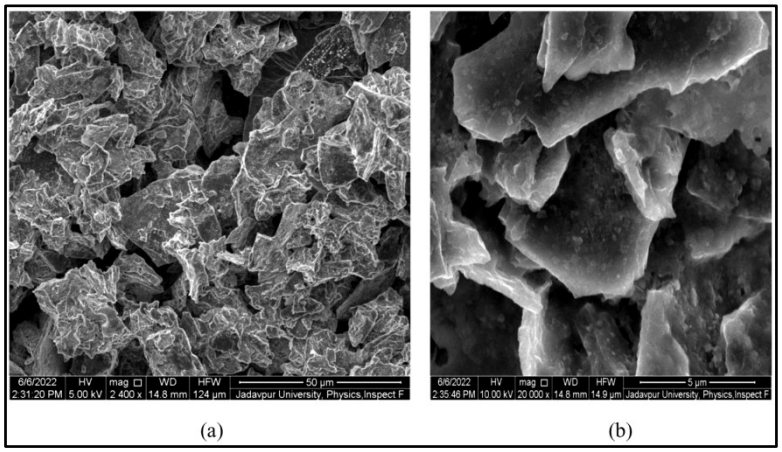


**Figure 1** FESEM of BPB (a) before adsorption of fluoride (b) after adsorption of fluoride

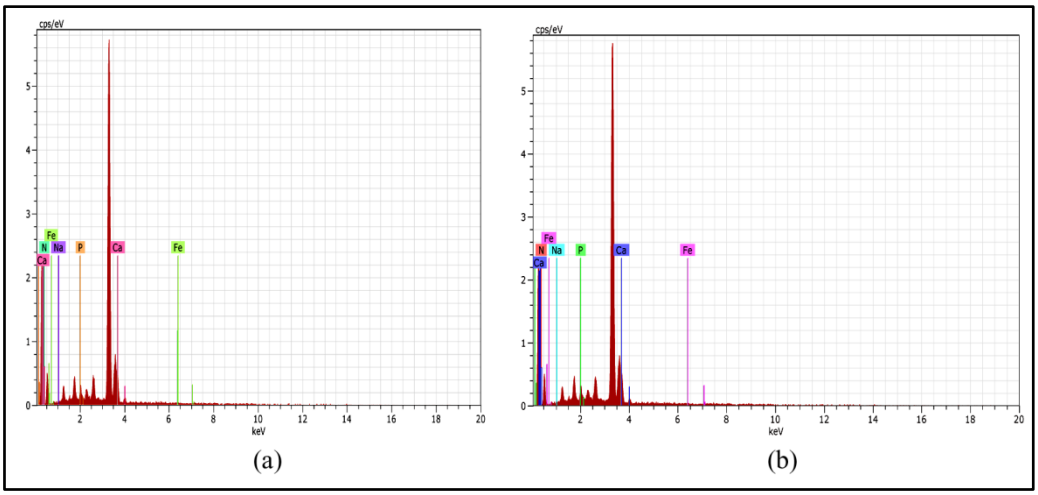


**Figure 2** EDX of BPB (a) before adsorption of fluoride (b) after adsorption of fluoride

The effects of parameter were analysed for optimization. The experiment result shows that BPB has fluoride adsorption efficiency of 92% in optimizing condition. In the batch study maximum fluoride adsorption was achieved at pH 4.0. This study shows that in room temperature at pH of 4, adsorbent dose of 2 gm/lit, contact time of 60 min and initial fluoride concentration of 10 mg/lit in the solution can be removed with efficiency of 92% by using BPB. The result shows good correlation with corresponding experimental data and well fitted with Langmuir isotherm.

## CONCLUSION

This study shows preparation of banana peel biochar in economic way with low cost and less time. Available adsorbent in market for fluoride adsorption is costly and other removal techniques are time consuming. Compare to other available adsorbent BPB shows more efficiency in fluoride adsorption from aqueous solution. The structural analysis represent that the material can be used in field application where fluoride concentration is higher. This experiment result state that room temperature at pH of 4, adsorbent dose of 2 gm/lit, contact time of 60 min and initial fluoride concentration of 10 mg/lit in the solution can be removed with efficiency of 92% by using BPB. Therefore use of banana peel biochar can be a cost effective adsorbent and may provide alternative solution to the available adsorbent.

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198_IEC9777

# A Critical Review on Biological Remediation of Per- and Polyfluoroalkyl Substances

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**Abstract:** Water pollution is a critical threat to the environment nowadays. Several pollutants are responsible for water pollution, out of which one emerging pollutant is per- and poly-fluoroalkyl substances (PFAS), a group of synthetic fluorinated organic compounds that have been used in the production of several consumer products like shampoo, nail polish, paints, nonstick cookware, etc. PFAS has been designated as an emerging pollutant of concern since 2000, with potential health risks such as cancer, liver damage, chronic kidney disorder, preeclampsia, etc. The Environmental Pollution Agency (EPA) has released multiple guidelines regarding the safe limit concentrations for PFAS. PFAS consists of a C-F bond, a stable covalent bond that is resistant to degradation, making PFAS persistent in the environment. Efficient methods for remediation are in high demand and this critical review highlights mitigation strategies for PFAS in detail, focusing on the advantages of bioremediation methods over conventional expensive, energy-intensive strategies like sonolysis, and independent and assisted photocatalysis. This review explores the alternative, sustainable, and feasible degradation strategies for PFAS, with an emphasis on bioremediation methods.

**Keywords:** Water Pollution; Per- And Polyfluoroalkyl Substances (PFAS); Forever Chemicals; Environmental Pollution Agency (EPA); Biological Remediation

## INTRODUCTION

Environmental pollution is the most critical issue faced by the planet today and has been increasing with each passing year, inflicting grave and irreparable damage. Currently, water pollution has become a severe global issue affecting all life forms. Multiple pollutants result in water contamination and among these, organic and inorganic pollutants are primarily significant due to their high toxicity, persistent nature, and difficult remediation strategies. One such emerging pollutant is per- and polyfluoroalkyl substances or PFAS, a group of synthetic fluorinated organic compounds, which have been used since the 1950s in several consumer products like shampoo, nail polish, fast food wrappers, paints, photographic films, etc. It has a unique property of oil, water, and fire resistance, and is used in Firefighting foams, raincoats, non-stick cookware, stain repellents, etc. Since the early 2000s, it has been designated as an emerging pollutant of concern leading to potential health risks such as cancer, liver damage, chronic kidney disorder, preeclampsia, immunity disorder, etc. In the same year, the Environmental Pollution Agency (EPA) released multiple guidelines regarding the safe limit concentrations for PFAS. USEPA has released new health advisory limits for most hazardous PFAS in drinking water which are stricter than the restrictions published in previous guidelines. Based on a 2007 survey by OECD under environment, health, and safety divisions,600 types of Per and Polyfluoro chemicals are present[1] and The Environmental Protection Agency[EPA] under the Safe Drinking Water Act in the year 2012 shortlisted the six most harmful PFAS which include perfluoroheptanoate (PFHpA), perfluorononanoate (PFNA), perfluorobutane sulfonate (PFBS), perfluorohexane sulfonate (PFHxS), Perfluorooctanoic acid(PFOA) and perfluorooctane sulfonic acid (PFOS)[2]. PFAS consist of C-F bonds, a stable covalent bond, and are very difficult to degrade, making PFAS a stubborn contaminant in the environment with the designated term ‘Forever chemicals’.

Efficient methods for remediation are in high demand, mitigation strategies include but are not restricted to sonolytic treatment, photocatalytic treatment, sonication-assisted photocatalytic treatment along with bioremediation methods. Conventional technologies have certain drawbacks, they are expensive, energy-intensive, require high temperatures and pressure, and sometimes indirectly harm the environment by releasing toxic by-products during the decomposition of the target pollutant.

**Table 1**

| Targeted PFAs | Bacterial Stain | Source | Preparation | Degrading Capacity | Treatment Time | Concentration | References |
|---|---|---|---|---|---|---|---|
| **BACTERIAL REMEDIATION** | | | | | | | |
| PFOA & PFOS | *Pseudomonas aeruginosa* & *Pseudomonas putida* | Purchased pure cultures | Initially inoculated on solid nutrient medium then single colony from each strain was transferred to liquid acetamide broth . | *P.aeruginosa* PFOA:27.9% PFOS:47.3%<br>*P. putida* PFOA:19% PFOS:46.9% | 96 h | 0.1mg/L | [9] |
| PFOA & PFOS | *Pseudomonas aeruginosa (PAO1), Pseudomonas aeruginosa (1688) & Burkholderia* FA1 | | The stains were grown on mineral salts medium (MSM) with PFOA and PFOS as the only source of carbon | PFOA:58% | 5 days | 10mg/L | [10] |
| PFOA | *Acidimicrobiaceae sp.* strain A6 | A6 enrichment culture, obtained from Feammox laboratory-scale continuous-flow membrane reactor | A6 cultures inoculated with PFOA in microbial electrolysis cells(MECs). | 77% | 18 days | 100mg/L | [11] |
| **MYCOREMEDIATION** | | | | | | | |
| PFOA | *Cunninghamella elegans DSM1908* | | The stain was initially streaked on Sabouraud dextrose agar plates and incubated for 4–5 days to grow the mycelia | 90% | 2 h of photocatalysis followed by 48 h of fungal incubation | 100mg/L | [12] |
| **ALGAL REMEDIATION** | | | | | | | |
| PFOA | *Microcystis aeruginosa* | *M.aeruginosa* Was provided by Freshwater Algae Culture Collection | *M.aeruginosa* Was cultured in BG-11 medium | 15.9%, 16.9%, 27.5%, & 25.8% | 2 days | 1mg/L, 10mg/L2 5mg/L,& 50mg/L | [13] |
| **PHYTOREMEDIATION** | | | | | | | |
| PFOA & PFOS | *Eichhornia crassipes* & *Pistia stratiotes* | Both *P.stratiotes* & *E.crassipes* were taken from greenhouse stock | Both *P. stratiotes* and *E. crassipes* were grown in water sample containing PFOA and PFOS in three different concentrations. | *E.crassipes* PFOA:4.02%, 5.15%, & 4.85% PFOS:5.62%, 7.52%, & 7.41%<br>*P.stratiotes* PFOA:3.59%,2.00%,& 2.56% PFOS:3.16%, 2.99%, &%3.43% | 7 days | 0.5mg/L, 1mg/L, & 2mg/L | [14] |

## SAFE-LIMIT CONCENTRATION OF PFAS IN DRINKING WATER

The Environment Protection Agency (EPA) has recently issued an interim Drinking Water Health Advisory (HAs) in 2022 for perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), PFBS and Gen X chemicals[3], where the safe limits of PFOA and PFOS have been lowered further as compared to that in 2016's HA. According to EPA's new HA [4] the health advisory level for PFOA, PFOS, GenX chemical, and PFBS are 0.004 ppt, 0.02 ppt,10 ppt, and 2000 ppt respectively[5][6]. The U.S. Environmental Protection Agency published a prepublication copy of its final rule under the Safe Drinking Water Act (SDWA) on April 10, 2024. This rule creates a National Primary Drinking Water Regulation (NPDWR) for six different types of per- and polyfluoroalkyl substances (PFAS), including mixtures of certain PFAS, PFOA, PFOS, PFHxS, PFNA, HFPO-DA (also known as Gen X chemicals), and PFBS[7]. In its Final Rule, EPA introduced the Maximum Contaminant Level (MCL) for PFAS detected by recent technologies and has set the MCL for PFOA and PFOS as 4 ppt, and for PFHxS, PFNA and HFPO-DA at 10 ppt. A

Hazardous Index (HI) of 1 has also been established by the Final Rule for mixes containing two or more of PFHxS, PFNA, HFPO-DA, and PFBS[7][8].

## BIOLOGICAL REMEDIATION OF PFAS

PFAS may be described as the most ubiquitous contaminant for drinking water due to its high persistence in the environment, mobility in groundwater, and bio-accumulation in nature. The presence of highly stable C-F covalent bonds makes PFAS degradation really challenging. Degradative techniques have been utilized successfully for years to remediate various organic pollutants in water including PFAS. Hydrogen abstraction utilizing hydroxyl radicals, which are created by electrolysis, photolysis, and other processes, has traditionally been used to degrade organic contaminants. However, these conventional technologies are not very effective and have multiple cons such as being expensive, energy-intensive, requiring high temperature and pressure, and sometimes indirectly harming the environment by releasing toxic by-products during the decomposition of the target pollutant. Biological remediation procedures have garnered interest among the researchers due to its low cost, sustainability and feasibility for large-scale applications. Bioremediation involves the activity of microorganisms (including both bacterial stains and fungi), referred to as mycoremediation; by plants, in the case of phytoremediation and algae. In the case of phytoremediation to decompose hazardous and emerging persistent pollutants (including PFAS) there is release of by-products which are less harmful and environmentally benign. The breakdown of the C-F bond by bioremediation is done by the enzymes that are released from the microbes, plants or algae that remove the fluorine atoms directly from these compounds by oxidation across the C-F bond, or by adding electrons across the C-F bond (reduction), allowing other normal assimilation enzymes to breakdown the rest of the compound. There is no proper evidence for the total removal of fluorine by bioremediation, the defluorination of monofluorinated compounds by some bacteria have been reported previously [9]. Some previously studied papers on bioremediation of PFAS have been tabulated in **Table 1**.

## CONCLUSION

Per- and polyfluoroalkyl substances or PFAS are a group of synthetic organic compounds or xenobiotic fluorinated compounds that have been considered as emerging pollutants of concern since the early 2000s. These complex chemical compounds are majorly comprised of the carbon-fluorine bonds, C-F, which are considered as the strongest covalent bonds in nature and is very hard to break environmentally. Indicating the persistent nature of PFAS due to this tendency, this compound is also termed as “forever chemicals”. PFAS are widely utilized in several consumer products, which basically act as direct precursors for PFAS such as nail polish, shampoo, food packages, photographic films, aqueous film-forming foams, etc. Human exposure mainly occurs through contaminated water, air, food, and utilization of products that contain PFAS, leading to potential health risks such as cancer, liver damage, chronic kidney disorder, preeclampsia, immune disorder, etc. Recent studies have demonstrated that PFAS have interspecies variation intoxication. The USEPA have lowered the maximum acceptable limits of PFAS as compared to the older guidelines. Multiple experimental works have been carried out for the mitigation of PFAS such as photocatalysis, sonolysis, laser irradiation, chemical oxidation, and bioremediation. However, the utilization of the advanced oxidation processes for PFAS degradation have highlighted some serious issues, and for that, scientists have been developing new innovative approaches for bioremediation of almost all emerging hazardous environmental pollutants achieving positive results in the initial phase. Though bioremediation offers a permanent solution for the degradation of pollutants both from soil and water there are some limitations, including, a time-consuming process, high dependency on environmental conditions, and limited applicability in areas with high levels of toxicity. Effective results, require proper monitoring, to prevent partial degradation. However, further research is required for the optimization of mitigation strategies and to assess their long-term effectiveness, sustainability, and feasibility for large-scale applications.

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204_IEC72985

# Facile Low Temperature Fabrication of B-$TiO_2$ using Sol-gel Method

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***Abstract:*** *Wastewater contamination, particularly by synthetic dyes, poses significant environmental and health risks. Traditional remediation methods are often ineffective for these non-biodegradable pollutants. Photocatalysis has emerged as a sustainable approach to degrade such pollutants, with titanium dioxide ($TiO_2$) being a preferred photocatalyst due to its stability and non-toxicity. However, $TiO_2$'s wide band gap restricts its photocatalytic activity to UV light. This study explores defect engineering of $TiO_2$, including the synthesis of b-$TiO_2$. We synthesized $TiO_2$ via a low-temperature route using $NaBH_4$ and polyethylene glycol (PEG) 4000 to promote oxygen vacancy formation and improve charge carrier separation.*

***Keywords:*** *Black Titania; Titanium Dioxide; Doping; Wastewater Treatment; Organic Dyes; Band Gap Reduction*

## INTRODUCTION

The contamination of water bodies by industrial wastewater, particularly synthetic dyes, has become a significant environmental concern. Industries such as textiles, paper, and plastics discharge large quantities of toxic organic dyes, which are resistant to biodegradation and conventional treatment methods. These pollutants not only affect aquatic ecosystems but also pose severe risks to human health due to their potential carcinogenic and mutagenic properties [1-3]. Photocatalysis has emerged as an efficient and green technology for the degradation of such pollutants. Among the various photocatalysts, titanium dioxide ($TiO_2$) has gained attention due to its chemical stability, non-toxic nature, and low cost [4-7]. However, $TiO_2$ exhibits a wide band gap of 3.2 eV, restricting its photocatalytic activity to the UV region, which constitutes only a small fraction of the solar spectrum. Furthermore, the rapid recombination of photogenerated electron-hole pairs in $TiO_2$ limits its overall photocatalytic efficiency [8-10]. To overcome these limitations, various strategies, including doping with metals or non-metals and defect engineering, have been explored. Defects can reduce the band gap of $TiO_2$, enabling its activation under visible light and enhancing charge separation [11-12]. In this study, we focus on synthesizing b-$TiO_2$ (black $TiO_2$) through a low-temperature process using $NaBH_4$ and polyethylene glycol (PEG) 4000.

## METHODOLOGY

### Synthesis of B-$TiO_2$

Black titanium dioxide (b-$TiO_2$) was synthesized using titanium butoxide [$Ti(OBu)_4$] as the precursor. Three distinct synthesis routes were employed to prepare different samples, designated as S-1, S-2, and S-3 (**Figure 1**).

Sample S-1: Titanium butoxide was dissolved in an aqueous solution containing $NaBH_4$, which served as a reducing agent. $NaBH_4$ facilitated the formation of oxygen vacancies and defects in the $TiO_2$ structure, improving its photocatalytic performance.

Sample S-2: Titanium butoxide was mixed with polyethylene glycol (PEG) 4000 in an aqueous solution and stirred for 24 hours at room temperature. PEG 4000 acted as a surfactant, aiding in uniform particle formation and reducing agglomeration.

Sample S-3: Similar to S-2, PEG 4000 was added to the titanium butoxide solution, but the mixture was sonicated for 3 hours (with 15-minute breaks every 30 minutes). Sonication helped in breaking down large particles and improving homogeneity. All samples were dried at 363 K for 24 hours and subsequently calcined at 523K for 2 hours in a preheated furnace to remove organic residues and promote crystallization.

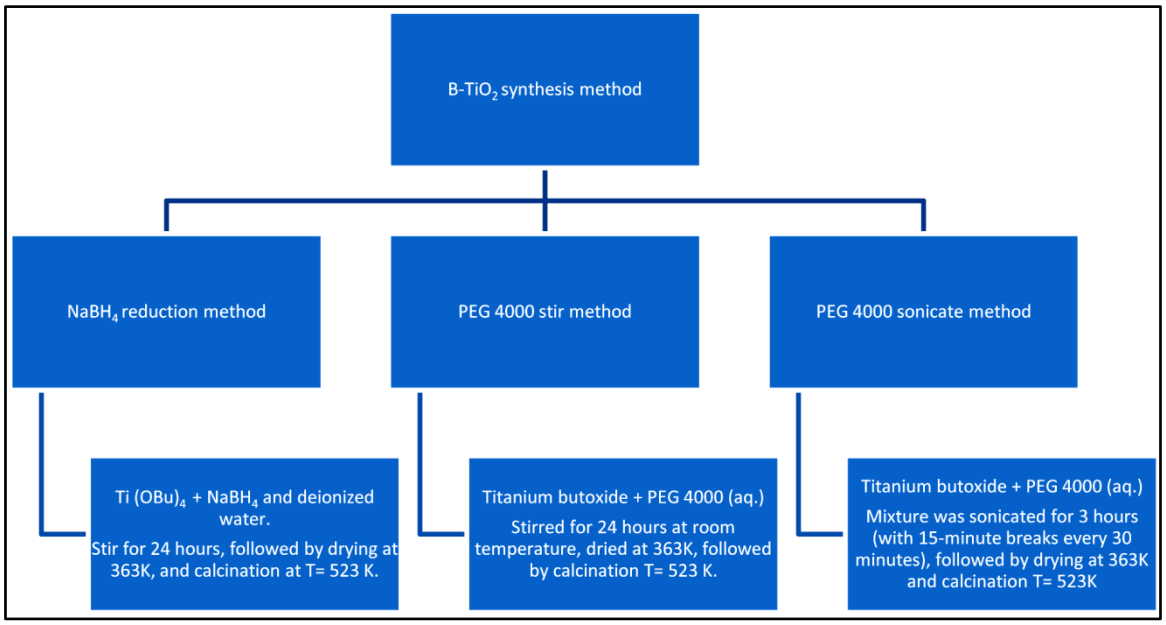


**Figure 1** Methods adopted for synthesis of B-$TiO_2$

**Characterization of Samples**

The synthesized photocatalysts were characterized using several techniques to assess their structural, morphological, and optical properties: X-ray Diffraction (XRD): XRD was performed to identify the crystalline phases of the synthesized $TiO_2$ and to confirm the presence of defects or dopants. Transmission Electron Microscopy (TEM): TEM provided high-resolution images to evaluate the particle size and atomic-level defects in the $TiO_2$ structure. UV-Vis Diffuse Reflectance Spectroscopy (UV-Vis DRS): UV-Vis DRS was used to investigate the optical properties of the samples, particularly focusing on band gap reduction due to the introduction of defects.

## RESULTS AND DISCUSSION

**Structural and Morphological Analysis**

X-ray Diffraction (XRD) analysis confirmed the formation of anatase $TiO_2$ as the predominant crystalline phase in all synthesized samples (S-1, S-2, and S-3). The XRD peaks corresponding to anatase were slightly broadened, indicating the presence of defects, which disrupt the crystalline order. These defects, particularly oxygen vacancies, are critical for enhancing photocatalytic activity. TEM images revealed that all samples exhibited relatively small particle sizes with a uniform dispersion of particles. Samples S-2 and S-3, synthesized with polyethylene glycol (PEG) 4000, demonstrated improved particle homogeneity and reduced agglomeration compared to sample S-1. The use of PEG and sonication in the synthesis of S-3 further reduced particle size and enhanced dispersion, which is beneficial for photocatalytic performance. UV-Vis Diffuse Reflectance Spectroscopy (DRS) measurements showed a significant redshift in the absorption edges of the doped $TiO_2$ samples compared to undoped $TiO_2$. This shift is attributed to the creation of mid-gap states due to oxygen vacancies and defects introduced during the synthesis process, effectively reducing the band gap of $TiO_2$. The reduced band gap facilitates visible light absorption, enhancing the photocatalytic activity of the samples under UV irradiation.

## CONCLUSION

In this study, b-$TiO_2$ is successfully synthesized using a low-temperature, facile method with the aid of NaBH4 and polyethylene glycol (PEG) 4000. The introduction of defects, particularly oxygen vacancies, reduced the band gap of $TiO_2$ and improved the separation of photogenerated electron-hole pairs The findings demonstrate that defect-engineered $TiO_2$, particularly b-$TiO_2$, holds great potential for environmental remediation, specifically in treating wastewater contaminated with persistent organic pollutants. Future studies should focus on the long-term stability and

reusability of these photocatalysts, as well as exploring the effects of varying synthesis conditions and doping agents to further optimize photocatalytic performance.

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207_IEC64320

# Preparation of Activated Biochar Doped Polyvinyl Alcohol (PVA) Aerogel and its Application in Wastewater Treatment

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***Abstract:*** *As pollution is gaining more attention with every passing day, different studies are being conducted to develop more suitable technologies to treat wastewater. This study puts a spotlight on the development of activated biochar doped PVA aerogel and its application in Phenol removal from wastewater. Aerogel is a new form of solid material with a high application potential. In this study activated carbon doped PVA aerogel was developed, and it was found that by using this material as an adsorbent a significant 80.27% removal can be achieved for Phenol from water solution after 180 min. Different parameters, viz., Phenol concentration (1-10 mg/L), aerogel dose (0.5-1.5 g/L), pH (2-10), and temperature (25℃- 40℃) varied during the batch study. From the FTIR analysis, the presence of functional groups, viz., C=O, C-H, and C-O was observed. From the XRD analysis, a characteristic peak of PVA at 19.3o was observed. The SEM and light microscopy study revealed the uneven and cavity-containing surface morphology of aerogel. From the observation, it can be stated that these characteristics of aerogel contribute significantly to the adsorption efficiency of prepared aerogel.*

***Keywords:*** *Biochar; Aerogel; Phenol; Adsorption; Wastewater Treatment*

## INTRODUCTION

With the development of civilisation, many environmental concerns are being raised. Over the last few decades, these issues have gained attention on both national and international platforms. The point source of water pollution is considered the most contributing factor to this issue and the main threat to waterbodies in both developed and developing countries[1]. Among many contaminants, organic pollutants are considered one of the main factors responsible for this issue. Phenol, one of the organic pollutants is a constituent of coal tar and was first partially separated in 1834 by Friedlieb Ferdinand Runge [2]. Phenols are present in the wastewater of various industries, viz., refineries, coking operations, coal processing, and petrochemical plants. According to OSHA and ACGIH 5 mg/L Phenol concentration is considerable in case of contact with skin and 1g is deadly for humans in case of oral consumption [3].Phenol exists as a white solid at room temperature and because of its' toxic effect, even in low concentration, it is considered one of the most hazardous pollutants. The presence of Phenol in water can also lead to the formation of different substituent compounds during the oxidation process. These compounds show an inhibitory effect on microorganisms during the biological treatment process and are known as secondary pollutants[2].

Apart from the traditional methods of wastewater treatment, to separate these pollutants from waterbodies alternative approaches are investigated for their ease of conduction and high efficiency. One of the alternative approaches is the adsorption of pollutants from water bodies. Recent decades have evidence of the development of new materials like aerogel with low density, high porosity and the presence of functional groups on its surface [4]. Organic carbon-based aerogels are developed by using different biopolymers, viz., aldehyde, hydroxy benzenes, polyvinyl alcohol (PVA), and polyvinyl chloride (PVC)[5]. Due to their nature, these materials can be used for wastewater treatment. A study reported that GO-Kaolinite clay PVA-derived aerogel showed an adsorption capacity of 535 mg/g in the case of methylene blue removal [6].

Phenol is being chosen very frequently in the research field as the pollutant of interest. Hence much data is available on its removal or distribution, especially concerning wastewater treatment. In the last decade, the treatment of aqueous effluents polluted with Phenol and Phenolic compounds has attracted much attention due to toxicity and low biodegradability. In industries, Phenolic compounds are hard to treat by using conventional methods [7].

In this study, activated biochar doped PVA aerogel was synthesized by using lyophilization and investigated to remove Phenol from wastewater.

## MATERIALS AND METHOD

### Materials

Polyvinyl alcohol (PVA), Glutaraldehyde, Sodium hydroxide (NaOH), and Phenol were purchased from Loba Chemie (India), and Hydrochloric acid (HCl) was purchased from Merck (Germany). All chemicals were used as received.

### Preparation of Activated Biochar

Rice husk was collected from a rice mill situated in Hooghly district. After collection, the husk was washed with DI water and dried under direct sunlight for 3 days. The cleaned husk was ground using a mixture grinder. Biochar was prepared from the rice husk using a muffle furnace at 600°C in the absence of oxygen and was activated by treating with 4% (w/v) NaOH solution for 24 hours. After the treatment, the biochar was collected and washed with DI water. The cleaned char was dried at 60°C in a hot air oven and stored for future use.

### Preparation of Aerogel

PVA was dissolved in 100 mL of DI water by heating the solution at 90°C. After the solution was prepared, it was cooled to room temperature and glutaraldehyde was added with 1g of activated biochar to the solution. The mixture was stirred for 15 minutes at room temperature, and HCl was added. The solution was stirred at 90°C till the sol converted to a hydrogel. The prepared hydrogel was then cooled to room temperature and lyophilized to convert it to aerogel.

### Preparation of Phenol Solution

10 mg of Phenol was dissolved into 1L of DI water to prepare the Phenol solution. Different concentrations of this solution were prepared by diluting the stock solution as required.

### Adsorption Study

The adsorption study was conducted by using a BOB shaker incubator (Remi) for 180 min. 100mL of Phenol solution was used for this study. Different parameters viz., aerogel dose (0.5 g/L-1.5 g/L), Phenol concentration (1 mg/L- 10 mg/L), pH (2-10) and temperature (25°C-40°C) were varied to understand the effect of different parameters on the Phenol removal process.

### Characterization of Aerogel:

ATR-FTIR, XRD (X-ray diffraction analysis), (Thermogravimetric analysis), light microscopy, and SEM (Scanning electron microscopy) were performed to understand different characteristics of the prepared aerogel.

## RESULT AND DISCUSSION

### Characterization of Aerogel

From ATR-FTIR analysis of the aerogel, it was observed that significant peaks are present at 3273, 2914, 1645 and 1091 $cm^{-1}$ respectively. The peak at 3273 $cm^{-1}$ represents the presence of the aldehyde group. It was also reported that 2914 $cm^{-1}$ represents C-H of alkyl groups and C = O groups are represented by 1645 $cm^{-1}$[8]. The presence of the C-O group is indicated by 1091 $cm^{-1}$ [9]. The result of the XRD analysis showed a sharp peak at 19.3°. As reported in previous studies this peak is a characteristic peak of PVA [10]. From the SEM analysis, it was shown that the aerogel contains a high number of cavities that contributed to the adsorption process. As reported previously, the H-bond present on the aerogel surface is responsible for its adsorption efficiency [11]. As observed under light microscope,

the aerogel contains an uneven surface morphology along with the distribution of biochar that is responsible for the adsorption efficiency of aerogels.

**Removal of Phenol by Batch Study**

From the data of the batch study, it was observed that all the parameters have a significant effect on Phenol removal from water solution. The study was conducted for 180 min. and as shown in **Figure 1**, the equilibrium was achieved after 120 min. with 64.02% removal. Three adsorbent doses viz., 0.5. 1, and 1.5 g/L were considered in this study and 1.5 g/L aerogel removed 76% of Phenol from the water solution. This is because of the availability of adsorbent sites with increasing doses. The effect of concentration on the removal %. From the result, it can be stated that with increasing concentration the removal % decreased significantly as increasing concentration caused competition to occupy the active sites on the adsorbent surface. The highest removal was observed for 1 mg/L Phenol concentration and the value is 79.46 %. From the acquired data, it was observed that the pH of the solution affected the removal significantly. With increasing pH, the removal % decreased from 76.85% to 42.63%. The effect of temperature on the removal % is significant. The increase in the temperature showed an increase in removal % from 56.32% to 80.27%. This result can be explained by the increasing intermolecular interaction of adsorbate with the adsorbent surface with increasing temperature.

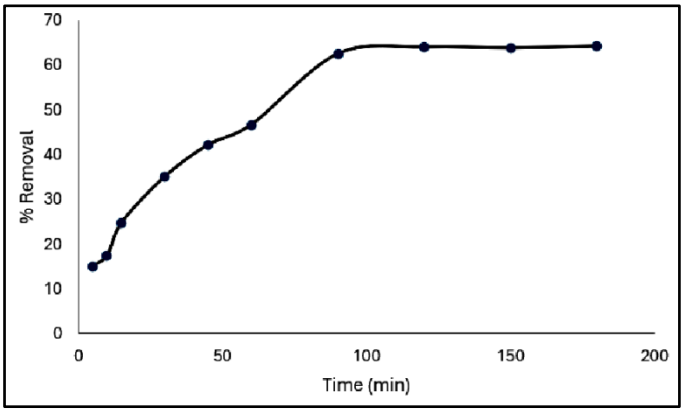


**Figure 1** Removal of Phenol from water solution by activated biochar doped PVA aerogel

**CONCLUSION**

In recent years, many studies have been conducted on wastewater treatment by different adsorbents. In this study activated biochar doped PVA aerogel was synthesised, and its effectiveness was investigated for Phenol removal from water solution. As observed in this study, the highest removal achieved in this experiment was 80.27% at 40oC and the lowest removal was 47.55% at 0.5 g/L aerogel dose. From the FTIR analysis, it was shown that the aerogel surface contains many functional groups responsible for the adsorption process along with uneven surfaces containing cavities as observed in SEM analysis. From this research, it can be concluded that activated biochar doped PVA-aerogel can be used for significant removal from water solution.

**ACKNOWLEDGEMENT**

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210_IEC35362

# Sustainable Solutions: Efficacy of Catalyst-Induced Co-Pyrolyzed Jute-PET Char in Congo Red Dye Removal from Wastewater

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***Abstract:*** *This study investigates the efficacy of catalyst-induced co-pyrolyzed Jute-PET char for the removal of Congo Red dye from wastewater, with Gypsum as the catalyst, addressing a critical environmental challenge posed by textile effluents. Congo Red, a carcinogenic azo dye, is notoriously resistant to degradation, necessitating effective removal techniques. The research emphasizes a sustainable approach by utilizing co-pyrolyzed char derived from jute and PET waste, which not only enhances adsorption capacity but also contributes to waste valorization. The pyrolysis process was optimized to maximize surface area and functional groups on the char, facilitating improved dye adsorption. Characterization techniques, including ATR-FTIR, SEM, XRD, CHNS analysis, confirmed the structural integrity and porosity of the char. Batch adsorption experiments were conducted to evaluate the influence of parameters such as contact time, initial dye concentration, pH, and temperature on removal efficiency. Results indicated a significant adsorption capacity, with kinetics fitting well to pseudo-second-order models. This innovative method presents a dual benefit: it provides an effective solution for wastewater treatment while promoting circular economy principles through the recycling of industrial waste materials. The findings underscore the potential of co-pyrolyzed Jute-PET char as a viable adsorbent for mitigating the environmental impact of dye pollutants in water bodies.*

***Keywords:*** *Adsorption; Wastewater Treatment; Co-Pyrolysis; Jute-PET Char; Waste-to-wealth*

## INTRODUCTION

Since the dawn of human civilization, people have been heavily dependent on the natural resources to meet their needs. Needless to say, industrialization eventually became the driving force behind the current development. As civilization advanced, so did the population and its needs, resulting in an increase in waste production. Because of their nature and our poor management, these wastes pollute the environment. Due to the durability, affordability, and portability of plastics, which make them more useful for daily usage, modern life has become more dependent on their use. "Plastic culture" has grown since the 1940s in tandem with expanding communities all over the world.[1] Plastic waste is produced by households as well as by industrial sectors such as packaging, construction, agriculture, and transportation most of which are not treated in an environmentally friendly manner. Similarly, various industries are using dyes for different purposes. Most of the dyes are harmful to living tissue if in contact for a long time. The discharge of dyes to waterbodies without proper treatment can cause ecosystem damage. Congo red is an example of an anionic dye that when discharged into an aquatic environment without proper and thorough treatment, CR can severely affect metabolic processes and development in photosynthetic organisms (flora) and aquatic fauna merely by altering the ecological functioning of the environment [2]. Based on the toxicity information, it is crucial to eliminate the pollution load caused by the release of this carcinogenic contaminant via the treatment of wastewater generated during various dye related industrial processes. In this study, the synthesis of char from municipal waste plastic in tandem with alkaline-treated Jute fibers was performed and followed by activation using Nitrogen as inert material. This study also investigates the role of the co-pyrolyzed char in the removal of one of the most common Azo dyes, named Congo Red in an aqueous solution. Along with that, this study aimed to understand the role of different conditions such as pH, Temperature, Dye-Adsorbent contact time, and Dosage in various adsorption kinetic and isotherm models.

## MATERIALS AND METHODS

### Preparation of Adsorbent

Locally obtained jute fibers were treated with 10% NaOH solution and then dried in a Hot-Air Oven. The feedstock, consisting of waste PET, of size 3-4 mm, along with alkaline treated Jute fibers in an equal weight ratio of 1:1, was pyrolyzed at high temperature in a digital pyrolysis reactor, producing solid, liquid, and gaseous products. The solid products of carbonaceous nature (char) were collected and washed with distilled water, dried in a Hot Air Oven, and crushed with a mortar and pestle for finer particle size.

### Batch Study

Congo Red was commercially obtained from Loba Chemicals, which was then used. For all estimations, 50ml Congo red solution was prepared in Erlenmeyer flasks. This experiment took into account several experimental parameters, including adsorbent dosage (0.5-2.0 g/lit), solution pH (2-10), contact time (0-180 min.), and temperature (298-313 K). The study was carried out in a BOD incubator with a constant rotation. Samples were extracted at predetermined timeslots. To determine the % removal, the absorbance of Congo Red was measured in a spectrophotometer (Shimadzu, UV-1800) at 498 nm λmax.

### Characterization of Nitrogen Influxed Pyrolyzed Char

The pyrolyzed char underwent different characterization process viz., Scanning Electron Microscopy (SEM) in an electron microscope (ZEISS EVO-MA 10, Germany) to study surface morphology, Fourier transform infrared spectroscopy (FTIR) to study the presence of different chemical bonds and X-Ray diffraction study (XRD) to determine the crystal structure of the substance. XRD study was conducted over a range (2θ) of 20-90 on a diffractometer. CHNS content was also analyzed using Elementar Vario Micro CHNS analyser.

## RESULTS AND DISCUSSIONS

### Characterization of the Adsorbent

The ATR analysis showed a medium peak of 3305 cm-1, denoting the presence of O–H, displaying either phenol or alcohol due to the breakage of hydrogen bonds, which released hydrogen and water [3-5]. Because of the existence of these groups, the char removed more adsorbate [6]. The image of SEM analysis of the adsorbent showcased thin, overlapping, crumpled structures with few rough edges. The folded surface structures are responsible for increasing the surface area of the char for better pollutant adsorption [7]. The char's XRD analysis revealed the presence of various peaks indicating that the char has a crystalline structure. The carbon content of the adsorbent was determined by CHNS analysis. The total carbon content of the substance was 67.56%. Due to this high carbon content, this char acts as an efficient adsorbent[8].

### Batch Study

The effects of various doses of the char have been portrayed in **Figure 1**. From the experiment, it was observed that the removal% of CR dye increased significantly from 37.92%-71.16%, with the increase in char dosage (0.5-2 g/L). This increase could be attributed to an increase in adsorption surface area and the active adsorption sites with higher dosages [7,8].

To understand the effects of dye concentration on the adsorption process, the study was conducted with 2g/L char across four concentration variations, namely 5, 10, 20, and 40 mg/L. The result showed the removal % tends to decrease (84.55-55.72%) with increasing dye concentration. This could be attributed to a decrease in active adsorption sites due to saturation from CR adsorption. Temperature is known to be a critical parameter as it tends to modify the equilibrium capacity in an adsorption process. To understand the effects of temperature on CR dye adsorption on the char, the study was conducted with 2g/L char along a temperature range of 298-313 K, across 180 minutes. It was observed that the removal % increased with increasing temperature. The highest removal % was

obtained at 313K (87.64%). Since pH plays a critical role in surface binding sites of adsorbent along with ionization of CR dye molecules in the solution, it affects the adsorption process to a large extent. Across the increasing pH range of 2-10, the removal% of CR showed a gradual decrease. The highest removal% was observed at pH2, which implies that the adsorption of CR was better under acidic conditions. Furthermore, CR dye is known to be anionic in nature. At lower pH conditions, the H+ ions increase, which get adsorbed on the adsorbent surfaces thereby increasing the positive charge on the adsorbent surface. This, in turn, attracts the anionic CR molecules to bind to the adsorbent easily[8]. However, at higher pH conditions, the adsorbent surface acquires a negative charge, due adsorption of OH- ions from the solution. This negative surface charge results in limited adsorption of anionic CR. To understand the effect of time on the adsorption of CR dye on the char, 2g/L dosage of char was used. It was observed that the removal % of CR increased rapidly by 120 minutes and then gradually till 180 minutes (73.07%). After that, the adsorption mechanism reached an equilibrium. The rapid uptake of CR on the adsorbent till 120 minutes could be attributed to the presence of a large number of available adsorption sites. Thereafter, as the number of adsorption sites decreased with increasing time, the removal% increased at a slower rate till it reached equilibrium at 180 minutes. Hence, for the entire batch study, 180 minutes was taken as the optimum time for analysis.

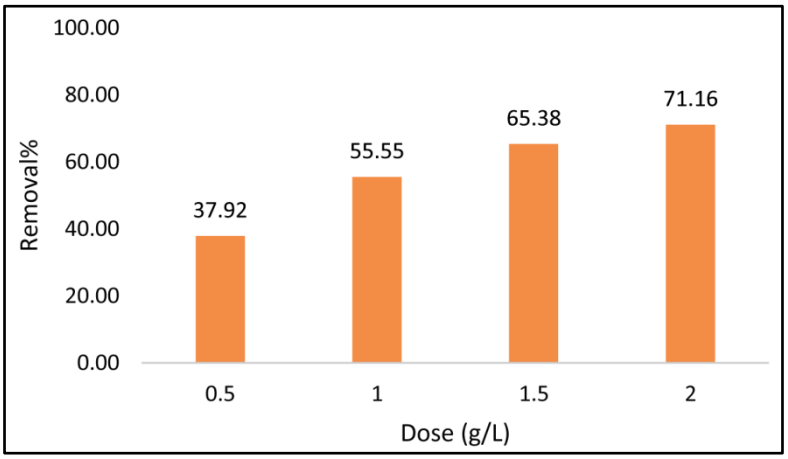


**Figure 1** Graphical representation of the effect of dose variation on the removal of congo red dye

## CONCLUSION

It has been estimated that, annually almost 1 million tons of dyes are produced around the world and the abundance of Azo dyes in the textile, and printing industries is significant due to the low cost and ease of use. As a consequence of the heavy discharge of untreated wastewater into the aquatic habitat, health risks like cancer may arise. Due to the presence of aromatic amines in its chemical structure, Congo Red is counted as a carcinogen and cannot be easily degraded naturally. In this study, it has been found that the catalyst induced co-pyrolyzed Jute-PET char can remove Congo Red from an aqueous solution in an efficient manner. The adsorbent was able to remove up to 87.64 % of Congo Red from an aqueous solution. The aforementioned results can help conclude that, the use of municipal plastic waste to synthesize Char not only can decrease the rate of plastic pollution, but also it can sustain as an effective removal technique of toxic dyes like Congo Red from wastewater.

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211_IEC57058

# Extraction of Silica from Sugarcane Bagasse and its Application in PVA Aerogel Preparation for Dye Removal from Water Solution

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**Abstract:** Wastewater treatment is one of the rising global issues and different studies are being conducted to study to understand the treatment process using suitable and cost-effective methods. Aerogel materials possess a wide variety of exceptional properties; hence a striking number of applications have been developed for them. Here, in this paper, we report an eco-friendly use of aerogel which is doped with silica that is extracted from sugarcane bagasse, and its application in the removal of organic soluble dye, Congo Red. In the study, it was observed 87.68% removal of the dye was observed after 180 minutes. Different parameters, viz., Congo Red dye concentration (10-50 mg/L), aerogel dose (0.5-1.5 g/L), pH (2-10), and temperature (25°C- 40°C) varied during the batch study. From the XRD analysis, a characteristic peak of PVA at 19.3°C was observed. From the FTIR analysis, the presence of functional groups, viz., C=O, C-H, and C-O was observed and SEM and light microscopy studies revealed the uneven and cavity-containing surface morphology of aerogel. From the observation, it can be understood that the mentioned characteristics of aerogel contribute significantly to the adsorption efficiency of prepared aerogel.

**Keywords:** Silica; Aerogel; Wastewater Treatment; Congo Red; Adsorption

## INTRODUCTION

Contamination of water has been a global issue due to the indiscriminate disposal of wastewater from industries which contains different kinds of soluble organic dyes and heavy metal ions. These contaminants are causing severe environmental problems that includemass mortality of aquatic life and distinction of species[1]. Industrialization has shown the serious need for treating wastewater and several methods for purification of wastewater have been introduced such as adsorption, reverse osmosis, precipitation, and ion exchange, among which adsorption has been observed as the most efficient and cost-effective method [2]. Therefore the presence of various toxic pollutants released from anthropogenic activities increases water contamination every day as these toxic pollutants have mutagenic and carcinogenic effects on the organisms [3]. Pollutants from water bodies enter small organisms' bodies, accumulating on larger scales, causing human effects like irritation, hemolytic anemia, skin cancer, digestive problems, and CNS abnormalities[4].

In recent years the wide application of aerogels has shown effectiveness in science and technology. Aerogel is a three-dimensional open network assembled by coherent polymer molecules and its recent advances have been recognized as a new state of matter. Aerogel has exhibited qualitative differences in bulk properties when in comparison to other states of matter [5]. Aerogel has very unique properties that have shown its application in wide ranges. Studies have shown that the density of aerogel ranges from 1000 kg/m3 to about 1 kg/m3 which is much lower than the density of the air. Aerogel induces dramatic changes in the properties due to its high porosity and dual structural natures of microscopic and macroscopic. Such properties make aerogel more versatile with properties such as low thermal conductivity, low refractive index, high specific surface area, and a wide range of adjustable densities and refractive index [5], [6], [7].

The development of silica aerogel by extracting liquid from wet silica gels via a supercritical drying method was first introduced by S. Kistler in 1931 and after several years in 1968, Teichner and in 1989, Pekala introduced Si-O2-based aerogel and carbon-based aerogel, respectively [8].Synthesis of aerogel is based on three steps viz.,

polymerization, drying, and carbonization. For the initial steps of polymerization, crosslinking of molecules is done by sol-gel method. The production of aerogel is played by the colloidal sol's conversion into a three-dimensional porous network upon the addition of a chemical cross-linker or under specific physical circumstances[9]. The "aging" procedure, which entails immersing the gel in an appropriate solvent for hours, comes next. Followed by the process of drying which plays a significant role in the process of aerogel formation, by drying the hydrogel, the solvent is extracted, leaving behind just the solid framework. Final gel products can be classified as aerogels (supercritical drying), xerogels (oven drying), or cryogels (freeze-drying) depending on the kind of drying process used. Nonetheless, dried gels produced using any of these techniques are now often referred to as aerogels[10], [11].The natural polymer material polyvinyl alcohol (PVA) has attracted interest in the production of aerogels due to its favorable chemical stability, biodegradability, and low cost. Since PVA-aerogels may be made with a straightforward freeze-drying procedure, supercritical drying is not required [11]. With the aid of glutaraldehyde as a connecting agent, fillers such as carbon nanotubes (CNT), silica, and graphene oxides have been utilized to boost the effectiveness of PVA-aerogels [12].

Sugarcane bagasse is used in this study for extracting silica that was incorporated into PVA-aerogels. Sugarcane (Saccharumofficinarum) is a widely cultivated tropical plant species that makes up a large proportion of the sugar industries in the world. The composition of sugarcane bagasse is found to consist of about 42 % cellulose, 25 % hemicellulose, and 20 % lignin and it is considered one of the underutilized agricultural wastes compared to other numerous biomass-based adsorbents which have received much attention[13]. In this study, PVA-based aerogel was synthesized with silica extracted from the sugarcane bagasse which is used as a filler for modifying the properties of the aerogel and to study the effect of fillers concerning adsorption capacity. The study also focuses on the preparation of aerogel cost-effectively by using freezing instead of solution substitution by acetone and freeze-drying in the place of critical drying.

## METHODOLOGY

### Materials

Polyvinyl alcohol (PVA), glutaraldehyde, sodium hydroxide (NaOH), and hydrochloric acid (HCl) were purchased commercially from Merck (Germany) and used as received. Sugarcane bagasse was collected from local vendors situated in Jadavpur, Kolkata, India.

### Methods

Preparation of fillers

To extract silica from biomass, the cleaned biomass was burnt in the presence of oxygen at 800°C and converted into ash. The ash was collected and treated with 12% NaOH solution (W/V) in a 1:7 ratio followed by stirring at 90°C for 90 minutes. After this treatment, the solution was filtered, and the liquid part was collected for acidification. The acidification reaction was performed by concentrated HCl at room temperature and continuous stirring. After the completion of acidification, a white precipitation of silica occurred. The precipitate was collected, washed with DI water, and dried in a hot air oven at 80°C.

Preparation of aerogel

To prepare aerogel, PVA was used as the base material. 5g of PVA was mixed with 100 mL of water and stirred at 90°C until the PVA dissolved completely. After the solution became transparent, it was cooled down to room temperature and then 100 µL of glutaraldehyde was added to the solution. After that, the mixture was again stirred for 10 minutes to distribute the glutaraldehyde homogeneously. Following that, 100 µL of concentrated HCl was added to the mixture and again stirred at 90°C until the sol converted to a hydrogel.

To produce Silica hydrogels, 100 mg of previously prepared filler Si was added to the PVA solution before adding glutaraldehyde. After that, the hydrogels were cooled down to room temperature and stored atroom temperature for

24 hours to stimulate the homogeneous distribution of water molecules inside the hydrogel matrix. After 24 hours, the hydrogels were lyophilized by using a freeze drier (SI Optic, model: SI-FD 70P3) to convert them to aerogels.

Preparation of congo red dye solution

10 mg of Congo Red was dissolved in 1L of DI water to prepare the dye solution. Different concentrations of this solution were prepared by diluting the stock solution as required.

Adsorption study

The adsorption study was conducted by using a BOB shaker incubator (Remi) for 240 min. 100mL of Congo Red dye solution was used for this study. Different parameters viz., aerogel dose (0.5g/L-1.5g/L), dye concentration (10mg/L-50mg/L), pH (2-10),and temperature (25°C-40°C) were varied to understand the effect of different parameters on the Congo Red dye removal process.

Characterization of aerogel

ATR-FTIR, XRD (X-ray diffraction analysis), (Thermogravimetric analysis), light microscopy, and SEM (Scanning electron microscopy) were performed to understand different characteristics of the prepared aerogel.

## RESULTS AND DISCUSSION

### Characterization of Aerogel

It was observed, that upon conducting ATR-FTIR analysis of the aerogel ha significant peaks at 3273, 2914, 1645, and 1091 cm -1respectively. The results observed from XRD analysis showed a sharp peak at 19.3°. From SEM analysis, aerogel has shown that it contains a high number of cavities that indicate its contribution to the adsorption process. Upon observation under the light microscope, the aerogel is seen to have an uneven surface morphology along with the distribution of silica which is responsible for the efficient adsorption of the aerogel.

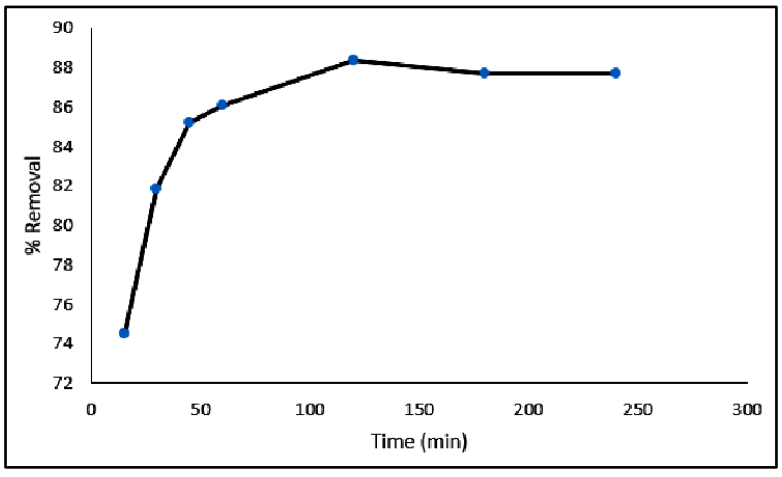


**Figure 1** Removal of Congo red dye by using PVA-Silica aerogel

### Removal of Dye by Batch Study

In the study conducted, effective changes in the removal of the dye Congo Red have been observed at different parameters from the aqueous solution. The study is conducted for 240 minutes as shown in **Figure 1**, where the equilibrium is achieved after 180 minutes with 87.68% removal. Three adsorbent doses, 0.5, 1, and 1.5 g/L were taken into consideration for this study, and for 1.5 g/L aerogel, 95.29% of removal was observed. With the increase in the dose, there is an increase in the availability of the adsorbent sites. The effect of concentration on removal percent was observed to significantly decrease with an increase in concentration of the dye. The highest removal was

observed for 10 mg/L with a removal percent of 88.38%. It can be observed that increasing the concentration causes a decrease in the occupancy of active sites on the adsorbent surface. Furthermore, the pH of the solution has a significant effect on the removal of the dye. With the increase in the pH, the removal percentage decreased from 88.73% to 65.63%. For the effect of temperature, an increase in temperature has shown an increase in removal percentage, from 66.32% to 99.27%. Therefore, this increase in removal can be concluded by the increase in the intermolecular interactions of the adsorbate with the adsorbent surface with the increase in temperature.

## CONCLUSION

Over the past few decades, several studies on aerogel and its application for wastewater treatment have been studied with different adsorbents. This study investigated the silica, which is extracted from sugarcane bagasse that is doped with PVA-aerogel, and its effectiveness in the removal of Congo Red dye. From the study, it has been observed that the highest removal achieved was 97.27% at 40°C, and the lowest removal recorded was 67.55% at 05 g/L dose of the adsorbent. The FTIR analysis shows the presence of several functional groups on the surface of the aerogel which are responsible for the adsorption process as well as the uneven surface containing cavities which is observed from the SEM analysis. Therefore, it can be concluded that silica-doped PVA aerogel can have effective removal from aqueous solution.

## ACKNOWLEDGMENT

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216_IEC61578

# Waste Leaf Biomass to Activated Carbon: A Sustainable Strategy for the Removal of Cationic Dye from Wastewater

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***Abstract:*** *Removal of toxic pollutants from the water bodies needs to be dealt with great concern as these pollutants have harmful effects on living beings. Among many removal strategies, adsorption is a very effective process as it is sustainable, low-cost, and easy to handle with great final results. Various waste biomass is now used widely to develop sustainable adsorbents for removing pollutants from wastewater. In this study, the waste leaf biomass of Polyalthialongifoliais used for preparing biochar at different temperatures for removal of Methylene Blue dye. The most efficient biochar at 485℃ was selected for synthesizing activated carbon by chemical method. The adsorption experiments were demonstrated at varying parameters by a batch study. The highest removal efficiency for the activated carbon was obtained as 99.957% when the conditions were 1g/L adsorbent dose, 20 mg/L initial dye concentration, 40℃ temperature, and 130 agitation speed. The results thus indicated the production of activated carbon from Polyalthialongifolia leaves is a well-sustainable strategy for dye adsorption.*

***Keywords:*** *Polyalthialongifolia; Waste Biomass; Adsorption; Methylene Blue; Biochar; Activated Carbon*

## INTRODUCTION

Industrialization has significantly escalated water pollution, particularly through the release of toxic pollutants, including dyes from the textile and chemical industries. These industries discharge substantial volumes of wastewater containing both cationic and anionic dyes, which can lead to acute toxicity in aquatic organisms, reducing biodiversity and compromising ecosystem health. Exposure to high concentrations of these dyes can cause oxidative stress and reproductive issues in fish and other aquatic species. Methylene blue (MB), a widely used synthetic cationic dye in textiles and pharmaceuticals, exemplifies this issue. Its persistence in the environment exacerbates its impact, as it does not readily degrade and can accumulate in the food chain[1].To combat the challenges of increasing water pollution, adsorption has emerged as an effective wastewater treatment technique. Adsorption is favored for its simplicity, flexibility, efficiency, non-toxicity, and economic feasibility for sustainable wastewater remediation [2]. To develop cheaper and more effective adsorbents, raw materials generated from leaf waste (Pine tree leaf, grape leaf, sugar beet leaf) as biosorbents are an excellent solution [3, 4, 5].

Pyrolysis is considered the most effective method to generate biocharowing to its relative simplicity of operation and wide range of scales. Temperature, heating rate, reaction time, and the content of biomass feedstock have profound effects on the characteristics of both activated carbon and biochar during the pyrolytic process. The pyrolysis parameters have a significant impact on the physical (surface area, pore structure), chemical (functional groups and activated oxygen species), and structural characteristics of the engineered biochar [6]. Pyrolysis of biochar within a range of 500-800°C elevates its adsorptive competence by eliminating volatile compounds while forming micropores. This translates into improved surface area, pore volume, and optimum pH values. The ideal pyrolysis temperature range is 500-800°C, which facilitates potent biochar removal from wastewater [7]. This relationship highlights the importance of optimizing pyrolysis conditions tailored for the specific type of biomass to maximize the efficacy of biochar undertaken for the removal of target contaminants from wastewater.

The evergreen plant of the Annonaceae family, Polyalthialongifolia is equipped with extensive medicinal properties and is available all over the Indian subcontinent. The dry leaves of the plant contribute to a large quantity of daily solid waste. There exists substantial research on biochar and activated carbon derived from leaf waste which has backed up the MB removal efficiency[3,8]. In this study, we have taken dried Polyalthia longifolia leaf, collected

from the Jadavpur University campus as our waste biomass. Investigation of the adsorption potential of biochar and activated carbon derived from P. longifolia was studied for revealing the removal efficiency of MB.

## MATERIALS AND METHODS

### Materials

To obtain the adsorbent prepared, the following chemicals were used- DI water, Methylene Blue (Merck), Zinc Chloride (Merck Life Sciences Pvt. Ltd.), and HCl (HiMedia).

### Methylene Blue Stock Preparation

For preparing the Methylene Blue dye stock solution, 100 mg/L dye was weighed and dissolved in 1000 mL distilled water. From this 100 mg/L stock solution, different experimental solutions were prepared for further adsorption studies.

### Leaf Powder Preparation

The dried leaves of Polyalthia longifolia were collected from the Jadavpur University campus, Kolkata. Leaves were washed with distilled water thoroughly to remove dirt particles. Afterward, they were oven-dried at 100°C and ground to 250-mesh particle size to obtain a fine powder of uniform particle size. The sieved material was then stored in an airtight plastic bag for further use.

### Biochar Preparation

The dried leaf powder was tightly packed inside a crucible and pyrolysis was carried out in the muffled furnace for 3 hours at 485°C, 550°C, and 600°C. The furnace was allowed to cool down to reach room temperature, the biochar was taken out. Three biochars were labeled LB-485, LB-550, and LB-600 and kept in an air-tight container for further use.

### Evaluation of the most Efficient Biochar

From the prepared biochar at different thermal conditions, the most efficient biochar was selected by a contact time-based adsorption study for further experiments. The experimental time range was 2 hrs. using the B.O.D. incubator shaker and the results were analyzed using a UV-VIS Spectrophotometer.

### Activated Carbon Preparation

Activated carbon was prepared through the chemical activation method as executed by Mahmud et al. with some slight modifications to tailor the biomass used in this study [9]; dried leaf powder biochar was transferred into a 500 mL beaker containing Zinc Chloride ($ZnCl_2$) with a ratio of 1:2 (Biochar: $ZnCl_2$) in gram. After water was added it was stirred with a glass rod and left undisturbed for 24 hours at room temperature (RT). It was then dried at 110°C for 24 hours followed by carbonization at 500°C for 1 hour. After cooling to RT, the carbonized sample was washed with 1.2M HCl followed by deionized water wash until neutralized. The sample was filtered and dried at 100°C for 24 hours, labeled as ACLB, and kept in an air-tight bag for further use.

### Batch Adsorption Study

The adsorption experiments of Methylene Blue dye were evaluated by a batch study system using the activated carbon ACLB varying the experimental conditions in a B.O.D. incubator shaker. All the experiments were done by considering the experimental solutions as 50 mL and the sampling interval was of 15 mins. The varying conditions for the batch study were adsorbent dose (0.5, 1, 2 g/L), contact time (15, 30, 45, 60 mins), agitation speed (100, 130, 160 rpm), temperature (20, 30, 40°C) and initial concentration of dye (10, 20, 50, 100 mg/L). After the specific time duration, the samples were collected, centrifuged, and the removal data was analyzed by UV-VIS Spectrophotometer. The adsorption efficiency and adsorption capacity were calculated using the following equations:

$$\text{Adsorption Efficiency} = \frac{C_0 - C_t}{C_0} \times 100 \quad (1)$$

$$\text{Adsorption Capacity, } Q_e = \frac{(C_0 - C_e) \times v}{m} \quad (2)$$

Where, $C_0$, $C_t$, $C_e$, v, m refer to the initial concentration of dye, the concentration of dye at the time 't', equilibrium concentration, experimental volume in L, the mass of adsorbent in g respectively.

## RESULT AND DISCUSSION

### Efficiency of Biochar

From the waste leaves of Polyalthialongifolia, three biochars were prepared at three different temperatures (485°C, 550°C, and 600°C). For the selection of the most efficient biochar in terms of adsorption of Methylene Blue dye, a contact time study was done for 60 min. The adsorption efficiency was highest for LB-485 as 98.633% and the adsorption capacity was 6.04 mg/g (**Figure 1**).

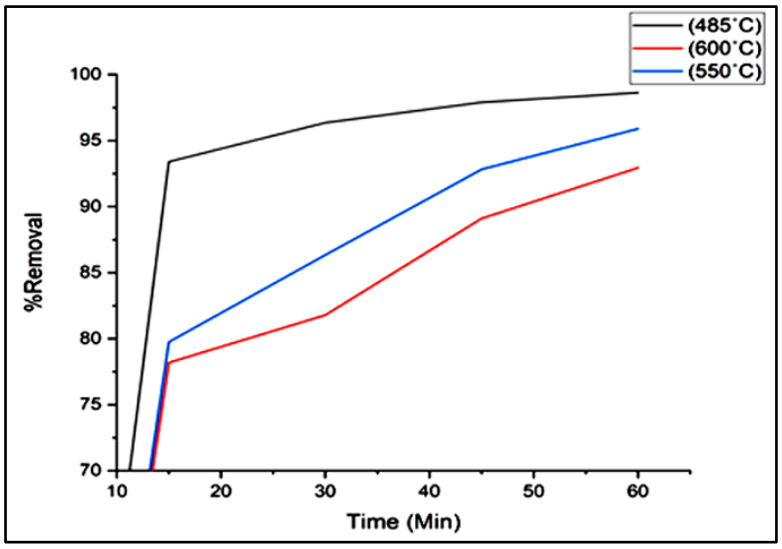


**Figure 1** %Removal in respect to time for biochars prepared at different temperatures.

### Effect of Varying Conditions in the Batch Study System

For the study of variation in adsorbent dose, other parameters were kept constant as 20 mg/L initial dye concentration, 30°C temperature, and 130 rpm agitation speed. The experimental doses were considered as 0.5 g/L, 1 g/L, and 2 g/L. Results showed that when the dose was 0.5 g/L, the removal efficiency was 87.219%. After increasing the amount of dose from 0.5 g/L to 1 g/L and 2 g/L, the removal percentage increased to 98.506% and 99.730% respectively (**Figure 2**). It is obvious from the obtained results that the increasing amount of adsorbent dose is directly proportional to removal percentage as the number of available active sites for effective adsorption on the surface of activated carbon ACLB increased with increasing dose. Hence the optimization of effective adsorbent dose was evaluated by this study and the optimum dose for further experiments was taken as 1 g/L.

To study the variation of initial concentration of Methylene Blue dye in the batch study, 4 different concentrations were taken as 10 mg/L, 20 mg/L, 40 mg/L, and 80 mg/L. Other experimental conditions were 1 g/L adsorbent dose, 30°C temperature, and 130 rpm agitation speed. On increasing the initial dye concentration, the number of adsorbate molecules in the experimental solution was raised but the constant adsorbent amount in each case provided similar active sites for the adsorption on its surface. As a result, the highest removal percentage decreased from 99.924% to 87.059% for 10 mg/L and 80 mg/L initial dye concentrations respectively (**Figure 3**).

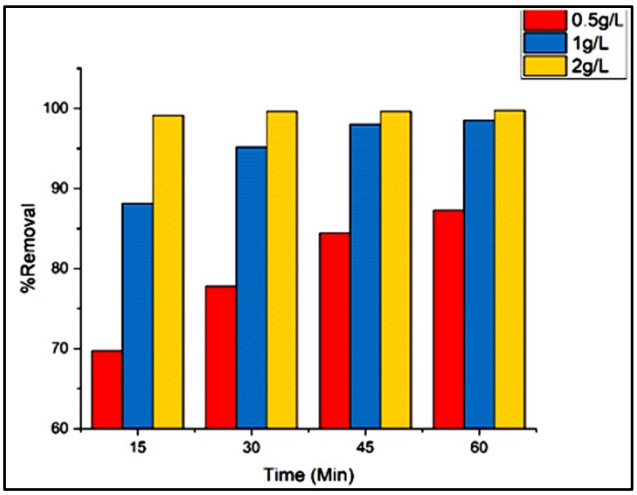


**Figure 2** Result of varying adsorbent dose study by ACLB

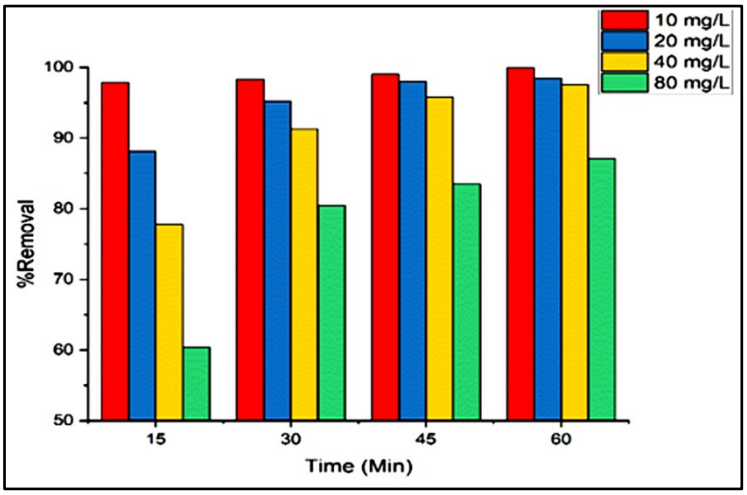


**Figure 3** Result of varying initial dye concentration study by ACLB.

For the contact time study, the samples were collected every 15 mins for 1 hr. As increasing contact time of the study provided more possibilities and duration for the adsorption of dye molecules on the ACLB adsorbents, the results showed increasement from 88.174% to 98.506% after 1 hr of study.

To evaluate the effect of temperature on the adsorption of methylene blue by ACLB adsorbent, three different temperatures (20°C, 30°C, 40°C) were taken for the experiment. The results showed that at a lower temperature, the removal was 98.309% and at a higher temperature the removal was better and the efficiency was 99.957%.

For the varying agitation speeds of 100 rpm, 130 rpm, and 160 rpm, the adsorptive removal trend showed an increment from 97.721% to 99.496% with increasing order of the speed. Other constant conditions were 1 g/L adsorbent dose, 20 mg/L dye concentration, and 30°C temperature.

## CONCLUSION

Industrialization in recent decades has exposed the threat of xenobiotic pollution to living beings. Methylene Blue being a cationic dye has several adverse effects on the environment. It is released in the water system with different industrial effluents and needs to be treated effectively before human consumption. The use of biochar and activated carbon as adsorbents for the removal of Methylene Blue dye has many research instances. In this study, the waste leaf biomass of Polyalthialongifolia was utilized to prepare biochar and activated carbon. The prepared biochar at 485°C

executed the highest removal efficiency. Activated carbon synthesized from this biochar demonstrated high adsorption efficiencies in all varying parameters of the batch study. The highest removal was 99.957% when the conditions were 1g/L adsorbent dose, 20 mg/L initial dye concentration, 40°C temperature, and 130 agitation speed. All the results indicated that the activated carbon produced from Polyalthialongifolia leaves is a well-effective, ecofriendly, and sustainable adsorbent.

## ACKNOWLEDGMENT

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# Environment & Sustainability

## Air Pollution and Control

320_IEC49345

# Phytoremediation Technique for Reducing Air Pollution in Indoor Environments

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***Abstract:*** *Phytoremediation is a promising, sustainable strategy to reduce indoor air pollution by utilizing houseplants to absorb, break down, or sequester airborne pollutants. Plants such as Sansevieria trifasciata (snake plant), Tulsi( the holy basil), Chlorophytum comosum (spider plant), and Epipremnum aureum (money plant) have been studied for their ability to remove harmful volatile organic compounds (VOCs) like formaldehyde, benzene, and xylene. These plants absorb pollutants through their leaves and roots, while microorganisms in the soil contribute to the breakdown of these compounds. However, the efficiency of phytoremediation varies based on the number of plants, species used, and environmental factors. The present research aims to bring forth a cost effective and natural mechanism to curtail the harmful effects of air pollutants in indoor environments like offices, households etc. The study was carried out for a period of one month duration with different plant varieties. The results show an average of 70-80% reduction in total pollutants.*

***Keywords:*** *Phytoremediation; Volatile Organic Compounds (VOC); Air Pollutants; Air Purification; Indoor Plants; Particulate Matter (PM)*

## INTRODUCTION

Air pollution, particularly indoors, poses a serious threat to human health, with pollutants like volatile organic compounds (VOCs), carbon monoxide, and particulate matter infiltrating homes from various sources. These pollutants contribute to respiratory diseases, allergies, and other health complications. Traditional methods for improving indoor air quality, such as ventilation and air purifiers, have their limitations in effectiveness and environmental sustainability. An emerging, eco-friendly solution to this issue is phytoremediation—the use of plants to naturally purify air by absorbing, filtering, and breaking down contaminants through their leaves, roots, and associated microorganisms[3,4,6,11].

A survey by the American Lung Association found that many people underestimate indoor air pollution, with over 50% unaware that indoor air can be more polluted than outdoor air.Research, such as NASA's Clean Air Study, has demonstrated the potential of common houseplants to remove up to 90% of indoor air pollutants like formaldehyde, benzene, and trichloroethylene under controlled conditions(NASA Technical Reports Server)[1]. Plants such as the snake plant ,tulsi, areca palm ,spider plant and peace lily have shown remarkable efficiency in absorbing harmful chemicals while improving oxygen levels. Additionally, more recent studies have explored the use of microalgae and biofilters in enhancing the air purification potential of indoor plants[2].

The growing awareness of phytoremediation's benefits has led to its adoption in homes, offices, and urban environments as a simple, low-maintenance strategy for reducing indoor pollution[7,8]. However, its real-world effectiveness depends on several factors, including the types of plants used, the number of plants, and environmental conditions. This article explores how phytoremediation works, the types of plants best suited for air purification, and the potential of this green solution to reduce indoor air pollution, promoting healthier living spaces.

## BACKGROUNDAND MOTIVATION

Air pollution is a significant environmental issue that affects health, ecosystems, and climate. It can result from various sources, including vehicle emissions, industrial processes, agriculture, and natural events like wildfires[10].

As per World Health Organization (WHO), indoor air pollution primarily due to cooking with solid fuels is responsible for about 4 million premature deaths each year. The EPA estimates that indoor air can be 2 to 5 times more polluted than outdoor air, sometimes even higher.

**Common Air Pollutants**

1. Particulate Matter (PM): Tiny particles that can penetrate the respiratory system, causing health problems[9].
2. Nitrogen Oxides ($NO_x$): Gases produced from burning fuel, contributing to smog and respiratory issues.
3. Sulfur Dioxide ($SO_2$): Emitted from burning fossil fuels, leading to acid rain and respiratory problems.
4. Carbon Monoxide (CO): A gas formed from incomplete combustion of carbon-containing fuels.
5. Volatile Organic Compounds (VOCs): Organic chemicals that evaporate and contribute to smog formation.
6. Particulate Matter (PM): Cooking, especially with gas stoves, can increase PM levels indoors. Research indicates that gas cooking can elevate PM levels significantly, with some homes showing levels exceeding recommended limits[9].

**How Indoor Plants Purify Air**

Using indoor plants for air purification is an appealing and natural way to enhance indoor air quality. Many houseplants can absorb pollutants and improve air conditions. Here's how they work and some effective options:

1. Photosynthesis: Plants absorb carbon dioxide and release oxygen, which improves air quality.
2. Absorption of Pollutants: Certain plants can take up volatile organic compounds (VOCs) and other toxins through their leaves and roots.
3. Transpiration: As plants release moisture, they can help maintain humidity levels, which can improve comfort and air quality.

**Sources of Indoor Pollution**

1. Cooking: A study found that cooking (especially frying) can increase indoor PM2.5 levels, sometimes to levels comparable to those found in urban air pollution[9].
2. Household Products: Cleaning products and personal care items can emit harmful chemicals. For example, air fresheners can release chemicals like phthalates, which are linked to respiratory issues.
3. Mold and Dust: Poor ventilation and humidity can lead to mold growth, which can impact health, particularly for those with allergies or asthma.

**Health Impacts**

Exposure to indoor air pollutants is linked to respiratory diseases, cardiovascular problems, and even cancer. For instance, long-term exposure to high levels of indoor PM2.5 can increase the risk of heart disease[9].

Indoor air pollution can lead to a wide range of health issues, particularly affecting the respiratory system and overall well-being. The most common diseases and health conditions caused by indoor air pollution include: Respiratory Diseases like Asthma, Lung Infections, Chronic Obstructive Pulmonary Disease, Cardiovascular Diseases like Heart Disease and Hypertension, Cancers like Lung Cancer and Bladder and Nasal Cancer, Allergic Reactions and Conditions like Allergic Rhinitis and Skin Irritation, Neurological and Cognitive Effects like Headaches, Dizziness, and Fatigue.

**METHODOLOGY**

In the present study few indoor plants like Tulsi, Spider plant, Peace lily, Money plant were used that gives good ambience and in turn purifies the air also. These plants were used for a period of one month. Before and after air quality was tested which showed a huge difference in the PM levels.

The technique of phytoremediation has five general pathways , phytoextraction, phytostabilization, phytovolatilization, phytotransformation and phytofiltration. These help in purifying the air in an indoor space. Overall process followed is shown in **Figure 1**.

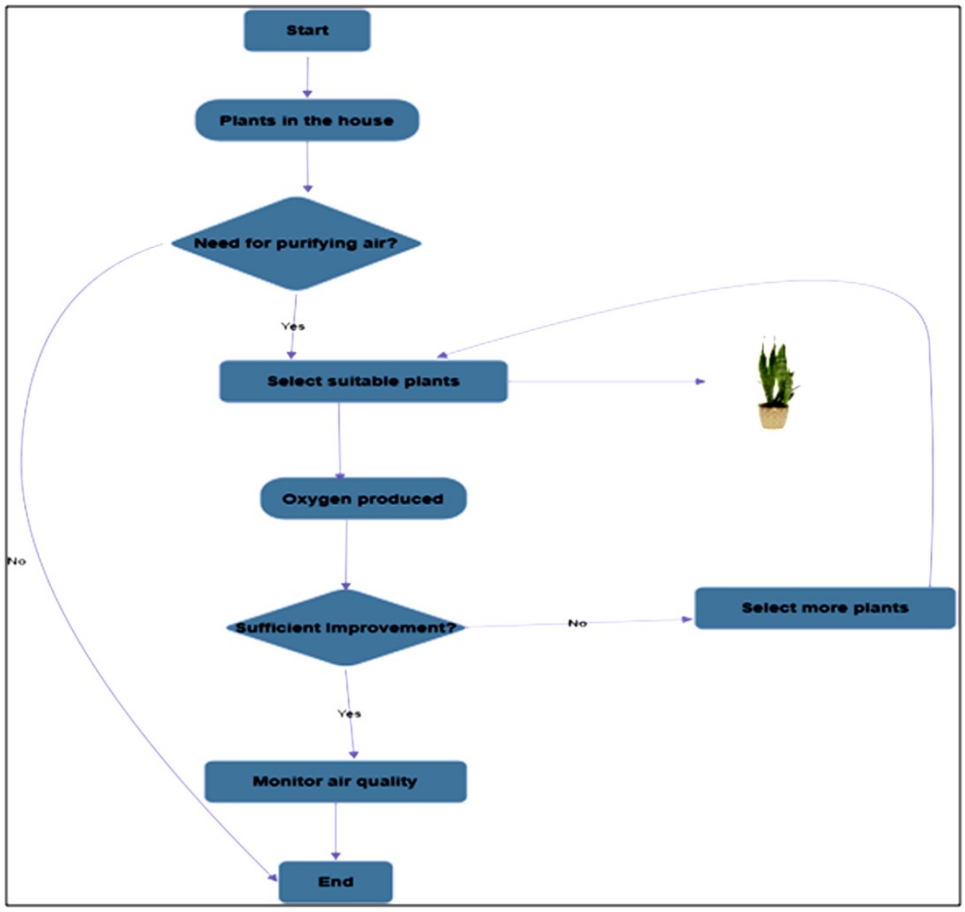


**Figure 1** Process followed for air purification using phytoremediation

**Table 1** Pollutants removed and %purification done by various Plants

| Plant Name | Pollutants Removed | % Purification of Air |
|---|---|---|
| Spider Plant | Formaldehyde, Carbon Monoxide, Xylene | Up to 90% for formaldehyde over 24 hours |
| Snake Plant | Benzene, Formaldehyde, Trichloroethylene, Xylene | 50-87% for VOCs like formaldehyde |
| Peace Lily | Benzene, Formaldehyde, Trichloroethylene, Ammonia | Up to 60% VOCs |
| Aloe Vera | Formaldehyde, Benzene | Approximately 50% VOCs |
| English Ivy | Formaldehyde, Benzene, Xylene, Toluene | Up to 78% mold and VOCs |
| Bamboo Palm | Formaldehyde, Benzene, Trichloroethylene | 40-60% VOCs |
| Money Plant | Formaldehyde, Benzene, Carbon Monoxide | 50-60% VOCs |
| Boston Fern | Formaldehyde, Xylene | Up to 80% formaldehyde |
| Tulsi (Holy Basil) | Carbon Dioxide ($CO_2$), Carbon Monoxide (CO), VOCs | Approx. 20-30% $CO_2$ and VOCs |
| Areca Palm | Toluene, Xylene, Carbon Dioxide ($CO_2$) | 50-60% VOCs |
| Rubber Plant | Formaldehyde | 50-70% formaldehyde |

## RESULTS

The level of pollutants before and after Phytoremediation were evaluated.

### Before Phytoremediation

1. VOC Levels (e.g., formaldehyde, benzene): Formaldehyde levelrange was 0.03 to 0.15 parts per million (ppm), while benzene and other VOCs between 0.002 to 0.02 ppm.

2. $CO_2$ Levels: $CO_2$ range between 400 to 1,000 parts per million (ppm).
3. Particulate Matter (PM2.5): PM2.5 levels in indoor environments was in between 10 to 30 µg/m³

**After Phytoremediation**

1. VOC: level reduced by up to 50-90% over a period of weeks. For example, formaldehyde levels dropped from 0.1 ppm to 0.02-0.05 ppm.
2. $CO_2$ :Reduced by 10-25
3. Particulate Matter (PM2.5): 20-30% decrease in PM2.5

## CONCLUSION

Phytoremediation offers a natural, sustainable solution for reducing indoor air pollution, making it an attractive alternative to mechanical air purification systems. Through the absorption and breakdown of airborne pollutants like volatile organic compounds (vocs), carbon dioxide ($CO_2$), and particulate matter, plants such as the snake plant, spider plant, and peace lily contribute to healthier indoor environments. Results show that before Phytoremediation the VOCs was 0.1 ppm formaldehyde while after Phytoremediation it was 0.02-0.05 ppm formaldehyde (70-80% reduction).$CO_2$ also 800 ppm before was reduced to 600-700 ppm (10-25% reduction).

While not a replacement for traditional ventilation and air purifiers, phytoremediation can complement these systems by continuously improving air quality without energy consumption. However, its effectiveness is influenced by factors such as plant type, quantity, and environmental conditions, suggesting the need for further real-world research. Integrating air-purifying plants into living spaces offers a low-cost, eco-friendly approach to reducing air pollution, ultimately enhancing health and well-being. Further research is needed to quantify the real-world effectiveness of this approach in diverse residential settings.

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# Environment & Sustainability

## Climate Change – Mitigation and Adaptation

189_IEC89545

# Impact of Metrological Parameters on Tea Yield in Assam (India)

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***Abstract:*** *India, specifically the northeastern part, is one of the top contributors to the growth and supply of tea across the world. To achieve a high yield of good quality tea in the tea gardens controlling various auxiliary parameters are of utmost significance. A model of how crops react to weather is necessary to predict the potential impacts of climate change on crop output. Utilizing different models techniques that have been trained on past yields and some standardized meteorological parameters, such as maximum and minimum temperature, rainfall, mean wind speed, sunshine hour, mean Evaporation etc. In order to achieve above-mentioned goal various parameters from the year 2010 to 2021 has been collected from (Borshilla, Borkatonee, Koombar and Tezpur) and analyzed in this paper using statistical & schematic modeling. It seemed that climate conditions had a significant impact on tea production. The four Assamese tea-growing regions' total rainfall, sunshine duration, maximum temperature, minimum temperatures have a major impact on tea produced. Among the statistical models, Time series Analysis and MLR models produced the best fits for monthly yields, probably indicates that the multivariate time series models may be better suited for expressing the short-term variations and long-term variations in the time series.*

374_xxxxxxxxx

# Dam Safety Act-2021 — Dam Rehabilitation & Improvement Project (DRIP of Govt. of India ): Practical Issues Related to Implementation

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***Abstract:*** *This article deals with the activities of human beings towards harnessing the huge water resources as well as saving them from devastating floods. Saving the peoples & properties from devastating floods definitively comes under a major activity of Disaster Management and all major dams play a very important role in mitigation through moderation of huge inflows. Construction of dams across a river started in the world from the ancient ages and with the result the world has created about 57000 major dams where India stands in 3rd position in the World with about 6000 or more major dams. Dams are assets of our country, and some are very old and serving the nation for last 50-60 years to a great extent. Many steps were earlier taken by the Govt of India in ensuring the safety & maintenance aspects of dams. But in the recent years, with the initiative of Ministry of Jal shakti ( Central water Commission), enactment of Dam Safety Act-2021 has been possible and the whole scenario has been changed and it has now become mandatory by all dam owners (generally States) to ensure the safety & proper maintenance of dams being operated by them. Further with the start of Dam Rehabilitation & Improvement Project (DRIP) in association with World Bank, funds have been arranged by Govt. of India for a large scale maintenance & ensuring all safety aspects of some of the major dams of our country.*

*So, in this article most of the aspects of Dam safety act and DRIP project in phases (Phase-I completed in 2021) has been highlighted. Presently, under DRIP-II & III projects ( duration 10 years), about 19 states and 3 Central agencies are participating (considered 736 dams). This article also highlighted some of the important issues or ground realities being faced by dam Owners in implementation of the DRIP scheme as per the guidelines of Central water Commission & World Bank.*

*It is really a very welcome approach of Ministry of Jal Shakti & Ministry of Water Resources & Ganga Rejuvenation, Government of India for realising the necessity of such activities with not only the enactment of Dam Safety Act, but taken up a large scale project DRIP for its implementation.*

***Keywords:*** *Dam Safety Act; DRIP; CPMU; SPMU; NHP; RTDAS; RTDSS*

## INTRODUCTION

### Civilisation with Water & Role of Dams

Under this chapter basically described the gradual growth of human beings through various civilisation along the banks of rivers with construction of dams across rivers basically to moderate floods and harnessing the water resources for drinking purpose & food production all over the world including our country.

This chapter also elaborate the history of construction of dams across rivers is very old as demand of people increases many folds with the population rise. Severe draughts with scarcity of water & lack of food production were the main reasons behind the construction of dams. Here name of some of the oldest dams have also been mentioned. Here it has also been mentioned how & why the demand of water & dams increased gradually due to population growth.

### Scenario during Before & after Independence of India

This chapter describes some of activities & initiatives taken up by Government before and just after the independence. It also highlights some of the names of river valley projects constituted during the period. Role of DVC in Nation building in last 70 years converting a river of sorrow to river of prosperity i.e. Damodar and always made a point of interesting discussion in social media during flood periods. A very few points on this issue will be discussed in the paper.

**Role of Government of India**

This chapter basically elaborates the role of Govt after the independence and problems faced with due to the floods & sharing of water in our country with respect to many rivers. The reasons of non- resolving the issues were also highlighted.

**Dam Safety Act-2021**

This chapter elaborates the earlier bodies constituted and finally the enactment of Dam Safety Act-2021. Here some of the provisions of Dam safety Act has been elaborated with introduction of projects like Dam Rehabilitation & Improvement Project (DRIP) & National Hydrology Project (NHP) brought by the Ministry of Jal Shakti, Govt, of India. The purpose of these projects were highlighted in this chapter a glimpse is those points are as below:

**Implementation of DRIP Project- Components**

As stated above the DRIP, Phase-I had the following main components:

**Component-I** — Rehabilitation of dams and Associated Appurtenances — Direct repair & rehabilitation of dam & associated all structures as per the guidelines of World Bank & CWC

**Component-II** — Dam Safety Institutional Strengthening — This included customised trainings, capacity building of Academic Institutions, preparation of guidelines & Manuals, DHARMA, SHAISYS, Logistic support to various DSO (Dam safety Organisations), Dam Safety Conferences.

**Component-III** —— Project Management — Support SPMU for activities related to procurement of goods and services, Consultancy services, Operating Costs, Outsourcing of support staff, Payment of audit fees, Office expenses such as purchase of computers, printers, office stationary etc., Expenses towards meetings, Miscellaneous expenses.

Under DRIP-Phase-II & III ( 2021-2031); One more component has been added as —"Incidental revenue Generation for Sustainable operation and maintenance of dams" as **Component-III** other components are similar in nature keeping Project Management as Component-IV.

**METHODOLOGY**

**Process of Implementation of DRIP Project by a Dam Owner**

Under this chapter the entire process of DRIP were elaborately explained considering the provisions of Dam safety Act & roles of different agencies. Some are as below:

As per the provision under Dam Safety Act, formation of a "State Project Monitoring Unit (SPMU)" by dam owner is mandatory, which will choose the dams to be considered under DRIP and names of such dams are sent to "Central Project Monitoring Unit (CPMU)" with the request for inclusion into DRIP.

After the confirmation of inclusion of any dam or a number of dams, the process of work implementation under DRIP by Dam Owner have been elaborately explained in a sequential manner as under:

1) Formation of a Dam Safety Review Panel (DSRP) from the list of experts as finalised under Dam Safety Act and complete the process of formation of a DSRP by SPMU.
2) On request of SPMU, DSRP team visit the specific dam or dams for physical inspection at site along with the representatives of SPMU. All available data report, design & drawings etc. are to be submitted to SDRP by SPMU in advance. A preliminary report of DSRP is submitted initially and finally after some studies such as flood review, etc. final report is submitted by DSRP.

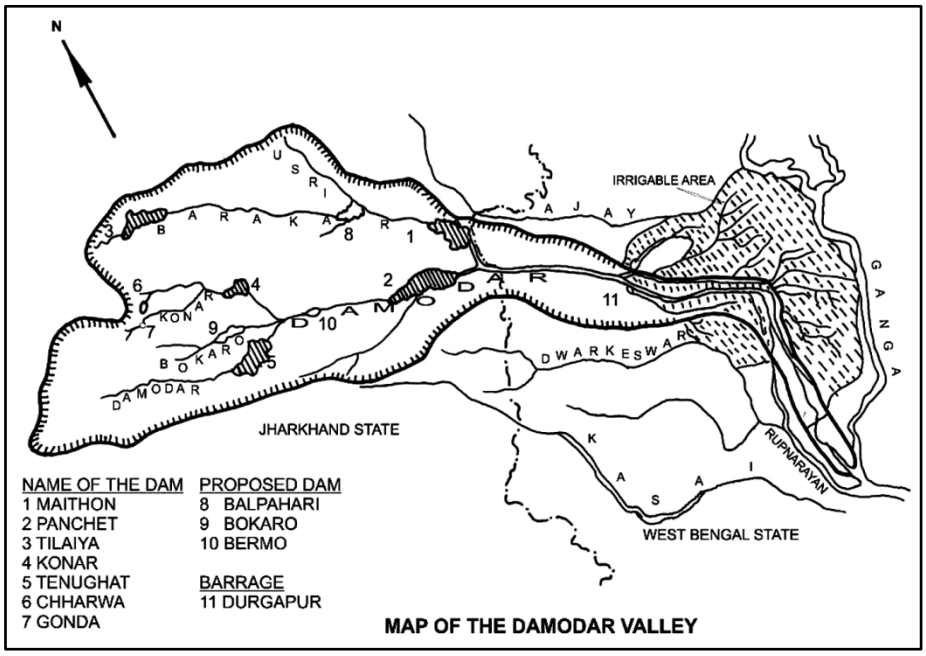
## RESULTS

### Issues Related to Implementation of DRIP – Some Ground Realities

Under this chapter the ground realities facing in actual implementation of this project DRIP by various agencies at different levels have been highlighted. Some are as below:

The issues have been identified and faced as per the experience gathered in the execution of DRIP-I project & later on in DRIP-II & III projects. Some of the issues are as under:

1) Availability of data: In most of the old dams practically no or very less data are available related to its design & drawings, not only historical but even the current rainfall & run-off data, sedimentation survey data, maps of catchment, the very purpose of creating dams with project reports etc. are not available. Data related to present & future demand & supply of water, past inflow flood intercepted & controlled etc. are also not available in many dams. Therefore in most of the cases reverse engineering become necessary. As it becomes a very difficult task by SPMU, it should be included as part of DRIP project.
2) In maintaining the above sequence of activities it becomes very difficult for SPMU to submit even initial PST, as it involves a lot of money in carrying out investigations as recommended by DSRP & reverse engineering etc. Therefore, many incomplete PSTs are initially submitted without following the above sequencing and demands are placed for incurring expenditures towards investigation & all studies, health check up etc. So it will be easier if the phases of PSTs are allowed to be submitted under DRIP as one initial PST ( including the cost of studies & investigations) with basic data as per availability and then final PST completing all recommended studies & investigations. CPMU & World bank may help in this regard.



MAP OF THE DAMODAR VALLEY

**Three Major DVC Dams — Maithon, Panchet & Konar Completed under DRIP-I in 2021**

## CONCLUSION

Final Conclusion as in the original document are placed here exactly as below:

So now after completing DRIP-I project successfully and trained many officials of SPMU, inclusion of a large number of technical institutions (IITs, & NITs), CSMRS, CWPRS etc. it is felt that such above mentioned situations will not arise in future in DRIP-II & III projects, if the above sequencing is followed by SPMU with the help of CPMU & their team with the experts of new EMC-SMEC-STUCKY.

De-Centralisation in CPMU & opening of regional offices at various places to review the activities in details of a vast no. of dams i.e. 736 all over India was a very welcome decision of the CWC, Ministry of Jal Shakti. Therefore, frequent inspection of CS/QA experts of EMC of CPMU posted at regional centres near to the dam sites will be possible as are very much necessary to maintain a good quality of work, following the proper construction methodology, technical specifications & guidelines. It must be remembered that such works in dams are being taken up by the Govt. of India with the involvement of huge funds, even after 50 years of commissioning of old dams and may not be taken up frequently in such a vast scale.

Role of Central Water Commission (CWC) under Ministry of Jal Shakti & Ministry of Water Resources & Ganga Rejuvenation, Government of India, are really appreciable and were the force behind the enactment of "Dam Safety Act". The enactment of Dam Safety Bill and start of DRIP project are really some extraordinary attempts taken up by the Govt. of India in saving and utilising our great assets dams & barrages, which are serving our nation over the years and such attempts will increase the life of these assets in future and people will be benefitted in many ways including moderation of huge devastating floods.

But we have long way to go further, as under DRIP project till now only 959 dams have been considered, whereas there are not less than 8000 major dams are situated in different parts of our country. So, it may be considered as a beginning of a marvellous attempt by the Central Government and being implemented by Dam Owners towards restoration of our national assets (Dams & Barrages) .

**ACKNOWLEDGEMENT**

The views expressed in this article is solely of the Author and no way related to the views of any organization or any Stakeholders and data placed are tentative as collected from various published documents.

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# Environment & Sustainability

# Environmental Pollution and Management

45_IEC51255

# Novel Approaches: Shipborne Oil Slick Detection and Mitigation

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***Abstract:*** *Marine ecosystems and coastal communities face catastrophic consequences from oil spills caused by ship collisions, grounding, and rig leaks. Effective prevention and detection strategies are crucial to reduce the risk of oil spills. Various treatment strategies such as booms, skimmers, in situ burning, adsorbents, dispersants, and bioremediation are used. The chosen treatment approach depends on factors like oil type, spill volume, location, weather, and sea conditions, in addition to technique efficacy. Detection methods involve satellite imaging and sensor technologies. The primary goal is to protect marine life, prevent shoreline contamination, and facilitate oil degradation.*

***Keywords:*** *Oil Slick; Biocides; Skimming; Optical Sensors; Sorbents*

## INTRODUCTION

The pathways of oil into the waterways are varied, ranging from accidental spills to deliberate discharges. Once oil enters seawater, it can wreak havoc on marine life, causing irreparable harm to delicate ecosystems. However, oil spills in lakes, rivers, streams, estuaries, and wetlands pose an equally significant threat, contaminating drinking water sources and imperiling human health. The sheer scale of this environmental catastrophe is staggering, with thousands of oil spills occurring annually due to the massive transportation of oil between producing and consuming nations. These spills encompass a wide range of oil products, from crude oil to refined fuels like diesel, gasoline, kerosene, lubricating oil, and jet fuels, each with its unique toxic profile. For example, numerous distinct toxic substances are reported in crude oil such as aliphatic and polycyclic aromatic hydrocarbons (PAHs), polar chemicals, heavy metals, and persistent volatile compounds. **Table 1** categorizes offshore oil spills into distinct types.

## SPILL DETECTION TECHNIQUES

With the increasing volume of offshore oil exploration and transportation, effective oil spill detection methods are essential to safeguard the world's oceans and waterways. **Table 2** highlights the evolving nature of oil spill detection.

## METHODS OF PREVENTION

It includes various techniques to mitigate oil contamination:

(a) Skimming: Oil skimming is the process of removing floating oil from a liquid surface using a machine. Various types of industrial oil skimmers exist, and selecting the appropriate one depends on factors like temperature, pH, and chemical presence. Effective oil skimming maximizes oil removal, minimizes costs, and extends water life, enabling reuse. Cleaned oil can be repurposed, reducing waste and pollution. Oil skimming also ensures equipment runs smoothly, maintains production uptime, and prevents environmental contamination. By choosing the right oil skimmer, industries can optimize operations, reduce costs, and contribute to a more sustainable future.

(b) Oil booming: An oil boom is a temporary, floating barrier designed to contain oil spills, mitigating pollution risks in water bodies. It consists of a floating partition and submerged curtain, in various configurations for different conditions. Three main types exist: hard boom for deflection, sorbent boom for absorption, and fire boom for containment and burning. Combining absorbent materials and mechanical devices enhances effectiveness. Ongoing research focuses on biodegradable and eco-friendly boom materials for sensitive ecosystems. As the primary defense against oil spills, oil booming protects marine environments and coastal areas, playing a crucial role in pollution prevention and mitigation.

(c) Emulsification: Emulsification is the process of breaking down oil into smaller droplets, mixing with water, and promoting biodegradation. Chemical dispersants can be used to induce emulsification, and are applied through aerial spraying, boat-based spraying, or subsea injection. These methods help prevent oil slicks from forming and spreading, reducing pollution and protecting marine ecosystems. Emulsifiers play a crucial role in safeguarding oceans, particularly in the context of maritime activities. By breaking down oil into smaller droplets, emulsifiers facilitate natural biodegradation, upholding the integrity of shipping lanes and ports, and protecting marine life and coastal environments for future generations.

(d) Bioremediation: Bioremediation is a promising approach to prevent and mitigate oil spills in oceans, utilizing microorganisms, plants, or enzymes to break down oil into harmless components. Bioremediation restores marine ecosystems, preserves biodiversity, and promotes sustainable aquatic life. It also reduces the risk of oil contamination, protects shorelines, and safeguards human health. Additionally, bioremediation enhances water quality, supports fisheries, and maintains the aesthetic value of coastal areas. By leveraging natural processes, bioremediation provides a long-term solution to oil spills, minimizing ecological damage and supporting the well-being of marine environments.

(e) Dispersants: The use of dispersants is a crucial method for preventing oil spills in oceans. Dispersants break down oil into smaller droplets, increasing its surface area and enhancing natural biodegradation. This approach reduces oil slicks, prevents shoreline contamination, and minimizes harm to marine life. Dispersants can be applied aerially or from boats, allowing for rapid response to spills. By dispersing oil quickly, the risk of long-term environmental damage is significantly reduced. Additionally, dispersants can reduce the amount of oil that reaches shorelines, protecting coastal ecosystems and preserving water quality. Effective dispersant use is a key strategy in mitigating oil spill impacts.

## COST OF EQUIPMENT

The cost analysis of oil spill prevention and response equipment involves considering various factors, including the initial investment, maintenance, and operational costs. The costs of equipment, personnel, and training are compared to the potential costs of oil spills, including cleanup, restoration, and legal liabilities. Additionally, the theory of risk management is applied, considering the likelihood and potential impact of oil spills, as well as the effectiveness of different prevention and response strategies. Ongoing maintenance and training costs add to the overall expenditure. However, these investments pale in comparison to the potential costs of oil spills, which can be catastrophic. By investing in prevention methods, organizations can mitigate risks and avoid enormous expenses, making proactive measures a cost-effective approach to oceanic oil spill prevention.

## CHALLENGES

The methods to prevent the oil pollution faces numerous challenges that are hindered by factors such as harsh weather conditions, oil properties, and oceanic dynamics. Emulsification is affected by oil type and salinity, while skimming booms are limited by wave height and oil viscosity. Bioremediation is slowed by nutrient availability, temperature, and microbial dynamics. Additionally, the vastness of oceans, complex currents, and tides disperse oil, making containment and treatment difficult. These obstacles underscore the need for continued research, technological advancements, and collaborative efforts to develop effective oil spill prevention and mitigation strategies that can address the unique complexities of oceanic environments and protect marine ecosystems.

**Table 1** Sources of oil spill [7]

| TYPE OF OIL SPILL | SOURCE | RESULT |
|---|---|---|
| CATASTROPHIC SPILLS | Major offshore platform accidents, tanker collisions | Massive oil slicks, widespread marine life deaths, coastal devastation |
| CHRONIC SPILL | Offshore equipment failure, corrosion, human error | Long-term marine ecosystem damage |
| NATURAL SEEPS | Seafloor oil seepage, offshore geological activity | Minimal environmental impact |
| ILLEGAL DISCHARGES | Intentional dumping of oil/oily waste from offshore vessels | Severe marine pollution, wildlife harm, legal consequences |

**Table 2** Detection techniques for oil spilling [6]

| DETECTION METHOD | TYPES | PROCESS | REMARK |
|---|---|---|---|
| **MICROWAVE SENSORS** | a) Passive Microwave Radio<br>b) Active Microwave Radar<br>c) SAR (Synthetic Aperture Radar) | a) Measures thermal radiation emitted by oil, distinguishing it from water.<br>b) Uses radar pulses to detect oil's dielectric properties<br>c) Uses radar pulses to detect oil's dielectric properties, even in cloudy or foggy conditions. | a) Useful for large-area surveillance, but limited by atmospheric conditions.<br>b) Effective for oil detection, but sensitive to weather and sea state.<br>c) Effective for oil detection, regardless of weather conditions, but sensitive to sea state and oil thickness. |
| **LASER FLUOROSENSORS** | a) Laser-Induced Fluorescence (LIF)<br>b) Ultraviolet (UV) Fluorosensing | a) Excites oil's fluorescent properties, detecting its presence.<br>b) Emits UV light, measures fluorescent response. | a) Highly sensitive, but limited by water depth and turbidity.<br>b) Effective for surface oil detection, but limited by water depth |
| **OPTICAL REMOTE SENSING** | a) Visible-Infrared (VIS-IR) Imaging<br>b) Hyperspectral Imaging | a) Detects oil's reflectance and absorption properties.<br>b) Analyzes detailed spectral signatures to identify oil. | a) Useful for surface oil detection, but limited by atmospheric conditions.<br>b) Highly effective for oil detection and identification, but requires advanced processing. |

## CONCLUSION

Oil prevention and detection in oceans are critical components of a comprehensive strategy to protect marine ecosystems. Emulsification, skimming, oil booms, bioremediation, and sensing systems, offer effective solutions for preventing and detecting oil spills. By integrating these approaches, which can minimize the impact of oil pollution on marine life and ecosystems. Ongoing research, innovation, and international collaboration are essential to stay ahead of emerging challenges and ensure the long-term health of our oceans.

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56_IEC19323

# Decarbonizing the Maritime Industry: The Way Ahead

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***Abstract:*** *Shipping accounts for 11% carbon dioxide emissions in the transportation sector and is likely to surge by 50% by 2050 if proactive measures are not taken, mainly due to the increase in global trade and the demand for maritime carriage of goods. Maritime decarbonization is the process of reducing greenhouse gas (GHG) emissions from the global maritime sector, with an overall goal of placing the sector on a pathway that limits global temperature rise to 1.5°C. Shipping is hard to decarbonize due to the wide spectrum in vessel types and sizes, the large amounts of energy they use, and the inherently global nature of maritime transport that necessitates working across geographies. The maritime transportation sector primarily relies on fossil fuels like marine gas oil and heavy fuel oil (HFO) and the combustion of HFO releases harmful gases including carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$), all of which contribute to the problem of climate change. Scaling up investment in new ships (hull form, engines, onboard technologies, crew skills), energy supply and bunkering infrastructure (i.e., alternative fuels availability and supply through dedicated and adequate production, bunkering facilities, and storage) is crucial.*

***Keywords:*** *Decarbonization; Greenhouse Gas; $CO_2$; Heavy Fuel Oil; Alternative Fuels*

## INTRODUCTION

Shipbuilding is a capital-intensive industry with several chemical and hazardous material exposures. Most of the traditional production processes such as Welding, Painting, Blasting and Fiberglass production have direct impacts on workers' health and safety as well as adverse effects on environment. The global shipping sector has a large potential to usher in a synchronized technology change and energy shift, guided by just and equitable transition objectives. If the international community can advance with a predictable regulatory framework and agree on clear, cost-effective technical and economic measures, the sector will minimize uncertainty and reduce transition costs.

## METHODOLOGY

The emission level depends on various factors like size, type of ships, dead weight, energy efficiency, fuel used, operational conditions and the distances they cover. Cargo ships are reported to produce 16.14 grams of $CO_2$ per kilometer for each metric ton of cargo they carry, while container ships release an annual average of 140 million metric tons of carbon dioxide and bulk carriers contribute a total of 440 million metric tons of carbon dioxide emissions each year. Various processes in ship building badly affects the environment. The activities in shipbuilding that are of highest direct environmental concern are Metal working activities, including thermal metal cutting, welding and grinding, Surface treatment operations, including abrasive blasting, coating and painting, Ship maintenance and repair activities, such as bilge and tank cleaning and noise. The Engine Room is the primary source of GHG emissions due to fuel combustion in the main engine, auxiliary engines, and boilers (around 80-90% of total GHG emissions). The Funnel releases exhaust gases from the Engine Room (5-10%) and Cargo Handling Equipment (2-5%) and other sources (1-3%) also emit GHGs, but to a lesser extent.

Decarbonization is the process of reducing carbon dioxide and other greenhouse gases emitted by burning fossil fuels, is therefore a critical focus for the shipping industry. The decarbonization of the shipping industry presents a complex array of challenges. Unlike other sectors where electrification offers a viable pathway to reducing emissions, the shipping industry's reliance on high-energy-density fuels, such as heavy fuel oil (HFO), for long-haul voyages poses a significant obstacle. Additionally, the diverse nature of the shipping fleet, ranging from small coastal vessels to large ocean-going ships, means that a one-size-fits-all solution is not feasible.

The International Maritime Organization (IMO) has implemented amendments to the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, which came into force on November 1, 2022. These

amendments aim to reduce greenhouse gas (GHG) emissions from ships, a significant contributor to global pollution. To achieve a 40% reduction in carbon intensity by 2030 relative to 2008 levels, (IMO) has mandated two key performance metrics for ships:

Energy Efficiency Existing Ship Index (EEXI): A mandatory rating system assessing a ship's energy efficiency, calculated based on its design and operational parameters. The attained EEXI of a ship represents its energy efficiency relative to a predetermined baseline. This value is then compared to a required EEXI, which is derived from the Energy Efficiency Design Index (EEDI) (it sets a minimum energy efficiency standard for new ships, ensuring they meet a certain level of energy efficiency) baseline and adjusted by a reduction factor expressed as a percentage. This reduction factor is specific to each ship type and size category. In accordance with regulatory requirements, the attained EEXI must be calculated for all ships with a Gross Tonnage (GT) of 400 or above. The calculation methodology takes into account various ship-specific parameters, including hull form, propulsion, and operational characteristics. To ensure compliance, the calculated attained EEXI value for each individual ship must be less than or equal to the required EEXI. This ensures that the ship meets the minimum energy efficiency standard, as mandated by the IMO.

Carbon Intensity Indicator (CII): An annual rating system measuring a ship's operational carbon intensity, calculated as the ratio of total greenhouse gas (GHG) emissions to the product of cargo capacity and distance traveled. The CII rating provides a standardized framework for evaluating a ship's carbon intensity, incentivizing shipowners and operators to implement energy-efficient technologies and operational best practices. By complying with these regulations, the shipping industry can significantly reduce its carbon footprint and contribute to a more sustainable maritime transportation system."

IMO has established a comprehensive strategy to mitigate greenhouse gas (GHG) emissions from international shipping. The 2023 IMO GHG Strategy outlines a clear vision for reducing emissions, with a focus on achieving net-zero GHG emissions as soon as possible. To achieve this goal firstly, the carbon intensity of new ships will be improved through enhanced energy efficiency measures, with a review of the energy efficiency design requirements for ships. Additionally, the carbon intensity of international shipping will be reduced, aiming to decrease CO2 emissions per transport work by at least 40% by 2030, relative to 2008 levels. Furthermore, the strategy emphasizes the uptake of zero or near-zero GHG emission technologies, fuels, and/or energy sources. The aim is to increase their share in the energy mix used by international shipping to at least 5%, with an aspirational target of 10%, by 2030. Ultimately, the strategy seeks to reach net zero GHG emissions from international shipping by or around 2050.To monitor progress, the strategy establishes indicative checkpoints. By 2030, total annual GHG emissions from international shipping should be reduced by at least 20%, with an aspirational target of 30%, compared to 2008 levels. By 2040, this reduction should increase to at least 70%, with an aspirational target of 80%, relative to 2008 levels. These checkpoints will ensure the shipping industry remains on track to meet its emissions reduction targets.

The International Maritime Organization (IMO) is working to reduce emissions from ships. In 2022, the IMO created a special zone in the Mediterranean Sea to limit sulfur and particle emissions. This zone is important because it's a busy shipping area, with 20% of global trade passing through it. The European Parliament has also taken action. They've expanded the EU's Emissions Trading System to include ships. This means that ships over 5,000 tons operating in European waters must report their greenhouse gas emissions and buy allowances to cover them. These changes aim to reduce the shipping industry's impact on the environment. By limiting emissions, we can improve air quality and help combat climate change. The IMO and European Parliament are working together to make shipping more sustainable.

**RESULTS**

Decarbonizing the maritime shipping industry is a complex challenge that requires collaboration from ship operators, governments, and innovators. Despite the challenges, progress is being made towards a more sustainable future. Regulatory pressure, market forces, and environmental awareness are driving this change. The industry is working together to reduce emissions and develop new technologies. While there's still much work to be done, the momentum towards a low-carbon future is building. A multifaceted approach is necessary for achieving the goal, encompassing

the harnessing of renewable energy sources, such as wind and solar power, to assist in propulsion and generate clean electricity. Furthermore, the transition to transition towards eco-friendly practices. By adopting a holistic approach, the shipping industry can mitigate its cleaner alternative fuels, including liquefied natural gas (LNG), hydrogen, and biofuels, is crucial. Optimizing vessel design and equipment, leveraging slow steaming, and embracing technological innovations will also enhance fuel efficiency. Additionally, supportive policy measures, such as carbon offset projects, financial incentives, and carbon pricing, will facilitate the environmental impact and achieve the IMO's vision of a sustainable and net-zero emissions future.

## CONCLUTIONS

The decarbonization of the shipping industry is an urgent and necessary response to the global climate crisis. By leveraging a combination of technological innovations, regulatory frameworks, and market-based mechanisms, the industry can reduce its carbon footprint and contribute to global efforts to mitigate climate change. This paper highlights the need for a collaborative approach, involving all stakeholders, to overcome the challenges and seize the opportunities presented by this transition. The future of shipping depends on its ability to adapt and innovate in response to the pressing need for decarbonization. With continued effort, the shipping industry can reduce its environmental impact and contribute to a more sustainable world.

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# Exploration and Optimisation of Eco-Friendly Dyeing with Natural Indigo

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**Abstract:** This study explores sustainable alternatives to conventional indigo dyeing methods and addresses the environmental concerns associated with conventional indigo dyeing processes, particularly the harmful effects of using sodium hydrosulphite as a reducing agent. By exploring natural alternatives such as Indian madder and honey, the research highlights the potential for eco-friendly practices in textile manufacturing. Indian madder demonstrated superior reduction potential and dye stability, producing rich indigo shades with minimal environmental impact. These findings offer sustainable pathways to mitigate pollution in denim production.

**Keywords:** Indigo; Madder; Reduction; Sustainable; Vat Dye

## INTRODUCTION

Textiles have long been a major consumer product, with a rich history spanning centuries. However, a troubling aspect of this history is the textile industry's significant contribution to pollution, dating back to the Industrial Revolution in the late eighteenth century. Denim made from cotton fibre are biodegradable, but their production remains far from eco-friendly behaviour. During the dyeing process, indigo is converted into a water-soluble form known as leuco indigo by adding a reducing agent in alkaline conditions (pH~10-12). Sodium hydrosulphite is the most commonly used reducing agent due to its cost-effectiveness but has significant drawbacks. It oxidises quickly in air, is flammable during storage, and can corrode wastewater pipelines. During wastewater treatment, sodium hydrosulphite can disrupt aerobic processes and produce toxic hydrogen sulphide from sulphate under anaerobic conditions [1]. Sodium hydroxide is often used alongside sodium hydrosulphite, but it is also harmful to the environment, can corrode concrete waste lines, and adds to the wastewater burden. A typical denim manufacturing plant can generate over 400,000 tons of wastewater annually during dyeing [2]. This wastewater contains high levels of salt, 20–30% of the original indigo dye, and traces of metals. The wastewater is problematic because of its high chemical oxygen demand (COD) and elevated pH, making it unsuitable for reuse or safe disposal [3]. The increasing environmental concerns and the global push towards sustainability have necessitated exploring eco-friendly dyeing techniques.

## FASHION TRENDS WITH INDIGO IN 2024

In 2024, fashion with indigo continues to be a dynamic and influential trend, deeply rooted in both tradition and innovation. Indigo, with its rich historical significance and timeless appeal, remains a staple in the fashion industry, particularly in denim and other casual wear. The fashion industry in 2024 has made substantial strides in adopting sustainable indigo dyeing methods. Traditional indigo dyeing, known for its intensive water use and reliance on synthetic chemicals, is being replaced by eco-friendly processes. Natural indigo, derived from plants such as Indigofera tinctoria, is gaining popularity as a sustainable alternative to synthetic indigo [4]. This plant-based dye not only reduces the environmental impact but also supports sustainable farming practices and biodiversity. Innovative dyeing technologies are also at the forefront of the indigo fashion trend in 2024. Techniques like foam dyeing and spray dyeing have become more widespread, significantly reducing water consumption and the use of harmful chemicals. These methods are particularly important in the production of denim. There is a growing appreciation for artisanal and heritage indigo dyeing techniques, which are being revived and celebrated in 2024. Craftsmanship and traditional methods, such as hand-dyeing and resist-dyeing techniques like shibori, are being integrated into modern

fashion collections. These methods not only produce unique, one-of-a-kind pieces but also preserve cultural heritage and provide livelihoods for artisans around the world. Fashion with indigo in 2024 is characterised by a blend of tradition and innovation, with a strong focus on sustainability and ethical practices [5]. The use of natural dyes, innovative dyeing techniques, and circular fashion principles are redefining how indigo is incorporated into modern wardrobes. As a result, indigo remains a powerful and enduring trend in the fashion industry, offering both timeless style and a commitment to a more sustainable future.The present study contributes to developing sustainable textile dyeing with natural indigo that can guide industry stakeholders in adopting environmentally friendly processes to reduce resource consumption and pollution, contributing to a more sustainable future for the textile industry. These methods may also minimise effluent load and enhance the sustainability of textile manufacturing.

## METHODOLOGY

### Materials

The present study used cotton fabric of the following specification, mentioned in **Table 1**.The natural indigo used in the study was obtained from Kumaon Earthcraft, Uttarakhand.

**Table 1** Fabric specification

| Sl. No. | Parameters | Specification |
|---|---|---|
| 1 | Weave | Plain |
| 2 | Material | 60 Ne cotton |
| 3 | Areal density | 140 G.S.M |
| 4 | EPI x PPI | 44 × 47 |

## METHODS

### Scouring of Cotton Fabric

The scouring was performed to remove natural and added impurities from the loom state cotton fabric and make the fabric absorbent.

### Reduction of Indigo with Natural Agent

Indigo dyeing is deeply rooted in complex chemical interactions and traditional methods. Indigo, an organic compound, belongs to the vat dye family, characterised by its insolubility in water in its natural oxidised form [6].The indigo dyeing process begins with the crucial step of reducing indigo to its water-soluble form, known as leuco-indigo. In this study, the reduction was typically achieved by using green reducing agents namely, Indian madder and honey in the presence of potassium hydroxide at a pH level between 11-13.

### Dyeing of Cotton Fabric

The fabric samples were dipped in the dye bath containing leuco-indigo and during dyeing, calcium hydroxide was used instead of potassium hydroxide. To achieve the desired depth and uniformity of colour, the fabric undergoes multiple immersions in the dye bath, each followed by exposure to air to initiate the process of oxidation to convert the leuco-indigo back to its original insoluble indigo form. After oxidation, the fabric was subjected to a series of washing steps to remove any unreacted dye molecules and residual chemicals.

### Measurement of Reduction Potential

Cyclic voltammetry (CV) is a widely used electrochemical technique for analysing the redox properties of chemical species, including organic reducing systems. It provides valuable information about the reduction potentials, which is essential for understanding redox reactions' thermodynamics and kinetics. The reduction potentials of different green reducing agents used in this study were determined in the cyclic voltmeter with platinum as the main electrode and Hg / $Hg_2Cl_2$ as the reference electrode, keeping all the auxiliary parameters constant.

## RESULTS AND DISCUSSIONS

**Table 2** depicts the result of reduction potential on day 0 and day 3 when Indian madder and honey were used as reducing agents in combination with potassium hydroxide. Fabrics dyed in Indian madder in the presence of calcium hydroxide produced a dark blue shade on day 0 and day 3 compared to honey when used as a reducing agent. Indian madder proved to be the most effective reducing agent among those tested, ensuring strong and enduring colour stability of indigo and giving bright shades of indigo. Honey vat produced light shades of blue, fading further on day 3. The reduction in shade intensity suggests that honey, while capable of reducing indigo, may not provide the strongest or most stable dyeing effect, leading to noticeable fading. Indian madder exhibited a high reduction potential that slightly increased with time, suggesting it maintains and enhances its reducing capability over time, making it highly effective for consistent dyeing results. Overall, the findings emphasised the importance of selecting a reduction system that provides a substantial reduction potential and remains stable to ensure high-quality, consistent indigo dyeing.

**Table 2** Reduction potential and shade achieved by ferrous and honey vat on day 0 and day 3

| Reducing agent | Reduction potential | | pH | No. of dips | Shade achieved (Day 0) | Shade achieved (Day3) |
|---|---|---|---|---|---|---|
| | Day 0 | Day 3 | | | | |
| Indian Madder | – 0.81 v | – 0.83 v | 11–13 | 2 |  |  |
| Honey | – 0.35 v | – 0.31 v | 11–13 | 2 |  |  |

## CONCLUSION

The study underscores the need for sustainable alternatives and draws attention to the adverse environmental effects of conventional indigo dyeing methods. Despite its widespread popularity, the production of denim adds significantly to pollution, particularly when hazardous reducing chemicals like sodium hydrosulphite are used. This study investigates more environmentally friendly reducing systems that substitute conventional reducing agents, viz., sodium hydrosulphite. The system that worked best was Indian madder, which produced rich, consistent colours of blue. On the other hand, honey lost its effectiveness with time. The results highlight the importance of choosing natural reducing chemicals for sustainable indigo dyeing with robust and persistent reduction qualities. This work encourages future research and adoption of green techniques in textile manufacturing by offering a promising path for lowering the denim industry's environmental impact while preserving high-quality dyeing results.

## ACKNOWLEDGEMENT

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# Sound Absorbing Textiles – A Review of Accomplishing Quiet Comfort

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***Abstract:*** *The increasing prevalence of noise pollution, exacerbated by industrial and transportation activities, harms human health and well-being. To mitigate these effects, the development of acoustic materials has gained prominence. Natural and synthetic textiles are being increasingly utilised for sound absorption, reduction, and barrier functions. This review explores advancements in developing sound-absorbing textiles using fibre composites from natural sources such as coconut, banana, ramie kenaf, etc. These fibres are gaining popularity due to their eco-friendly and non-toxic nature. While different synthetic materials like polypropylene and polyurethane are commonly used as matrices in composites, this review explores the potential of substituting these with polymers from natural sources. These innovations highlight the potential of sustainable materials in noise control applications.*

***Keywords****: Acoustic; Composites; Environment; Fibre; Noise Pollution*

## INTRODUCTION

Acoustics derives from the Greek word ‘akoustikos’, which means ‘to hear’. In Latin, ‘acoustic’ also acts as a synonym for the word ‘sonic’. ‘Acoustics’ as a scientific term is the science of sound that constitutes the generation, transmission, and biological or psychological effects of sound waves when the emission occurs in a specific area and its surroundings [1]. The acoustic materials are thus comprised of materials that are involved not only with the principles of generation, emission, transmission, and conversion of sound waves but also help with determining, analysing, and understanding the characteristics, behaviour and effect of a sound wave on the environment.

## MECHANISM OF SOUND GENERATION

A sound wave is characterised by mechanical energy that, during its transmission through solid, liquid, or gas, causes concussive pressure, further generating air compression. This produces vibrations that propagate as a wave through the medium (solid, liquid, or gas) from the emitter to a transmitter [2].

## POLLUTION DUE TO THE GENERATION OF NOISE

Pollution due to the generation of noise has resulted in undesirable consequences on the environment and the health of living beings [3]. Due to the increasing progress in industrial activities, transportation, the use of certain home appliances generating unpleasant noise, and huge traffic in metropolitan cities, noise pollution has thus become one of the major problems encountered by our society. According to the World Health Organization (WHO), continuous and uncontrollable exposure to noise levels above 65 dB hazards the well-being of humans, wildlife and other living beings, resulting in various medical conditions affecting the cardiovascular system, nervous system, loss of hearing ability, anxiety, stress, insomnia, poor concentration, communication, and productivity [4].

## NOISE CONTROL – A NECESSARY ACTION

The need for controlling the exposure towards excessive generation of noise is important for the severely adverse effects on various aspects of the environment. Awareness towards this issue draws the attention of various researchers and manufacturers to search for sustainable methods and materials to develop various acoustic materials that possess the capability of absorbing, reducing or acting as a barrier to the transmission of sound energy [5].

## METHODS OF NOISE CONTROL

The mechanism of controlling noise transmission can be performed in two ways i.e., the active method and the passive method. The active method is performed when two sounds with nearly identical amplitudes interact

destructively; their effects cancel each other out. This technique uses digital signal processing to transfer power from an external source. It works well for regulating low-frequency sounds. On the other hand, the passive method is the process of converting sound energy into thermal energy. It happens when sound waves interact with porous materials, dissipating heat energy due to their void structure. The effectiveness of this method relies on how well the material reduces noise, and it works best with higher sound frequencies [1,3].

## CLASSIFICATION OF MATERIALS PERFORMING AS SOUND ABSORBERS

The sound absorbing materials can be classified based on various categories:

Based on the raw materials

(a) Virgin (natural/synthetic)
(b) Recycled (natural/synthetic)

Based on physical characteristics

(a) Porous absorbers
Solid materials that contain pores or gaps within them which allow the sound wave to enter into them are known as porous sound absorbers. They are either in fibrous (e.g., textile structures prepared from natural, synthetic and natural/synthetic blends), cellular (e.g., foams, polyurethane) or granular (clay, asphalts etc.) form.
(b) Panel absorber
The sound absorbing materials mainly contain flat surfaces with holes present in them. An example of a panel absorber is gypsum. The utilisation of these materials is mainly observed in ceilings, and walls for acoustic application.
(c) Materials coated, sprayed or embedded with fillers
To achieve acoustic properties some materials are often bonded, embedded or coated with certain substances according to their suitability.

**Based on functional characteristics**

(a) Noise absorption type
This type of material suppresses the sound when it passes through.
(b) Noise reduction type
This kind of material reduces the sound when it passes through (Padhye et al., 2016).

## ACOUSTIC TEXTILES

The versatility of textile material has been witnessed in almost every aspect. Textile material either inherently possesses or is incorporated with various functional properties like antimicrobial, fire-resistant/retardant, UV-resistant, wrinkle-resistant, waterproof, water-repellant, and so on [6]. There has been extensive use of textile material, natural or synthetic, woven or knitted or non-woven fibre composites to act as sound absorbers, reducers, or barriers to transmit waves generated by sound energy.

### Evolution of Natural Fibres as Acoustic Panels

Fibre composites produced from natural sources like coconut, banana, ramie, kenaf, etc. are increasingly used as sound-absorbing materials due to their biodegradability, cost-effectiveness, and non-toxicity nature. Moreover, natural fibres with appropriate mechanical properties have been observed to be suitable options for developing composite materials with high performances without causing any harm to society [7].Yang et al. (2012) investigated the acoustic absorption performance of three fabric composites, each made of jute, ramie, and flax fibres. The analysis results were later compared to the performance properties of composites reinforced with glass and carbon fibres for sound absorption coefficient. It was observed that composites made of jute fibre demonstrated the most effective result of sound absorption properties. The sound absorption coefficient was such a high frequency that it

was considered beneficial for aeronautical applications [8]. Jayamani et al. (2013) investigated the sound absorption coefficient of kenaf fibres mixed with two kinds of polymers that influenced the results. The composite showed effective results when compared to glass and mineral fibre composites [8].

**Recycled Textile Waste for Sound Absorption**

The rapid rise in environmental concern due to the growing population of the world has become a severe issue as the rate of consumption is increasing day by day, and using non-biodegradable materials and their disposal as waste after usage leads to a severe increase in landfills [9]. Awareness towards sustainability has resulted in the development of various methods and materials that involve the reuse and recycling of wastes generated from various industries or small sectors as raw materials to reduce the enormous percentage of landfill generation to a certain level. Wastes obtained from the agriculture, textile, and apparel industries are suitable as sound-absorbing materials when manufactured as non-woven composites [10].Researchers also developed non-woven composites by using apparel waste of cotton and polyester fibres as raw materials and polyurethane foam as a binder to produce sound-absorbing and sound-insulating fabrics. The findings showed that the porous nature of the composites retains admirable performance regarding the absorption of high-frequency sound waves. The effect of microfibres obtained from flax wastes was also studied by Gliscinska et al. (2016), where cellulose fibres, i.e., cotton and flax, were used as reinforcement materials and polylactic fibres as a matrix to produce an effective sound-absorbing material. As the sound wave passed through the fibres, vibration occurred, resulting in friction. Thus, the energy conversion mechanism occurred, and the sound energy was transformed into heat energy. Higher sound absorption was obtained with a higher fibre percentage [10].

## CONCLUSION

It is crucial to produce ecologically friendly composites using components derived from renewable resources to benefit the environment and the economy. Natural fibres are grabbing much attention for being used as cost-effective, non-abrasive, lightweight, and biodegradable. However, various synthetic polymers like polypropylene and polyurethane have been observed to be used as matrix material, which can be substituted with various polymers obtained from natural sources.

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# An Investigation on Quantity of Domestic Wastes Generated from Packed Utilities

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***Abstract:*** *The quantity of domestic dry waste generated from all kind of packed food materials as packing covers, usage of medicines, costumes and other commodities contributes a large to the total amount of solid waste generated in a town or city. The disposal of solid waste by the city municipal authorities become a task and cause environmental degradation, flooding and health hazards. So, this study has focused on investigating the total quantity of domestic dry waste generated under Indian urban living conditions and finding ways to recycle the same. The methodology adopted was collecting dry domestic wastes from four different size residences for four months and weighing daily. Accordingly the daily average and monthly average quantity of waste was determined as 16.49 g and 494.78 g respectively per residence. So the quantity of waste to be generated in cities with population of various ranges was also forecasted. Hence it is concluded that there is no waste at our home and all such dry covers, containers, bottles can be recycled through proper storing procedures at our premises without dumping or throwing away to attain the Goals Of Sustainable Development.*

***Keywords:*** *Quantity Of Household Waste; Food Waste; Kitchen Waste; Packing Waste; Costumes Waste*

## INTRODUCTION

Generally we buy various food materials as ingredients for preparing food in terms of packages. It includes covers of milk, oil, biscuits, curd, ginger, garlic, tea, chocolate, masala powder, pepper, sweets etc. We also buy cosmetics as canned and bottled items like shampoo, hair oil, creams, perfumes etc. In addition to these usages, we buy cleaning materials to wash clothes and wash rooms like washing powder, washing liquids as packed items. To safeguard our health we buy packed and bottled medicines. Having considering all these usages, it was decided to collect such covers, containers and bottles and find ways to restore those valuables. Similar studies were carried out by the researchers on; percapita municipal solid waste generation [1], management of food waste [2], household food waste [3], innovations in food waste management [4], challenges and priorities of municipal solid waste management in Combodia [5], quantity of food and vegetable wastes [6], impacts caused by food wastes [7], quantity of wastes generated at residences [8], food waste generation is a critical issue in urban centres [9], household solid waste generation [10], household food wastes [11] and household solid waste management [12].

## MATERIALS AND METHODOLOGY

The packed covers of ingredients for food preparation, plastic bottles of cosmetics and wash rooms, glass bottles of medicines etc were collected daily from four different size residents for four months viz. December 2023, January 2024, February 2024 and March 2024. These covers, plastic containers, glass bottles were weighed daily and the daily average and monthly average quantity of wastes determined. So, it is essential to forecast the quantity of domestic wastes generated in urban centres. Accordingly the proposed quantity of domestic dry wastes generated in cities with respect to their population was forecasted.

## RESULTS AND DISCUSSIONS

The collected covers, containers and bottles from four residences for four months were weighed and tabulated daily. So the weighed observations are shown in figures 1, 2, 3 & 4 for the month of December 2023, January 2024, February 2024 & March 2024.

Hence the collected materials from residences 1, 2, 3 & 4 for the month of December 2023 were 933.50 g, 245.50 g, 438.80 g and 161.60 g respectively. Its average weight was 444.85 g.

The materials from residences 1, 2, 3 & 4 for the month of January 2024 were 636.0 g, 121.0 g, 463.50 g and 237.50 g respectively. Its average weight was 364.50 g.

The materials from residences 1, 2, 3 & 4 for the month of February 2024 were 437.0 g, 372.6 g, 895.50 g and 291.50 g respectively. Its average weight was 499.15 g.

The materials from residences 1, 2, 3 & 4 for the month of March 2024 were 1274.0 g, 305.0 g, 727.50 g and 376.10 g respectively. Its average weight was 670.65 g.

All together the monthly average weight of materials was 494.78 g. Using the daily average weight of 16.49 g, the quantity of wastes to be generated in cities with population range from 10 lakhs to 130 lakhs for an year were also forecasted.

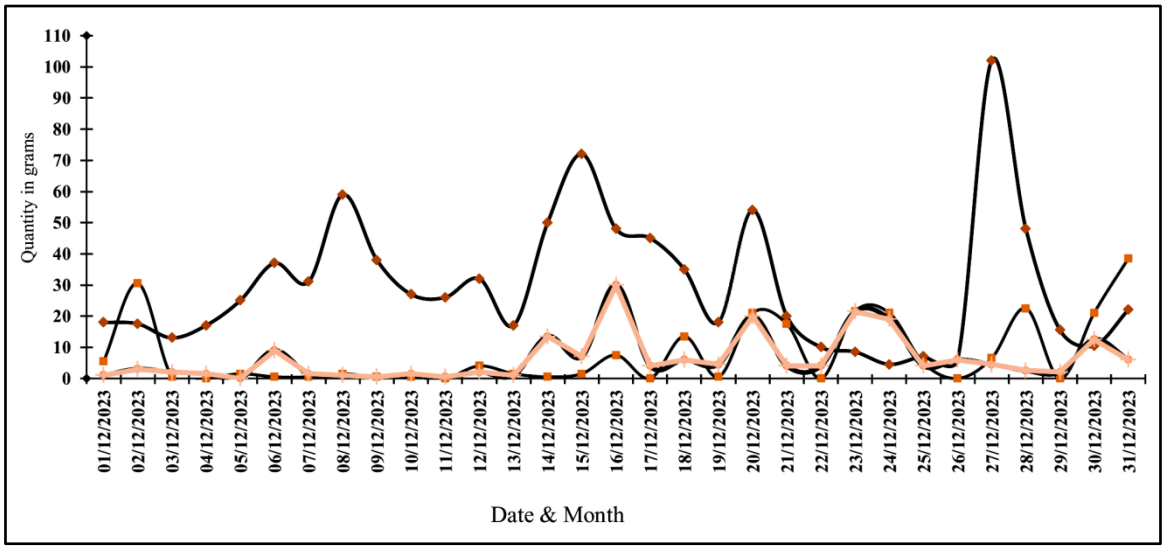


**Figure 1** Quantity of dry domestic waste generated in the month of December 2023 form four residents

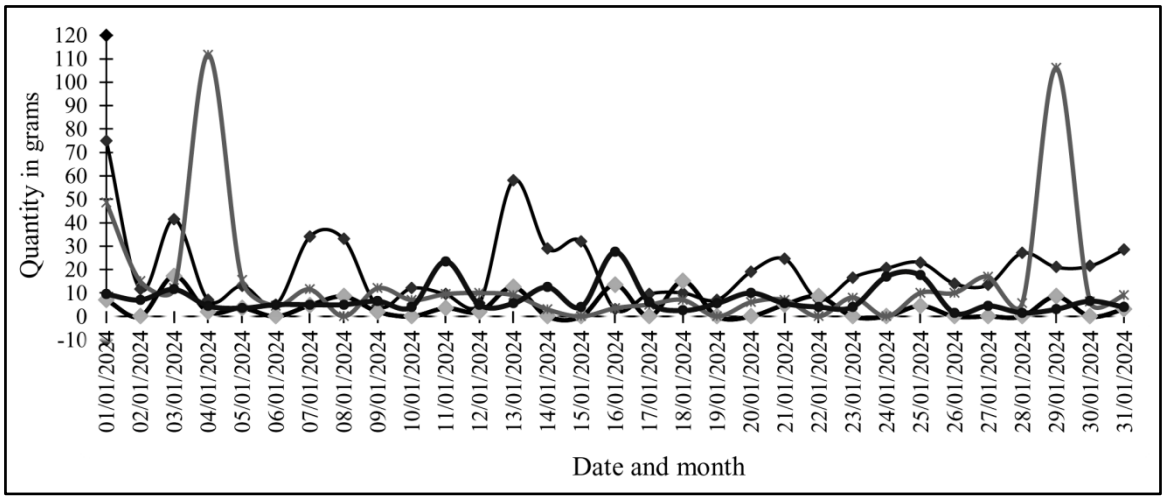


**Figure 2** Quantity of dry domestic waste generated in the month of January 2024 form four residents

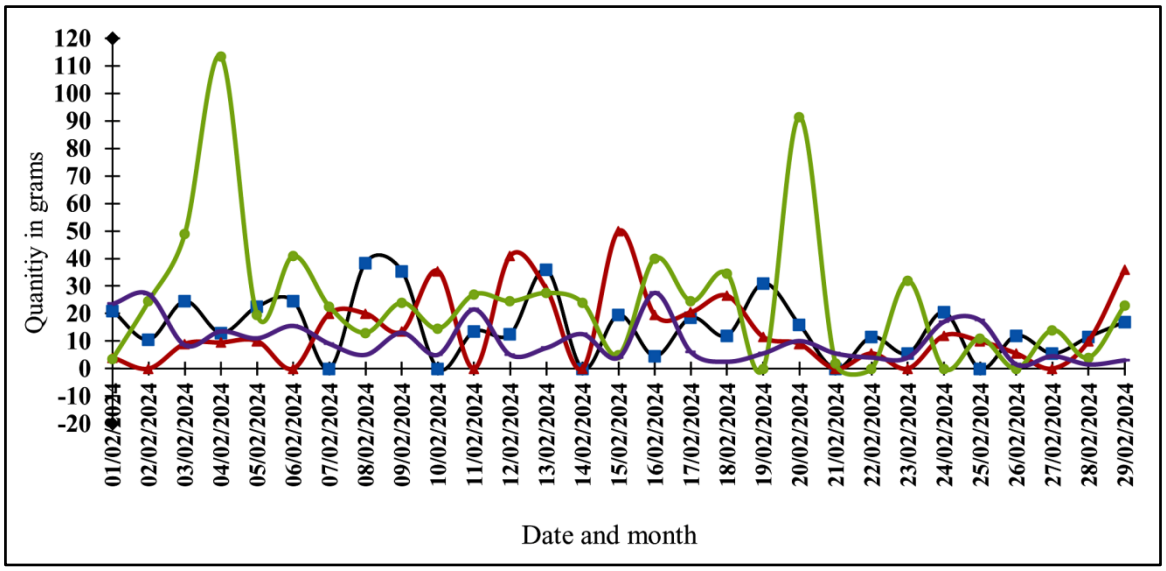


**Figure 3** Quantity of dry domestic waste generated in the month of February 2024 form four residents

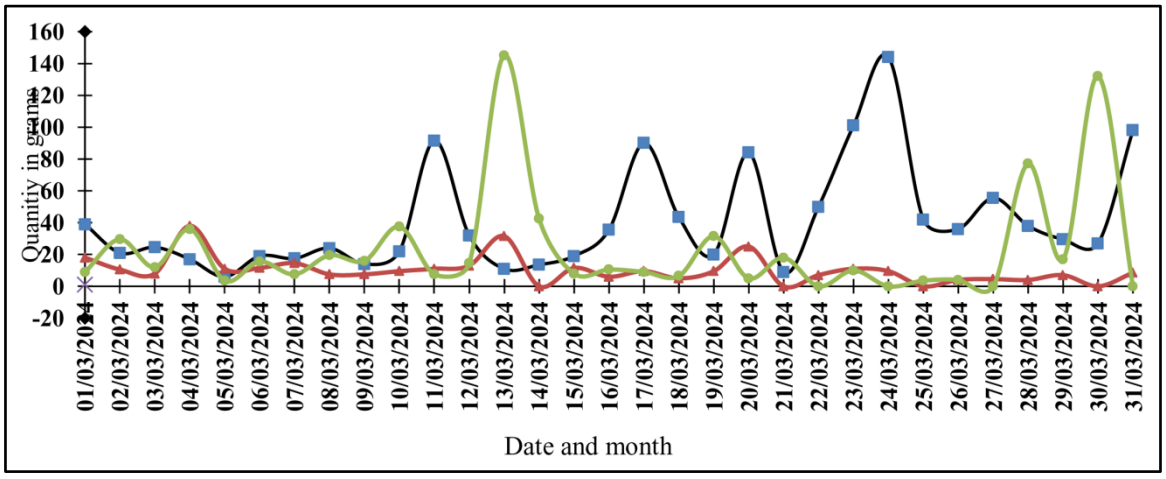


**Figure 4** Quantity of dry domestic waste generated in the month of March 2024 form four residents

## CONCLUSIONS

As per the aim of this investigation on determining the quantity of dry domestic wastes generated from packed utilities, the daily average and monthly average quantity of waste was found to be 16.49 g and 494.78 g respectively per residence. So the proposed quantity of waste for the cities with a population of 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130 lakhs is forecasted as 4.12, 8.25, 12.37, 16.49, 20.61, 24.72, 28.86, 32.98, 37.10, 41.23, 45.35, 49.47 and 53.59 tons per year. Hence it is suggested that every citizen is to take care of their domestic wastes and not to waste those materials by throwing simply into a dust bin. These materials are reusable and can be handed over to authorized recycling agents for a sustainable material handling processes and sustainable globe.

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# Utilization of a Biochar Synthesized from Rice Straw and Modified by a Hummer's Method for the Purpose of Removing Carbamazepine from its Aqueous Solution: Batch Study and Fixed Bed Study

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***Abstract***: *Pharmaceuticals forms a significant part of the recalcitrant group of pollutants which is affecting the aquatic environments in recent times. In this particular study, a biochar was synthesized from rice straw which was then activated by a modified Hummers method. The finished product was named Activated Rice Straw Biochar (ARSB) which was then used for treating the widely used pharmaceutical Carbamazepine (CBZ), which has been widely found in the aquatic ecosystem around the world. The synthesized ARSB was characterized by Fourier Transfer Infrared Spectroscopy (FTIR), X-ray Diffractometer (XRD), Scanning Electron Microscopy (SEM) and Raman Spectroscopy. The effect of different experimental parameters on the efficacy of ARSB to remove CBZ from its aqueous solution was investigated by virtue of a batch study. From there it was observed that the highest removal of CBZ by ARSB was achieved at CBZ concentration of 15 mg/L (60.56 %), ARSB dosage of 2 g/L (57.84 %), pH 6 (60.19 %) and 313 K (61.51 %). The process was further optimized by Response Surface Methodology (RSM) study which investigates the effect of different experimental parameters on the removal of CBZ by ARSB. From there the highest removal of CBZ by ARSB was observed to be 66.64 % which was attained at pH 4, ARSB dosage of 3 g/L and contact time of 150 minutes. The removal of CBZ by ARSB under a dynamic condition was investigated by virtue of a column study. From there it was observed that the removal of CBZ by ARSB which was evaluated by virtue of a break-through point, increased with the increase in bed height and decreased with the increase in concentration of CBZ. Overall it can be stated that ARSB is an effective adsorbent which could be utilized for successfully removing trace pollutants like CBZ from water.*

***Keywords***: *Carbamazepine; Activated Rice Straw Biochar; Adsorption; Batch Study; Column Study*

## INTRODUCTION

In recent times pharmaceutical compounds are becoming one of the most rapidly emerging pollutants. Carbamazepine (CBZ) is one of the most widely utilized pharmaceutical compounds in the world with more than one thousand tons of annual consumption (Naghdi et al., 2019). As with all other emerging contaminants, the conventional waste water treatment systems are unable to effectively remove this type of pollutants from (Baghdadi et al., 2016; Naghdi et al., 2019; Nielsen et al., 2015). Therefore non-conventional methods of waste water treatment needs to be utilized for the purpose of removing these trace pollutants from water (Baghdadi et al., 2016). For this particular study, rice straw which is an abundantly available agricultural byproduct was utilized for synthesizing a biochar. The biochar was then activated by a modified Hummer's method. Then final product which was termed Activated Rice Straw Biochar (ARSB) was utilized for removing CBZ from its aqueous solution by adsorption. A set of batch studies were performed to find the effect of different experimental conditions on the removal of CBZ by ARSB. The data from the batch study was utilized for calculating the adsorption isotherm, adsorption kinetics and adsorption thermodynamics. The effect of the operating parameters on the removal of CBZ by ARSB was further optimized by Response Surface Methodology (RSM). The removal of CBZ under a dynamic flowing condition was evaluated by conducting a continuous column study. The main objective of this particular study was to synthesize a cost effective adsorbent followed by testing of its efficacy for the purpose of removing a recalcitrant pollutant CBZ from water.

## METHODOLOGY

### Synthesis of Activated Rice Straw Biochar (ARSB)

The activated rice straw biochar (ARSB) was synthesized by the method described in (Goswami et al., 2017) and

(Bhattacharya et al., 2021). Firstly the rice straw was washed with tap water followed by which it was dried by sunlight and then it was cut into small pieces. Then it was washed with distilled water to wash away all the dirt, dust and any other impurity. Then the rice straw was carbonized at 450°C for 4 hours in an inert nitrogenous atmosphere to synthesize a rice straw biochar. Then the biochar was homogenized by crushing and sieving to get a material of uniform particle size. Then this biochar was activated by a modified Hummer's method to synthesize ARSB.

**Characterization**

The synthesized ARSB was characterized by Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), X-ray Diffractometer (XRD) and Raman Spectroscopy to determine the functional groups, surface morphology, crystal structure and the ratio of $sp^2/sp^3$ carbons in the structure of ARSB.

**Batch Study**

A set of batch studies were conducted to evaluate the effect of different experimental parameters on the removal of CBZ by ARSB. The experimental volume were kept constant at 50 ml. Samples were extracted at predetermined time intervals. Then these solutions were centrifuged to remove the ARSB particles from the solution. The level of CBZ remaining in the experimental solution was determined by UV-Vis spectrophotometry.

**Response Surface Methodology**

In order to optimize adsorption of CBZ by ARSB, a response surface methodology study was performed. The software Design Expert Version 7.0 (Stat Ease, USA) was used for conducting the RSM study and the Central Composite Design (CCD) model of RSM was used. The three parameters that were considered for the RSM study were the pH, dosage of the adsorbent (mg/100 ml) and experimental time (minutes). For each of these experimental parameters, a particular range has to be put in the software. On the basis of the information that is entered into the software, it suggests a group of experiments denoted as runs. Each of this particular run consists of a set of different parameters whose collective effect on the removal of CBZ by ARSB was evaluated (Banerjee et al., 2017; Ganguly et al., 2020). After performing the experiment, the outcome (which in this case is the percentage removal of CBZ by ARSB) has to be re-entered into the system. These output response were used by the software to perform an ANOVA analysis on the ground of which a quadratic polynomial model was obtained which was used for optimizing the experimental parameters (Bhattacharya et al., 2024).

**Column Study**

The continuous column study was performed to evaluate the efficacy of ARSB for the purpose of removing CBZ under a dynamic condition. The glass column that was used in this experiment had a height of 50 cm and an internal diameter of 3 cm. The flow of CBZ and the pH of the experimental solution was kept constant at 10 ml/min and pH 7 respectively for this study. Two different parameters were considered for the column study; bed height and concentration of the experimental solution. The bed height was varied from 1 inch to 3 inch and the concentration of the experimental solution was varied from 10 mg/l to 20 mg/l. The experimental solution was extracted from this setup at pre-determined time intervals and the level of CBZ in the experimental solution was measured spectrophotometrically. The performance of the column study was evaluated by virtue of a break through curve.

**RESULTS**

**Characterization of ARSB**

From the FTIR analysis of ARSB it was observed that the prominent peaks of ARSB were present at the points 1090 $cm^{-1}$, 1620 $cm^{-1}$, 1732 $cm^{-1}$ and 3506 $cm^{-1}$ which denotes the C-O bond, C=C bond, C=O bond and O-H bond respectively (Banerjee et al., 2015). The peaks denoted at 1396.5 $cm^{-1}$, 1462 $cm^{-1}$, 2924.7 $cm^{-1}$ and 2854 $cm^{-1}$ denotes the C-H bonds respectively (Balasubramani et al., 2020). From the FTIR analysis of ARSB it was observed that many functional groups were present on the surface of ARSB which could facilitate the adsorption of compounds like CBZ on its surface.

From the SEM analysis of ARSB it was observed that the surface of ARSB composed of thin overlapping and creased sheets of carbon. The rough and uneven structures on the surface of ARSB could reportedly enhance the adsorption of CBZ on its surface (Bhattacharya et al., 2021; Mukherjee et al., 2019).

From the XRD analysis of ARSB it was observed that the two main peaks are present at the points 13.7° and 27.5°. The peaks at 13.7° can be attributed to the functional groups present on the surface of ARSB and the peak at 27.5° can be assigned to the un-oxidized graphitic layers present on the surface of ARSB (Saleem et al., 2018).

From the Raman spectra of ARSB it was observed that the D-band and the G-band were present at 1332.75 cm-1 and 1587.67 $cm^{-1}$ respectively. In case of the Raman spectra of ARSB it was observed that the ratio of D-band and G-band, i.e; ID/IG as per their respective peak intensities was 1.19 thereby denoting large number of structural defects in the sp3 hybridized carbon atoms of ARSB (Nawaz et al., 2017).

**Batch Study Results**

From the batch study results it was observed that that the removal of CBZ by ARSB increased with the increase in concentration from 5 mg/L to 15 mg/L (49.54% to 60.56%) followed by which it decreased when the concentration of CBZ increased to 20 mg/L (56.01%) (**Figure 1**). This could be attributed to the fact that the uptake of CBZ by ARSB increased initially due to a gradient based transfer of CBZ molecules followed by which it decreased due to the saturation of the surface of ARSB by CBZ molecules (Banerjee et al., 2016).

Similarly when the dosage of ARSB was increased from 0.5 g/L to 2 g/L, the removal of CBZ increased from 39.56% to 57.84% (**Figure 2**). This could be attributed to the availability of greater surface area for the uptake of CBZ molecules with the increase in the dosage of ARSB (Banerjee et al., 2016).

The effect of pH on the removal of CBZ by ARSB was detected over five different pH namely pH 2, pH 4, pH 6, pH 8 and pH 10. From the experimental result it was observed that the removal of CBZ by ARSB was almost constant over the observed pH range. Still when the pH increased from pH 2 to pH 6 the removal of CBZ increased from 58.13 % to 60.19 %. Then when the pH was increased to pH 8 to pH 10 the removal decreased from 58.87 % to 57.02 %. This could be attributed to the fact that the pHpzc of ARSB was 4.5 and the dissociation constant of CBZ was 13.9 (Bhattacharya et al., 2020). Therefore at the lower pH and higher pH there might have been some electrostatic force of repulsion between the surface of ARSB and the CBZ molecules due to which there might have some reduction in the removal of CBZ. Thus the highest removal of CBZ by ARSB was obtained at the neutral pH 6.

The effect of temperature on the removal of CBZ by ARSB was observed for four different temperatures namely at 298 K, 303 K, 308 K and 313 K. From there it was observed that the removal of CBZ by ARSB increased with the increase in temperature (57.96 % to 61.51 % for 298 K to 313 K). This could be attributed to the fact that with the increase in temperature the pore size of ARSB increased and greater interaction took place between the molecules of CBZ and the surface of ARSB which resulted in the greater removal of CBZ with the increase in temperature (Bhattacharya et al., 2020, 2021).

**Adsorption Isotherm, Adsorption Kinetics and Adsorption Thermodynamics**

The adsorption of CBZ on the surface of ARSB was best described by Tempkin isotherm ($R^2$ = 0.99) (**Table 1**) thereby denoting that the adsorption process was uniform in nature and the heat of adsorption moieties decreased in a linear fashion (Banerjee et al., 2016). From the adsorption kinetic study (**Table 2**) it was observed that the adsorption of CBZ by ARSB was best described by pseudo second order adsorption ($R^2$ = 0.98). From the thermodynamic study it was observed that the adsorption of CBZ by ARSB was endothermic in nature and it went ahead by consuming energy from the surrounding (Banerjee et al., 2016) and both the molecules of ARSB and CBZ underwent active site interaction during the adsorption process.

**Response Surface Methodology**

As per the outcome of the RSM study it was observed that the quadratic RSM model was highly effective for optimizing the adsorption study with a high correlation coefficient ($R^2$ = 0. 98 ) and the probability value of much less than 1 (< 0.0001). From the RSM study, the experimental condition under which the highest removal of CBZ was obtained were pH 4, adsorbent dosage of 3 g/L and experimental time of 150 minutes.

**Column Study Result**

As per the outcome of the column study it was observed that when the length of the bed height increased the time required to reach the breakthrough point also increased. The breakthrough time for 1 inch bed height was 40 minutes, for 2 inch bed height was 60 minutes and for 3 inch bed height was 100 minutes. This phenomena could be attributed to the greater availability of ARSB particles for the uptake of CBZ (Bhattacharya et al., 2021). Similarly, when the bed height was kept constant at 1 inch, the breakthrough time for 10 mg/l concentration was 30 minutes, for 15 mg/l concentration was also 30 minutes (although the Ct/C0 value for 10 mg/l at 30 minutes was 0.02 whereas that for 15 mg/l was 0.03) and for 20 mg/L was 20 minutes. This could be attributed to the saturation of ARSB particles by CBZ molecules (Das et al., 2021).

## CONCLUSION

From the result of the experimental study it was observed that the synthesized ARSB was able to remove sufficient amount of CBZ from its aqueous solution. The removal of CBZ by ARSB increased with increase in concentration up-to 15 mg/L, with increase in dosage up-to 2 gm/L, was found to be highest at pH 6 and increased with increase in temperature up-to 313 K. From the RSM study it was observed that the highest removal of CBZ by ARSB was obtained at the experimental condition of pH 4, dosage of 3 gm /L and experimental time of 150 minutes. From the column study result it was observed that the time for the breakthrough point increased with the increase of bed height and decreased with the increase in concentration of the experimental solution. Overall it can be stated that ARSB acted as an effective adsorbent for the purpose of removing CBZ from its aqueous solution.

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# Ship Operation for Net Zero Emission

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***Abstract:*** *Industrial Revolution in Europe is the tipping point at which greenhouse gas (GHG) emissions released into the atmosphere began to skyrocket. With the growth of Cargo transportation across the world the demand and production of energy increased. Energy demand was satisfied mainly through burning fossil fuels, which has been easily available across the World. Excessive burning of Fossil Fuel resulted in the global increase in temperature of approximately 1.07°C since the pre-industrial period. This rise is proportional to the global cumulative emissions over the period. Global cumulative emissions determine the global temperature that will be reached. To limit the increase in global temperature, the cumulative emissions must stay within a Global Carbon Budget. The Amount of Carbon Budget left is 500 $GtCO_2$ for limiting temperature rise to 1.5 degrees and 1350 $GtCO_2$ for 2 degrees.*

*Globally the shipping industry emits about 3% of the world's $CO_2$ emissions. India's efforts to cut its carbon footprint will also help in meeting the International Maritime Organization's target to reduce overall greenhouse gas emissions from ships by 50% of 2008 levels by 2050. International Maritime Organisation has introduced Mandatory reporting of fuel consumption data by ships above 5000 MT.*

*As per IMO's New Data Collection System, almost 29000 ships reported on the consumption of fuel consumed by them. This number shows that about 800 ships more than 2021 data has reported on fuel consumption. These ships reported the use of 213 million tonnes of fuel, which is just slightly higher than in 2021 (212 million tonnes in 2021).*

***Keywords:*** *Global Warming; Energy Efficiency; Net-Zero; Renewable Energy; Decarbonisation*

## ACTIONS REQUIRED FOR NET- ZERO EMISSION

In order to achieve the Target of Net Zero emission, the industries and general public worldwide needto prevent uncontrolled addition to the stock of GHGs, beyond the global carbon budget through following activities.

- Mitigation of emissions –Energy, Transportation, Industry etc
- Removals of $CO_2$ from atmosphere through Direct Air Capture (CCUS), Forests and Oceans

## INDIAN AIM FOR GREEN SHIPPING

India aims for green shipping for Inland waterways as early as possible:

As per information from Ministry of Ports, Shipping & Waterways, India aims to convert its entire coastal and inland waterways shipping to renewable energy in the next five years. India's current share of renewable energy at major ports is less than 10% according to government estimates.

India, further plans to add around 5,000 new vessels as per Global Emission Standards over the next decade to its existing capacity of about 1,500 vessels to reduce $CO_2$ emission and avoid dependency on foreign shipping.

Government is implementing the National Action Plan on Climate Change (NAPCC) through National Missions that address climate change mitigation and adaptation across arrange of sectors. NAPCC is the over-arching policy frame work and comprises of national missions in specific areas of solar energy, enhanced energy efficiency, water, agriculture, Himalayan ecosystem, sustainable habitat, green India and strategic knowledge on climate change.

## UNDERSTANDING GLOBAL WARMING POTENTIALS

Greenhouse gases (GHGs) warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space; they act like a blanket insulating the Earth. Different GHGs can have different effects on the Earth's warming.

Two key ways in which these gases differ from each other are their ability to absorb energy (their "radiative efficiency"), and how long they stay in the atmosphere (also known as their "lifetime").

The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period, relative to the emissions of 1 ton of carbon dioxide ($CO_2$). The larger the GWP, the more that a given gas warms the Earth compared to $CO_2$ over that period. The time period usually used for GWPs is 100 years. GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases and allows policymakers to compare emission reduction opportunities across sectors and gases.

Though the GWP of $CO_2$ is low but it's effect on Global Warming is maximum because of large volume of $CO_2$ produced daily due to burning of fossil fuel by people.

- Methane ($CH_4$) is estimated to have a GWP of 28–36 over 100 years. $CH_4$ emitted today lasts about a decade on average, which is much less time than $CO_2$. But CH4 also absorbs much more energy than $CO_2$. The net effect of the shorter lifetime and higher energy absorption is reflected in the GWP.
- Nitrous Oxide ($N_2O$) has a GWP 265–298 times that of $CO_2$ for a 100-year timescale. $N_2O$ emitted today remains in the atmosphere for more than 100 years, on average. MARPOL Annex VI of IMO has taken sufficient measures for reduction of $NO_x$ emission.
- Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) are high-GWP gases

**CARBON FOOTPRINT**

Carbon footprint is the amount of carbon dioxide ($CO_2$) emissions associated with all the activities of a person or other entity (e.g., building, corporation, country, etc.). It includes direct emissions from fossil-fuel combustion in manufacturing, heating, and transportation, as well as emissions required to produce the electricity associated with goods and services consumed. In addition, the carbon footprint concept also often includes the emissions of other greenhouse gases, such as methane, nitrous oxide, or chlorofluorocarbons (CFCs). A carbon footprint is usually expressed as a measure of weight, as in tons of $CO_2$ or $CO_2$ equivalent per year.

**CARBON FOOTPRINT REDUCTION**

Carbon footprints can be reduced through improving Energy Efficiency and changing lifestyles and purchasing habits. Switching one's energy and transportation use can have an impact on primary carbon footprints. Individuals and corporations can reduce their respective carbon footprints by installing energy-efficient lighting, adding insulation in buildings, or using renewable energy sources to generate the electricity they require, use public transport etc.

Electricity generation from wind power produces no direct carbon emissions. Reducing one's consumption of meat and switching one's purchasing habits to products that require fewer carbon emissions to produce and transport, also reduces Carbon Footprint.

**USE OF FOSSIL FUELS : INDIA vs OTHER MAJORS**

| Per Capita Total Fossil Fuel Consumption (2018) | Coal Consumption (MT per capita) | Natural Gas Consumption (Cu.M per capita) | Oil Consumption (MT per capita) |
|---|---|---|---|
| USA | 1.91 | 2.59 | 2.37 |
| Germany | 2.62 | 1.12 | 1.14 |
| Australia | 4.52 | 1.84 | 1.96 |
| UK | 0.20 | 1.20 | 0.89 |
| China | 2.70 | 0.20 | 0.42 |
| India | 0.73 | 0.04 | 0.16 |

## INTERNATIONAL MARITIME ORGANISATION (IMO)

In1948 an international conference under United Nations in Geneva adopted a convention formally establishing Inter-Governmental Maritime Consultative Organization (IMCO). The name was changed to International Maritime Organisation (IMO) in the year 1982. The IMO Convention entered into force in 1958 and the new Organization met for the first time the following year.

The purposes of the Organization, as summarized by Article 1(a) of the Convention, are "to provide machinery for cooperation among Governments in the field of Governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade; to encourage and facilitate the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships". The Organization is also empowered to deal with administrative and legal matters related to these purposes.

IMO implements various decisions through Conventions, Protocols, Codes etc for safe and clean shipping. SOLAS, Load Line, MARPOL are a few of important Conventions. MARPOL 73/78 deals with Prevention of Pollution by Ships. MARPOL Annex – VI deals with Prevention of Pollution of Air by Ships.

## STRATEGIES OF INTRNATIONAL MARITIME ORGANISATION

IMO plans for Reduction of $CO_2$/GWG Emission through following measures:

- ENERGY EFFICIENT MEASURES (Short term measure).
- USE ALTERNATIVE FUEL & RENEWABLE ENERGY (SOLAR / WIND / OCEAN) (Medium term measure)
- USE CARBON FREE FUEL (Long term measure)

## ENERGY EFFICIENCY (NET ZERO) MEASURES OF IMO

IMO is committed to support UN Sustainable Development Goal 13 - to take urgent action to combat climate change and its impacts – in line with the 2015 Paris Agreement to cut greenhouse gas (GHG) emissions which cause global warming.

The International Maritime Organization (IMO) adopted the first set of international mandatory measures to improve ships' energy efficiency on 15 July 2011. Since then, IMO has taken additional action including further regulatory measures like the adoption of the Initial IMO GHG strategy in 2018 & 2023, and the revised Strategy on Reduction of GHG Emissions from Ships.

The revised IMO GHG Strategy, adopted at the Marine Environment Protection Committee (MEPC 80) includes an enhanced common ambition to reach net-zero GHG emissions from international shipping by or around2050.

In particular, the 2023 IMO GHG Strategy envisages a reduction in carbon intensity of international shipping (to reduce $CO_2$ emissions per transport work), as an average across international shipping, by at least 40% by 2030. The new level of ambition relates to the use of zero or near-zero GHG emission technologies, new fuels and/or energy sources (at least 5%, striving for 10%, of the energy used by international shipping).

## ENERGY EFFICIENCY DESIGN INDEX (EEDI)

In January 2013, the IMO introduced Energy Efficiency Design Index, requiring newbuilds to function at a minimum energy efficiency level per ton mile. New vessel designs had to meet energy thresholds specific to their ship type, and comply with a carbon reduction level set to increase every five years.

The latest milestone for the EEDI was agreed at the June 2021 meeting of the IMO’s

Marine Environment Protection Committee (MEPC). Instead of entering into force in 2025, Phase 3 of the EEDI has been implemented on April 1, 2022, for certain type of vessels. These are applicable to container ships, general cargoships, refrigerated cargo carriers, combination carriers, gas carriers, LNG carriers and cruise ships.

**ENERGY EFFICIENCY EXISTING SHIP INDEX (EEXI) & CII**

In June 2021, the MEPC put forward two regulations – the Energy Efficiency Existing Ship Indes (EEXI) and the Carbon Intensity Indicator (CII) – to minimize marine emissions. Like the EEDI, the EEXI is a framework for determining the energy consumption and $CO_2$ emissions of in-service vessels over 400 GT. The CII requires in-service ships of over 5,000 GT to measure and report $CO_2$ emissions rating of vessels on a scale A – B – C – D – E for performance.

Latest IMO amendments of MARPOL Annex VI now require existing ships to improve their technical efficiency, achieving parity of performance with equivalent newbuilds. Regulation 28, which concerns operational measures, imposes a linear reduction of in-service ships' carbon intensity from 2022 to 2030. Regulations for both the EEXI and the CII have entered into force on November 1, 2022.

**SHIP ENERGY EFFICIENCY MANAGEMENT PLAN (SEEMP)**

IMO has developed SEEMP to assist ship operators for preparation of the Ship Energy Efficiency Management Plan (SEEMP). The Purpose of three parts to a SEEMP:

(a) SEEMP Part-I, is to provide an approach to monitor ship and fleet efficiency performance over time and describe ways to improve the ship's energy efficiency performance and carbon intensity. This applies to any ship of 400 GT and above.
(b) SEEMP Part-II is to provide a description of the methodologies be used to collect the data required pursuant to regulation 27 of MARPOL Annex VI and the processes to report the data to the ship's Administration or any Recognised Organization (RO). Part II of the SEEMP applies to any ship of 5,000 GT and above.
(c) SEEMP Part-III is to provide guidelines to ship for calculation of Carbon Intensity Index value, the required CII values for the next three years, a three-year, implementation plan, and self-evaluation and improvement procedures. This is mandatory for ships above 5000MT.

**EFFECT OF SHORT TERM ENERGY EFFICIENCY MEASURE**

About 29000 ships submitted their fuel oil consumption data to the IMO Ship Fuel Oil Consumption Database (reporting year: 2022). There was an increase of over 800 ships compared to 2021. These ships reported the use of 213 million tonnes of fuel, which is just slightly higher than in 2021 (212 million tonnes in 2021).

**NEW MARINE FUELS WORKPLAN**

**New Generation Energy Source for Ship**

As mandatory carbon dioxide (CO2) regulation increases in strength, shipowners will have to initiate adequate steps to satisfy international requirement for trading globally. To meet these stringent requirements of IMO, Shipping companies are exploring a range of clean fuel alternatives. From increasingly common LNG solutions, via "start-up" fuels such as LPG, Methanol and biofuels, to less developed options such as hydrogen and ammonia and even Nuclear Fuels. Shipowners will have to equip vessels for the fuel, most appropriate to a ship's type, route, cargo and technology.

IMO is considering several Market Based Measures (MBM) which would be useful for shipowners for critical investment decisions to make about its fleet, probably several times over the next few decades, particularly as the life expectancy for the average ship is 25-30 years. Some vessels will be refitted with entire new propulsion systems, others will be scrapped and replaced.

**RENEWABLE ENERGY**

1. Wind Energy
2. Sea/ Ocean Currents
3. Solar Power

**Wind Energy (Flettner Rotor)**

Flettner rotors are being used successfully on ships for use of wind power. They are vertical cylinders which are mechanically driven to spin and Develop Lift due to the Magnus effect as the wind blows across them. This rotor propulsion is often called Flettner rotors, after the German innovator who invented and installed such a system on board a ship for the first timeduring 1920s. These are used on tankers andgearless bulk carriers where rotors will not interfere with the required air-space for loading and unloading. The range of cost for a Flettner Rotor is $400,000 to $950,000 (USD) depending on the model (size) of the rotor. The reduction potential of a Flettner motor is 3% to 15% on main engine fuel consumption.

**SOLAR POWER**

Solar panels installed on the decks of ships and even integrated into sails are capturing sunlight to generate electricity. This power is being used for onboard systems, reducing the need for fossil fuels and cutting emissions. In India Solar Power is being extensively use for Inland waterways. The Water Metro at Kochi is most famous of all. Following are a few.

- Aditya, India's First Solar Ferry, 75 passenger boat is operating in Vaikom, Kerala, India.
- Avalon solar cruise boat at Thriprayar, Kerala. In operation since 2022.
- Barracuda, India's Fastest Solar-electric Boat, 12 passenger work boat is operating in Mumbai, Maharashtra, India. It was launched in Kochi in December, 2023.
- Indra is the largest solar boat in India. It is a 27 m long, 7 m wide catamaran, double deck GRP boat with air-conditioned space for 100 passengers in the upper deck and open space for 100 passengers in the tier above. The boat started operations in Kochi waters in December, 2023.

THE ALTERNATIVE FUELS

1. LNG / LPG
2. Ethanol / Methanol / Biofuels
3. Synthetic methane/substitute natural gas (SNG) and bio-methane

**OPPORTUNITIES & CHALLENGES FOR ALTERNATE FUELS**

**LNG: The Front Runner**

Liquefied natural gas (LNG) is now a well-known alternative fuel within the shipping industry. GHG emissions between 7 and 22% depending on engine type. Additionally, LNG in combination with a combined cycle diesel/carbonate fuel cell could reduce CO2 emissions by up to 80%. However, LNG is not the solution for Zero Carbon emission because LNG is still a fossil fuel, and it poses the challenge of methane slip. However LNG faces challenge of limited bunkering infrastructure and higher CAPEX.

As LNG gains traction as a clean fuel solution, greater numbers of LNG-powered vessels are being built; the global order book for 2019 lists 17% of newbuild orders (in gross tonnage) as LNG-powered.

Methanol, Ethanol, LNG, LPG are a set of good alternative fuels. It is necessary to develop bunkering and handling facilities for these fuels. Engine builders like Wartsila and others are working on development of dual fuel engines for use of these alternative fuels.

**Carbon Free Fuels**

Ammonia

Ammonia is a compound of nitrogen and hydrogen. As ammonia contains no carbon it does not emit any $CO_2$ when used to fuel an internal combustion engine, hence it is truly zero carbon propulsion. The survey showed the industry expect ammonia usage to grow to 7% of fuel by 2030 and 20% by 2050. Ammonia is also central to several national decarbonisation strategies.

Advantages of Ammonia

- Acceptable energy densitymaking onboard storage economically feasible.
- Relatively easy to handle
- It is being readily used in shipping industry.
- Can be stored easily at about -33 degree C
- Shipping industry is experienced with Safe handling of Ammonia.

Industry is advancing fast for use of Ammonia as fuel. Several ammonia-fuelled vessel designs have been approved in principle, including an ultra-large container ship concept in both China and Korea as well as a deep-sea tanker design due for commercialisation by 2024.

**Carbon Capture on Board**

Onboard carbon capture and storage was discussed during the Working Group on Air Pollution and Energy Efficiency. MEPC instructed a correspondence group to further consider issues related to onboard carbon capture and develop a work plan on the development of a regulatory framework for the use of onboard carbon capture systems and report to MEPC 83.

329_IEC74956

# Effluent Discharge from Metal & Metallurgical Industries — Environmental Impact and Control

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***Abstract:*** *The metallurgical industries, encompassing both ferrous and non-ferrous sectors, significantly contributes to environmental pollution through the discharge of effluents containing heavy metals such as lead, copper, cadmium, mercury, zinc, arsenic, and chromium. These contaminants pose severe risks to soil health, groundwater, drinking water sources, and aquatic ecosystems.*

*This study explores the environmental impact of these effluents, the regulatory frameworks in place across various countries, and the industry's role in mitigating these effects.*

*Due to the presence of high amount of toxic, carcinogen, and heavy metals in the effluents, researchers are highly concerned with its effect on the environment and health of mankind. These led to imposing different rules and regulations on the industrial discharges by local authorities and governments throughout the world, which got stricter for last few years.*

*As a result, various corrective measures have been explored to reduce and remove these contaminants from the industrial effluents for sustainable environment.*

*Case studies from the Iron & Steel Industry, Ferro-chrome plants, and Copper Smelters illustrate typical effluent characteristics and treatment methods.*

*Steel Plant effluents: Major effluent generated are slurry from gas cleaning plant of blast furnace and BOF; oil, grease and iron scales from caster and rolling mills; effluents from coke oven by-product plant containing high amount of BOD and COD; effluents from cold rolling mill containing chromium, acid, Zn and other contaminants.*

*Ferrochrome plant Effluent: Effluents generated from metal bearing slag and recovered metal stockpiles run-off, product pre-breaking area, bleed from jigging plant contain highly toxic Chromium (+6) metal.*

*Copper Smelter Effluent: Major effluents are generated from off-gas cleaning plant of smelter which is acidic carrying a significant amount of dissolved heavy metals, specifically Cu, Fe, Zn, Pb and As. In these processes, arsenic is usually found as arsenite (As(III)) or arsenate (As(V)) inorganic oxyanions.*

*Treatment Methodology: It is also elaborated in this study how the treatment procedures and remedies for each industry have been evolved throughout past decade in view of reducing contaminants from effluents as well as reusing the treated water to reduce water consumption from external sources.*

*From various case studies and actual implementation in metal industries, it is observed that continuous research and studies to reduce the environmental impact of industrial effluents opened a new horizon to solve water scarcity problems by reusing the treated effluent within the industry which leads to Zero Liquid Discharge (ZLD) concept.*

***Keywords:*** *Industrialization; Contaminant; Effluent; Zero Liquid Discharge*

## INTRODUCTION

Industrialization has become the ultimate driving force to the development of a country's economy, through the establishment of plants and factories. Specifically, the metal and metallurgical industries have significant impact on the country's economy. However, these metal industries have also hugely impacted on the environment status of

these countries. The waste or by-products discharged from them consisting of various kind of contaminant are severely disastrous to the environment which contaminate the surface water, ground water and soil.

This article deals with various effluents discharged from various metal and metallurgical industries, their characteristics, and effects on environment and human health.

## METHODOLOGY & CASE STUDY

Due to the presence of high amount of toxic, carcinogen, and heavy metals in the effluents, researchers are highly concerned with its effect on the environment and health of mankind. These led to imposing different rules and regulations on the industrial discharges by local authorities and governments throughout the world, which got stricter for last few years.

As a result, various corrective measures have been explored to reduce and remove these contaminants from the industrial effluents for sustainable environment.

Effluent generated from few metallurgical industries like steel, ferro-chrome, copper and aluminium industry have been outlined in this article with the treatment schemes implemented for each case.

**Steel Plant Effluents**: Major effluent generated are slurry from gas cleaning plant of blast furnace and BOF; oil, grease and iron scales from caster and rolling mills; effluents from coke oven by-product plant containing high amount of BOD and COD; effluents from cold rolling mill containing chromium, acid, Zn and other contaminants.

**Ferrochrome Plant Effluent**: Effluents generated from metal bearing slag and recovered metal stockpiles run-off, product pre-breaking area, bleed from jigging plant contain highly toxic Chromium (+6) metal.

**Copper Smelter Effluent**: Major effluents are generated from off-gas cleaning plant of smelter which is acidic carrying a significant amount of dissolved heavy metals, specifically Cu, Fe, Zn, Pb and As. In these processes, arsenic is usually found as arsenite (As(III)) or arsenate (As(V)) inorganic oxyanions.

**Aluminium Smelter Effluent**: Major effluents from Aluminium smelter consists of high TDS and considerable amount of fluoride.

### Treatment Methodology

It is also elaborated how the treatment procedures and remedies for each industry have been evolved throughout past decade in view of reducing contaminants from effluents as well as reusing the treated water to reduce water consumption from external sources.

This evolution leads to the Zero Liquid Discharge (ZLD) concept, which addresses environmental pollution and enhances water sustainability for the future.

## CONCLUSION

From various case studies and actual implementation in metal industries, it is observed that continuous research and studies to reduce the environmental impact of industrial effluents opened a new horizon to solve water scarcity problems by reusing the treated effluent within the industry.

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351_IEC53107

# The Recycling Gap: Assessing India's E-Waste Management Infrastructure

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***Abstract:*** *This study focuses on the Indian e-waste generation, formal processing and recycling of e-waste and number of authorized recyclers with its capacity and investigating past and future trends using Auto ARIMA, LGBM Regressor, XGB Regressor, and Random Forest Regressor, Time GPT models, commonly used in time series analysis and forecasting the e-waste generation up to financial year 2031-2032. In this study it is observed that for all the cases the values of error matrices (such as MAE, MAPE, RMSE etc) of XGB Regressor is lowest among all the models. So, we choose this model for forecasting the e-waste generation. The study predicts that the E-waste generation in India will rise up to 7.269 MT at 2032 as per GEM report and 4.14 MT at 2031-32 financial year as per CPCB annual report. The prediction also shows that the e-waste will be formally recycled is 2.25 MT which is about 54.34% of e-waste generation and the capacity of recycler will be increased up to 5.06 MT with the 1442 number of authorised recyclers at 2031-32 financial year.*

***Keywords:*** *E-Waste; Forecasting; Machine Learning Modeling; Recycling*

## INTRODUCTION

Electronic waste or e-waste refers to large number of electrical and electronic products which includes TV, washing machine, mobile phone, computers, laptop, printers, refrigerator etc. As per e-waste management rule,2016 it includes only 21 types of electrical and electronic components. Recently in e-waste management rule, 2022, CPCB has added more than 100 types of EEE items, into the e-waste categories. Stake of the global electronic system manufacturing industry for India has grown from 1.3 % at 2012 to 3.6 % at 2019 (Invest India. 2022a). Although electronic appliances are made to make human life simpler, but their disposal and recycling is a threat to the human life because of the presence of toxic constituents in them (Needhidasan et al., 2014). The present study focuses on the E-waste generation in India and trend analysis and recycling data the fluctuations at national level. Further, the study was also intended to investigate the role of E- waste recycling/dismantling capacity and number of recyclers of E- waste in India and forecasting up to 2032 using Auto Regressive Integrated Moving Average (ARIMA), Light Gradient Boosting Machine (LGBM) Regressor, Extreme Gradient Boosting (XGB) Regressor, and Random Forest Regressor, Time GPT models (Gaza and Mergenthaler, 2023) commonly used in time series analysis and forecasting the e-waste generation. The error matrices like RMSE, MAPE, MAE etc are used to select the best model. By forecasting the e-waste recycling capacity, it will be predicted the future requirements of formal e-waste recycling, technological improvements, policies and market trends. Moreover, stakeholders will plan to allocate resources effectively to meet the rising demand for E-waste recycling in a sustainable manner (Bagwan,2024).

## METHODOLOGY

Data on e-waste generation, recycling volumes, recycler capacity, and the number of authorized recyclers in India were gathered from the Global E-Waste Monitoring Report, the CPCB Annual Report, and press releases from the Ministry of Environment, Forest, and Climate Change.

As the data from CPCB of e-waste generation of India is very less, so, we first check the train and accuracy by the data of global e-waste monitoring report. After checking the accuracy, best model is used for prediction for the both the data set i.e; Global E-waste monitoring data & CPCB data of Indian e-waste generation. Then take the e-waste generation as a factor, we forecast the quantity of e-waste recycling at 2032, and similar way we take the previous result as a factor we forecast the capacity of recycler and number of authorised or formal recycler at 2032.

**Table 1** E-Waste Data As per CPCB, Ministry of Environment, Forest and Climate Change

| Financial Year | Number of Authorized Dismantlers/Recyclers | Total Capacity (Tonnes per Annum) | Recycled/ processed (T) | E-Waste Generation (T) |
|---|---|---|---|---|
| 2016-17 | 178 | 4,38,086 | 23330.3 | |
| 2017-18 | 275 | 5,10,950 | 69413.61 | 7,08,445.00 |
| 2018-19 | 312 | 7,82,080. 62 | 1,64,663 | 7,71,215.00 |
| 2019-20 | 407 | 11,10,103.22 | 2,24,041 | 10,14,961.21 |
| 2020-21 | 468 | 13,85,932.22 | 354540.7 | 13,46,496.31 |
| 2021-22 | 472 | 14,26,685.22 | 5,27,131.57 | 16,01,155.36 |
| 2022-23 | 569 | 17,90,348.27 | | |

**Table 2** E-Waste generation data as per Global E-Waste Monitoring Report

| Year | E-Waste generation GEM Report (MT) |
|---|---|
| 2014 | 1.641 |
| 2015 | 1.975 |
| 2016 | 2.22 |
| 2017 | 2.53 |
| 2018 | 2.86 |
| 2019 | 3.23 |
| 2020 | 3.35 |
| 2021 | 3.73 |
| 2022 | 4.14 |

All the above data are used for forecasting according to the following steps.

1. Data Preparation:

- The time series data was collected and pre-processed (handling missing values, scaling, etc.).
- Lag features were created to transform the time series data into a supervised learning format.
- The data was divided into training and validation sets.

2. Model Training:

- Each model (LGBM, XGB, Random Forest) was initialized with appropriate hyperparameters.
- The models were trained on the training data.
- Cross-validation was performed to tune hyperparameters and avoid overfitting.

3. Model Evaluation:

- Model performance was evaluated using metrics such as Mean Absolute Error (MAE), Mean Squared Error (MSE), or Root Mean Squared Error (RMSE).
- The performance of each model was compared.

4. Forecasting:

- The trained models were used to predict future values.
- Predictions were aggregated for ensemble methods where necessary (Breiman,2001), (Friedman,2002).

## RESULT & DISCUSSIONS

Analysis of training data and error metrics revealed that the XGB Regressor demonstrated the lowest error values (MAE: 67334.17, RMSE: 78754.49, MAPE: 1.91, SMAPE:1.88, MdAPE:1.58, GMRAE: 0.01) for e-waste generation and it is used for further forecasting. Due to limited e-waste generation data from CPCB, which restricts extensive training and accuracy validation, the XGB Regressor was also applied to forecast with this dataset.

By the forecasting model it is predicted that India will generate 7.269 MT e-waste as per GEM report and as per CPCB the generation will be 4.14 MT at 2031-32. This discrepancy arises because CPCB considers 21 categories of electronic and electrical equipment (EEE) as e-waste, while the Global E-Waste Monitoring Report includes 54 categories.

Using the projected e-waste generation, the model forecasts that 2.25 MT, or approximately 54.34%, will be formally recycled by 2032. Following similar training and evaluation, the XGB Regressor consistently achieved the lowest error metrics (MAE: 191,159.12, RMSE: 196,139.00, MAPE: 12.35, SMAPE: 11.56, MdAPE: 12.35, GMRAE: 0.11), enabling predictions on recycler capacity. By 2032, recycler capacity is expected to increase to 5.06 MT.

Using recycler capacity as an input factor, further training and accuracy checks affirmed XGB Regressor's strong performance (MAE: 39, RMSE: 42.95, MAPE: 7.88, SMAPE: 7.50, MdAPE: 7.88, GMRAE: 0.066). The model forecasts that the number of authorized recyclers will rise to 1,442 by 2032.

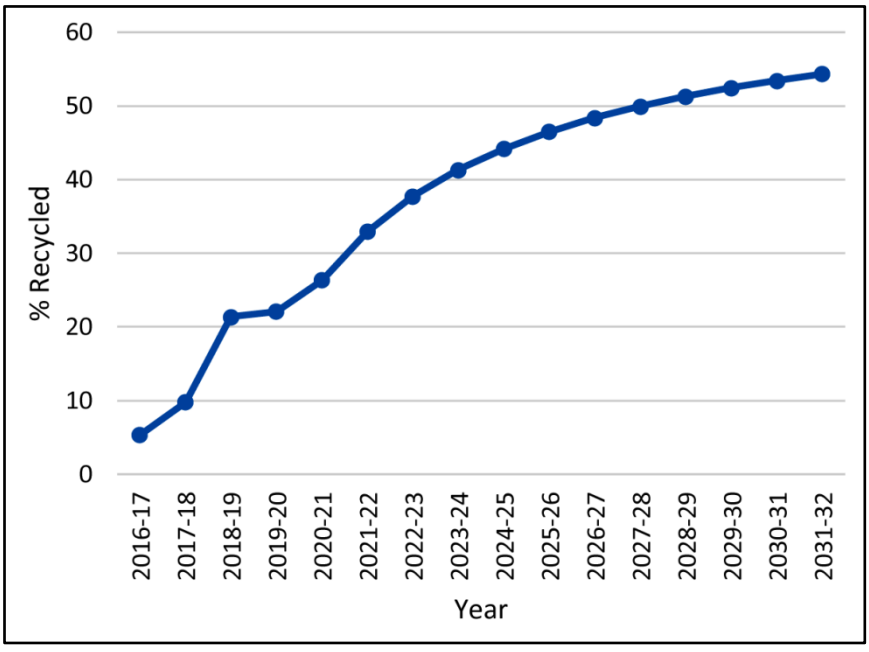


**Figure 1** Present and future analysis of percentage recycled of e-waste

From **Figure 1**, it is observed that, in the financial year 2016-17 the formal recycling was done only 5.32%, and now it is increased to 32.92% in the financial year 2021-22. The rest 67.08% has still undefined end point. The formal collection and recycling may rise up to 54.32% in the financial year 2031-32.

It is found that all the data sets are fitted with the XGB Regressor model.

### Extreme Gradient Boosting (XGBoost) Regressor

XGBoost (Extreme Gradient Boosting) is a commanding gradient boosting algorithm that is optimized for performance and speed. Several advanced features such as regularization to prevent overfitting, sparsity awareness, and weighted quantile sketch for approximate tree learning have been incorporated.

Algorithm Details:

1. Data Preparation: Similar to LGBM, the time series data was prepared by creating lag features.
2. Model Initialization: The XGBoost regressor was initialized with parameters like max depth, learning rate, and gamma.
3. Training: The model was fitted on the training data. XGBoost built trees sequentially, with each tree trying to minimize a specific loss function by using second-order gradients (Hessians) to achieve more accurate approximations.
4. Prediction: Future values were forecasted using the ensemble of trees built during training (James et al.,2013).

## CONCLUSION

India is now the third-largest e-waste-generating country, yet currently only formally processes and recycles 32.92% of its e-waste. This rate is expected to increase to 54.32% by FY 2031-32. It's important to note that under the 2016 E-Waste Management Rules, only 21 types of discarded electronic and electrical equipment (EEE) were classified as e-waste; this has since expanded to over 100 types. The forecasts rely on data aligned with the earlier 2016 regulations, so with more categories now included, e-waste generation will likely increase significantly. Therefore, the number of authorized recyclers must grow at a matching pace.

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377_IEC318

# Wreck Removal of MV Green Opal

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**Abstract**: Kolkata Port Trust (Shyamprassad Mukherjee Port Trust at present) is situated 123 nautical miles from Sand heads where the Hoogly River falls in the Bay of Bengal. River Hoogly is considered as one of the most difficult waterways for navigation in the world. River Hoogly is called "A Navigator's Nightmare and a river scientist's delight".

Half of the narrow channel was occupied by the sunken vessel. Kolkata port Pilots as usual displayed superb skill in guiding ships to Calcutta Dock System through one half of the channel. This was obviously a dangerous proposition. KoPT started negotiating with the concerned UK P&I Club for the removal of the wreck. Due to court cases and other formalities the actual salvage operation started in December 1997.The P&I Club awarded the job to a Greek salvage company Travliris Russ. The objective of the present work is to investigate the problem and solution related to the above fact.

**Keywords** : Wreck Removal; Salvage; P&I Club; Bends; Bars; Bore

## INTRODUCTION

In short, the problems of navigation in river Hooghly can be described by 3B'S. Bars Bends and Bores. The River Hoogly meandering down the deltaic region of Bengal is notoriously famous for its bars, bends and bores. It is tidal from the sand heads to Tribeni around 29 Nautical miles upstream of Kolkata with Semi-diurnal tides; two high tides and two low tides in a span of around 24 Hours 30 Minutes.

### Bars

Bars in the river are those shallow stretches lurking below the waters formed by siltation because of scouring of the banks, shifting of sands or at places where owing to the flow of the river the incoming flood tides and the outgoing ebb tides do not run fair. There are 15 numbers of bars which a ship has to cross to reach sandheads from Kolkata.

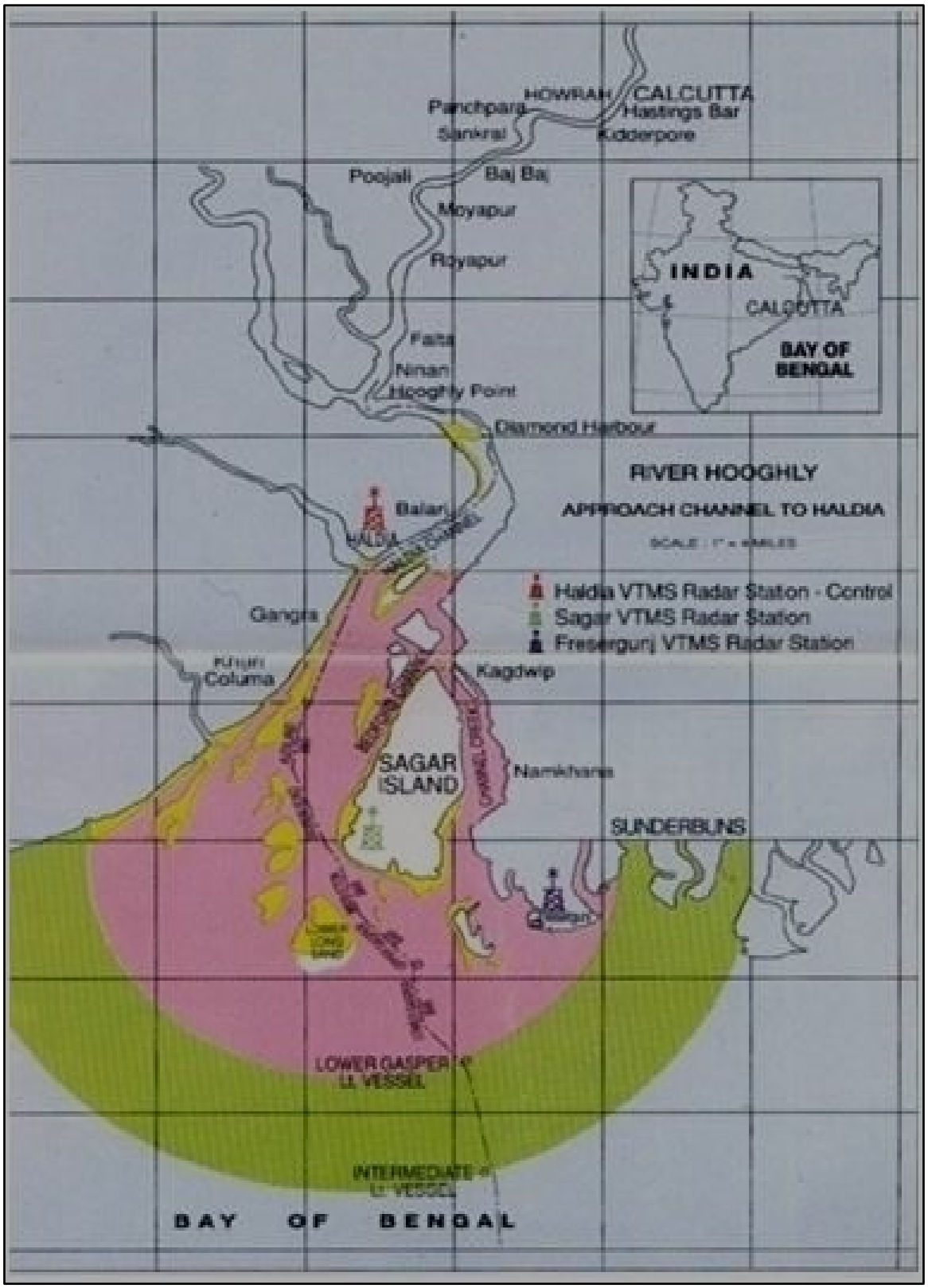
### Bends

The upper reaches of river extending 25 nm downstream of Kolkata up to Diamond harbor are tortuous with numerous turns that restrict the length and beam of the ships that can ply to Kolkata.

### Bores

The upper reaches of the river are frequented by the 'bore tides', a phenomenon that occurs during the spring tides when the predicted tidal range at Garden Reach exceeds 4.0 mtrs. As an example, when the range is in 5.0 mtrs i.e. low waters is 1.2 mtrs and succeeding high water 6.2 mtrs, the ingress flood tide shortly after low water, surges it to 'fill', the sand chocked stretches of the river. The first surge of a bore can attain a speed of 7-8 knots. A steep wall of water 3-4 feet high could be seen sweeping along the shallower side banks, fast and furious. Small crafts get swamped, ships riding at anchor if caught the wrong way fear snapping of anchor chain.

In this respect I would like to mention about 'Farakka barrage' which was commissioned in 1975. This barrage is always criticized as if it has not served its desired objectives. But I would like to point out that due to this barrage need for dredging of five of the bars in upper reaches of the river is eliminated and number of bore-days had been reduced considerably, easing shipping operation in the port.




In spite of superb skill of Hoogly River pilots, running aground of ships in the river because of above mentioned problems cannot be avoided. Sinkage of ships in Kolkata port is very rare. But unfortunately, when I took charge as Director Marine Department, within a few months of that a vessel M.V Green Opal sank due to unavoidable circumstances. Singapore bound ship MV Green Opal flying Panama flag sunk in the river Hoogly on June 19, 1997 after colliding with a lash barge in a Titanic - type encounter. The 106-meter-long, 16.31-meter broad ship had sunk

within half an hour at Birlapur with cargo of 5806 tons of wire coils and steel bars. All the Officers and Crew were rescued by Port vessels immediately.

Then the real problem started. Half of the narrow channel was occupied by the sunken vessel. Kolkata port Pilots as usual displayed superb skill in guiding ships to Calcutta Dock System through one half of the channel. This was obviously a dangerous proposition. KoPT started negotiating with the concerned UK P&I Club for the removal of the wreck. Due to court cases and other formalities the actual salvage operation started in December 1997.The P&I Club awarded the job to a Greek salvage company Travliris Russ.

The salvage company was successful in removing all the Cargo, oil etc. from the ship by March. By this time the ship had broken her back and the salvors had cut the ship into two halves. The Company tried to lift the halves by three sea-camels and 30 air lift bags. Sea-camels are steel cisterns and air lift bags are heavy duty balloons.

The balloons were blown with the hope that the ship parts will be lifted by the buoyancy, but the operation proved unsuccessful.

After a painful wait, Port authorities requested UK P&I Club to change the Salvage company. After a lot of negotiations, the P&I Club appointed a new salvage company, the Singapore based Smit International.

The company brought one 1000T Crane Vessel and a Heavy-duty Tug. This Company placed a heavy chain under the ship and started moving the chain up and down like a saw by alternately slackening and pulling the chain from the crane and the tug. In the process, the salvors cut the vessel in six parts and with the help of the crane vessel put the parts one by one ashore. We checked the river bottom by our own survey vessels as well as by Indian Navy vessels. It was seen that no part of the ship or cargo was lying on the river bed.

Thus, with the help of UK P&I Club and the Salvage Companies Kolkata Port had overcome one of the biggest hazards in the history of the port.


**CONCLUSION**

Sinking of the ship MV Green Opal in the river Hugli was one of the greatest disasters in the history of Kolkata Port.

With the combined and sincere effort of U K P&I Club, two Salvage Companies, local Agents of the shipping company and Port officials the herculean task of removal of the wreck was successfully achieved. This was really an achievement.

# Environment & Sustainability

## Natural Disaster Mitigation

104_IEC99914

# Fractal Dimension and Earthquake Frequency Magnitude Distribution in West Patna Fault, Bihar

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***Abstract:*** *The state of Bihar is situated within foredeep plain bordering foothills of Himalaya, and is almost entirely occupied by Indo Gangetic Alluvium Belt. In terms seismogenic sources, the earthquake prone history of Bihar has a twofold character: (1) On the north, there are the E-W trending seismogenic thrusts of the Himalayan fold-thrust belt, and (2) there are several NE-SW to NW-SE trending transverse faults. Several major earthquakes had caused widespread damages and loss of life in Bihar in the historical past, namely Nepal earthquake of 1833 and Bihar-Nepal earthquakes of 1934 and 1988. They originate in the basement rocks beneath Indo Gangetic Alluvium Belt and continue into the tectonically active Himalayan fold-thrust belt. The West Patna Fault (WPF) is one of the notable transverse faults (**Figure 1**). The 2015 Nepal earthquake initiated enhanced seismicity rate of micro earthquakes recorded in temporary station network in and around West Patna fault in Bihar. The frequency magnitude distribution (FMD); Gutenberg and Richter and fractal dimension (Dc) have been adopted as effective approaches for understanding the local seismotectonic activities in the study area (latitude: 24° - 29°; longitude: 84° - 86°). The b values and fractal dimensions estimated from epicenter clusters of two different depth constraints, 0-50 km and 50-100 km, show a positive correlation among them through regression analysis by least square (LS) method. Moreover, a positive correlation between b-value and Dc for spatiotemporal evaluation of the resulting seismicity is due to progressive alignment of epicenters along incipient fault plane towards the deeper part of the crust and is also well reflected in the hypocentral depth section. The modified Griffith's criterion also predicts an increase of potential energy release rate in presence of an interaction potential.*

*In above study, frequency magnitude distribution of earthquakes, b-values and fractal values, Dc attribute that there is a change in geological heterogeneity as well as rheological characteristic of rock material within the depth level 40-50 km. secondly, the fracture density in the upper part, ≤ 50 km is comparatively more homogeneously distributed epicenters which probably follow a linear fault system (Wyss et al., 2004). The result also shows that there is a tendency of coalescence of unstable due to more concentrated appearance of epicenter clusters in the lower part than the upper part which may give rise to mechanical weakening effect within the fault region of WPF. Moreover, a sharp change of b value (**Figure 2a**, **Figure 2b**) manifests a sharp change of heterogeneity within 40-50 km depth which also suggest improper stress balance within the small focal zone of WPF.*

171_IEC68944

# Remote Sensing based Disaster Management

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***Abstract:*** *Disasters are becoming more and more frequent. The new technological evolution can help rescue missions in an area where disasters have been hit hard. This paper explores the problem of less visibility during disaster using satellite platform based active sensing modalities to generate visualization which can be understood by human and rapid orient, decide and act of OODA (observe, Orient, Decide and Act) framework can be facilitated. The proposed method uses Synthetic Aperture Radar (SAR) modality data which can penetrate through translucent layers which normal passive sensing Electro Optical (EO) modalities like Hyperspectral, Multispectral or RGB fail. The Generative AI based approach is used to fuse EO and SAR data to train a model. During inference time SAR data is given as input and EO modality image as output is expected from the model.*

***Keywords:*** *Remote Sensing; Disaster Management; SAR; Image translation; Generative AI*

## INTRODUCTION

Communities across the globe are facing grave impacts of disasters. It is worrisome to note that frequency of disaster events has increased up to five times in the last four decades. In 2023, 399 disastrous events were recorded across the world relating to natural hazards resulting in 86,473 deaths, affecting 93.1 million people, and causing approximately 202.7 billion US$ of economic losses[1]. With climate change acting as an amplifier for increasing the hazards, vulnerabilities and exposure, risk of people getting killed or affected by disasters has increased significantly.

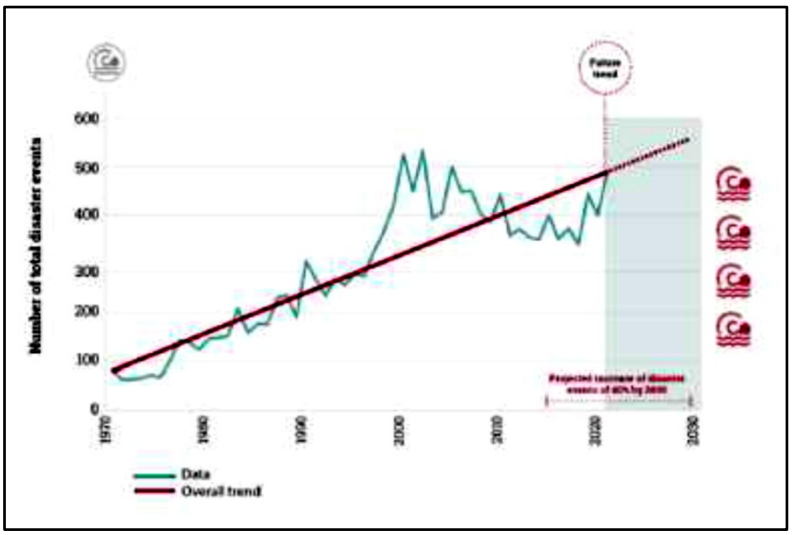


**Figure 1** Increasing number of Disaster events [2]

Climate change has amplified the frequency and intensity of weather-related hazards, as well as steadily increased the vulnerability and eroded the resilience of exposed populations. While the global annual average of catastrophic events during period 2001 to 2020 was 357, in 2023 alone, 399 such events were recorded1. Every passing decade, there is substantial increase in number of disaster events. Climate change has impacted basic resources like land, access to water, and stable mean temperatures and rainfall. Increase in extreme weather events, wildfire, droughts, sea level rise, infectious diseases were experienced across the globe. During the last two years, communities and governments

have been dealing with a compound challenge of double disasters caused by pandemic along with other natural hazards.

As the understanding of disasters is evolving, there is a significant shift in approach for addressing disasters. Lessons have been learnt facilitating a shift from reactive approach of disaster response to proactive of management of 'disaster risk'. It has put necessary emphasis for reducing the hazard impacts, reducing exposure, reducing vulnerabilities, and increasing coping capacities of communities.

As per WMO (World Meteorological Organization), due to advent of end to end of early warning systems and grassroot level mobilization based on the same, number of deaths due to cyclone (hurricanes) have reduced, making a compelling case for investing significantly in disaster risk mitigation strategies and interventions.

In this paper we discuss the use of technology as an integral part of disaster mitigation strategy and summarize our approach of using multi-modal sensing by integrating SAR (Synthetic Aperture Radar) and Optical images in disaster management scenario to providing rapid and accurate information during and after the events.

**Disaster Risk Reduction Framework**

It's important to factor the critical aspects that need to be kept in consideration towards effective disaster risk mitigation strategy. Guided by a structured framework, we can holistically view the disaster risks, evaluate mitigation options and leverage the key enablers in executing interventions.

The Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-2030 was adopted at the Third UN World Conference in Sendai, Japan, 2015. The SFDRR was an outcome of extensive stakeholder consultations and inter-governmental negotiations and was supported by the United Nations Office for Disaster Risk Reduction at the request of the UN General Assembly. It focuses on preventing new risks, reducing existing risks and strengthening resilience. Under guiding principles, it clarifies primary responsibility of states to prevent and reduce disaster risk, through all of-society and all-of-State institutions engagement.

For disaster risk reduction(mitigation), SFDRR highlights 4 priorities of action:

- Understanding Disaster Risk
- Strengthening disaster risk governance to manage disaster risk
- Investing in Disaster risk reduction for resilience
- Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation, and reconstruction.

**Technology as a Key Lever in Natural Disaster Mitigation**

Technology and innovation can help reduce the impact of climate and disaster risks by improving risk and impact understanding. Hence, it is critical to understand how technology forms an integral piece in DRR scheme of things.

A wide spectrum of technologies is instrumental in disaster risk mitigation (DRM). These technologies have roots in relevant applied sciences like geology, seismology, ecology, meteorology, hydrology, engineering etc. Emerging digital and virtual technologies build upon these core technologies to enhance the output and thereby making it more relevant for its users, decision makers and public. An opportunistic combination of established and emerging technologies forms a complex web of systems catering to different aspects DRM simultaneously. This ultimately ensures effective disaster risk reduction and management across the risk assessment, governance, investments in resilience, and preparedness for response and recovery.

For technology to be truly a force multiplier, it requires cross cutting enablers across different stages of its impact chain. These enablers are infrastructure, education and training, institutional capacities, research and development, and regulations and protocols to reinforce the framework.

**Using SAR–Optical image analysis for better accuracy and precision for Natural Disaster Mitigation** (Technology Type: Physical + Digital, Technologies used: Remote Sensing, SAR, GIS, Mobile Apps & Weather Databases)

In scope of exploring the use of technology as a key lever in disaster risk mitigation and management, we envisaged to create a system and mechanism to analyze SAR (synthetic aperture radar) and Optical images for enhanced accuracy and precision to suitably deploy interventions.

In times of disaster, the visibility is compromised so active sensors need to be used. The geo registration needs to be accurate the active sensors data needs to be presented in near real time as human interpretable data for humans in the loop AI systems.

The image registration refers to the alignment of images of the same scene captured from two different sensors: Optical and SAR. Optical sensors rely on the scene's illumination by external sources such as the Sun. SAR uses a radar source fixed on the platform to illuminate the scene, and then records the back-scattered signal's magnitude, range, and Doppler shift to produce the images.

By leveraging the multimodal data fusion, leveraging available large public data set and using deep learning techniques, we can get much better precision and accuracy.

Disaster Management can be divided into three parts:

- Pre-Disaster – Access the situation, infrastructure, and surroundings to plan the mitigation. There are many established methods to understand the 8 climatic physical risk stress and new methods are evolving in creating twins for cities or critical areas / infrastructures. There is a lot of work already done by our team for climatic risk modeling and many in pipeline for twins.
- During Disaster – Normally disasters happen very rapidly apart from floods. There is very little that can be done apart from monitoring the damage done and dynamically creating the best-case recovery plan. These are mostly at times part of the mitigation plan done in step 1 and validated using simulations.
- Post-Disaster – The management of areas impacted by the disaster is very critical and time bound. The discussion covered in the approach and experiments here addresses this stage of disaster.

Mostly post disaster the visibility is poor due to dust or clouds, or it can be nighttime and passive sensing like RGB or Multispectral or Hyperspectral might not work. The area struck by disaster might be harsh or remote and directly reaching there will take time. The situation might be chaotic and partial knowledge about the situation might not help in optimum recovery planning. In this scenario arial based monitoring using active sensing from LAP, MAP or HAP based platforms would be ideal. Specifically Synthetic Aperture Radar (SAR) based imaging would be helpful, but the data visualization and interpretation is difficult for common man.

We envisaged the following approach for enhancing the interpretability and assessment:

1. Take SAR images and register the image with stale Electro Optical image with high accuracy [3]
2. Translate the SAR image to Electro Optical image using Gen AI and multi modal, multi temporal, multi resolution data fusion – this paper is related to this step, and we will share our initial results here
3. Do the change detection and show the changes on a map.

Previously collected and registered SAR and EO data are used to train a Deep Generative Model (like a Generative Adversarial Network (GAN)) and this trained model can later be used in inferencing mode during disaster to translate SAR image to EO image for easier human understanding. In inferencing mode, only Generator-1 is used to generate EO image from input SAR image. The emerging architectural representation is as follows:

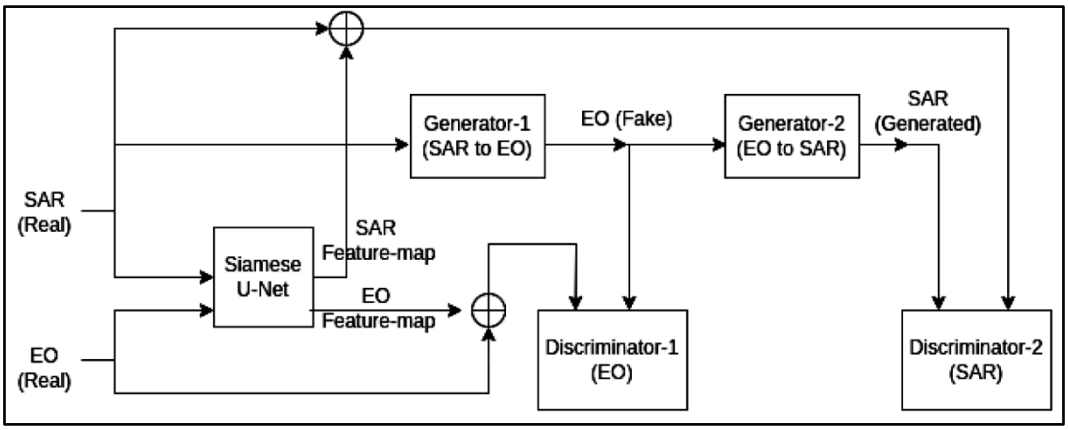


**Figure 2** Initial Architecture Diagram for the proposed SAR-to-EO Image Translation

**Table 1** Initial Results for SAR-to-EO Image Translation

| Method | PSNR ↑ | SSIM ↑ | FID ↓ | LPIPS ↓ | SAM ↓ |
|---|---|---|---|---|---|
| UGATIT [4] | 13.42 | 0.262 | 128.6 | 0.6211 | 6.16 |
| SCC-CycleGAN [5] | 13.21 | 0.224 | 132.9 | 0.6415 | 6.36 |
| FG-GAN [6] | 13.10 | 0.300 | 313.8 | 0.6470 | 6.20 |
| MS-GAN [7] | 14.62 | 0.304 | 162.2 | 0.5727 | 5.44 |
| **Ours** | 13.32 | 0.257 | 150.3 | 0.6390 | 6.17 |

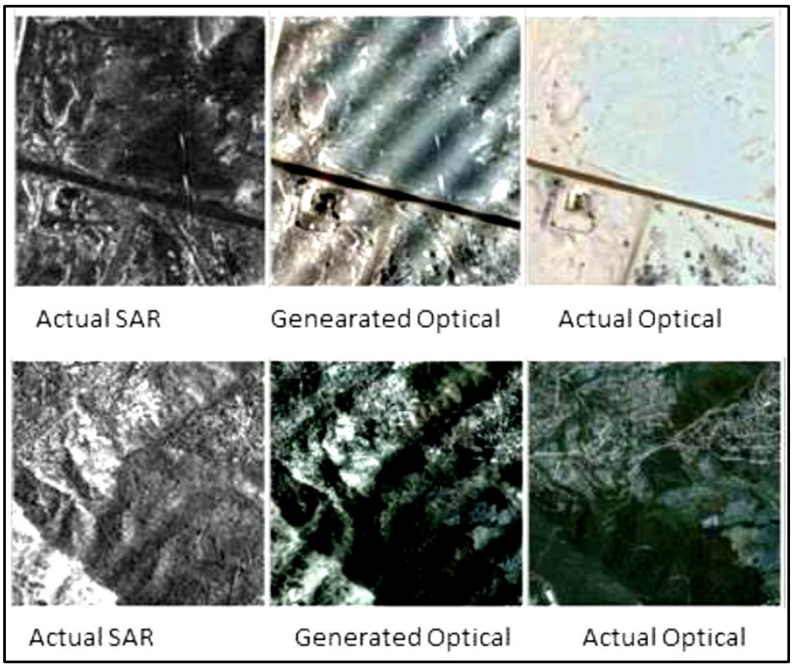


**Figure 3** Generated output for SAR-to-EO Image Translation

## FURTHER WORK AND FUTURE DIRECTION

While we continue to work on improving the results, the early findings are encouraging. We aspire to help in change detection and represent the changes in map for better usability and inference by consuming applications. We also foresee integration with several other technologies, platforms and devices, leveraging superior computational

methods to deploy the techniques in real-time disaster management scenarios. In this regard we are also exploring collaboration with ecosystem partners and disaster management agencies to expedite the prototype building and commercialization.

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# Environment & Sustainability

## River Rejuvenation

80_IEC8422

# Water Quality Index and Sediment Analysis in the Lower Basin of the River Hooghly

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***Abstract:*** *The River Ganges, often referred to the Ganga plays a central role in Indian civilization and nourishes the cultural, economical, spiritual and social development of India. The lower basin of the River Ganga named as the River Hooghly flows through West Bengal. The twin city of Howrah and Kolkata on the bank of the River Hooghly are the major sources of water pollution. The present work examines the water quality of the River Hooghly before the river enters in the city of Howrah and Kolkata. The samples collected from five stations are examined and the results analyzed for sediment loading, seasonal variation of water quality for different physicochemical parameters (turbidity, pH, alkalinity, dissolved oxygen, total dissolved solids, BOD etc.) and other flow parameters which are important for river rejuvenation. The results of this work can be used for the maintenance of required water quality of the River Hooghly that in return will nourish the mankind in the lower basins of the River Hooghly.*

***Keywords:*** *Water Quality Index (WQI); Physicochemical Parameters of Water; Sediment Loading; River Rejuvenation*

## INTRODUCTION

In India, rivers play an important role in the economy, ecology, agriculture, transportation, fisheries and regional culture. For the generation of river meandering due to disturbance in the river hydrodynamics, the sediment load from upstream carried forward to the downstream and get deposited there, which affects the downstream in water quality, navigability and the accommodation of discharge coming from the upstream. Hence the sediment transport plays an important role in the river morphology, ecosystem and affects the health of the river significantly. On the other hand, quality of the river water is getting degraded due to the anthropogenic activities day by day. Considering the holistic issues, in terms of physical devastation and socio-economic vulnerability, the study of the water quality and sediment loading is crucial, now a days, for the effective management of the rivers.

This paper presents a study of water quality of the River Hooghly in terms of physicochemical parameters at different seasons and sediment charge present in the river water. Transported sediment from upstream and regular human activities both are key reasons for the degradation of water quality of the river Hooghly. Moreover, the tidal fluctuation of the river affect the sediment load of the river water in the lower basin significantly. The water quality index (WQI) model has been a popular tool now a days for the evaluation of the quality of surface water. It allows conversion of extensive water quality data into a single value or index by the use of aggregation techniques. Collected samples from five different stations have been tested for different parameters and water quality index (WQI) has been determined to understand the present quality of the river water which in turn help in health monitoring of the river as well as may be useful for the rejuvenation of the river.

## STUDY AREA

Water samples has been collected from five different ghats of the River Hooghly of Hooghly and Howrah district, e.g., Mayurpankhi Ghat (Hooghly), Chandannagar Strand Ghat (Hooghly), Bhadreshwar Babu Ghat (Hooghly), Sheoraphuli Ghat (Hooghly) and Bally Ganga ghat (Howrah) for the determination of different physicochemical characteristics of the river water.

The collected water samples has been examined for different physicochemical characteristics like turbidity, pH, alkalinity, dissolved oxygen, total dissolved solids, BOD etc. during pre-bathing and mass-bathing period in winter season of 2023 and summer season of 2024 and the sediment load is also determined. Some of the experimented

results are shown here through bar charts. Further this study will correlate the degradation of water quality due to the presence of sediment.


**Figure 1** Hooghly Mayurpankhi Ghat (pic courtesy google maps)


**Figure 2** Chandannagar Strand Ghat (pic courtesy google maps)

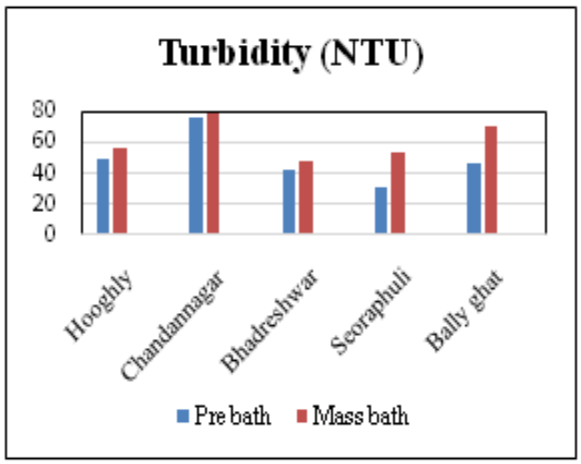


**Figure 3** Bar Chart of Turbidity(Winter 2023)

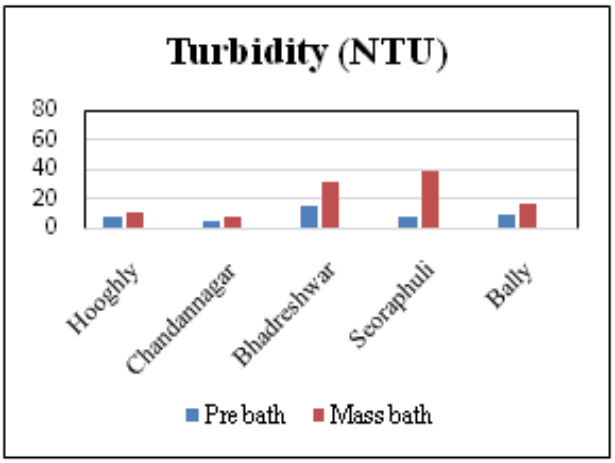


**Figure 4** Bar Chart of Turbidity (Summer 2024)

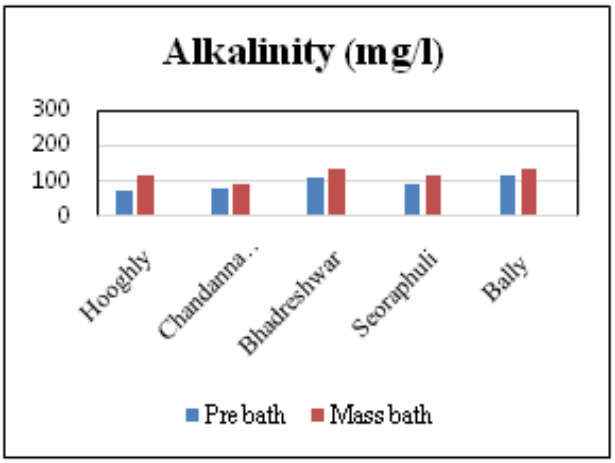


**Figure 5** Bar Chart of Alkalinity (Winter 2023)

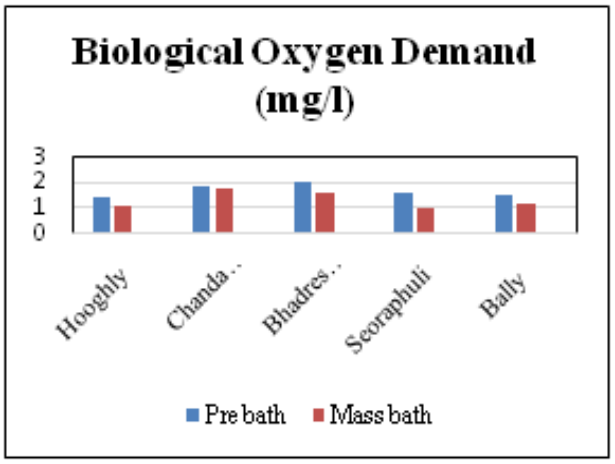


**Figure 5** Bar Chart of BOD (Winter 2023)

**ACKNOWLEDGMENT**

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280_IEC99195

# Antibiotic Detection in River Water by Electric Field Enhanced Graphene Electrochemical Sensor

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***Abstract:*** *In this paper, a novel graphene electrochemical sensor for detection of antibiotic Ciprofloxacin (Cfx) in river water is developed. The device was fabricated using a coplanar configuration of electrodes fabricated on printed circuit boards that enhance the sensitivity due to dielectrophoretic capture techniques. Immobilization of the surface of thermally reduced graphene with anti-Cfx antibodies is essential for specific detection, and therefore assessment of sensor performance takes place. Results from sensor testing demonstrate its ability to detect Cfx at extremely low concentrations of 10 pM, thereby making it potentially useful in real-time monitoring of pharmaceutical residues in aquatic ecosystems. This research represents an extremely crucial need due to environmental risks brought by levels of antibiotic contaminants and increasing resistant bacteria. The findings contribute to efforts targeted toward developing sensitive devices that are simple and cost-effective at monitoring levels of pollutants in water sources, underlining consideration of pharmaceutical contaminants in the environment.*

***Keywords****: Antibiotic Detection; River Water; Graphene; Electrochemical; Electric Field*

## INTRODUCTION

Over the past two decades, the disposal of natural and synthetic chemicals like pharmaceuticals and personal care products (PPCPs), as well as active pharmaceutical ingredients or pharmaceutically active compounds have turned our environment a dumping ground [1]. The environment risk associated with abundance of PPCPs has been established incorporating occurrence, toxicity, and bioaccumulation [2]. According to estimation by World Health Organization (WHO) drug-resistant microorganism infections may become the leading cause of death worldwide by 2050, therefore requiring the urgent need to address the crisis. A growing effort has been made by the scientific community and policymakers in relation to the need to comprehend the environmental occurrence and effects of antibiotic (AB) contaminants, as these are quite harmful to human beings, marine organisms and the environment even in low level of concentration. In aquatic environments, AB residues can release or spread antibiotic resistance genes (ARGs), enabling the development of more antibiotic-resistant bacteria [4]. In the environment, these emerging contaminants (ECs) exist at minute concentrations, commonly in micrograms per milliliter range or nanograms per milliliter. Traditional instruments and analytical techniques were incapable of discovering chemicals at minute concentration and hence, hindering research on their prevalence until recent innovations in detection techniques. Thus, it is very essential to develop rapid and sensitive devices to sense the presence of these contaminants.

Electrochemical sensors have emerged as a suitable alternative for on-site detection of active pharmaceutical residues due to their automatics, miniaturization, and reliability [5]. These sensors work on the principle of electric signal generation from surface chemical reactions rendering them able to detect specific target molecules even at very low concentration. This makes them suitable for pollution monitoring, medical diagnosis, and food sanitation etc. At the most, there have been few studies that detail the development of electrochemical approaches that have been used in the detection of pharmaceuticals in water samples. Among several antibiotics, second-generation fluoroquinolone Ciprofloxacin (Cfx) is one of the main antibiotics found abundantly in the water of River Ganges. Recent research has shown that electrochemical sensors are highly sensitive for detecting antibiotics in the range of μM in milk [6]. Graphene oxide and poly(phenol red) glassy carbon electrodes have also provided high sensitivity and have performing toward detection limits of 2nM [7]. Other strategies featured the use of carbon nanotubes (CNTs), mention but are not limited to oxygen functionalized CNT with polydopamine and silver nanoparticles [8] and porous MWCNT Nafion composite film electrodes [9]; these with detection limit of 5nM. The achieved detection limits of

most of these sensors have been limited to nM range which urges the immediate need to design sensors in order to detect even minor traces of antibiotics in water with reduced design complexities.

This work demonstrates a custom fabricated graphene electrochemical sensor with coplanar counter and reference electrode using printable inks on copper plated PCBs to enhance the sensitivity by dielectrophoretic (DEP) capture of antibiotics. This strategy enables Cfx detection in river water down to 10pM with low fabrication cost, minimal sample preparation and easy integrability, thus showing a promising approach in the field of pharmaceutical residue detection.

## MATERIALS AND METHODS

### Device Fabrication

A custom-made electrochemical sensor has been successfully designed and fabricated on a polyimide substrate-based printed circuit board (PCB), using Eagle CAD (Autodesk Inc., USA, v-9.6.2). The sensor features a three-electrode configuration, comprising a working electrode, reference electrode, and counter electrode, positioned at a radial distance of 1 mm from the working electrode for better electrochemical performance. The designed layout has been realized on the polyimide substrate with the help of a commercial etcher (Lpkf ++ Protomat S64) with standard protocols. Following fabrication, the electrode substrates were cleaned with acetone and deionized (DI) water in series to remove residual impurities. Later on, the counter electrode was modified by depositing silver (Ag) paste (Sigma Aldrich), ensuring the coverage of the electrode area. Similarly, Ag/AgCl paste was deposited onto the reference electrode. The device was then dried at 60°C for 1 hour to stabilize the deposited materials. To functionalize the working electrode, thermal reduction of graphene oxide (GO) was done, wherein 1 µL of commercially available GO solution (Terracarb Ltd.) was drop-casted onto the working electrode and annealed at 300°C, reducing GO to reduced graphene oxide (rGO). This customised sensor design, carried by precise engineering and material optimization, improves the electrochemical sensing capabilities in this proposed work. The immobilization of anti-ciprofloxacin (anti-Cfx) antibody on graphene has been performed through physical adsorption.

### Device Characterization

The Raman spectroscopy studies were carried out using a WITEC UHTS 300 Raman system with a 100x objective lens attachment. Raman sessions were excited by using a source of a 785 nm laser. The successful immobilization of the antibodies that were tested as well the effectiveness of dielectrophoresis (DEP) is supported by fluorescein isothiocyanate (FITC)-labelled antibodies on the graphene surface. A fluorescence microscope (Nikon Eclipse Ti-U, Japan) was also used to carry out fluorescent measurement on the antibody coated graphene substrates whereby the excitation and emission wavelengths were set at 495 nm and 520 nm, respectively.

### Test Samples

Initially, river water was filtered through 0.2µm filter paper to filter out micron-sized bacterial cells, then it is spiked with Ciprofloxacin (Cfx) of various concentrations. For real-time measurements, an initial test was conducted using 10 mM phosphate-buffered saline (PBS) at pH 7.4 as a baseline. Following a 30-minute incubation, readings were taken as a negative control with 8.4 pH of PBS. Next, the working electrode was immobilized with anti-Ciprofloxacin (anti-Cfx) antibodies on graphene and kept in incubation for 30 minutes. The sensor was then exposed to Ciprofloxacin-spiked River water, with intermediate washing steps to remove non-specifically adsorbed molecules during buffer measurements. Three sensors were tested for each Cfx concentration and readings were recorded.

### Electrochemical Characterization

Cyclic Voltammetry (CV) and Electrochemical Impedance Spectroscopy (EIS) were employed to observe the electrochemical behaviour of the reduced graphene oxide (RGO) based electrochemical sensor. CV measurements were performed using a custom-built potentiostat. The CV response of the sensor was recorded with phosphate-buffered saline (PBS) and afterwards antibody immobilization. Subsequently for different concentration of Cfx. The

CV scans were conducted in a 0.1 mmol mL-1 potassium hexacyanoferrate (II) trihydrate solution, containing 50 mmol mL-1 KCl. The raw CV data were smoothed using Origin2024 software. EIS measurements were carried out using an LCR meter varying the frequency from 0.1 kHz to 200 kHz at a constant voltage of 0.1V. The real and imaginary components of the impedance were calculated and the appropriate models using ZSimpWin 3.20 Software with their parameters were extracted.

## RESULTS AND DISCUSSION

### Structural Characterization

The graphene-based electrochemical sensor design is shown in **Figure 1(a)** and the quality of the graphene layer after deposition is analyzed by Raman spectroscopy is shown in **Figure 1(b)**. After the antibody was immobilized, various amounts of anti-Cfx were added to the obtained plate to reach different binding densities and after incubation for 30 minutes electrochemical measurements were done as shown in figure 1c. The effectiveness of (DEP) in capturing biomolecules was also verified with fluorescently tagged anti-Cfx. (**Figure 1(d)** and **Figure 1(e)**). Without any external forces, antibodies naturally adsorb onto the surface of due to its inherent properties and physical forces. When AC field of 1V and 1MHz was applied for 10 minutes, electric dipole of AC field and molecules was applied for effective separation, hence improving the capture efficiency. Therefore, DEP-induced pre-concentration is initially done for antibiotic capture and then measurements were taken.

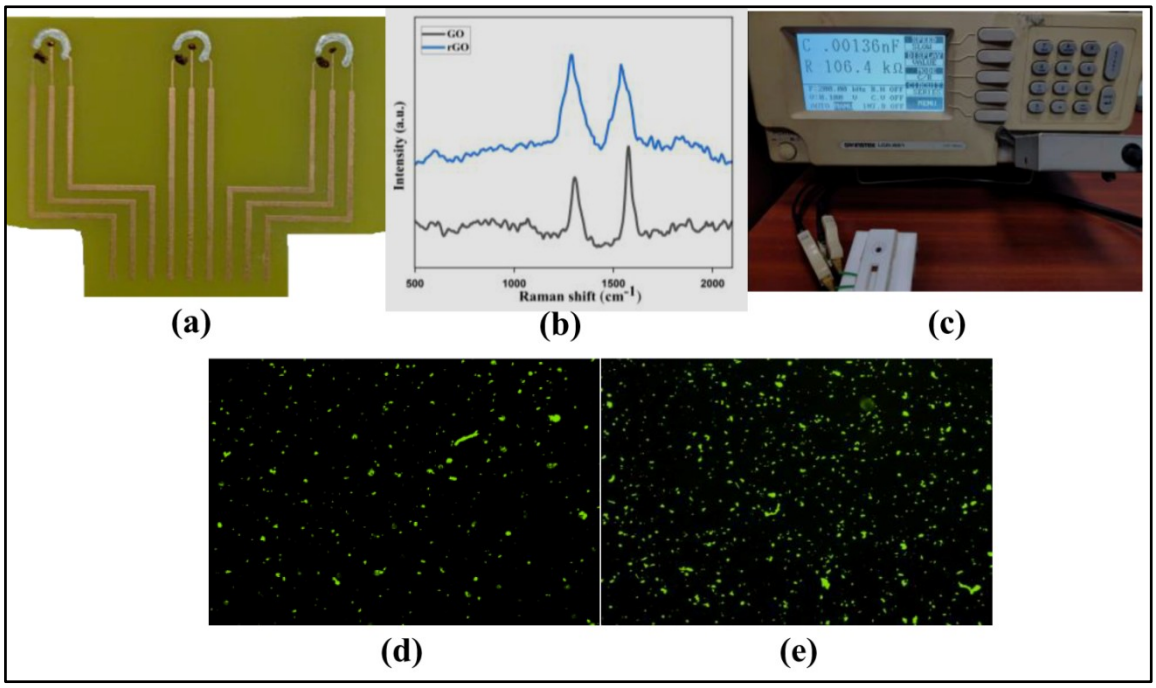


**Figure 1** (a) Custom fabricated graphene Electrochemical sensor design, (b) Raman spectra of GO and rGO, (c) Measurement Setup Fluorescence images of antibody immobilization (d) before and (e) after DEP

### Electrochemical Characterization

The custom fabricated Electrochemical sensors for the detection of Cfx in water has been shown in **Figure 1(c)** which depicts the sensor along with the measurement setup. It has been observed from the CV characteristics in **Figure 2(a)** that the Faradaic current increases and the impedance from **Figure 2(b)** decreases upon attachment of negatively charged antibiotics which is primarily attributed to the increase in positive carriers within the carbon working electrode. Also, it has been observed that the fractional change in impedance increases with increasing concentration and the sensor shows a linear response (**Figure 2(c)**). The circuit model for the Electrochemical sensor has been extracted from EIS shown in (**Figure 2(i)**). The comparison of the electrical field enhanced graphene Electrochemical sensor with the existing reports on antibiotic detection in contaminated water is represented in **Table 1**.

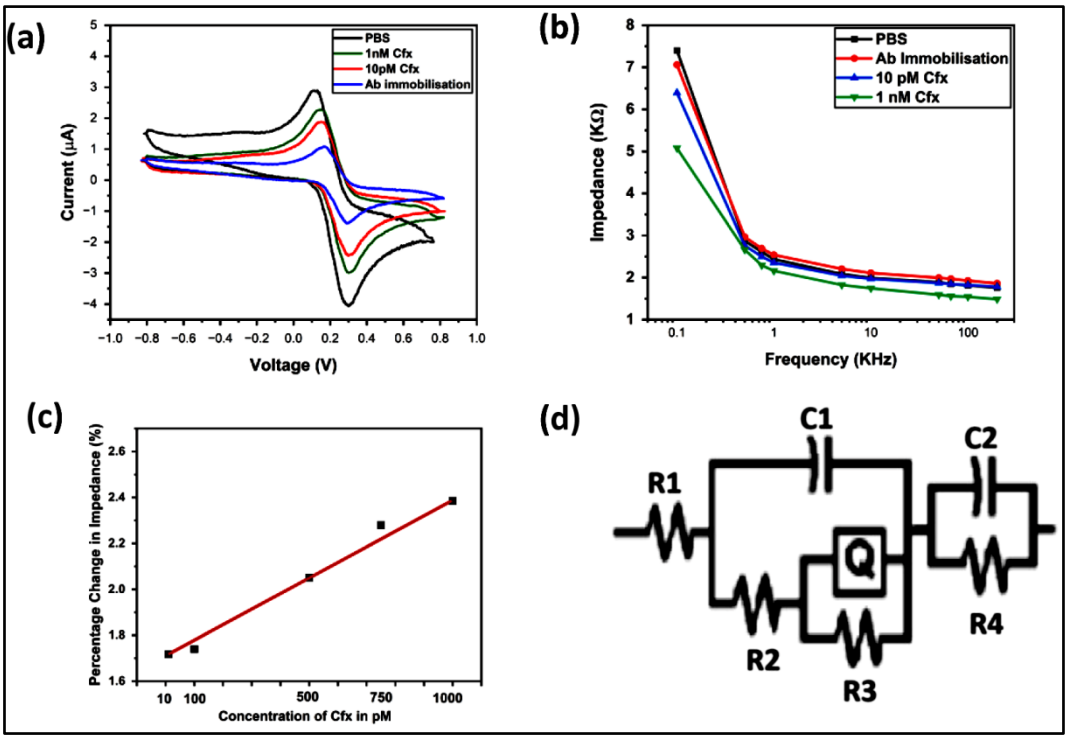


**Figure 2** (a) Cyclic Voltammetry of PBS, after Ab incubation and 1nM and 10pM Concetration of Cfx, (b) Impedance vs Frequency plot of PBS, after Ab incubation and 1nM and 10pM Concetration of Cfx (c) Percentage change impedance Vs Concentration of Cx Graph (d) Circuit Model Extracted from EIS

**Table 1** Comparison with previous reports on antibiotic detection

| Ref No. | Sensing Mechanism | LOD | Target Analyte |
|---|---|---|---|
| 6 | Electrochemical | 22.5 µM, 3.4 µM | Tetracycline and streptomycin in milk |
| 7 | Electrochemical | 2 nM | Ciprofloxacin in serum sample |
| 8 | Electrochemical | 5 nM | Ciprofloxacin in Tap Water |
| 9 | Electrochemical | 5 nM | Ciprofloxacin in Water |
| 10 | Electrochemical | 0.02 µM | Ciprofloxacin hydrochloride drugs |
| This work | Electric Field enhanced Electrochemical | 10 pM | Ciprofloxacin in River Water |

## CONCLUSION

This research work developed the graphene electrochemical sensor for detection of trace amounts of antibiotics in river water. The application of DEP technology considerably enhances capture efficiency of the sensor, so thereby letting the Cfx detection at unprecedented sensitivity levels. Therefore, the new achievement is very important since pharmaceutical contaminants can lead to the proliferation of antibiotic-resistant bacteria through risks in the environment. Its low manufacturing cost, especially its ease of usage, makes this a worthwhile device to use for on-site monitoring of water quality. Future work should expand the sensor's applicability for other pharmaceutical compounds and environmental samples, establishing the understanding and management of pharmaceutical pollution in aquatic ecosystems.

## ACKNOWLEDGMENT

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# Environment & Sustainability

## Sustainable Development and Smart Cities

67_IEC76553

# Soil Slope Stabilization using MSW Incineration Ash

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***Abstract:*** *Soil slope stabilization is crucial in infrastructure development, especially in erosion-prone areas. Traditional methods often rely on costly materials with environmental drawbacks. This study explores an innovative approach using municipal solid waste incineration ash (MSWIA) and fly ash as a partial replacement for conventional stabilizers. Fly ash, a waste product of thermal power plants, is used as a soil stabilizer for embankment slopes. The study mixes soil with 5-25% fly ash by dry weight and conducts modified Proctor compaction and direct shear tests. Results show increased dry density and cohesion, but decreased angle of internal friction with higher fly ash content. Incorporating MSWIA enhances soil slope stability while addressing waste disposal challenges. Environmental impact assessments demonstrate the sustainability of this approach, offering a promising eco-friendly solution for soil stabilization. This innovative method reduces reliance on costly materials with negative environmental effects, making it suitable for infrastructure development in erosion-prone areas. The study's findings suggest a viable alternative for soil slope stabilization, promoting sustainable infrastructure development.*

***Keywords:*** *Fly Ash; Slope; Stabilized Soil*

## INTRODUCTION

Soil slope stabilization is a fundamental concern in civil engineering, particularly in regions characterized by steep terrain, heavy rainfall, and geological instability. Traditional stabilization techniques often rely on the use of virgin materials such as cement, lime, or chemical additives, which not only incur significant costs but also pose environmental challenges related to resource depletion and carbon emissions. In this context, there is a growing imperative to explore alternative, sustainable approaches that mitigate these drawbacks while ensuring the stability and longevity of engineered slopes.

Most of the thermal power plants in India are facing difficulty for disposal and utilization of fly ash. Total generation of fly ash is about 184.14 million tons from 145 Nos. of thermal power plants of India (Report of central electricity authority, 2014-15). Only 55.69% of fly ash is utilized for the construction work i.e. brick, cement, concrete production etc. Remaining fly ash has to be suitably disposed of. Several researchers have worked for its effective utilization as embankment materials, stabilization of soft soils, road sub-base constructions and other geotechnical fields. Still, there is requirement to explore different fields for the utilization of fly ash and its safe disposal. Notification issued by Ministry of Environment and Forest (MoEF) made compulsory to utilize fly ash for construction of road and embankments, reclamation and compaction of lowlying areas within the radius of 100 km from thermal power plants. Fly ash is a non-plastic material, having very negligible cohesion in dry condition, while it shows some cohesion under wet conditions due to its self-cementing properties. Fly ash consists of hollow spheres of silicon, aluminum, iron oxides and unoxidized carbon. Fly ash is pozzolanic in nature and contains some lime.

This delves into the promising avenue of utilizing municipal solid waste incineration ash (MSWIA) as a partial replacement for conventional stabilizing agents in soil stabilization applications. MSWIA is a byproduct of municipal solid waste incineration processes, which, if not managed properly, can pose significant environmental risks. By repurposing MSWIA as a stabilizing agent in soil, not only can the environmental burden of waste disposal be alleviated, but also the mechanical properties of soil can be enhanced to withstand slope instability

In the present study, fly ash is used as soil stabilizer for embankment slope of clay pebble soil. The shear strength parameter of native soil and stabilized soil with different percentages of fly ash (5%, 10%, 15%, 20%, and 25%) has been analyzed. An assessment of stability of fly ash stabilized soil slope using plaxis 2D software. The parametric study has been done to calculate the factor of safety (FoS). In conclusion, the findings of this study underscore the

potential of MSWIA as a sustainable alternative for soil slope stabilization, offering both technical efficacy and environmental benefits. By embracing innovative solutions that harness waste materials for engineering applications, the civil engineering community can contribute to the transition towards a more circular and sustainable economy, while ensuring the resilience and safety of critical infrastructure in a changing climate.

**LITERATURE REVIEW**

Arun Kumar and Anupam Mittal (2018). Soil stabilization involves modifying soil properties to meet engineering requirements, with common methods including compaction and admixtures. Municipal solid waste (MSW) ash, an increasing waste material, can be used to improve soil properties. This study investigated the stabilization of clayey soil with MSW ash and its effects on geotechnical properties. The soil collected from NIT campus and MSW ash were tested for parameters like grain size distribution, specific gravity, Atterberg's limit, Proctor compaction test, and unconfined compressive strength. Results showed that the specific gravity of soil was 2.53, and the specific gravity of MSW ash was 2.24. The study highlights the importance of safe disposal of waste materials, as the exponential growth of MSW waste has created environmental and public health problems.

Vipin Madadh (2013). Soil stabilization using burnt municipal solid waste ash involves tests on different soil proportions and additives, such as bottom ash. Researchers analyze ash and inert material for their physical and engineering properties. Municipal incinerated bottom ash (MIBA) is highly puzzolonic and has been used in recent engineering studies for highway construction. Soil-improvement techniques involve changing soil characteristics through physical action or the inclusion of stronger materials. Geotechnical engineers design foundations and structures on soil, using synthetic materials like geotextiles, geomembranes, geogrids, and geocomposits. Burnt Municipal Solid Waste (BMSW) is generated due to population growth, urbanization, and industrialization. Various stabilization techniques, and reduce waste disposal costs. The optimal value for ash for soil stabilization is 8%, with a lower plasticity index and higher CBR value.

Dimitrios Zekkos (2016). A study on the geotechnical characterization of Municipal Solid Waste Incineration Ash at Carleton Farms monofill in Michigan found that the grain size distribution was similar but compaction characteristics varied significantly. Specific gravities were lower than silicic soils, and shear strengths were higher than typically reported for sandy soils. Strain rate did not impact shear resistance. In situ shear wave velocities ranged from 500 to 800 m/s at a depth of 8 m to 1100–1200 m/s at a depth of 50 m. This study may promote unbound utilization of MSWI ash in civil infrastructure.

Saride, S., et al. (2019). Utilization of industrial waste materials for stabilization of problematic soils: A review. Journal of Cleaner Production, 220, 45-66. This review article discusses the utilization of various industrial waste materials for soil stabilization purposes, providing insights into the potential use of MSW incineration ash.

Sivapullaiah, P. V., et al. (2008). Utilization of municipal solid waste incineration (MSWI) ash in controlled low-strength material (CLSM). Waste Management, 28(12), 2518-2529. This study investigates the potential of using MSW incineration ash in controlled low-strength material, which could have implications for soil stabilization applications.

Mitchell, J. K., & Soga, K. (2005). Fundamentals of Soil Behavior. John Wiley & Sons. This comprehensive book covers various aspects of soil behavior and stabilization techniques, providing a foundational understanding for soil stabilization studies.

Indraratna, B., et al. (2018). Recent advances in soil reinforcement and ground improvement techniques using geosynthetics. Geotextiles and Geomembranes, 46(6), 703-717. While not specific to waste materials, this review article discusses recent advances in soil reinforcement and ground improvement techniques, which could include methods applicable to soil stabilization.

European Commission. (2017). Guidance document on the use of waste materials in civil engineering applications - Status quo and future scenarios. Publications Office of the European Union. This document provides guidance on the

use of waste materials, including regulatory aspects, in civil engineering applications, which could be relevant when considering MSW incineration ash for soil stabilization.

**Objectives**

1. To determine the OMC and MDD of different MSW incineration ash mixtures
2. To determine the Soil strength characteristics of different MSW incineration ash mixtures
3. To determine the Deformation and FOS of slope stabilization from different MSW incineration ash mixtures.

**METHODOLOGY**

- Collection of municipal solid waste incineration ash from the plant
- Proportioning the soil for different percentages of MSW incineration ash
- Experimenting all the samples of different proportioning of ash mixed samples
- Soil slope analysis for values of MSW incineration ash mixes using plaxis 2d software
- Result and conclusion

**RESULTS**

**Analysis of Slope Stability using PLAXIZ 2D Software**

PLAXIS 2D is a powerful finite element analysis software commonly used for geotechnical engineering applications, including slope stability analysis. It allows engineers to model and analyze complex soil-structure interaction problems in two dimensions. With PLAXIS 2D, users can simulate various slope stability scenarios by considering factors such as soil properties, groundwater conditions, and external loading. The software provides comprehensive tools for evaluating slope stability, analyzing failure mechanisms, and designing appropriate stabilization measures. Its intuitive interface and advanced capabilities make it a preferred choice for geotechnical engineers worldwide when assessing slope stability and ensuring the safety and stability of civil engineering projects.

**Steps to be Perform in Plaxis 2D Software**

- STEP 1: Define the project and geometry of structural element
- STEP 2: Defining of material properties of each layer
- STEP 3: Creation of mesh for the structure
- STEP 4: Creation of deformation and FOS layers
- STEP 5: Calculation of results
- STEP 6: Analyze the results of deformation and FOS

**Results of 0% MSW Incineration Ash Mixed Soil**

These results collectively provide valuable information for engineers to assess the stability, deformation behavior, and failure mechanisms of slopes. Engineers can use these results to optimize slope designs, identify critical failure surfaces, and implement effective stabilization measures to mitigate potential risks

Deformation Patterns: PLAXIS visualizes deformation patterns illustrating how the slope deforms under applied loads and boundary conditions. By observing deformation patterns over time or during different construction phases, engineers can evaluate the behavior of the slope and assess the effectiveness of stabilization measures.

**Results of 20% MSW Incineration Ash Mixed Soil**

The above fig shows the deformations of the embankment for long years of 20% msw ash mixed soil. Here the deformations are less compared to the original soil.

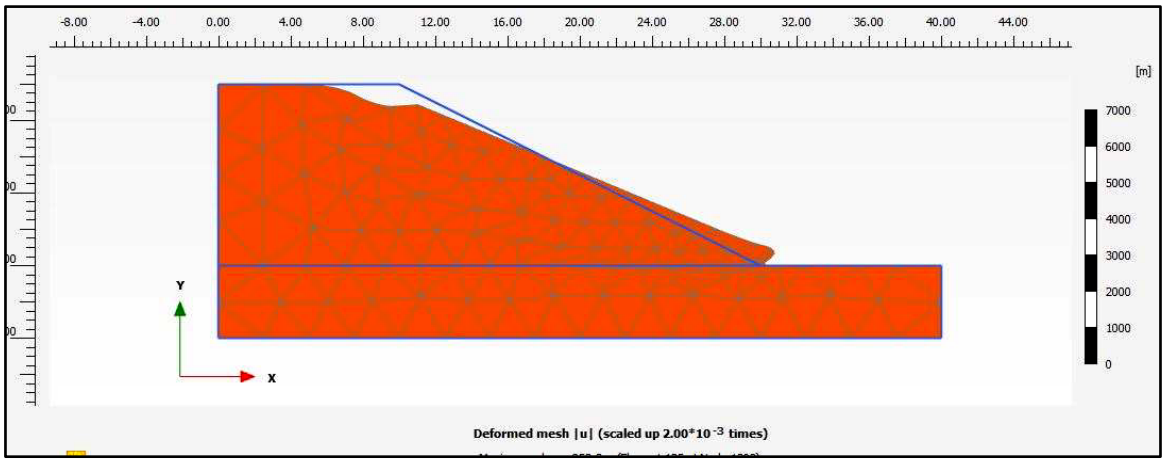


**Figure 15** Figure indicating deformations for the input original soil PLAXIS 2D software

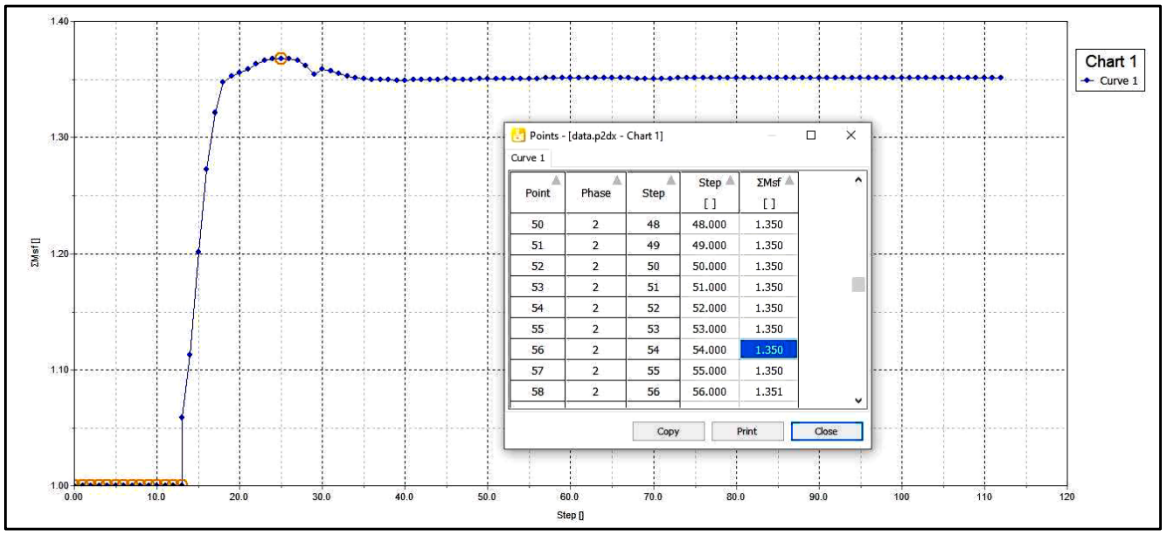


**Figure 16** Figure indicating graph of FoS for an original soil in plaxis 2d software

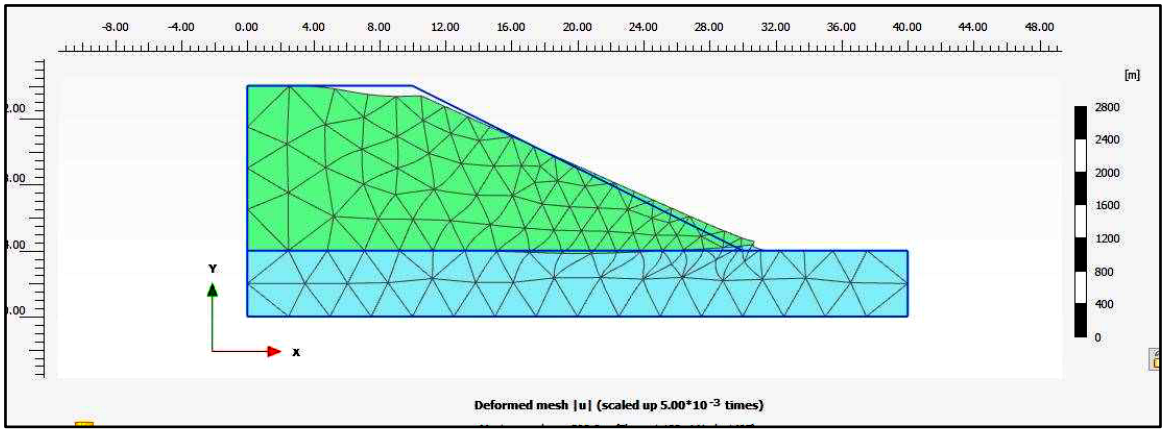


**Figure 18** Figure indicating deformations for the input 20% ash mixed soil plaxis 2d software

## CONCLUSION

- The MDD of the soil increases with increase in the percentage of msw incineration ash in soil.

- The increase in the percentage of msw incineration fly ash decreases the angle of internal friction and increases the cohesion of the soil.
- The increase in the percentage of msw incineration fly ash increases the FoS up to addition of 20% msw incineration ash Based on the value of FoS optimum value of fly ash is 20% for stabilizing the soil.

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125_IEC53884

# Structural Conservation Work of Rumi Gate, Lucknow — An Overview

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**Abstract:** This case study paper discusses the sustainability efforts for conservation of Rumi Gate (an iconic historical structure and centrally protected monument of Archaeological Survey of India) Lucknow, India. This structure situated on the right bank of river Gomati and suffers many major flood in past times like 1891, 1894, 1960 and more. Due to many flood, the foundation settlements suffered and whole structure bear a major vertical crack, from top of super structure to foundation. For structural strengthen and safety of the structure, many efforts taken place in past time, from British period to present. Since last few years, due to climatic changes in this region and pollution around this structure and due to heavy vehicle movement through the gate was one of the major causes for the development of the cracks in the edifice. Therefore, during the session 2022 and 2023, ASI Lucknow circle carried out the structural conservation work with the help of traditional lime mortar (mix of Lime, Sand and Surkhi) used in a specific ratio with natural adhesives like bel fruit gel, babbol gum, gur/malaises, urad dal pest, chicken egg gel within a desired manner and proportion. During the process of conservation the cracks were filled through proper grouting & stitching work also provided wherever required. After 2 year study, it found that no any weathering effect seems. So, it may be point out that carbonation effect may be reduced in lime mortar by addition of natural adhesives. This case study may be useful for other relevant structures for conservation with sustainability effort.

**Keywords:** Lime Mortar; Sustainability; Natural Adhesive; Climate Change; Pollution; Conservation

## INTRODUCTION

The historical building and monuments are the landmark of any region and the Conservation and sustainability of such structures should to be on priority. “Conservation” means all the processes of preserving and maintaining a place so as to retain its historical or architectural or aesthetic or cultural significance and includes maintenance, preservation, restoration, reconstruction and adoption of a combination of one or more of these measures.

Rumi gate in Lucknow, India was built in 1784 and later became the symbol for the city of Lucknow. From top center chatri to ground level, its height is 100 feet. Many major flood in past times like 1891, 1894, 1960 and presently presence of Carbon Dioxide in atmosphere affected the sustainability of the structure.

During conservation of Rumi gate and its adjoining structures, it found that in last few decades, carbonation affects the lime mortar due to presence of Carbon Dioxide in atmosphere and similarly climate change like temperature and humidity in such region. Due to Carbonation effect, the lime mortar gradually losses it’s binding strength and overall the structure gradually decreases its structural strength and after regular weathering effects, there were a big problems regarding sustainability for structures.

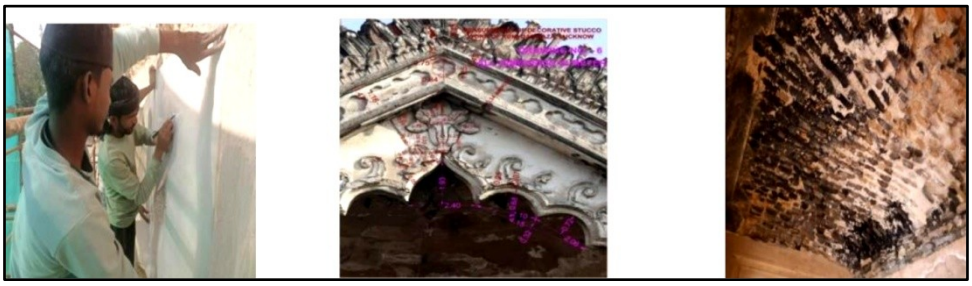
## METHODOLOGY

These are some stages from starting to completion of Structural Conservation works:

- First Phase : Barricading the area of Rumi Gate for diversion of heavy traffic & tourist (**Image 1**);
- Second Phase : Proper Documentation like photo, video, drawings, site plan, sectional plan of each and every part of structure and study the causes of structural problems. (**Images 2A, 2B & 2C**);
- Third Phase : Detailed Estimate with analysis of mortar required for conservation as per problems;
- Fourth Phase : Stitching and grouting the structural cracks and leakages at required area of Rumi gate;

- Fifth Phase : Stucco work, design moulding work, highly rich intricate plaster work in traditional lime mortar with natural adhesives (**Images 3A & 3B**);
- Six Phase : Carbonation testing of lime mortar executed and maintenance of the proper rain water drainage system around Rumi gate for safety and sustainability of foundation. (**Image 4A & 4B**).

**Images 1** Barricading the area of Rumi Gate for diversion of heavy traffic & tourist (Photo taken during conservation)



**Images 2A, 2B & 2C** Proper Documentation like photo, video, drawings, site plan, sectional plan of each and every part of structure and study the causes of structural problems

**Images 3A & 3B** Stucco work, design moulding work, highly rich intricate plaster work in traditional lime mortar with natural adhesives

**Images 4A & 4B** Carbonation testing of lime mortar executed

**Images 5A & 5B** Rumi Gate main structure before, during and after major conservation works

## DISCUSSIONS FOR CONSERVATION APPROACH ADOPTED

- Historical monuments are culturally, the key aspects for nation pride, therefore conservation of the monuments require serious and sustainable efforts for future generation. Further, the study delineates measures to be adopted proactively for mitigating the severe damaging effects of carbon dioxide in atmosphere on cultural and historical/heritage buildings.
- Traditional lime mortar is a combination of lime putty and aggregate (usually sand and surkhi). A typical modern lime mortar mix would be 1 part lime putty to 3 parts washed, well graded sand. Other materials have been used as aggregate instead of sand. The theory is that the voids of empty space between the sand particles account for a 1/3 of the volume of the sand. The lime putty when mixed at a 1 to 3 ratio, fill these voids to create a compact mortar. Analysis of mortar samples from historic buildings typically indicates a higher ratio of around 1 part lime to 2 part aggregate/sand was commonly used. A traditional course plaster mix also had horse hair or jute fibers added for reinforcing and control of shrinkage.
- “Ref. [5]”The higher relative humidity around and inside the monuments/structures, there is a every possibilities of reaction between the calcium carbonate and carbon dioxide changing into bicarbonates with time, and causing loosening of the grains and after this type of regular happenings, the weathering effect damages to the monuments and their structure.
- “Ref. [2]”Carbonation in lime mortar depends on grain size of sand and other binding materials with presence of carbon dioxide in humid atmosphere with more than average daily temperature.
- “Ref. [3]”Buildings in the region suffers mostly, where temperature almost three months in every year above than varying from average daily temperature between 30 to 45 °C and humidity due to rainy season and fog in winter season.
- “Ref. [4]”The nature of lime mortar is alkaline and pH more than 12.5. Its alkalinity reduces due to carbonation and results are detoriation of lime mortar. The detoriation effect an expansion in volume of binding mortar

course layers/joints with stone or bricks. This expansion in volume creates cracks in lime concrete or mortar. These cracks further create a situation for carbon dioxide thus the regular cycle continues and ultimately structures in a critical state. Carbonation is the result of the dissolution of carbon dioxide in the lime mortar or lime concrete pore fluid and this reacts with calcium from calcium hydroxide to form calcite ($CaCO_3$).

- "Ref. [2]"Carbonation test may be better to know the effect of the atmospheric carbon dioxide on the lime mortar of monuments/structure. The carbonation test for in-situ lime mortar cube is associated with the detoriation often occurs on the building facades which are exposed to moisture, rainfall and shaded from sunlight.
- For knowing the carbonated area of lime mortar used, the carbonation test done in INTACH lab luck now and found very good indication result as shown in **Table 1** and **Images 4A & 4B**.

**Table 1** Carbonation Test of lime mortar after 2 years of conservation/execution

| Group of sample | Test Result | Remark |
|---|---|---|
| 1st group of sample | 2% area carbonated | 98% Safe condition of lime mortar for sustainability indication |
| 2nd group of sample | 1% area carbonated | 99% Safe condition of lime mortar for sustainability indication |
| 3rd group of sample | 2% area carbonated | 98% Safe condition of lime mortar for sustainability indication |

## CONCLUSION

The structural conservation work with the help of traditional lime mortar (mix of Lime, Sand and Surkhi) used in a specific ratio with necessary and important natural adhesives like Bel fruit gel, Babbol gum, Gur/malaises, Urad dal pest, chicken egg gel within a desired manner and proportion may be excellent to conservation, for sustainability of lime mortar to avoiding the carbonation of mortar. The structural cracks should to be controlled through proper grouting & stitching work, wherever required in lime mortar by addition of natural adhesives. Proper drainage system and traffic diverges are very important aspects for further sustainability.

After study, it found that no any weathering effect seems. So, it may be point out that carbonation effect may be reduced in lime mortar by addition of natural adhesives. This case study may be useful for other relevant structures for conservation with sustainability effort.

## ACKNOWLEDGMENT

1. Archaeological Survey of India, Lucknow Circle
2. Carbonation concept creation of Prof. Devendra Mohan, CED, IIT-BHU, Varanasi
3. Testing Lab, INTAC, Lucknow

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238_IEC9009

# Pathways to Sustainability for Higher Education Institutions: NIRF induced SDGs

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***Abstract:*** *No collective effort from human beings have been closer to nature than sustainable development goals (SDGs). The societal benefits brought about by its impact are nothing less than revolutionary. More than bringing changes at the ground level it succeeds in planting the seeds of sustainability in the minds of our future generations. Technologies have helped the humans not just to survive and thrive in his environment, but also to drive the course of nature. Being a double-edged sword, technology is hurting the civilization more than ever now. Presence of micro-plastics inside human body should serve as the decisive reminder that should push any common man to adopt SDGs every living moment. Higher Educational Institutes (HEIs) are where manifestation of the best version of every student should happen. India utilises NIRF as a parameter, to set forth the guidelines for lucrative pathways, where SDGs have taken roots in the recently released NIRF-2024 rankings. Institutes are expected to explore and adopt these pathways to become a world class institution. In this paper, poignant perspectives through the watch glass of NIRF and SDGs are embarked to the benefit of the stakeholders of HEIs including the teachers, students, management, common public and employers.*

***Keywords:*** *SDG; NIRF; HEI; Stakeholder; Societal Impact; Technology*

## INTRODUCTION

Education encourages critical thinking and open-mindedness by providing access to transformative learning allowing individuals to shoulder social responsibility. Educational institutions help to improve knowledge of the individuals and the society by maintaining high standards in teaching, curriculum creation, and research. They are accountable for developing competent professionals as the skilled workforce capable of solving global concerns. Higher education institutions provide high-quality education emphasising academic rigour, critical thinking, and creativity for a smaller yet strategic part of the population of a country [1,2]. India being a country with a major share of vibrant youth from diverse cultures, it is important to develop a fool-proof system of education. It becomes the responsibility of the HEIs to develop an inclusive learning environment catering to varied student needs while ensuring equitable access to resources and opportunities [3].

Learning process is also crucial in addressing complex societal challenges like inequality, environmental degradation, and social justice. It should motivate communities to act for gender equality, human rights, and poverty reduction [4,5]. Good quality education should lay pathways to eradicate ignorance, enhance self-respect and develop basic understanding of social life of the individuals. This need is felt more tenacious now than ever in the past [6,7]. Only such transformation would lead to economic growth, poverty reduction, social equality, empowerment, improved health, well-being, cultural development and democratic decision-making culminating into a more inclusive society that practices sustainable development as its second nature.

As a more recent development, the orientation of the activities pursued by most of the HEIs are directed by the targets derived from the National Institutional Ranking Framework (NIRF). The parameters adopted by NIRF broadly cover Teaching, Learning and Resources, Research and Professional Practices, Graduation Outcomes, Outreach and Inclusivity, and Perception [8]. Sub-parameters, tools and data are used to arrive at the results published every year for various domains like Engineering, Overall, Management and so on. Being majorly transparent about the entire process, NIRF provides a fair listing of institutes for the aspirants to make informed choices in their chosen domain of interest. This framework adapts to the changing times more efficiently than any other entity and the recent inclusion of SDGs as a sub-parameter marks a new era of NIRF ranking system.

**SDGs AS A MATRIX OF LIFE**

SDGs were adopted in 2015 by all the United Nations Member States, as they provide a shared blueprint for peace and prosperity for people and the planet, now and into the future [9]. A surprisingly clean unifying factor, SDGs provide a fresh impetus and a logical platform to initiate clear communications across the earnestly divided human inhabitants, spread over all corners of the Earth. With a potential to be a common man's powerful weapon SDGs are adopted world over, even in proven domains like renewable energy. However, the reach of this panacea is limited by the lack of awareness starting at grass-root levels right up to the top. Hence, the need to incorporate SDGs judiciously into the core of education system, specifically at HEIs.

Literature showcases the preliminary impact of SDGs on the education domain leading to well-groomed courses and activities involving sustainability. The benefits are encouraging but meagre. Any visionary could understand that SDGs are to be made the matrix on which education system is built, since SDGs are the matrix over which life must be built, now and into the future. Limited forays into the research aspects of blending SDGs, NIRF and education system is the motivation for the authors to pursue the work presented in this paper.

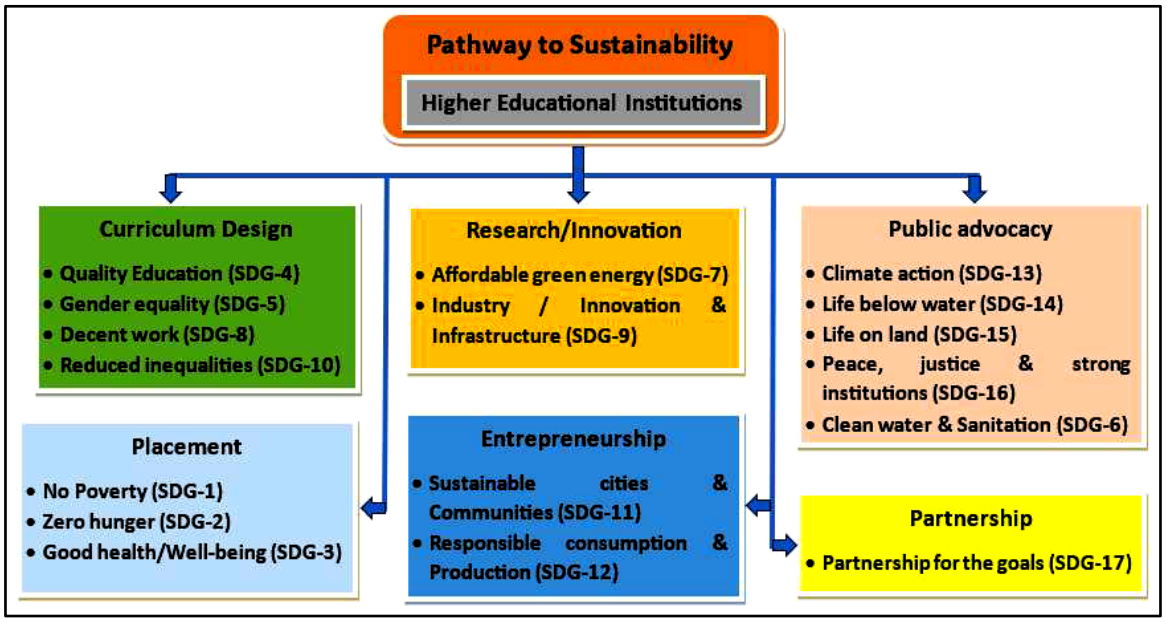


**Figure 1** Prioritized SDGs for comparation of HEIs

As a first step SDGs are prioritized under different heads commonly utilized for comparing the performance of HEIs. **Figure 1** shows the primary activities that define the success of an HEI under the different heads like curriculum design, placement, entrepreneurship, Research/innovation, public advocacy and partnership. Under each head, grouped are the SDGs that are most relevant to the identified group. For this paper, the constraints followed are:

- No repetition of SDGs: This is done to identify the most binding affiliation for any group.
- Order of appearance as order of priority: This is adopted for the ease of choice.

Other SDGs could be listed under each group; however, that discussion is not considered under the scope of this paper. **Figure 1** might change from country to country but is expected to fit all corners within a country, to ensure equality. The following section presents the justifications and the need for each of these SDGs under the head of curriculum design.

**Curriculum Design**

Though Teaching-Learning process is the foundation on which the vision of any educational institution rests, grounding of fundamentals is achieved through a thoroughly designed curriculum based on the philosophy of

education the management believes in. A strong curriculum deeply rooted in SDGs would be groundbreaking for various reasons listed below. Since the curriculum to be conceptualized, organized, developed, and implemented depends on the educational objectives [10] of the management implementation of SDGs should start here. Four SDGs are prioritized under this head for the reasoning enumerated below in **Table 1**.

**Table 1** Reasons for SDGs mapped under Curriculum design

| Quality education (SDG-4) | Gender equality (SDG-5) |
|---|---|
| • Ensures equitable access for girls, third gender, rural/urban divide and physically challenged students<br>• Enhances critical thinking and problem-solving ability by posing global challenges in their day-to-day life | • Encourages equal participation<br>• Addresses gender-based discrimination & violence<br>• Promotes women leadership<br>• Limits gender stereotypes |
| **Decent work (SDG-8)** | **Reduced inequalities (SDG-10)** |
| • Skill enhancement towards employability<br>• Promotes entrepreneurship<br>• Economic upliftment through placement & internships<br>• Bounded by laws/regulations – ethical labour practices | • Enhances social inclusion<br>• Eliminates racial, gender based, economical inequalities<br>• Culture of global citizenship<br>• Life-long learning |

Since TLR, the first metric of NIRF, depends on student strength (SS) and faculty-student ratio (FSR) it might appear unrelated to curriculum design. However, it is to be counter intuitively understood that only a curriculum that demands gender equality and by being inherently inclusive could provide a strong student base. This metric reveals the admission status of an institution for the aspirants. For the management it provides evidence towards the need for changes in the admission policies and to adopt new strategies for improving enrolment. For the teacher it helps to showcase unique selling points, promote the department and the institute while meeting the customer expectation honourably.

Catering to the demands of a strong curriculum world class universities like MIT, Oxford pin the teacher-student ratio low. A lower teacher-student ratio indicates involvement of a greater number of faculties in the teaching learning process. Focussed attention on the students through monitoring, mentoring and knowledge transfer are the direct benefits that gets translated into a good student strength. The increased faculty holding cost thus could be easily compensated. Thus, better FSR will attract the common public and the potential employers too.

The mutual interaction between SS and FSR is beautifully captured under TLR. From the above discussion it is clearly understood that by carefully designing the curriculum a better score is ensured in NIRF. It is also understood that other SDGs too get benefitted from this action, however, the purpose of SDGs would be lost when the priorities are altered. The authors recommend strong advocacy to the understandings presented in **Table 1** not just based on the years of experience in the education sector but because of the analysis shown in the later section.

To add another perspective, SDGs 4, 5, 8 & 10 are very closely related to the NIRF metric 'RP' (Research/ Professional practices) [11]. On a similar scale, 5 &10 are associated to 'PR'(Perception). Discussions are limited to only the curriculum design aspect of **Figure 1** as per the scope of this paper. However, detailed discussion on the individual topics could be handled in the extended version of the paper.

## STAKEHOLDERS' TAKEAWAY

Stakeholders are the pillars that uplift the HEIs by providing continuous feedback into the system. These beneficiaries could be presented with a deep insight into the data for signs of growth, deviations from the promised deliverables, positive affirmations of earlier changes incorporated and lateral effects of sustainability among others. **Table 2** show cases the prominent takeaways from this effort for different stakeholders.

**Table 2** Association between NIRF metric to stakeholder takeaways

| Stakeholders | NIRF Metrics | Inference/Takeaway |
|---|---|---|
| Management | WD | • Reservation policy for women enrolment.<br>• Recruitment policy and promotional policies for women. |
| | FRU | • Investment policies on research.<br>• Develop research infrastructure for continuing research.<br>• Promote process automation and ERP. |
| | FQE | • Validate the Research Culture of the institution.<br>• Orientation on the process and not on the end results. |
| | PR | • Mentoring system effectiveness.<br>• Attention for Alumni & Admission policy for alumni kids.<br>• Strength of Industry–Institute cell. |
| Students | SS | • Ecosystem for teaching, learning and research.<br>• Encourages National and International participation |
| | PR | • Points to good Career Development and Innovation.<br>• Promotes Entrepreneurship and Start-ups. |
| | RD | • Mix of students from various states and countries.<br>• Promotes cultural exchange and inclusivity. |
| | GO | • High Placement Rates and Median Salary<br>• Industry Internships and Collaborations |
| Employers | GUE | • Technical Competence, Real time problem-solving<br>• Business management skills & innovation.<br>• Critical Thinking, Teamwork and Collaboration skills. |
| | GO | • Retention Rate.<br>• Adaptability & Flexibility in learning new skills.<br>• Embrace changes in workflow of the organisation. |
| Common public | GO | • Career Development.<br>• Promotes Entrepreneurship, Innovation and Start-ups. |
| | PR | • Quality Education and Skilled Graduates<br>• Affordable and Accessible Education<br>• Global Competitiveness, Ethics and Sustainability |
| Faculty | FQE | • Training and skill building exercises to be pursued |
| | PR | • Efforts on promoting self and institute on social media |
| | FPPP | • Training for technology transfer research/product. |
| Government | IPR | • Intellectual property to compete at global level |

## A GLIMPSE OF NIRF RANKING 2024

NIRF ranking 2024 had minimum change from the earlier version, for most of the institutes. However, there are institutes that moved up by 17 ranks and some institutes dropping by up to 14 ranks. The system has derived a stabilized feel to it and hence the infuse of SDGs into the system of evaluation. Most institutes were caught unawares by this induction. However, it is a very positive move and would benefit the education system and the country in the longer run, when implemented appropriately.

**Figure 2** compares the top three institutes with the highest upward movers in terms of ranking. It is interesting to note these two movers are private institutes and the top three are centrally funded institutes as expected. Some interesting features to notice:

- SRM & Koneru along with IIT Madras have 30/30 on FSR.
- Koneru along with IIT Madras have 15/15 on GUE.
- PR of both the private institutes are well below 20, while Top 3 are above 90.
- On FQE & SS both these institutes are on par with Top 3.

- FPPP has Top 3 above 6 and the private institutes are < 0.4.
- Both the private institutes fare better than Top 3 in WD.
- All the institutes have scored 20/20 on PCS.

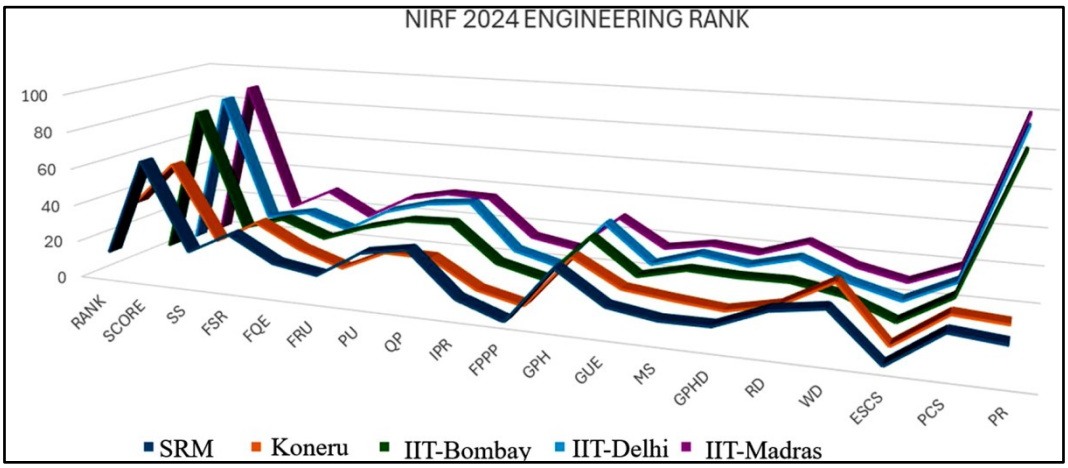


**Figure 2** Comparison chart for Engineering ranks NIRF 2024

Translating all these observations under the purview of the earlier discussions in this paper, FSR contributes to SDGs 4, 5, 8 &10 to a larger extent. The same has been valued by NIRF ranking criteria too. However, a closer look at the effect on SDG 5 (gender equality) could be derived from 'WD' metric of NIRF, where the Top 3 institutes are well below 50% of the total score. The private universities perform better under this SDG. It is heartening to see all the institutes scoring 20/20 for PCS addressing SDG 10 in full. From this discussion it could be easily understood that a closer look of the interactions between SDGs and NIRF ranking metrics would serve as a microscope to read the nuances of the game and could be used to learn, predict and forecast the growth and development of HEIs. It could be used to develop a tool that would help monitor the HEIs from the sustainability perspective which is very much the intention of the authors.

## CONCLUSIONS

HEIs provide a fertile ground to sow, groom and nurture the seeds of sustainability in the minds of the young blood. By adopting the NIRF parameters the chance to bring SDGs into reality in the immediate future is enhanced multifold. This paper discussed in detail the cross-linked pattern that could be established between HEI, SDGs and NIRF parameters. Some of the unusual relationships and counterintuitive understandings were brought out clearly. To complete the paper, an effort was made to connect these parameters and the benefits that the stakeholders of HEIs derive. Since this a preliminary effort relating inherent characteristics brought about by three seemingly unrelated aspects, deeper analyses are required to validate and thus expanding its scope. The other major expectancy is improved awareness on SDGs. Only with all these efforts, the 2030 agenda for sustainable development would become a possibility.

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241_IEC29740

# Circular Economy of Water: Production to Reuse for Sustainability

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***Abstract:*** *The circular economy promotes resource conservation through loops. Circulation efficiency depends on how much potable and non-potable water is returned to the supply system after usage. Circular economy quantifies a product's utilization by evaluating its whole life cycle. This covers direct and indirect water use and contaminated water. Water circularity depends on water supplied, lost, and reused. Water needs vary by human settlement, but one of them is enough clean water. Humans desire to use water efficiently, maintain water sources, and recycle to optimize water needs in an environmentally responsible way. This will reduce the stress on the water sources. One problem is creating long-term sustainable water sources without harming local biodiversity and ecosystems. Investments in water boost its value to society. The origin, post-use treatment, circularity, and sustainability of water are more important than throughput. The water footsteps estimations need to embrace circular economy ideas and lower production and water usage estimates.*

***Keywords:*** *Circular Economy; Water Production; Water Recycle; Water Reuse; Sustainability*

244_IEC1595

# Smart Precision Irrigation System: Matrix-Driven Capacitive Sensing Optimization with Machine Learning

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***Abstract:*** *The smart precision irrigation system that includes current technologies for precision farming, aimed at optimizing water use and enhancing agricultural yield. Key components include capacitive soil moisture sensors that are arranged in a matrix structure in the plantation area for real-time moisture level tracking, an analog TDS (Total Dissolved Solids) sensor for assessing irrigation water quality, and a strategically placed water outlet network for precise irrigation. The system is augmented with a weather station that monitors local environmental conditions and alters watering schedules accordingly. Utilizing LoRA and ESP32 modules, it offers powerful connection and data processing, allowing farmers to administer the system remotely via a smartphone app. A machine learning system analyses historical and real-time data to change irrigation plans, boosting optimal water utilization while preventing waste. The system's versatility to varied soil types and weather patterns, together with its user-friendly design, gives farmers with actionable data and alerts. By applying predictive analytics, the smart irrigation system assists farmers to make intelligent decisions, eventually promoting sustainable agriculture and enhancing overall crop yield.*

***Keywords:*** *Capacitive Soil Moisture Sensors; Matrix Structure; Machine Learning; Total Dissolved Solids (TDS); LoRA; ESP32*

## INTRODUCTION

The rising global population and rising food demand necessitate the development of efficient agricultural systems. Traditional irrigation techniques, which often lead to excessive water consumption or poor crop hydration, provide major challenges. Consequently, producers face the competing objectives of protecting water resources while assuring optimal agricultural returns. This work provides a revolutionary smart irrigation system that utilizes capacitive soil moisture sensors, total dissolved solids (TDS) sensors, and current communication technologies to deliver a comprehensive solution to these challenges. By utilizing machine learning, the system predicts optimal watering schedules suited to the particular needs of crops, therefore promoting sustainable agricultural practices and improving total production.

The significance of precision agriculture in current farming cannot be overstated. With the advancement of technology, farmers are now equipped with tools that allow them to make data-driven decisions, ultimately leading to better resource management. The smart irrigation system indicated below symbolizes the convergence of technology and agriculture, designed to maximize irrigation practices by integrating real-time data analysis, automation, and adaptability to environmental situations.

### Data Resources

The smart irrigation system incorporates several data sources that aid to accurate and informed decision-making. The first critical component is the capacitive soil moisture sensors positioned over the field. These sensors constantly monitor moisture content, offering real-time data that is crucial for irrigation planning. By monitoring changes in capacitance, these sensors deliver detailed data that teach farmers about when and how much to water. This degree of accuracy is vital in minimizing overwatering or underwatering, which may have harmful repercussions for crop health.

In addition to soil moisture levels, the system features an analog TDS sensor that verifies the quality of irrigation water by measuring the concentration of dissolved solids. Water quality is vital for sustaining healthy crops, as it directly influences plant growth and productivity. By monitoring TDS levels, farmers may make informed decisions about the suitability of water for irrigation needs. Moreover, the system features a weather station equipped with sensors that monitor local environmental elements such as temperature, humidity, rainfall, and wind speed. This

information is crucial for altering irrigation schedules according to changing weather patterns. By merging so various data sources, the smart irrigation system gives a complete approach to water management in agriculture.

**Neural Network**

To increase decision-making abilities, the system uses a powerful machine learning model based on neural networks. This model uses both historical and real-time data to enhance irrigation schedules. The neural network is trained using a dataset that incorporates soil moisture readings, TDS levels, and climatic variables, allowing it to estimate the unique water demands of distinct areas of the field. As the system runs, it constantly learns from incoming data, improving its predictions over time. This adaptive learning ability is crucial for fine-tuning irrigation schedules based on changing weather conditions and crop demands. By recognizing patterns in the data, the machine learning system can make smart decisions about when and how much to irrigate, ultimately enhancing water efficiency and crop health. The introduction of machine learning into irrigation management not only minimizes water loss but also strengthens the resilience of agricultural operations in the face of climate uncertainty. Farmers can rely on the system to give timely and accurate irrigation advice, hence improving their resource allocation and boosting overall crop yields.

**Architecture**

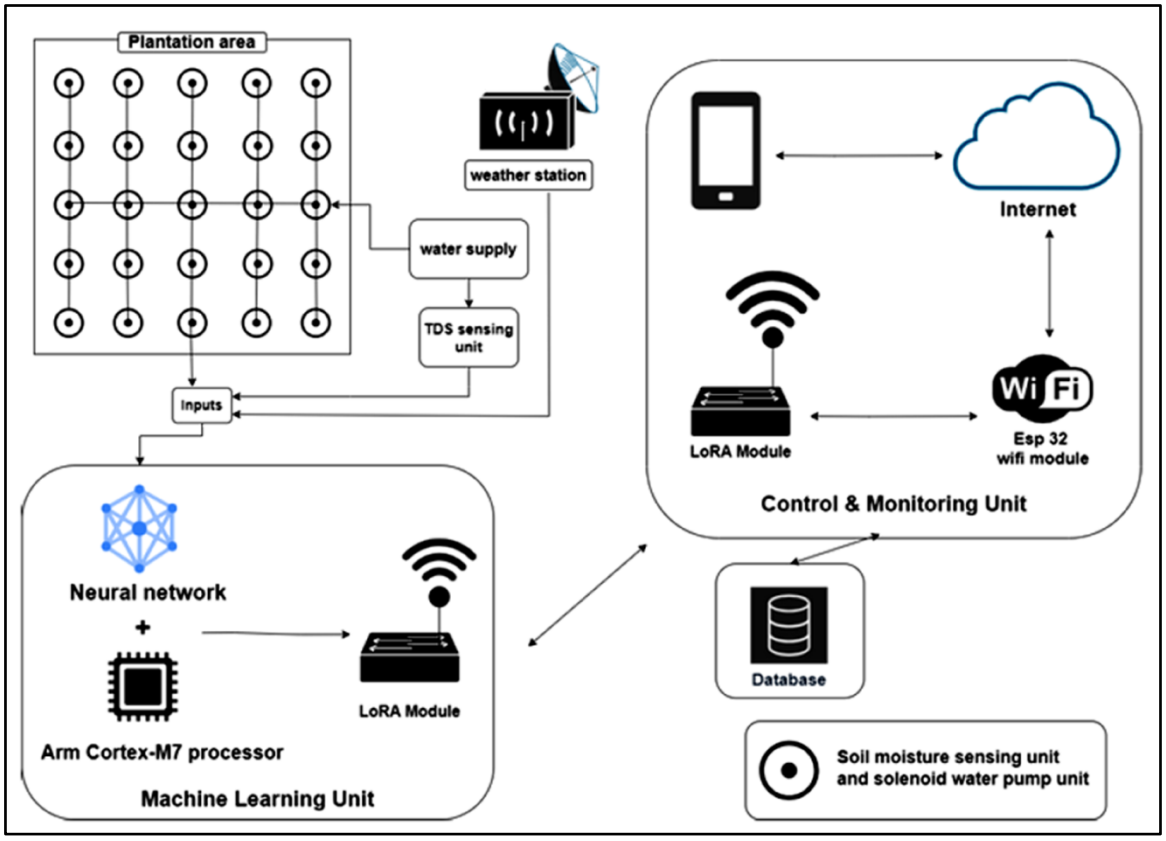


**Figure 1** System Architecture

**Components**

The smart irrigation system is constructed of numerous core components, each playing a crucial role in its functioning.

First, the capacitive soil moisture sensors are carefully scattered over the field to monitor moisture levels appropriately.

These sensors work based on the principle of capacitance, producing real-time readings that teach farmers about the precise hydration needs of their crops. The data acquired from these sensors provides for timely irrigation selections, ensuring that crops get optimum moisture without additional water.

The second key component is the analog TDS sensor, which detects the concentration of dissolved solids in the irrigation water. By monitoring water quality, farmers can assure that their crops enjoy the finest potential conditions for development. Poor water quality may lead to stunted growth or even crop loss; hence, monitoring TDS levels is vital for preserving healthy plants.

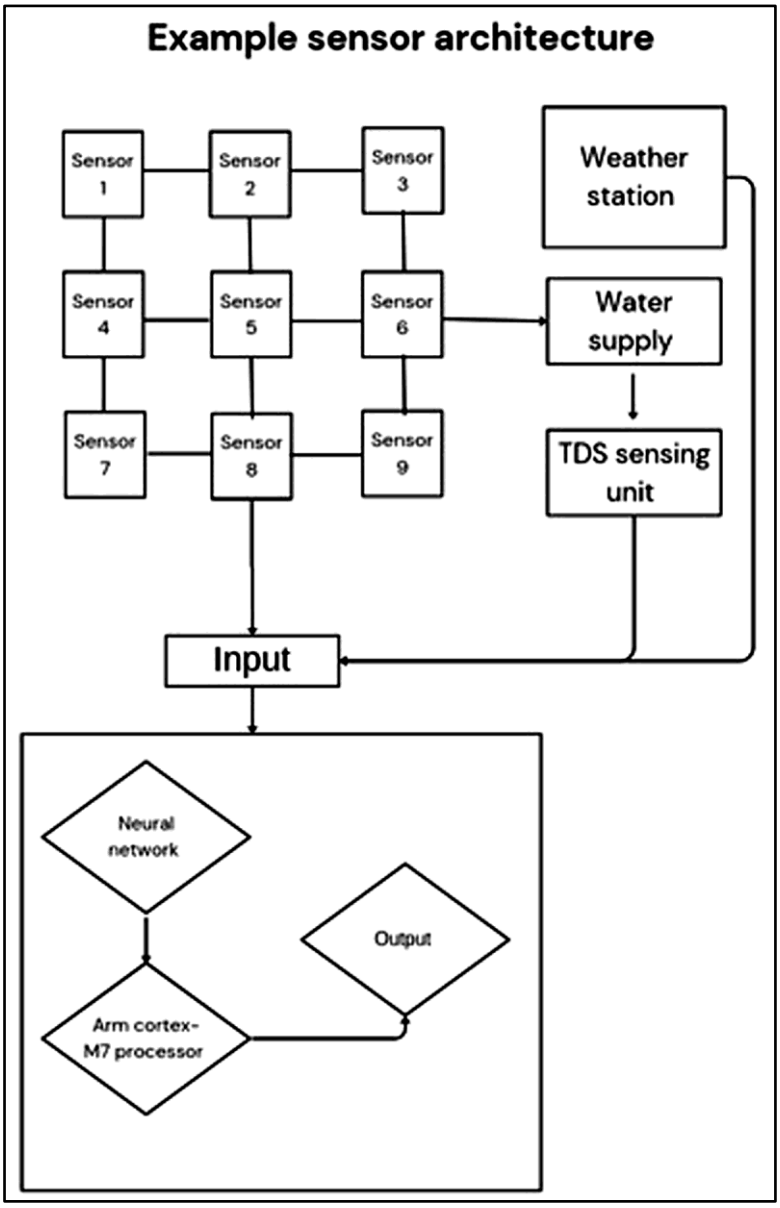


**Figure 2** Sensor Architecture

The system also features a water outlet network designed to supply water precisely where it is necessary. This network includes of solenoid valves powered by relay drivers, which enable for targeted watering based on real-time data from the sensors. By precisely arranging water outlets over the field, the system avoids waste and improves water distribution, insuring that every crop receives the needed hydration. Additionally, the weather station regularly monitors environmental conditions, delivering crucial data such as temperature, humidity, rainfall, and wind speed. This information is crucial for modifying irrigation schedules in response to changing weather patterns, hence

enhancing the efficiency of water usage. The combination of these components allows the system to work smoothly, equipping farmers with the tools they need to manage their water resources properly.

**Functionality**

The operation of the smart irrigation system is underpinned by numerous key factors. The first is matrix monitoring, which employs a grid of capacitive soil moisture sensors that allow I2C connection. This design enables for accurate monitoring of soil conditions throughout the complete field, regardless of the land's topography. The matrix approach delivers comprehensive coverage and enables the system to adjust dynamically to altering soil moisture levels.

The second piece is the machine learning system, which employs a neural network to assess data from the sensors and weather station to produce appropriate watering schedules. By examining parameters such as soil moisture levels, historical weather data, and crop sorts, the algorithm calculates the best times and amounts of water necessary for each section of the field. This data-driven strategy decreases the risk of over- or under-watering, leading to healthier plants and increased harvests.

The third aspect of the system's functioning is the smartphone application, which works as the interface for farmers to monitor real-time data about soil and weather conditions. The app enables users to receive alerts, review irrigation schedules, and operate the irrigation system remotely. This user-friendly design offers farmers with critical information, helping them manage their crops more successfully. With the potential to make intelligent decisions from anywhere, farmers can optimize their irrigation operations and adjust quickly to changing conditions.

The third aspect of the system's functioning is the smartphone application, which works as the interface for farmers to monitor real-time data about soil and weather conditions. The app enables users to receive alerts, review irrigation schedules, and operate the irrigation system remotely. This user-friendly design offers farmers with critical information, helping them manage their crops more successfully. With the potential to make intelligent decisions from anywhere, farmers can optimize their irrigation operations and adjust quickly to changing conditions.

**OBSERVATION**

**Problem Addressed**

The smart irrigation system answers numerous fundamental difficulties in agriculture, particularly in relation to water management. One of its major purposes is to assure optimal water usage. By combining real-time data from soil moisture sensors and meteorological stations, the system delivers exactly the amount of water that crops demand at any given moment. This concentrated strategy promotes crop hydration, ultimately leading to increased yields and decreased water demand. The system's flexibility to adapt to changing environmental conditions is crucial for reaching these purposes.

Adaptability is another key part of the smart irrigation system. It is meant to perform in diverse soil types, geographical topographies, and weather patterns. Whether the farm is located on flat terrain or uneven land, the sensors and water outputs may modify irrigation schedules based on the particular needs of the region. Additionally, the weather station enables the system to adjust proactively to changing weather circumstances, such as rainfall or drought, ensuring that crops receive the proper amount of water.

Furthermore, the system offers data-driven irrigation control, greatly lowering the requirement for human involvement. By regularly gathering and reviewing data, the system automates decision-making processes, providing precise irrigation scheduling. This method not only cuts labor expenditures but also decreases the risk for human error, allowing farmers to focus on other vital elements of their company.

**Metrics**

The smart irrigation system relies on a robust technology stack to assure optimal performance. The moisture sensor grid incorporates capacitive soil moisture sensors with a range of 0-100% volumetric water content (VWC). These

sensors produce dependable readings of soil moisture levels, which are crucial for irrigation options. The water outlet matrix includes of solenoid valves powered by relay drivers, giving correct water delivery to crops.

The weather station sensing equipment constantly measures environmental factors, including temperature (±0.5°C), humidity (±2% relative humidity), rainfall (0-500 mmv/hr), and wind speed (0-150 kmv/hr). This data is vital for adjusting irrigation schedules based on environmental circumstances. The machine learning component employs neural networks and operates on an ARM Cortex-M7 CPU, assuring quick data processing and decision-making capabilities. By combining these contemporary technologies, the smart irrigation system achieves an unsurpassed degree of efficiency and agility in water management.

## CONCLUSION

In conclusion, the smart irrigation system provides a major advance in agricultural operations, tackling the basic challenges of water management and crop growth. By integrating capacitive soil moisture sensors, TDS sensors, a weather station, and machine learning algorithms, the system gives a comprehensive solution that enhances watering methods. Its unique design permits for real-time data analysis, enabling farmers to make intelligent decisions that enhance resource efficiency and sustainability. As the agricultural landscape continues to alter, the adoption of smart irrigation technology will be vital for addressing the requirements of a burgeoning population while maintaining scarce water resources. The benefits of this strategy extend beyond immediate crop yields; it contributes to long-term sustainability in agriculture. Ultimately, the smart irrigation system reveals the potential of technology to transform traditional farming processes, clearing the path for a more robust and efficient agricultural future.

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269_IEC41020

# Water Harvesting from Air Conditioners: A Green Approach

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***Abstract:*** *Water is essential to human survival and the lives on our planet. Owing to the massive increase in urbanisation, one of the most important issues in the fields of environmental sustainability and water resource conservation is the demand for water. To provide a sustainable solution to the water management system it is imperative to utilize the naturally available resources as much as possible to minimize the generation of greenhouse gas in order to reduce the carbon foot prints. It is possible to view a considerable amount of water in the form of moisture in the surrounding air as a potential source of water. The source has the capacity to generate clean water that is suitable for home, engineering and agricultural uses. Condensate water which can normally be extracted from air conditioners are disposed in sanitary drains has been identified as the possible source of clean water. This technique can be especially useful as an inventive approach to water management in crowded urban areas with limited space and resources in regions with high humidity, such as tropical and subtropical climates. At first the assessment of quality of condensate water has been done through Water Quality Index system proposed by Horton. The paper is an attempt to understand the quantity of water acquired from air conditioners for satisfying the need of the water requirement for different activities in a warm-humid tropical urban area.*

***Keywords:*** *Water Demand; Water Quality Index; Condensate; Sustainability; BOD; Air-Conditioner*

## INTRODUCTION

Freshwater is becoming increasingly rare and contaminated; as the population grows, more of it is needed, depleting conventional supplies and at the same time, the level of water contamination is rising. Drought is occurring in various areas that were previously water-rich due to climate change, which is another significant factor in the complicated water problem. Unconventional sources have been researched and used in recent decades to counteract the shortage of freshwater. Research on the extraction of water from air is becoming increasingly interesting, as it is one of the most widely used technologies, similar to the desalination of sea water. The majority of the Earth is covered by water, with a total volume of around 1.4 billion km3, of which fresh water resources account for only 2.5% (Anonymous, 2017a). According to the World Health Organization (WHO), more than one in every six individuals lacks access to safe drinking water. Fresh water shortage is common in many developing and industrialized countries. As a result of the scarcity of potable water, activities such as the use of water through practices, procedures, and technology for its optimal use have become critical for future generations.

## THE PROCESS

Air conditioners operate by cooling air through a process called condensation. Inside an AC unit, warm, humid air is drawn over evaporator coils, which are cooled by refrigerant. As the air cools, its capacity to hold moisture decreases, causing water vapor to condense into liquid form on the coils. This condensate typically drips into a collection pan and is then channelled out through a drainage pipe. During this process, a large amount of moisture in the atmosphere gets condensed. By harnessing this condensate, it is possible to collect and repurpose water that would otherwise be discarded. Till date no significant efforts have been made to recover this water in India and neighbouring countries.

## BENEFITS

1. Sustainable Water Source
2. Water Waste reduction
3. Cleaner water saves energy for treatment

## METHODOLOGY

The overall study method used in this study was based on an interdisciplinary and integrated approach comprises of a combination of directions. This study is mostly field based. Scholarly articles and books consist of literature studies of published materials and data in line with the area of interest were reviewed and considered as secondary source of information. The secondary sources were concerning the condensate water assessments, water standards, and generated water quantities produced by cooling systems. In addition, the primary source of data on condensate water quality and quantity was collected through sampling campaigns in summer time.

In order to formulate an overview about the condensate water yield generated from the air conditioning systems, a quantity assessment process was conducted in the three places within and outside the city of Agartala. From the three locations multiple samples of Air Conditioning Condensate Water capacity plastic bottles were collected in two liter capacity plastic bottles and quality of all the samples were tested as per the prodess proposed by Horton's 'Water Quality index' and found to be good for use.

## CONCLUSION

Water harvesting from air conditioners is an innovative and practical solution to water constraint. This technology, which captures and utilizes the condensate produced by AC units, provides a sustainable and effective approach to replenish water sources while reducing waste. While problems persist, technological developments and improved knowledge can help this solution become more effective and widely adopted. As we progress toward a future in which resource conservation and sustainability are key, innovative solutions such as water harvesting from air conditioners will be critical in providing a resilient and equitable water supply for all.

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316_IEC67101

# Transport Sustainability in Extreme Weather Conditions: An Indian Perspective

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**Abstract:** The interplay between transportation systems and extreme weather conditions has profound implications for commuter preferences and system sustainability. This study investigates how environmental factors, including extreme heat, humidity, and rainfall, influence transportation mode choices in India, with a focus on the outskirts of Kolkata. Employing a multi-criteria decision-making framework, the research integrates commuters' perceptions of convenience, comfort, safety, and cost with environmental and socio-economic variables. The findings reveal significant seasonal variations in mode preferences: air-conditioned buses dominate during the summer, while cars and personalized public transport are preferred during heavy rainfall due to enhanced comfort and protection.The study also highlights how extreme weather exacerbates challenges such as increased emissions during peak hours and shifts in demand across transport modes. These insights underscore the need for adaptive strategies and policies to enhance the resilience and sustainability of transport systems under varying climatic conditions. Despite limitations in data collection during extreme weather, this research provides valuable guidance for policymakers to optimize transportation services, improve last-mile connectivity, and ensure seamless integration of public transport. By addressing these dynamics, the study contributes to advancing sustainable mobility solutions in the face of climate change.

**Keywords:** Sustainable Transportation Systems; Transport Mode Choices; Weather Conditions; Socio-Economic Factors; Transport Footprint Measurement

## INTRODUCTION

The built environment plays a critical role in shaping commuter preferences. In general, mass rapid transit systems are preferred over buses for longer trips[1]. However, extreme weather conditions can pose significant challenges for travellers, especially when they become difficult to tolerate. A study in Sweden using an extended national travel survey and comprehensive weather data across various regions and seasons found that in winter, individuals are more likely to choose walking and public transport while cycling declines. In contrast, summer increases the likelihood of cycling and reduces walking and public transport use[2]. In the Netherlands, during extremely low temperatures, individuals tend to transition from cycling to using cars and public transportation. However, as temperature rises, there is an increased preference for walking and cycling[3]. Mass rapid transit ridership data in Beijing indicates that weekend trips are more affected by weather conditions compared to weekdays. Monthly temperature fluctuations have a greater impact on ridership than daily variations. Specifically, a one-degree increase in effective temperature leads to a roughly 0.5 percent rise in ridership on weekends, while heavy rainfall causes an approximate 8 percent decline in ridership[4]. The results of a fairly recent study indicate that heavy rainfall generally disrupts passenger flow, exacerbating spatio-temporal imbalances[5].

To address this gap, the study aims to enhance our understanding of how weather-related factors, such as heat, humidity, and rain, affect commuters' choice of transportation modes. Its primary objective is to create a platform that supports the development of adaptive strategies and policies, thereby improving the resilience and sustainability of transportation systems in response to climate change. The research approach is twofold: first, it examines commuter behaviour in selecting transportation modes, and second, it evaluates how such behaviour impacts near-road air quality. The field-based hypothesis in this context indicates that the share of air-conditioned buses and

personalised public transport increases during peak hours in the summer but declines in demand during the monsoon season. Additionally, the usage of two-wheelers decreases significantly during heavy rainfall. By incorporating these elements, the study aims to equip transportation analysts with the insights necessary to manage weather-induced challenges effectively without compromising commuters' transportation needs.

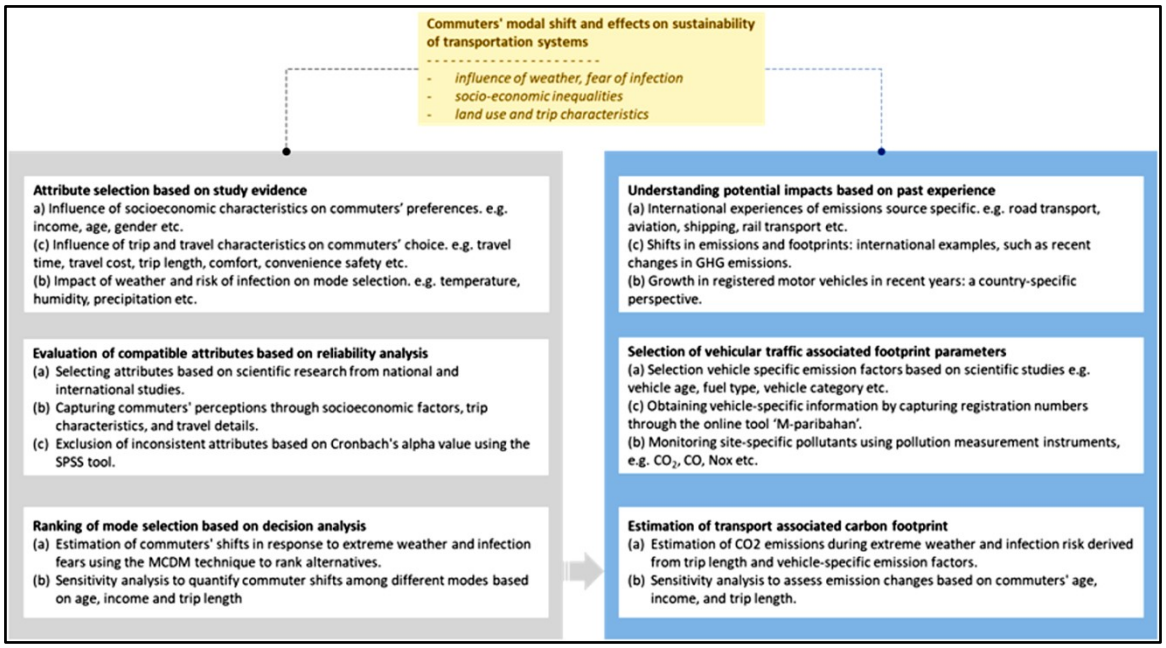


**Figure 1**A schematic depiction of the methodological framework adopted for this study

## METHODOLOGY

The evaluation of transportation modes plays a crucial role in selecting the most suitable options for travel [6]. Multi-criteria decision-making (MCDM) frameworks are particularly suitable in this regard, as they enable decision-makers to simultaneously assess and prioritize multiple factors [7]. These frameworks incorporate a range of criteria, including weather conditions, travel time, cost, safety, and environmental impact, offering a holistic approach to evaluating and optimizing transport choices under diverse climate scenarios. To address the growing challenges posed by changing weather patterns, this study investigates the influence of weather conditions on commuters' transportation preferences. By systematically analysing the relationship between weather variability and commuter behaviour, the research offers valuable insights for the development of adaptive strategies and policies. These strategies are intended to strengthen the resilience and sustainability of transport systems, ensuring their ability to function effectively in the face of climate change impacts. **Figure 1** illustrates a step-by-step framework designed to effectively analyse the problem at hand. This process provides a blueprint for systematically addressing the complexities associated with transport mode selection, particularly in variable weather conditions. By integrating diverse criteria within a structured framework, decision-makers can better understand how different factors influence commuters' choices and develop solutions that enhance the adaptability and efficiency of transportation systems.

## RESULTS

The commuter preferences, including convenience, comfort, safety, trip length, age, income, travel time and cost gathered from the perception study conducted on the outskirts of Kolkata, were evaluated for consistency using Cronbach's alpha. Inconsistent attributes were removed, leaving only the consistent attributes to serve as inputs for the decision analysis. The findings of this analysis, presented as the consistency ratio (CR) for each mode, are illustrated in **Figure 2**.The figure demonstrates how commuters' priorities for different modes vary under different weather conditions.CR for AC buses reach its peak during hot weather conditions, signifying a heightened demand for AC buses in the summer months relative to other transportation modes. This trend indicates that commuters

prioritize travelling via AC buses, with cars and shared cabs being their second and third preferences, respectively, during this season. In contrast, during periods of heavy rainfall, commuters display a marked preference for cars over alternative modes of transport. This inclination is followed by a preference for trains and metro services, with shared cabs being the least favoured option during such conditions. The tendency to choose cars during monsoon is likely influenced by the commuters' desire to stay dry and comfortable throughout their journeys. Consequently, the CR for cars experiences an increase in the rainy season, surpassing that of trains, metros, and shared cabs.

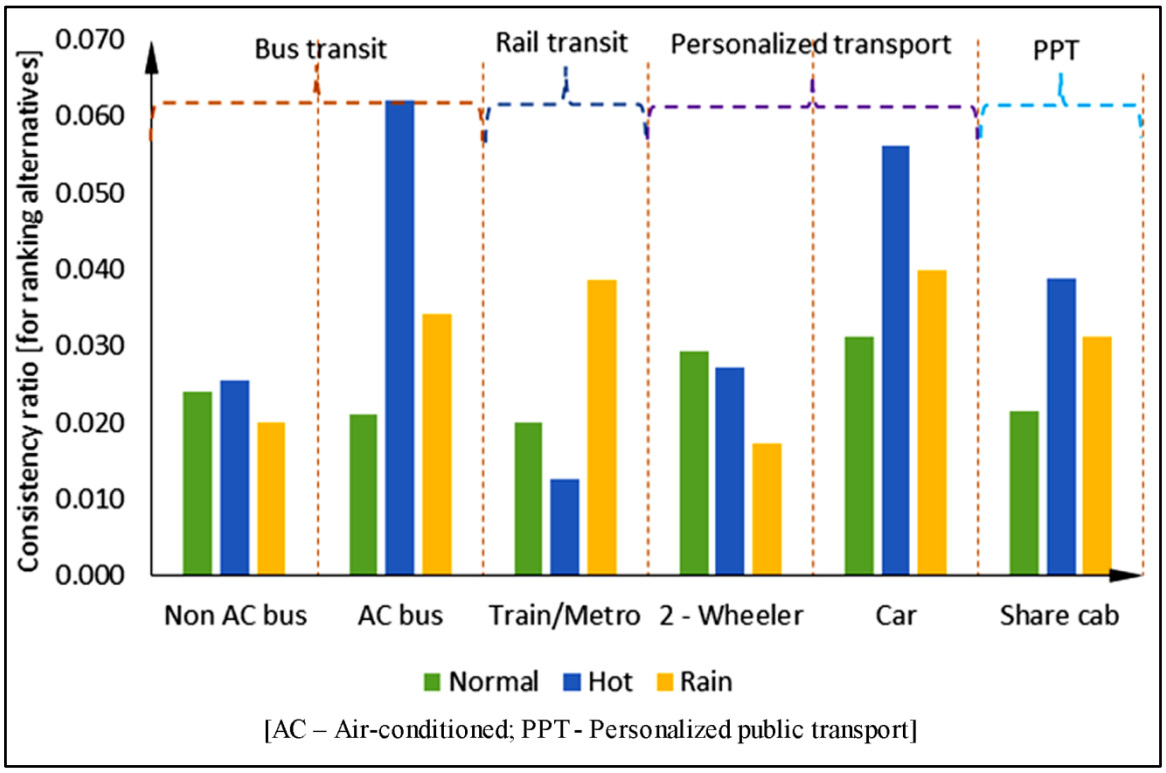


**Figure 2** The consistency ratio for each mode, observed under different weather conditions in the study area

This behaviour reflects the impact of weather conditions on commuter preferences and highlights the adaptability of travel choices in response to weather factors. It underscores the importance of understanding seasonal variations in demand for different transportation modes, which can aid in optimizing transport services and planning. Transport authorities and service providers may consider these preferences when designing strategies to enhance service availability and customer satisfaction during varying weather conditions. The prioritization of transportation modes varies with weather conditions, and as commuters' choices shift, the corresponding emissions also change, as depicted in **Figure 2**. The associated carbon footprints, determined by commuters' daily travel distances and vehicle-specific emission factors, reflect mode choice-induced emissions across different study areas within the city outskirts.

A look into data across different seasons reveals that during extreme summer, commuters show a higher preference for air-conditioned buses and shared cabs compared to normal weather conditions. Conversely, during heavy rainfall, the share of two-wheelers declines, while the use of normal buses and personalized public transport (PPT) increases during both morning and evening peak hours and the share of air-conditioned buses decreases. Moreover, the study observed that generally, the availability of air-conditioned buses is higher during peak traffic hours but declines during off-peak periods, contributing to an increase in emissions during peak hours. The use of PPT, like shared cabs, is also notably higher during the morning peak and diminishes in the evening peak. **Figure 3** presents the hourly variations in $CO_2$ and CO emissions from road transport at the study sites, highlighting significant peaks during morning and evening rush hours as anticipated. During these peak periods, the high volume of passenger and public transport vehicles results in the maximum emissions of both $CO_2$ and CO. In contrast, during off-peak hours, emissions are notably lower due to reduced traffic flow.

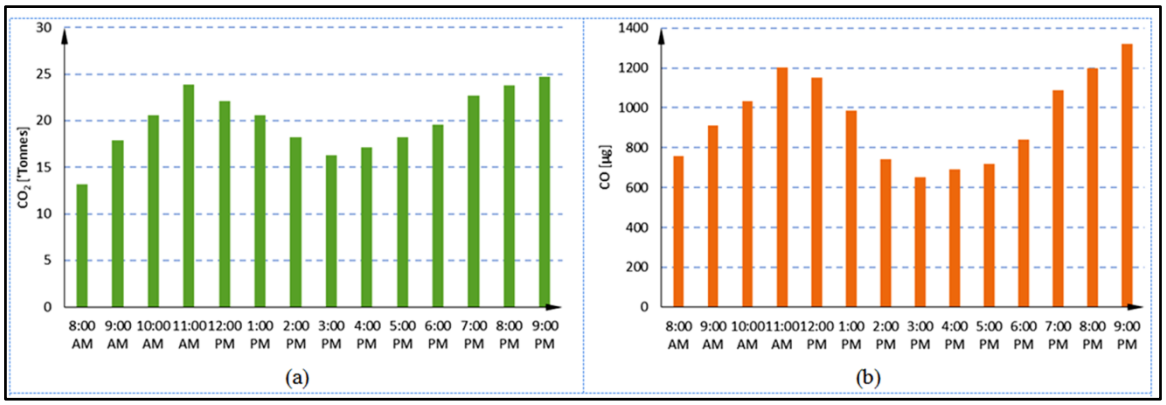


**Figure 3**Measured emissions of pollutant gases from road transport on an hourly basis (a) $CO_2$ and (b) CO

## CONCLUSION

This study provides an in-depth examination of how extreme weather conditions affect commuters' transportation mode choices, with a particular emphasis on work-related travel. By utilizing perception data, the research investigates the impact of various weather extremes on commuting behaviours, considering a range of factors such as demographics, commuting habits, and the specific purposes of travel to gain insights into modal preferences. The findings indicate that extreme heat and high humidity often prompt commuters to switch their preferred transportation modes. Many individuals tend to avoid non-air-conditioned public transport during the sweltering summer months, opting instead for air-conditioned alternatives that offer greater comfort. This shift in preferences highlights the importance of comfort influencing commuting decisions, particularly in adverse weather conditions. Moreover, the study reveals that socioeconomic factors play a crucial role in shaping transportation choices. Factors such as income levels and access to alternative transport options significantly affect commuters' decisions. Individuals with higher incomes may have greater flexibility in choosing more comfortable modes of transport, while those with limited financial resources may rely more heavily on public transport, even under uncomfortable conditions.

In addition to temperature extremes, the study also addresses commuter behaviour during heavy rainfall. In such conditions, commuters exhibit a clear preference for covered transportation modes that provide enhanced protection. Furthermore, the preference for modes that facilitate last-mile connectivity becomes evident, as commuters seek to minimize the number of transfers required between different transport modes. This behaviour underscores the importance of seamless integration in public transportation systems, particularly in adverse weather conditions. This comprehensive analysis highlights the intricate relationship between environmental conditions and personal characteristics in shaping mode choice decisions. By understanding these dynamics, transportation planners and policymakers can better cater to commuters' needs during extreme weather events, potentially improving the overall efficiency and effectiveness of transport systems.

However, the study witnessed several limitations, particularly regarding the challenge of accurately capturing commuters' choices during heavy rain or in excessively hot and humid conditions through field surveys. These extreme conditions may discourage individuals from participating in surveys, leading to potential biases in the data collected. Additionally, the variability of personal experiences with weather can result in diverse responses that may not fully represent the broader commuting population. Addressing these limitations in future research will be crucial for gaining a more comprehensive understanding of how extreme weather influences commuting behaviour and for developing effective transport strategies that accommodate these challenges.

## ACKNOWLEDGEMENTS

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# Environment & Sustainability

## Sustainable Industrial Processing and Green Technologies

23_IEC80660

# Bio Treatment of Jute for Sustainable Scouring: An Alternative Approach

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***Abstract:*** *Jute is a lignocellulosic fibre and cultivated widely in eastern part of India particularly in West Bengal, Bihar, Assam Orissa etc. The fibre is long and strong and generally used as packaging material for food grains. Recently it is used in making diversified and value-added products like different types of bags, handicraft items and to some extent as ornamental fabric. So, chemical processing like scouring, bleaching, dying has become important unit operations now a days. In this experiment jute fibre has been treated with three commercial enzyme preparations as an alternative to chemical scouring and they were applied at three different pH levels. It was found from the experiment that there is a weight loss after enzymolysis and the fibre becomes softer, pliable, finer, and hygroscopic with a small loss of tensile property. The look, feel and performance are better than that produced by conventional scouring method in terms of water absorbance, wicking length and floating time on water surface. So, this bio treatment process has potential to replace the conventional scouring process. The analysis through FTIR and scanning electron microscopy is also showing the same outcome.*

***Keywords:*** *Jute; Scouring; Enzymes; Tensile Strength; Soft Feel; Water Absorbency*

## INTRODUCTION

Natural fibres are fibres produced by plant, animals and geological processes. The plant fibres can be obtained from different parts of the plant like leaves, bast, core, seeds, wood and root. Jute, hemp, kenaf, cotton are some examples of natural fibres. These natural fibres are used in different textile and non-textile uses [1]. Jute is an important agricultural crop in India, China, Bangladesh and other tropical countries. It is of high importance as it is a natural, biodegradable, non-toxic and eco-friendly fibre. Although due to the advent of synthetic fibres, jute industry has declined, still jute has great importance in daily life. Jute fibres are used for making packaging materials, grocery bags, shopping bags, ropes, floor mats, basket, home decor materials like table mats, table covers, cushion covers, wall hanging [2]. The components comprising the jute fibres are cellulose (58-63%), hemicellulose (20-24%) and lignin (12-15%), and some other small quantities of constituents like fats, pectin [3]. Natural fibres have both advantages as well as disadvantages. In order to overcome the disadvantages, textile industries make use of physical, chemical and biological pre-treatment methods. Physical treatment helps in surface modification of the fibre. This is a relatively environment friendly process than chemical treatment of fibre [4]. Chemical treatment of jute in textile industry is an inevitable process to improve the quality and processibility of jute fibres. Chemical treatment helps in improving the flexibility of the fibres but it reduces the strength [5]. Scouring is a process that involves removal of non-cellulosic components from the jute fibre before bleaching, dyeing, printing and finishing. Success of all the downstream processes depends on the efficiency of scouring process. Scouring is a common pre-treatment process involving use of sodium hydroxide along with anionic detergents. Chemical scouring is done at higher temperature under alkaline conditions, which affects the quality of the fibre with high-energy demand and produces a large quantity of polluted water. Concerns about environmental hazards have increased in recent times. Considering the environmental issues, textile industries are inclining more towards the use of biological pre-treatment methods of the natural fibres [6].

Enzymatic scouring is an alternative and eco-friendly method to conventional alkaline scouring for removing non-cellulosic impurities and to make the fibre hydrophilic, preserves the fibre's strength, lessens energy consumption, and decreases pollution-related problems due to conventional alkaline treatments. The jute fibre being lignocellulosic has a potential for improvement of its feel and softness through intervention of biological process like treatment of these fibres with bio catalysts like cellulase, xylanase, pectinase, laccase either alone or in combination [6]. Due to

the effect of these biocatalysts the fibre will undergo enzymolysis and some chemical constituents like cellulose, hemicellulose, lignin and pectin will degrade and after removal of these degraded materials the fibre will lose weight and become soft, fine and hydrophilic. So, these biotreated fibres will be clean and will find use in making value-added and finer textile items. This process does not cause any harmful effluent and due to higher pliability and fineness can be utilized in textile alone or blend with other fibre.

Hence, the objective of our study

1. Replacement of conventional chemical scouring method by biological scouring method to make the fibre clean and absorbent.
2. To make the fibre soft and pliable for making finer textiles through biological intervention.
3. To make the fibre suitable for further processing of bleaching and dying using lower doses of chemicals.

## MATERIALS AND METHODS

### Material

Jute fibre of NTD-3 Grade was used in the study.

### Enzymes

The present investigation was carried out to treat raw and scoured Jute using biocatalyst for improvement of its scouring, bleaching and handle properties by using following three enzymes mentioned in **Table 1** along with their assay result.

**Table 1** Assay of three commercial enzymes

| Commercial Enzymes | Enzyme Activity (U/ml) | | | |
|---|---|---|---|---|
| | Cellulase | Pectinase | Xylanase | Laccase |
| Enzyme X | 0.17 | 3.61 | 19.32 | 2.77E-05 |
| Enzyme Y | 0.25 | 2.04 | 21.10 | 0.022 |
| Enzyme Z | 0.52 | 2.70 | 68.88 | 0.020 |

### Conventional Scouring of Jute Fibre

Raw jute fibres were cut into pieces of length of 1ft and bundled for scouring. The material was put in a solution containing sodium carbonate (4% on the weight of the material) and non-ionic detergent ( 2 ml /L) using a material to liquor ratio of 1:15) at ambient temperature. The temperature gradually raised to 80℃ and the process continued for one hour with constant agitation of the material. After 1 hour the jute fibres were taken out from the solution and washed properly with running tap water. The excess water from the bundles was drained off and kept to air dry. The weight loss during the process was measured and the fibre samples were finally evaluated for their optical and physical properties.

### Bio Treatment of the Jute Fibre

Raw Jute samples of length 1ft were taken separately for the enzyme treatment. Buffer solution of pH 5 and pH 9 were made separately in beakers. For pH 7, normal water was used. The Enzymes were added in the buffered solutions and after a thorough mixing of the solutions, the raw jute fibres were entered in the bath. The temperatures were raised slowly to 65-70°C and continued the treatment for 3 hours. During the treatment the samples were agitated and pH was maintained constant. After 3 hrs the temperature was raised to about 100℃ for deactivation of the enzyme. The fibres were then washed thoroughly and allowed to dry in air completely.

### Characterization of Untreated and Treated Jute fibres

Raw and enzyme treated jute fibres were characterized for their weight loss, bundle strength, fineness, flexural

rigidity, SEM, capillary rise test and composition analysis was done.

## RESULT AND DISCUSSION

In the present study jute fibre was subjected to scouring to remove the inherent and added impurities present in the fibre. The raw fibres were subjected to different commercial mixed enzyme preparation at three different pH levels as pretreatment. As the jute fibre is lignocellulosic in nature, the selected enzyme containing cellulase, xylanase, pectinase and laccase in different proportion in different enzymes acted on these chemical constituents like cellulose, hemicellulose, lignin, pectin, etc. at a suitable condition of pH, temperature and duration for enzymolysis. Their effect on lignocellulosic fibre has been evaluated with respect to optical, physical and structural properties and has been discussed through **Table 2**, **Table 3** and **Table 4**.

Abbreviations: A- Raw Jute, B- Scoured Jute

X- Enzyme X, Y- Enzyme Y, Z- Enzyme Z,

5- pH 5, 7- pH 7, 9- pH 9

Analysis of the tables indicate that scouring makes the fibre clean, soft, finer, more hygroscopic with marginal loss of strength and weight loss compared to grey fibre. From the detailed study of effect of enzyme treatment on physical and optical properties of raw jute fibres reveals that there is a weight loss due to enzymolysis, improvement of fineness due to lowering of mass per unit length, improvement of pliability of jute fibres due to removal of impurities and components and improvement of hydrophilicity. When optical property is considered, fibres become clean resulting in improvement of whiteness and brightness and reduction in yellowness indices. Considering three enzymes X, Y and Z the property modification is found to be more in case of enzyme Z and the application condition clearly says that enzymolysis and consequently property change is maximum at pH 7.. So, the overall effect of enzyme treatment is found to be maximum when enzyme Z is used at pH 7. It is also apparent from the study that enzyme treatment on raw jute fabric produces sufficient hydrophilicity, improvement of pliability, improvement of fineness and hydrophobicity and fineness is near similar in case of chemically scoured jute fibre with additional advantage of pliability and improvement of fineness. So, biotreatment has the potential to replace conventional chemical scouring process with additional improvement in fineness and pliability. SEM of enzyme treated raw jute fibres shows that there is a progressive improvement in surface smoothness due to removal of impurities on the fibre surface which is generally expected after scouring and further surface property improvement is found after enzyme treatment.

**Table 2** Effect of different enzyme treatment of raw jute on its physical properties

| Name of the Samples | Weight Loss (%) | Bundle Strength (gm/tex) | Flexural Rigidity ($N.m^2$) | Fineness (tex) |
|---|---|---|---|---|
| Raw jute | | 24.11 | 15.75 | 2.8 |
| Scoured Jute | 6.5 | 22.87 | 12.39 | 2.6 |
| Raw Jute pH 5 Enzyme X | 3.8 | 20.41 | 13.79 | 2.8 |
| Raw Jute pH 7 Enzyme X | 6.2 | 19.51 | 12.82 | 2.6 |
| Raw Jute pH 9 Enzyme X | 5.2 | 20.17 | 11.42 | 2.6 |
| Raw Jute pH 5 Enzyme Y | 3.2 | 16.41 | 9.49 | 2.7 |
| Raw Jute pH 7 Enzyme Y | 6.0 | 18.51 | 7.53 | 2.5 |
| Raw Jute pH 9 Enzyme Y | 4.8 | 18.07 | 10.40 | 2.6 |
| Raw Jute pH 5 Enzyme Z | 6.6 | 18.41 | 6.27 | 2.6 |
| Raw Jute pH 7 Enzyme Z | 7.6 | 20.16 | 7.86 | 2.4 |
| Raw Jute pH 9 Enzyme Z | 7.4 | 18.30 | 9.46 | 2.4 |

**Table 3** Effect of different enzyme treatment of raw jute on its water absorption properties

| Name of the Samples | Wicking Length (cm) | Floating Time (sec) | Absorbency (%) |
|---|---|---|---|
| Raw jute | 3.2 | 291 | 157 |
| Scoured Jute | 3.0 | 42 | 156 |
| Raw Jute pH 5 Enzyme X | 3.1 | 158 | 161 |
| Raw Jute pH 7 Enzyme X | 3.6 | 177 | 170 |
| Raw Jute pH 9 Enzyme X | 3.2 | 120 | 152 |
| Raw Jute pH 5 Enzyme Y | 2.9 | 115 | 168 |
| Raw Jute pH 7 Enzyme Y | 3.5 | 130 | 170 |
| Raw Jute pH 9 Enzyme Y | 3.2 | 125 | 176 |
| Raw Jute pH 5 Enzyme Z | 3.2 | 95 | 177 |
| Raw Jute pH 7 Enzyme Z | 5.5 | 79 | 189 |
| Raw Jute pH 9 Enzyme Z | 5.1 | 90 | 181 |

**Table 4** Effect of different enzyme treatment of raw jute on its water optical properties

| Name of the Samples | K/S | RFL | L | a | b | WI | YI | BI |
|---|---|---|---|---|---|---|---|---|
| Raw jute | 4.03 | 10.02 | 50.88 | 5.02 | 15.06 | 40.24 | 48.53 | 13.16 |
| Scoured Jute | 3.28 | 11.83 | 53.99 | 4.64 | 15.21 | 43.22 | 46.39 | 15.32 |
| Raw Jute pH 5 Enzyme X | 4.20 | 9.68 | 50.12 | 3.43 | 14.80 | 39.59 | 45.82 | 12.82 |
| Raw Jute pH 7 Enzyme X | 4.05 | 9.98 | 51.41 | 5.22 | 16.05 | 40.51 | 50.60 | 13.19 |
| Raw Jute pH 9 Enzyme X | 4.15 | 9.80 | 50.18 | 5.56 | 14.96 | 39.61 | 49.47 | 12.77 |
| Raw Jute pH 5 Enzyme Y | 4.06 | 9.97 | 51.09 | 5.64 | 15.86 | 40.24 | 51.06 | 13.00 |
| Raw Jute pH 7 Enzyme Y | 3.42 | 11.43 | 53.20 | 3.81 | 14.82 | 42.55 | 44.75 | 14.94 |
| Raw Jute pH 9 Enzyme Y | 3.81 | 10.49 | 52.32 | 5.39 | 16.01 | 41.39 | 50.25 | 13.83 |
| Raw Jute pH 5 Enzyme Z | 3.28 | 11.83 | 54.31 | 3.89 | 15.32 | 43.50 | 45.37 | 15.53 |
| Raw Jute pH 7 Enzyme Z | 2.87 | 13.13 | 57.68 | 4.47 | 16.83 | 46.46 | 47.49 | 17.58 |
| Raw Jute pH 9 Enzyme Z | 3.87 | 10.36 | 50.64 | 4.43 | 14.23 | 40.23 | 45.78 | 13.32 |

## CONCLUSIONS

- Scouring makes the fibre clean, soft, finer, more hygroscopic with loss of strength and weight loss compared to grey fibre and makes the fibre suitable for further processing like bleaching, dyeing, etc.
- Biotreatment of jute fibres results in improvement of softness, fineness, colour, hygroscopic properties with a minimum loss in tensile strength when treated at Ph 7, ie, neutral condition.
- Considering the fibre properties, biotreatment has the potential to replace the conservational chemical scouring process so that the process becomes environment friendly.

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38_IEC4270

# Fragrance Finishing on Textiles through Microencapsulation

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***Abstract:*** *Microencapsulation has much potential for the advancement and development of compounds for the long-term conservation of naturally derived products having low storage life. Fragrance in textiles represents a fascinating conjunction of sensory experience and functional enhancement in textile technology. Essential oil is volatile, and the most challenging task is to lengthen textiles' fragrance emissions. The exposure problems of essential oils can be minimised by using the compounds in encapsulated form, which uses a masked shell, to restrict the loss of aroma during finishing application and storage; it also helps control compound release at the time and site as required. The study investigates the efficiency of aromatic finishing on textiles using the microencapsulation process of essential oil with the help of β-cyclodextrin. Additionally, the study assesses the physical properties of treated fabrics and an olfactometric analysis is employed to evaluate the intensity of the odour. The study's findings exhibit the viability of fragrance finishing on cotton and rayon fabrics.*

***Keywords:*** *Aromatic; Fragrance; Microencapsulation; Olfactometric, Textile*

## INTRODUCTION

A rise of environmental concerns and demands for eco-friendly processing of textiles has led to the development of many new cleaner and greener technologies viz. enzymatic finishing, plasma technology, finishing by natural products, microencapsulation etc. Microencapsulation is a technology for packaging particles of finely ground solids, droplets of liquids, or gaseous materials with the help of protective membranes. The material inside the microcapsule is called the core, whereas the wall is called a shell, coating, or membrane. Normally, microcapsules are produced in the range of 1 – 1000 µm, with those produced above 1000 µm are microcapsules and below 1 µm are called nanocapsules. Microcapsules with a wall thickness of less than 2 µm and a diameter in the 20 – 40 µm range are useful in textile applications. The release of the core components from the microcapsules depends on the type of material used in the shell, the number of layers present around the core and the thickness of the shell (Martel 2002). This encapsulation has allowed moisturisers, essential and therapeutic oils and insecticides to be incorporated into fabrics. Microencapsulation of anti-microbial agents is also gaining popularity in sportswear and medical textiles. Microencapsulation has a lot of potential for the advancement and development of compounds for the long-term conservation of naturally derived products which has low storage life.

Fragrances are used in an array of everyday products and the use of fragrance in textiles represents a fascinating conjunction of sensory experience and functional enhancement in textile technology.

Essential oils, popular in aromatherapy are complex and multiple-component mixtures derived from plant metabolites. It is a preferred choice for those seeking alternative or complementary therapies for health and wellness[1].These biologically active compounds have infinite potential for a healthy lifestyle by preventing microbial growth and due to different environmental factors, the bioactive properties of those oils differ, thus giving them various functionalities[2,3].

Essential oil is volatile and the most challenging task is to lengthen the emission of fragrance in textiles. The exposure problems of essential oils can be minimised by using the compounds in encapsulated form, which uses a masked shell, to restrict the loss of aroma during finishing application and storage. It can act as the core substance for fragrance-finished textiles through encapsulation and also helps control compound release at the time and site as required[1].

β-cyclodextrin is a cyclic oligosaccharide composed of seven glucose units linked by α-1,4 glycosidic bonds, forming a truncated cone-shaped structure with a hydrophobic cavity and hydrophilic outer surface. Appropriately sized guest

molecule ranging from 100 and 400 g $mol^{-1}$ is held within the cavity to form an inclusion complex. The β-cyclodextrin has no mutagenic effect and is also safe for the skin as it doesn't cause any skin sensitivity or irritation. The encapsulation with β-cyclodextrin can reduce the volatility of the compound encapsulated and also act as a barrier against oxidative damage, and degradation of the capsulated molecules against light and heat[4].

## APPLICATION OF THE FRAGRANCE FINISH TO THE TEXTILE

The fragrance-finished microcapsules are formed by the inclusion of β -cyclodextrin and essential oil. These complexes can be applied through padding or exhaust processes. Due to the formation of the inclusion complex, the durability of the fragrance finish is increased due to the steady gradual release of the core material. The application of fragrance to textiles serves various purposes and finds application in several sectors for its olfactometric sensations. Some of the applications are in home textiles, apparel, fashion accessories, speciality textiles, hospitality industries, retail and marketing, healthcare etc.

## THE OBJECTIVE OF THE WORK

The present work is aimed at producing aromatic textiles by the process of microencapsulation of essential oil with the help of β-cyclodextrin. A survey is also conducted through a structured questionnaire to understand the necessity and interest of the respondents in aromatic textiles. The olfactometric analysis with different time intervals and after-wash cycles is also done for controlled and treated fabrics.

## RAW MATERIAL

Ready for Dyeing (RFD) cotton and rayon fabrics were used in the present study. The specifications of the fabrics are mentioned in **Table 1**.

**Table 1** The specifications of the fabrics

| Material | Fabric specification | | | | |
|---|---|---|---|---|---|
| | GSM | EPI | PPI | Warp count | Weft count |
| Rayon | 110 | 84 | 64 | 14 Ne | 13 Ne |
| Cotton | 90 | 160 | 100 | 35 Ne | 30 Ne |

## METHODS

### Application of Essential Oil in the Absence of β – cyclodextrin

At first, a homogeneous solution of methanol and distilled water was made by stirring in a high-speed stirrer. The lavender essential oil was mixedwith the solution dropwiseand stirred. The rayon and cotton fabrics were dipped separately in that solution and soaked. The individual fabrics were then padded in a laboratory padding mangle at an expression of 100% and dried, further cured.

### Application of Essential Oil in the Presence of β – cyclodextrin

At first, a homogeneous solution of methanol and distilled water was made by stirring in a high-speed stirrer. An emulsion of β-cyclodextrin, polyethylene glycol and essential oil was also prepared and was added to the solution and stirred. Cotton and rayon fabrics were used to develop aromatic textiles through the process sequences as depicted in **Figure 1**.

## TESTING AND CHARACTERISATION

### Bending Length

The stiffness of different fabrics before and after microencapsulation was measured following the IS: 6490 – 1971

test method [5].

**Fabric Thickness**

The thickness of the controlled fabrics and fabrics treated with β-cyclodextrin was measured following IS: 7702 – 2012 [6].

**Olfactometric Analysis**

It is a human sensory analysis done by the opinion poll of a group of respondents. It is done to analyse the presence and intensity of the odour of essential oil by nasal sensory opinion by the respondent [7].

**AATCC Wash Cycles**

Wash durability tests equivalent to 5 home washing was performed according to AATCC 61 2A. The process was carried out twice, equivalent to 10 home wash cycles.

**GC-MS Analysis**

The gas chromatography test is required to analyse and quantify the presence of aromatic compounds.

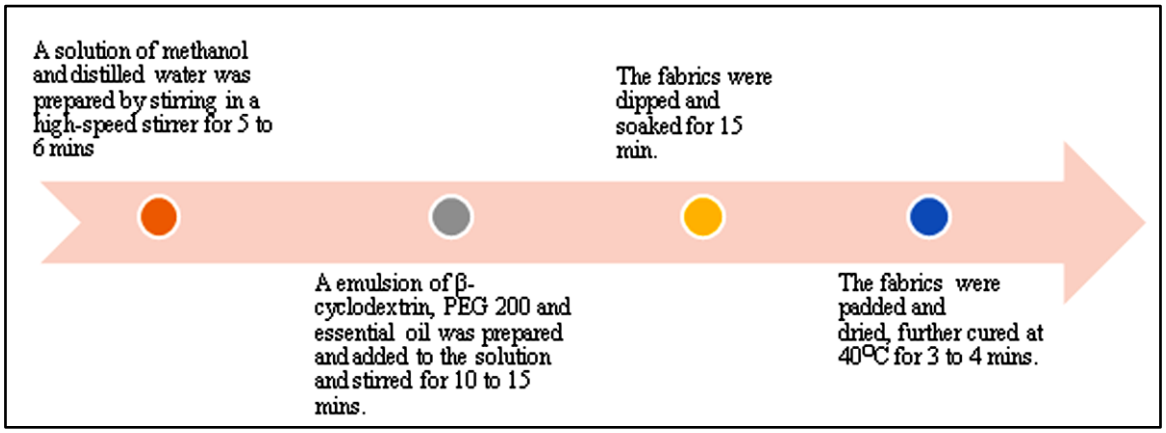


**Figure 1** Process flow diagram of producing aromatic textiles with β-cyclodextrin

**RESULTS AND DISCUSSIONS**

**Mechanism of β-cyclodextrin**

The formation of the inclusion complex is thermodynamically driven by the increase in entropy resulting from the release of water molecules from the hydrophobic cavity of β-cyclodextrin and their replacement by the more hydrophobic guest molecule to form non-polar–non-polar association [8, 9].

**Olfactometric Analysis of Odour Retention**

The controlled cotton and rayon fabrics and such fabrics treated with β-cyclodextrin and essential oil in the pad dry cure methodare rated using olfactometric analysis. **Figure 2** and **Figure 3** representthe analysis of the untreated and treated cotton and rayon fabrics on day 1, day 10, day 20 days and day 30 of storage without washing. **Figure 4** depicts the olfactometric analysis result of the treated rayon fabrics after 10 wash cycles according to AATCC 61 2A.

**Figure 2** shows cotton producedmoderate results on storage for up to 30 days when the samples were treated with β-cyclodextrin in the pad-dry-cure method. Figure 3 represents the analysis of the treated rayon after 30 days of storage and 10 wash cycles. It shows that rayon produces better results compared to cotton. Cotton didn't give the desired results in the processes and thus was not further considered for other testing and characterisation.

**Figure 3** also represents the olfactometric analysis of the treated rayon fabric after 10 wash cycles according to AATCC 61 2A. The result is also encouraging for rayon compared.

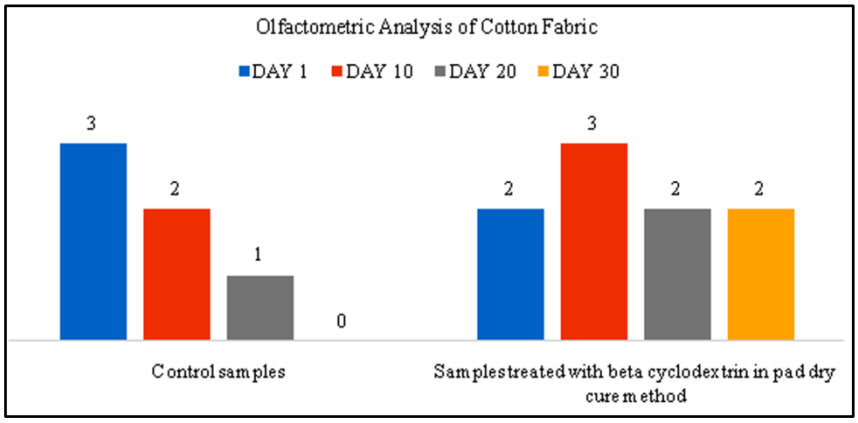


**Figure 2** Olfactometric analysis of the treated cotton samples

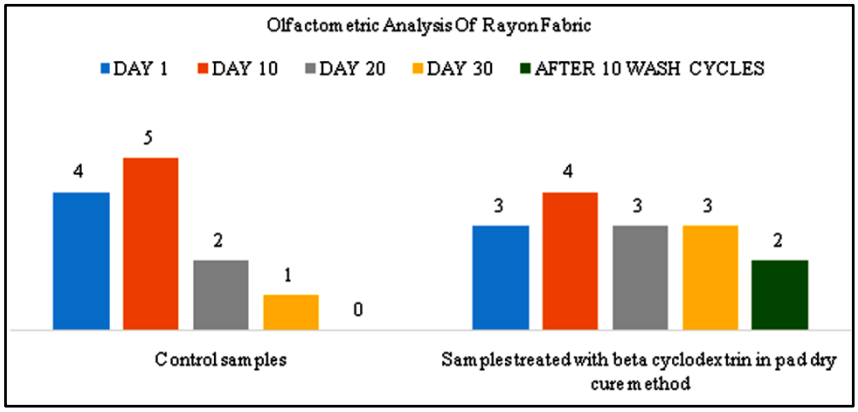


**Figure 3** Olfactometric analysis of the treated rayon samples

**Bending Length and Thickness**

During olfactometric analysis cotton didn't produce the desired results as compared to rayon fabrics thus it was not further considered during the study. The bending length of rayon when treated with β- cyclodextrin through padding did not show much difference in change of bending length as well as thickness in the treated fabric.

**Table 1** The bending length and thickness of the controlled and treated fabrics

| Sl. No. | Fabric | Bending Length (cm) | Thickness (mm) |
|---|---|---|---|
| **Controlled** | | | |
| 1 | Rayon | 1.49 | 0.21 |
| **Treated with β-cyclodextrin through the padding process** | | | |
| 3 | Rayon | 1.52 | 0.22 |

## CONCLUSION

Cotton and rayon fabrics were treated with β- cyclodextrin and essential oil following the microencapsulation technique. The olfactometric analysis on the treated fabric reveals the presence of aroma on both fabrics. As compared to rayon, cotton did not produce satisfactory results in terms of retention of aroma and stiffness of the fabric after treatment.

**PRODUCT DEVELOPED**

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48_IEC97495

# Study of Compressive Strength of Concrete Modified with Pulverized Water Hyacinth

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***Abstract:*** *Water hyacinth, a fast-growing aquatic plant, imposes significant environmental challenges by clogging waterways and damaging aquatic ecosystems. To address these issues, researchers have been investigating the uses of water hyacinth fibers in different forms with concrete. In the same line present study investigates the effects of incorporating pulverized WH at varying levels—0%, 0.25%, 0.5%, and 0.75% as fine aggregate—on the compressive strength and durability of concrete. Firstly, the workability of test specimens is studied, and then concrete cubes are cast and tested after 7, 14, and 28 days of curing. All the tests and results are compared with that of the control mix results. Thereafter, some actual and practical conclusions are drawn based on current investigation. The authors have also pointed out field problems and the future scope of work after all these experimental works.*

***Keywords:*** *Compressive Strength, Durability, Fine Aggregate, M25, Concrete, Pulverized, Water Hyacinth, Workability*

## INTRODUCTION

Water hyacinth (Eichhornia crassipes) is renowned for its rapid growth and the substantial ecological challenges it poses. This invasive aquatic plant can quickly dominate water bodies, causing serious issues such as blocking sunlight, depleting oxygen levels, and disrupting aquatic ecosystems. The traditional methods of managing and removing water hyacinths have proven to be both costly and labor-intensive [1]. In recent years, academic research has increasingly focused on harnessing the potential of water hyacinth as a valuable resource rather than treating it solely as a waste product. One promising approach involves pulverizing water hyacinth into a fine powder, or very small pieces known as pulverized water hyacinth (WHP). This method not only addresses the environmental impact of water hyacinth but also offers a sustainable material for use in the construction industry. Previousresearch work has alreadydemonstrated that WHP can be effectively utilized as a cementitious additive, contributing to both the sustainability and performance of concrete [2]. The study indicates that WHP can improve the mechanical properties of concrete, especially when used in precise proportions. In another finding it has been suggested that incorporation ofWHP into concrete not only enhances its overall performance but also increases its resistance to environmental degradation, demonstrating WHP's potential for improving both the durability and sustainability of concrete mixes [3].These studies emphasize that the use of WHP not only contributes to waste management by repurposing an invasive species but also reduces the demand for natural sand, which is a finite resource. The research also highlights the importance of optimizing the percentage of WHP used in concrete to achieve a balance between environmental sustainability and structural integrity.

## LITERATURE REVIEW

The fast and growing world of concrete construction is not only the mark of continuous growth of society but gradually becoming a potential threat to the environment. Emission of GHG and waste management of these materials further add fuel to these devastating issues [4]. The search for sustainable and eco-friendly materials in construction has gained significant momentum in recent years. One innovative approach involves utilizing agricultural and aquatic waste products as additives in concrete. Water hyacinth (Eichhornia crassipes), an invasive aquatic plant, has emerged as a potential resource due to its abundance and ability to be processed into a fine powder known as pulverized water hyacinth (WHP). The chemical composition of WH fiber has cleared that the cellulose content of these fibers is 68.4%, which is way ahead of that of banana and sisal fibers[5]. With this fact also it has become the fascination of scientists and researchers to explore more on WH in different forms along with concrete. In one of the latest review research works [6], authors have discussed issues related with waste management of water

hyacinths and its use as admixture to concrete, and replacement of cement and sand in different practices. Studies have found that concrete mixtures incorporating pulverized WH exhibited a variation in compressive strength compared to conventional concrete. While the compressive strength of concrete with WHP was generally lower than that of traditional concrete, the strength levels remained within acceptable limits for many construction applications. The results suggest that WHP can be used effectively as a partial replacement in concrete without compromising overall structural integrity, provided it is used in optimal proportions. [7]. This initiative will provide a two-fold solution. One sustainable solution is an alternate/modified form of concrete and a smart way handling of water hyacinth plants, without affecting the financial aspects of the entire project work.

## RESEARCH GAP

However, this area of research is still at a very young level. It requires further important facts to be explored, such as what is the optimum value of water hyacinth? which form is most effective for concrete strength and durability? Impact on higher grades of concrete? Effect of surface treatment? Etc. and many more.

In this present research work to understand the behaviour of concrete mixed with water hyacinth, authors have used the pulverized form of these plants' stems. The effect of different percentages of pulverized water hyacinth mixed with concrete has been investigated for workability and strength.

## MATERIALS

The studies have also found that concrete mixtures incorporating WHP showed variations in compressive strength compared to conventional concrete. Research indicates that WHP can be effectively used as a partial replacement for fine aggregates in concrete, provided it is utilized in optimal proportions. This approach ensures that the structural integrity of the concrete is not compromised, while also contributing to sustainable construction practices.[8]. Clean, potable water is crucial for the concrete mixture as it hydrates the cement, initiating the chemical reactions necessary for curing. As a sustainable additive, it not only enhances the properties of the concrete but also addresses waste management challenges by providing an eco-friendly alternative. This integration can contribute to the overall sustainability of construction materials, potentially improving their environmental footprint while supporting effective waste utilization. [9,10 & 11].

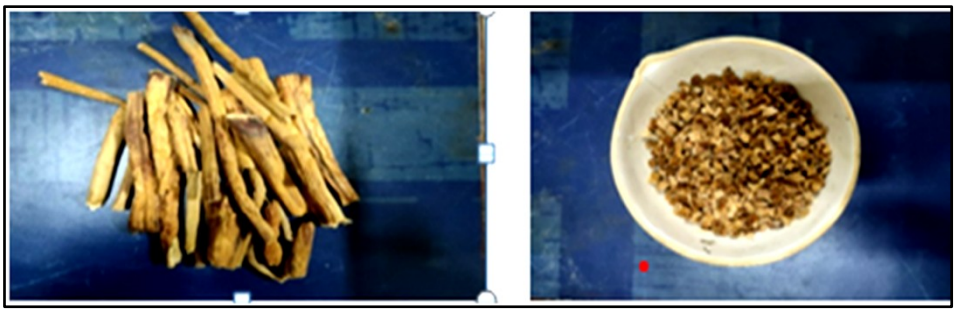


**Figure 1** Water hyacinth stems and Pulverised Water Hyacinth

Water hyacinth stems were collected from a local trader. Whereas Cement ard aggregates are supplied by university lab. Considered the Specific gravity of composite cement PCC = 2.88 [12],Coarse aggregate [at saturated surface dry (SSD) Condition]=2.74 [IS-10262], Fine aggregate [at saturated surface dry (SSD) Condition]=2.65[IS-10262], Pulverised Water hyacinth=1.33[13].

## METHODOLOGY

To prepare test specimens PCC cement [as per JSW cement manufacturing company, conforming to IS 16415], natural river sand and coarse aggregate with, maximum size of 20 mm were used. Then collected water hyacinth stems were, dried in an oven at 160°C - 180°C for 4hr to 5hr for 3 consecutive days, and then pulverized it into fine powder/pieces. The required amount of cement, sand, stone chips, water, and WHP were weighed and mixed in dried

condition (refer **Table 2**). The mix designed to achieve cube strength of 25 MPa after 28 days curing was casted. After one day demoulding of all the moulds were done and curing of moulds were done for 7 days, 14 days and 28 days. Tests for fresh concrete and hardened concrete were conducted after specific days of curing.

**Table 2** Material Proportion

| Concrete Type | Cement (kg) | Sand (kg) | Stone chips (kg) | Water (kg) | WHP (kg) | WHP % | W/C ratio |
|---|---|---|---|---|---|---|---|
| $M_0$ | 2.64 | 4.53 | 7.73 | 1.29 | 0 | 0 | 0.49 |
| $M_{0.25}$ | 2.64 | 4.53 | 7.73 | 1.29 | 0.007 | 0.25 | 0.49 |
| $M_{0.5}$ | 2.64 | 4.53 | 7.73 | 1.29 | 0.013 | 0.50 | 0.49 |
| $M_{0.75}$ | 2.64 | 4.53 | 7.73 | 1.29 | 0.020 | 0.75 | 0.49 |

## EXPERIMENTAL WORK

The physical properties of the composite cement (cement mixed with WHP) to be evaluated include:

Workability: Measure the workability of the concrete mix using the slump test as per IS 1199. This test indicates the ease with which the concrete can be mixed, placed, and compacted.

Non-destructive test: Perform the rebound hammer test according to IS 13311 (Part 2). This non-destructive test provides an estimate of the concrete's surface hardness, which correlates with compressive strength.

Compressive Strength: Measure the compressive strength of the concrete cubes as per IS 516-1959. This test determines how the addition of WHP affects the load-bearing capacity of the concrete.

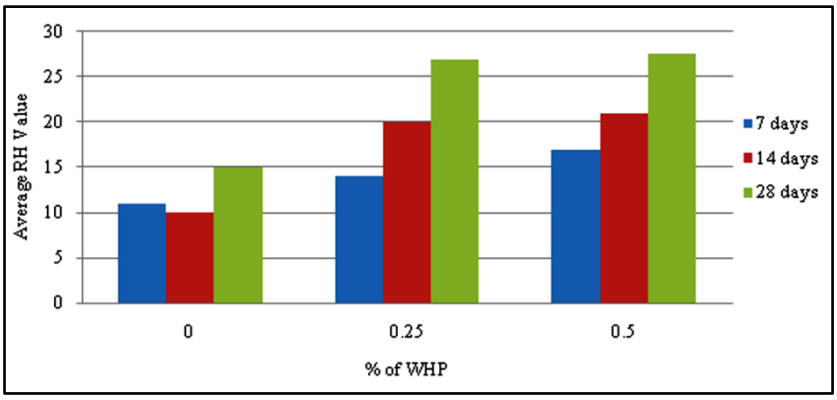
**Figure 2** Rebound hammer test and Cube test of a typical concrete cube

## RESULTS & DISCUSSIONS

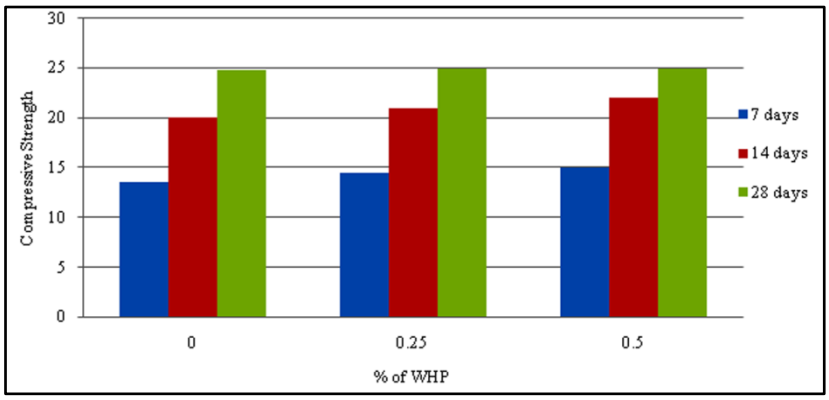
To evaluate the effect of incorporating different percentages of pulverized water hyacinth (WHP) into M25 grade concrete by casting and testing concrete cubes. The percentages of WHP used are 0%, 0.25%, 0.50%, and 0.75% by volume of the concrete mix. However, results of 0.75% of Pulverised water hyacinth is still in progress.

The reduction in workability with increasing WHP content suggests that mixes incorporating WHP might require additional water or the use of plasticizers to maintain desired workability levels. Further it is noted from above graphs (1, 2),that compressive strength of concrete cubes with WHP content of 0.25% -0.5% appears to be the most favorable, as it has the least impact on compressive strength while still contributing to sustainability goals. However higher percentages more than 0.75% should be further investigated. This result can be also validated with those of rebound hammer average values. All these comparisons are made with control mix cube that is concrete with 0% WHP.

It can be inferred that concrete with less amount of WHP can be used for structural purposes while that with higher amount cab be used for some of non-structural or decorative purposes. However, even this small amount can be useful to make concrete cheaper as compared to conventional concrete.




**Graph 1** NDT test results




**Graph 2** Compressive strength vs % of WHP

## CONCLUSIONS

After careful observations following conclusions can be drawn:

1. WHP as a Sustainable Additive: Pulverized water hyacinth can be used as an additive in concrete, contributing to environmental sustainability by recycling an invasive aquatic plant. However, its incorporation should be carefully controlled to avoid compromising the concrete's structural integrity.
2. Optimal WHP Percentage: Based on the results, a WHP content of 0.25% appears to be the most favourable.
3. Impact on workability: Workability of concrete gets compromised with more percentage of pulverised WH. To maintain workability either some super plasticiser should be used or surface treatment of WH stems can explored.
4. Cost efficiency: Less/cheap cost or easy availability of WH plant helps in reducing the cost of entire project work.
5. Durability: A detailed study for durability of such kind of modified concrete is must.
6. Further Research: To optimize the use of WHP in concrete, further studies could explore the use of chemical admixtures, different curing methods, or varying the water-cement ratio to counteract the effects observed with higher WHP percentages.

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# The Promise of Syzygium Aromaticum (Clove Oil) in Developing Antimicrobial and Green Textiles

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***Abstract:*** *The research investigates the antibacterial efficacy of clove oil (Syzygium aromaticum) as a sustainable and environmentally acceptable substitute for synthetic agents in textile applications. Clove oil, mainly composed of eugenol, has prominent antibacterial, antioxidant, and therapeutic benefits. Modern extraction techniques, such as microwave assisted and ultrasonic assisted methods, enhance clove oil yield and quality while minimizing environmental impacts. This research highlights clove oil's superior antibacterial efficacy against Staphylococcus aureus and Escherichia coli on cellulosic substrates, achieving over 99% microbial reduction. Its phytochemical richness and bioactive compounds, including phenolic acids, position it as an effective, biodegradable, and renewable solution for antimicrobial finishes. Compared to other herbal extracts, clove oil demonstrates broad spectrum activity with promising applications in intimate apparel and moisture prone textiles. Future studies must concentrate on compatibility with various textile substrates, durability during wash cycles, and the engineering of patented formulations to enhance their potential in sustainable textile processing.*

***Keywords:*** *Antimicrobial; Clove; Herbal; Pathogen; Sustainable*

## INTRODUCTION

Antimicrobial finishes are vital for hygiene and durability in textiles, but commercial agents pose environmental and health risks. Hence, exploring eco friendly alternatives, like herbal agents, is imperative. Microorganisms such as mold, mildew, and bacteria are ubiquitous in textiles and must be understood for adequate control. Herbal solutions offer promise, aligning sustainability with antimicrobial efficacy[1, 2].

Herbal agents, like clove, offer advantages over commercial counterparts due to their natural sourcing, renewability, biodegradability, and eco friendliness. This study emphasizes clove's significance as an antimicrobial finishing agent in textiles, advocating a shift from commercial to herbal alternatives to meet consumer demand for environmentally conscious, non toxic products [2].

## CLOVE OIL

Research indicates its diverse health benefits, encompassing antimicrobial, antioxidant, analgesic, antiinflammatory, and anti carcinogenic properties.

Clove oil, primarily composed of eugenol, is a key product derived from Syzygium Aromaticum, a member of the Myrtaceae family.

It has been cultivated in the following countries: Indonesia, Sri Lanka, India, Brazil, Vietnam, Rwanda, Nigeria, Tanzania, Malaysia, Madagascar and Pakistan [3-6].

## PHYTOCHEMICALS AND BIO ACTIVE COMPOUNDS

Clove is rich in phenolic compounds like eugenol and gallic acid, another prominent constituent. Other phenolic acids include caffeic, ferulic, and salicylic acids. [4,7].

Traditional medicine has long relied on medicinal plants containing phytogenic compounds to manage lifestyle related risks such as inflammatory diseases, This compound and others in clove oil underscore its therapeutic

properties.

The components from clove were identified, and eugenol (76.23%) was the major component. Several researchers report this. Clove oil is generally considered safe for low dose consumption, indicating potential risks at higher concentrations. [8 11]

## ANTIMICROBIAL ACTIVITIES OF CLOVE

Clove oil demonstrated greater antimicrobial efficacy than clove extract and a standard food preservative (sodium propionate) against various food borne pathogens and dermophytes. [12 13]

These may lead to the development of innovative and new applications in intimate skin garments like underwear, lingerie, etc., especially during the summer whenmoisture and temperature play a crucial role in the growth of harmful fungal injections on human skin. [14 17]

## OIL EXTRACTION

Clove oil, traditionally extracted via methods like cold pressing and steam distillation, can now benefit from modern techniques such as microwave assisted hydro distillation and ohmic heating assisted extraction.

Innovative techniques like microwave assisted extraction (MAE) and ultrasonic assisted extraction (UAE) revolutionize clove oil extraction, optimizing output and quality while minimizing environmental impact and energy consumption. [18 19]

## ITS SIGNIFICANCE IN DIFFERENT FIBRES

Utilizing clove oil as an antimicrobial agent in various fibres presents several implications. Its natural antibacterial properties can offer an eco friendly alternative to synthetic antimicrobials, reducing reliance on chemical treatments. Comparison to the control was notably higher against both S. aureus and E. coli. [20]

## COMPARISON WITH OTHER HERBAL EXTRACTS

The Comparison highlights the diverse antimicrobial properties of these herbal extracts, each with its own unique active compounds and application methods. Study shows clove, tulsi, neem, and lemon oil exhibit broad spectrum activity and demonstrate significant antimicrobial potential against various pathogens. [21]

## EXPERIMENTAL

### Materials and Methods

Cellulosic knitted substrate (Excel fabric-also known as Lyocell) of commercial grade of 250 GSM (CPI-60, WPI-50) has been used as test sample. This was treated with herbal antimicrobial finishing agent (clove extract) of commercial grade by exhaust method.

### Organisms used

Two bacterial strains namely (a) Staphylococcus aureus Strain No. ATCC 6538 (Gram Positive Bacteria) and (b) Escherchia coli Strain No. ATCC 10799 (Gram Negative Bacteria) have been used to evaluate the antimicrobial properties of the clove extract.

### Testing and Evaluation

The Antimicrobial properties of the clove extract treated test samples were evaluated using testing standard Antibacterial Testing AATCC 100 and the FTIR spectrum of the same has also been analysed.

## RESULTS AND DISCUSSION

This experimental study on the clove extract shows excellent antimicrobial properties (99% reduction) when applied on excel (as shown in **Table 1** and **Figure 1**), which is further authenticated by the FTIR spectrum of clove oil with a broad absorption band at 3500 $cm^{-1}$ indicating alcoholic O-H stretching with another sharp band at 2935 $cm^{-1}$ indicating sp 3 C-H stretching corresponds to the bioactive component Methyl salicylate, betacaryophyllene, Eugenol acetate.

**Table 1** Antibacterial efficacy of clove oil (5% conc.) on Excel substrates

| Substrate | Herbal Agent | Application method | Test Culture | No. of colonies recovered at "0" hrs. | No. of colonies recovered at "24" hrs. | Reduction of Microorganisms |
|---|---|---|---|---|---|---|
| Excel | Clove | Exhaust | E.coli | 1.79 X 10^5 | 1.5 X 10^3 | 99.16% |
| Excel | Clove | Exhaust | S.aureus | 1.68 X 10^5 | 1.2 X 10^3 | 99.28% |

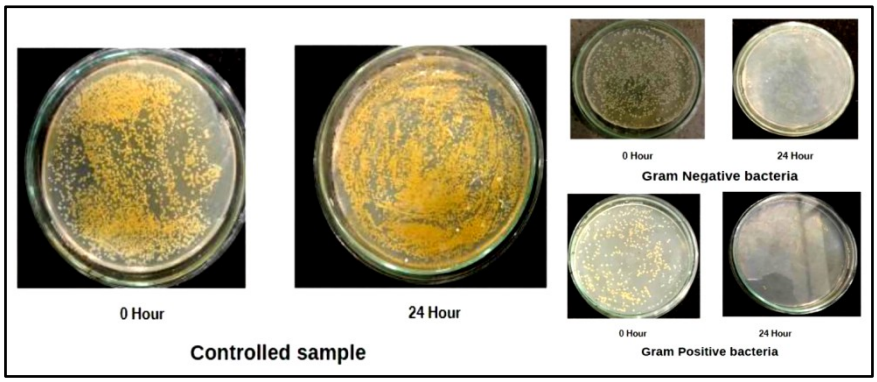


**Figure 1** Photograph of Antibacterial Testing AATCC 100

This suggests that clove can be a promising natural alternative to synthetic antibacterial finishes, contributing to more sustainable and eco friendly textile processing. This natural agent offers a promising alternative to synthetic antibacterial finishes, contributing to more sustainable and eco friendly textile processing.

## CONCLUSION

This study shows that Syzygium aromaticum (clove oil) has a lot of potential as a flexible and long lasting antimicrobial agent in textiles (cellulosic substrate).

Furthermore, the study emphasizes the necessity for future research to address

## FUTURE SCOPES

There is a lot of potential for future research into clove as an antimicrobial agent. Here are several future scopes for research in this:

- There has been little comprehensive scientific exploration of their antimicrobial potential.
- Clove might not have patented formulations or technologies for use as an antimicrobial agent.
- Further studies can help understand the compatibility of clove treatments with different textile substrates.
- More quantitative research is needed to precisely measure the antimicrobial efficacy of clove treated textiles.
- More needs to be understood about the sustainability of these properties over repeated wash cycles.
- There are few studies focusing on the antibacterial properties of clove, where bacterial growth has been explored extensively.

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# Diversified use of Water Hyacinth

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***Abstract**: Water hyacinth, also known as the 'Terror of Bengal' in India, is a rapidly growing aquatic weed that clogs streams, limiting activities like fishing and boating, affecting aquatic life, native plants, and animal communities, and causing significant economic loss. The study explores using water hyacinth in biodegradable packaging to address these issues. By incorporating various techniques, the woven mats from water hyacinth are also produced, contributing to the upliftment of crafts sectors. The fibres from water hyacinth stems are extracted and used to develop sanitary napkins and woven and knitted fabrics by blending them with other natural fibres. This versatile approach can transform water hyacinth from a hazardous weed to a valuable resource, contributing to economic development and environmental sustainability.*

***Keywords:** Air Permeability; Excel; Handicraft; Viscose, Water Hyacinth*

## INTRODUCTION

Water hyacinth, the 'Terror of Bengal' in India, is an invasive plant species with thick, rounded green leaves, lavender-blue flowers, and dark purple to black roots. It chokes streams, limiting activities like fishing and boating, impedes photosynthesis, lowers oxygen levels, and deteriorates water quality, affecting aquatic life, native plants, and animal communities [1]. Despite its negative impact on human health, the 'Terror of Bengal' has several benefits, making it a potential solution for a sustainable world. It has extraordinary properties, including producing biofuel, nitrocellulose, and paper and absorbing dye effluent. In different parts of India, various crafts are produced from water hyacinths. The present study helps partially clean the water bodies to save aquatic life by collecting raw materials. It aims to convert this weed into valuable products to add value to the waste and replace single-use synthetic material with a sustainable and biodegradable product.

## PRODUCT DIVERSIFICATION

### Development of Woven Mats from Water Hyacinth Stem

The water hyacinth craft has been practised for several years throughout various regions of the world. In the present study, a different technique was used to produce the woven mats of water hyacinth by forming a rope. This work is aimed at improving the crafts sector.

Raw cotton yarn, water hyacinth stems, etc were used in the present work. A hobby loom consisting of four heald shafts, a spinning wheel (charkha), bobbins, drawing hooks, sticks, etc were used during the production process. **Figure 1** depicts the weaving process in a hobby loom.

**Figure 2** depicts different mats and coasters developed with water hyacinth stems as weft and cotton yarn in the warp direction.

### Handmade Paper from Water Hyacinth for Packaging

Water hyacinths and other waste-based fibres were used as environmentally friendly alternatives to replace single-use plastic and excessive tree use in packaging.

The handmade papers made from only water hyacinth have very low strength as the fibre-fibre entanglement is not there. Also, with increasing thickness, the papers became rigid. The raw stems and leaves are also produced paper of very low strength. Results conclude that Water hyacinth has the potential to develop paper from it.

However, some fibrous material must be added to increase its strength and flexibility when using paper as packaging material. Different types of agro waste, such as banana pseudo stems and sugarcane bagasse can help increase its strength. These papers are appropriate for making biodegradable packaging, replacing single-use plastic bags made from polyethylene, and promoting sustainability. **Figure 3** shows handmade paper made from water hyacinth.

**Figure 1** Weaving process

**Figure 2** Mat produced from water hyacinth stem

**Figure 3** Handmade paper making

**Needle-punched Nonwoven Made from Water Hyacinth**

Needle-punched nonwoven fabric was produced from the water hyacinth fibre to use its potential in various fields. The properties of the nonwoven fabric, including water absorbency, imbibition, air permeability, thermal insulation, and flexibility, were also measured. The needle-punched nonwoven fabric from water hyacinth fibre was produced in the DILO nonwoven plant. The outcome demonstrates that nonwoven fabric from water hyacinth has excellent water absorption properties, making it appropriate for various unique uses such as underpads, sanitary napkins, and diapers.

**Woven and Knitted Fabric from Water Hyacinth and its Blends**

Researchers have explored using water hyacinth and its stem for various purposes, including thermal insulation, biogas production, and nonwoven fabrication. Wet-laid web formation was used to create nonwoven fabrics, and needle-punched nonwoven fabrics were created by blending water hyacinth and Sansevieria stuckyi fibre [2]. Nanocellulose filament fabrication from water hyacinth through the wet spinning method has been reported in the literature [3]. Bio-composites were produced using water hyacinth fibres, polyester resin, and low-density polyethylene, and researchers also developed woven water hyacinth fibre-reinforced composites with epoxy resin [4]. In this work, an initiative was taken to produce yarn from water hyacinth fibre to analyse its potential as a textile raw material.

## MATERIALS

Water hyacinth fibres, viscose fibre, excel fibre, anti-static agent, desizing agent(Rexasize ECE liquid), and softener (RucofinGSQ) were used in the present study.

## METHODS

In this work, an initiative was taken to produce yarn from water hyacinth fibre. Two different spinning systems were used to produce yarn. The yarns were converted into woven and knitted fabrics and used to form garments. The properties like air permeability, pilling tendency, moisture management, thermal behaviour, etc., were tested and compared with the cotton and Excel fabrics having similar specifications. After analyzing all the testing results, it can be concluded that the water hyacinth fibre has the potential to be used in apparel.

## CONCLUSION

The water hyacinth rope is a flexible and strong component that can produce handicraft items such as mats, bags, blinds, etc. Due to its high moisture absorbency, it can be used to produce summer blinds to keep the room cooler. The usage can be diversified in many other ways, such as replacing synthetic material in the market. Practising these handicrafts will add value to the water hyacinth handicraft sectors, which will eventually help craftspeople develop economically and add value to the ultimate waste. Despite being viewed as an endangering species to human health, the environment, and aquatic life, the ‘terror of Bengal’ has several benefits. Considering all the facts associated with the versatile approach, the water hyacinth can be transformed from ‘weed to wealth’.

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110_IEC38742

# The Functional Aspects of Natural Dyes used in Traditional Textiles

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***Abstract**: The discovery and development of synthetic dyes in the mid-nineteenth century led to a sudden downfall in the demand and production of natural dyes and materials dyed from natural resources. Natural dyes are biodegradable, eco-friendly, and possess various functional properties, viz., antimicrobial, UV-protection, and mosquito repellent. Despite these benefits, natural dyes also exhibit some drawbacks, such as their inability to reproduce colour consistently, poor light fastness and perspiration, etc. The present study demonstrates the dyeing, printing and painting of textiles with natural colourants. Different analyses such as phytochemical, FTIR and UV-visible spectroscopic studies of the natural dye were done to evaluate functional groups in the natural colourants used in traditional textiles. Developed fabrics were subjected to various tests to evaluate their performances. The results highlight the diverse possibilities of natural dyes on textiles. A collection of accessories and garments using natural colours of cotton and silk has also been developed*

***Keywords**: Antibacterial; Functional; Natural Dye; Phytochemical; Traditional*

## INTRODUCTION

Historically, ancient textiles were dyed with natural sources derived from different parts of plants, minerals, fungi, insects, etc. Natural dyes, mainly used for textiles, are generally obtained from vegetable resources, i.e., barks, roots, flowers, fruits, leaves, seeds, etc. Dyeing and other surface embellishments with natural dyes on textile substrates were practised dating to the dawn of human civilisation to enhance the aesthetic appeal and cure specific diseases due to their proximity to the skin. This fabric, often called Ayurvastra, is used in apparel, floor mats, towels, and medicinal clothes [1,2]. The accidental discovery and gradual development of synthetic dyes in the mid-nineteenth century led to a sudden downfall in the demand and production of natural dyes and materials dyed from natural resources. Today, there is a market for the alternative options preferred by environmentally conscious consumers.

Natural dyes are biodegradable, eco-friendly, and not harmful to the environment if used judiciously. They are safe for skin, food, and children. Natural dyes also have functional properties, viz., antimicrobial, UV-protection, and mosquito repellent [3-5]. The waste materials after dye extraction can also be used as fertilisers (indigo, myrobalan, etc.). However, customer-driven massive industrial production is becoming a significant economic and cultural issue and potentially threatening some biodiversity. Despite these benefits, natural dyes have inherent drawbacks that are primarily to blame for the decline of this age-old, traditional craft [6]. One of the biggest obstacles to using natural dyes on textiles is standardising the recipe and ensuring that the shades are reproducible. It is expensive as it has comparatively low colour yields. The colour also may change when exposed to light, perspiration, air, etc. Some dye sources may have harmful effects on the environment. The dye bath containing various inorganic heavy metals may create a severe disposal problem [7, 8].

In the present study, dyeing and printing/painting textiles with natural colourants to achieve functional aspects of end products have been examined and reported.Today craftspeople are also opting for newer sources of dye materials. A detailed and comprehensive documentation of the traditional process of textile colourationsurely opened newer opportunities.

## MATERIALS

### Fabric

Handspun handwoven cotton fabrics and matka silk fabric used in the study were sourced from the Burdwan and Murshidabad districts respectively.

**Dyes and Chemicals**

Myrobalan (Terminalia chebula), fermented scrap iron and molasses solution, Indian madder (Rubia cordifolia), catechu (Acacia catechu), and indigo (Indigofera tinctoria) were used in the present study. Alum as mordant, and Gum Acacia as thickener were also used in the study as and when required. All the materials were sourced from the local markets, and Burrabazar, Kolkata, and Bolpur. Indigo wasprocured from KMA Exports, Tamil Nadu, and Assam. Indigo produced from the researcher's farm was also used. All the laboratory reagent grade chemicalswere obtained from Merck Life Science Private Limited, Mumbai, India.

## METHODS

Phytochemical, FTIR and UV-visible spectroscopic studies of the natural dye were done to identify functional groups in the natural colourants used in traditional textiles. The extraction, required for the phytochemical and UV-visible spectroscopic study was done on a magnetic stirrer at 50 mph for 45 min at 90OC and then filtered using Whatman filter paper. The functional groups and bioactive components present in the natural dye sources were further quantitatively analysed through a spectrophotometer at a resolution of 1 cm -1 in between 400 – 4000 cm -1 by using the FT-IR spectroscopic technique. UV-visible spectroscopic studies were also employed at a wavelength of 200-900 nm.

All the dyed fabrics were tested for their colourfastness to washing, light and rubbing. Colour fastness to washing was assessed following the ISO standards. Colour fastness to rubbing and light was assessed employing a Crockmeter and MBTF light fastness tester [9].

The evaluation of antifungal activity for the dyed fabric samples was quantitatively assessed by the percentage reduction method following the AATCC 30: Part 3-2017 standards. The evaluation of antibacterial activity for all the undyed and dyed fabric samples was quantitatively measured following the AATCC 100-2019 standards by the percentage reduction of microorganisms.

## CONCLUSION

These dye sources have been used for various shades on cotton and matka silk fabrics. Myrobalan, madder, catechu, and indigo-dyed silk fabrics showed no zone of inhibition but no fungal growth on the fabric and excellent antibacterial activity over gram +ve and gram -ve bacterial growth. The colourfastness properties of dyed samples are also good to excellent.

After analysing the results, a collection of accessories and garments using natural colours of cotton and silk has been developed.

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# Exploration of Resist Technique with Natural Dyes

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***Abstract***: *Batik is one of the most popular surface ornamentation techniques commonly used in textiles. It is a wax-resisting technique which imparts value and aesthetics to the fabric. The batik work most commonly uses naphthol colour due to its known advantages. However, present environmental legislation has stopped the use of naphthol colour in the export market due to its known adverse effects. Hence, sustainable and eco-friendly alternatives have become a matter of significant importance. The present study discusses using natural dyes in batik work to achieve a more sustainable alternative to popularly used naphthol or azoic colour to maintain balance in the ecosystem and rejuvenate the age-old batik practice.*

***Keywords***: *Batik; Indigo; Natural dye; Resist; Wax*

## INTRODUCTION

Batik is one of the most popular surface ornamentation techniques used in textiles to achieve value and aesthetic appeal. It is a method of creating patterns on the fabric surface using wax-resist techniques. Batik is derived from the Javanese word [1]. This age-old resist printing technique is prevalently practised in both Indonesia and India. The two countries have a different essence to their designs, which has deep cultural significance and unique stylized characters. Sophisticated intricate lines to bold motifs, the range is mesmerizing. Indian and Indonesian batik can be identified based on their fundamental pattern differences and colour choices.

The basic process of batik includes using a resisting agent,particularly beeswax and paraffin wax to achieve a cracked effect hence creating a pattern when the wax is removed from the dyed cloth. Naphthol colours are commonly used in batik work due to their known advantages i.e., producing vibrant shades and being dyed at room temperature in a very short time. However, present environmental legislation has stopped the use of naphthol colour in the export market due to adverse health and environmental hazards. Hence, sustainable and eco-friendly alternatives have become a matter of significant importance due to the increased environmental awareness among consumers. The present consumers are looking for a sustainable product in addition to its aesthetic appeal.

The present study aims at using natural dyes in batik work to achieve a more sustainable alternative to popularly used naphthol colour.

## EXPERIMENTAL

### Materials

Fabric

The cloth used in batik work should be strong enough to withstand the heat during the waxing process. In the present work, cotton fabric was used, because of its good absorbing power to absorb the wax very easily.

Natural dyes

Natural dyes like indigo, tea leaves and onion peels were used to achieve the desired outcome through the resist technique. Tea is a beverage produced from the leaves of the tea plant Camellia sinensis [1]. The colours obtained from onion skins have a natural and organic quality and produce earthy tones ranging from soft yellows to deep oranges and browns. Indigo is one of the most globally widespread dyes of antiquity, and the history of indigo cultivation is closely associated with colonial Bengal. Today, there is growing interest worldwide in reviving natural indigo on ecological grounds [2].

Resisting agent

Beeswax and paraffin wax were used as resisting agents in the present work. Beeswax is soft and acts as a strong shield against the dye. It does not allow the dye to sweep through. On the other hand,paraffinwax is hard and brittle. The crispness and brittle quality of this wax allow it to form more cracks in the waxed area. Therefore, it is mainly used for creating cracks. In the present work, a mixture of cold PVA and clay mud was also used as a resisting agent.

**Tools and Equipment**

Canting (Tjanting pen)

It is the traditional method of applying wax on the fabric by hand. It is a pen-like tool with a metal cup to hold the molten wax with a tiny spout at the far side to drip the hot wax. The process requires skills with precision because sometimes the patterns used in the batik are very complex. In the present work, this was used for the application of beeswax.

Brushing

It is quite similar to painting with colours using a brush. Paraffin wax was applied through a brushing technique.

**METHODS**

**Preparation of Fabric**

To remove natural and added impurities to make cotton fabric absorbent, scouring was performed in the presence of sodium hydroxide, sodium silicate, sodium carbonate, turkey red oil and detergent as per the standard procedure.

**Cold PVA and Clay as Resisting Agents**

Polyvinyl alcohol is a water-soluble polymer and the mixture of PVA and clay provides a desirable viscosity that can be used as a resisting agent. The results achieved were similar to those of wax-resisted fabric. **Figure 1** shows fabric developed with an aqueous extract of tea leaves and cold PVA and clay as resisting agents.

**Batik Work with Natural Indigo**

Batik work with indigo is one of the most popular techniques to achieve value and aesthetic appeal in textiles. It is a method of dyeing fabric by resisting selected portions with beeswax and/or paraffin wax. The batik technique involves four steps drawing, waxing, dyeing, and wax removing.

**Figure 1** Cotton fabric dyed with tea leaves

**Figure 2** Wax application

The drawing was traced out on a fabric as per theme, mood and design. The waxing process (**Figure 2**) was done with the help of a Tjanting pen and brush. Indigofera tinctoria (20%) was first pasted with Turkey Red Oil and cold water to prepare a dye dispersion. Sodium hydrosulphite and sodium hydroxide were used for the reduction and subsequent solubilisation of Indigofera tinctoria. The vatting process was performed at room temperature. The amount of hydrosulphite required during vatting was four times that of the indigo, whereas sodium hydroxide was taken equal to the amount of dye [2]. After dyeing, oxidation with hydrogen peroxide in the presence of acetic acid at room temperature for 15-20 min was performed. It is essential to rinse the goods in cold water before oxidation to enhance oxidation efficiency. After the waxing and dyeing process, the wax was removed in a solution containing non-ionic detergent and emulsifying agent under boiling conditions for 10 min. After removing the wax, the motifs that have previously been drawn are visible (**Figure 3**).

**Figure 3** Indigo-dyed fabric

## CONCLUSION

Batik is an art with high artistic value in ancient culture. It is a fusion between art and technology. It offers more freedom to a designer to create an enormous number of patterns and also experiment with materials to create something from their spirit. Thus, batik work is not limited to any acceptable products. Traditional batik is very laborious and labour-intensive. It needs skilled manpower which increases the cost of production and is thus suitable only for producing specialty products in the cottage sector.

The traditional methods of Batik work are threatened by printed batik with the help of screen and block. The work presented in the report is an attempt to use an alternate methodology using natural dyes and other resist techniques to achieve results similar to batik. The use of natural dyes makes the outcome more sustainable. Natural colourants are recommended due to their non-toxic, biodegradable, non-allergic nature. Natural dyes have beneficial healthcare characteristics as well. The use of natural dyes instead of azoic colours is a sustainable approach to maintaining balance in the ecosystem and also rejuvenating the age-old practice of batik.

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178_IEC87726

# Improving Power Plant Efficiency through Carbon Capture and Utilization: $CO_2$ Capture in a Rotating Packed Bed Pilot Plant of One TPD Capacity.

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***Abstract:*** *Net-Zero targets for hard-to-abate industries such as thermal power plants can be achieved through effective Carbon Capture. These technologies can either remove the $CO_2$ from the exhaust stream or produce a concentrated $CO_2$ stream that can be utilized or stored safely. But, these $CO_2$ capture processes result in significant efficiency penalties when used in power plants. However, by utilizing the process intensification technique on Carbon Capture, the energy penalties can be reduced. This work involves the absorption of $CO_2$ in a process intensified Rotating Packed Bed (RPB) gas absorber using aqueous monoethanolamine (MEA) as a solvent for $CO_2$ capture. A one-tonne per day capacity RPB pilot plant has been installed at our department's R&D centre. The experimental results on the $CO_2$ absorption process in RPB encompass operating variables, such as rotating speed, solvent concentration, liquid and gas flow rate, temperature., etc. This RPB $CO_2$ capture process is more efficient concerning overall performance as compared to a conventional column-based absorption-regeneration system. Retrofitting this process in the pulverised coal power plants and other processes has also been discussed.*

***Keywords:*** *Carbon Dioxide; Chemical Absorption; Rotating Packed Bed; $CO_2$ Capture*

## INTRODUCTION

On the heels of nations and industries wanting to reduce their carbon footprint to contribute less to climate change, the global energy landscape is transforming. The Paris Agreement and the net-zero ambitions both emphasise the acceleration of decarbonization and carbon capture, utilization and storage (CCUS) can be considered an effective method for addressing hard-to-abate industries including fossil-fuel-based power plants. CCUS is a process that includes the separation of Carbon dioxide ($CO_2$) from power stations or industrial plant exhaust gases, to be used as a feedstock for useful products and/or permanently stored in deep underground geological formations[1].

$CO_2$ is the primary Greenhouse gas that comes from thermal power plants with a huge volume, and hence these power generation plants are in major focus. Pulverised coal (PC), natural gas combined cycle (NGCC), and integrated gasification combined cycle (IGCC) plants provide power generation with $CO_2$ capture. Three process routes can be considered for the application of carbon capture to electricity generation based on oil, coal, or natural gas. These include:

- pre-combustion capture
- post-combustion capture
- oxyfuel combustion.

Pre-combustion capture systems are designed to separate $CO_2$ and hydrogen ($H_2$) from the syngas stream produced by the gasifier in integrated gasification combined cycle (IGCC) power plants. Research and development is underway to develop technologies based on advanced solvents, sorbents, membranes, hybrid systems, and other novel concepts in pre-combustion capture. combustion is one of the leading technologies considered for capturing $CO_2$ from power plants with CCS. Oxyfuel involves the process of burning fuel with nearly pure oxygen instead of air. To control the flame temperature, some parts of the flue gas are recycled back into the furnace/boiler.

Post-combustion capture refers to capturing $CO_2$ from a flue gas that is generated after combusting a carbon-based fuel, such as coal or natural gas. In conventional fossil fuel power plants, coal or natural gas is burned with air to generate heat energy which is converted to electricity. Instead of being discharged directly into the atmosphere, flue

gas is passed through the $CO_2$ capture process that separates most of the $CO_2$. After compression, the $CO_2$ is fed to a storage reservoir and the remaining flue gas is discharged to the atmosphere. A chemical sorbent would normally be used for the $CO_2$ separation from the exhaust gas. Pre-combustion and oxy-fuel combustion are not so mature technology hence these technologies are not at such an advanced stage of development. We discuss the post-combustion $CO_2$ capture process by solvent technology here. **Figure 2** depicts an ultra-supercritical pulverised coal-fired steam cycle (USCPC), with post-combustion carbon capture.

In this process, the $CO_2$ capture system can be retrofitted after gas treatment 1 and 2 (**Figure 1**). The gas treatment consists of selective catalytic reduction (SCR) to eliminate nitrous oxides ($NO_x$), an electrostatic precipitator (ESP) to remove particulates, and limestone scrubbing to separate sulphur dioxide ($SO_2$) if any. Gas treatment-2 is used to remove any threshold amount of contaminant that is harmful to the solvents used in $CO_2$capture by absorption and regeneration process.

**Figure 2** presents a schematic diagram of a combined cycle gas turbine (CCGT) with $CO_2$ capture, consisting with, two G-class gas turbines and a single steam turbine equipped with its heat recovery steam generator (HRSG) system. An amine-based post-combustion carbon capture process that uses 30 wt.% aqueous monoethanolamine (MEA). This process is similar to that employed at the pulverised coal plant.

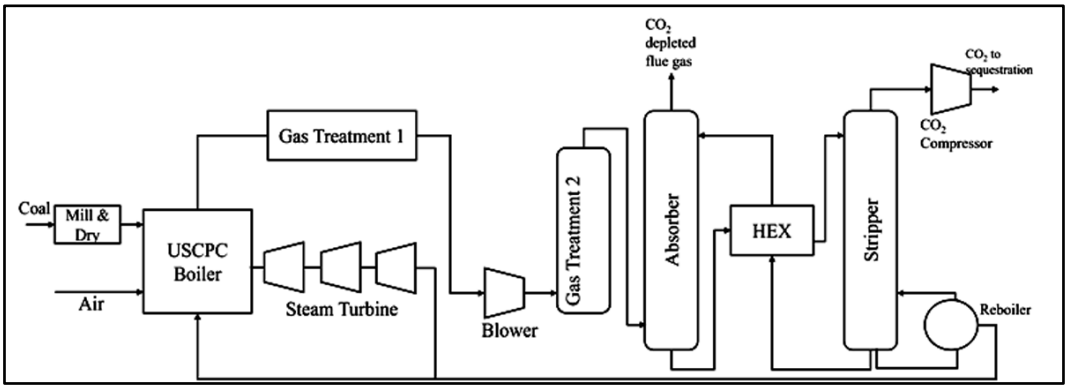


**Figure 1** Ultra-supercritical pulverised coal-fired steam cycle, with post-combustion carbon capture (PCC)

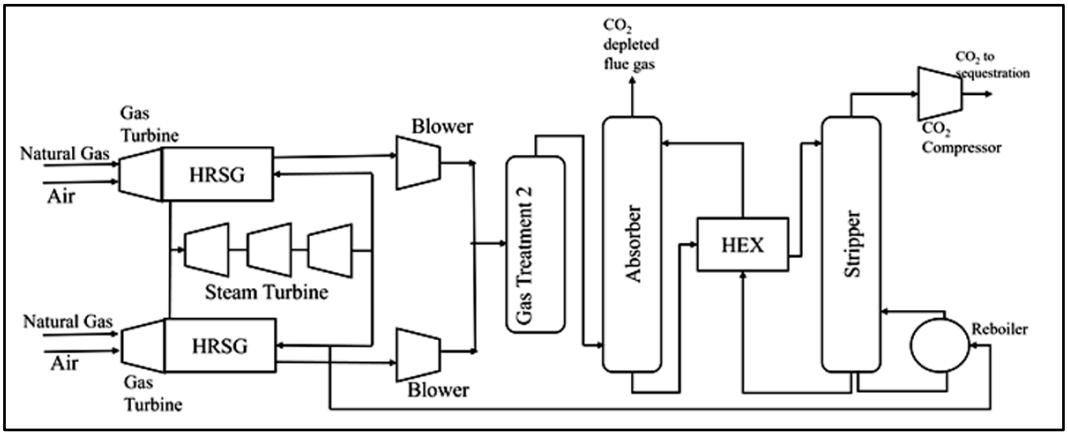


**Figure 2** Schematic diagram of a combined cycle gas turbine (CCGT) with $CO_2$ capture

In both these processes (**Figures 1** and **2**), we can retrofitan (MEA)-based post-combustion unit, which is presently the most extensively tested technology for capturing $CO_2$ after combustion. However, this retrofitting results in two primary additional energy burdens and many smaller burdens. Firstly, a substantial amount of low-pressure steam is needed to regenerate the solvent, which decreases the electrical power produced by the steam turbine generator. The second load refers to the amount of electricity required to operate the $CO_2$ compressor[2]. Hence, when carbon capture is implemented in power generation, it diminishes the overall efficiency of the plant by introducing various

parasitic loads, which consume additional energy within the power plant. The parasitic loads can arise from either electrical loads, such as extra rotating machinery, or thermal loads, such as the heat needed for regenerating the solvents. The power output is diminished due to the diversion of steam, which would have been utilised for electricity generation, to serve as a heat source. But this $CO_2$ capture system is very important to meet the net-zero targets and the parasitic load can be deduced by implementing integrated process intensification in the $CO_2$ removal section and other approaches described here.

To enhance the total efficiency of a power plant equipped with carbon capture, it is imperative to minimise or eradicate energy demand, be it in the form of heat or electricity. Enhancing the efficiency of a solvent by further cooling, which reduces the amount of heat needed for regeneration which is about 55-60 % of the energy required for $CO_2$ capture, may be a viable option. Again, it is essential to analyse the power plant system comprehensively to determine specific areas where cost reductions might be achieved. $CO_2$ compression normally takes 30-35% of energy and the flue gas blower takes about 4-5 % energy [3]. This blower is necessary to increase the pressure of the total flue gas flow enough to compensate for the pressure decrease over the absorption column and any related heat exchangers. Additional minor loads include the energy required for pumping and/or fan operation with a substantial amount of cooling substance, as well as the transportation of the solvent across the capture plant loop which comes about 6-7%. However, the large size of the conventional column has been cited as a hindrance to $CO_2$ capture since it demands significant capital and operating costs, uses a lot of energy, and requires inter-cooling with heat integration. Thus, more efficient gas-liquid reactors employing new principles and technology for carbon dioxide capture are the need of the hour 4]. Process intensification technology is used to achieve a significant reduction in capital cost and improve process dynamics. Equipment can be made smaller with the use of centrifugal forces, electrical fields, and microwaves, or by downsizing to the meso-or microscale. One of these intensification technologies is currently the rotating packed bed (RPB), which is an innovative concept that is used in this study. For the absorption of $CO_2$, packed bed columns are highly used. The utilisation of a Rotating Packed Bed (RPB), allows for a substantial reduction in column size while maintaining its production capacity [2,3,5]. There has been a substantial study conducted on $CO_2$ absorption through the utilisation of RPB [6,7,9]. But even with implementing RPB technology in $CO_2$ capture, the overall cost remains nearly the same. Hence, tougher climate targets, higher stakeholder expectations and new investment incentives mean that CCUS can play a vital role in the transition to net zero.

**Pilot Plant Study of $CO_2$ Capture in MEA Solvent**

We conducted a pilot plant study of $CO_2$ separation in a one-tonne-per-day capacity RPB absorber and conventional regeneration system. The experimental setup and the process block diagram are presented in Figure 3. The setup consists of an RPB with a solvent and gas-feeding system. The solvent flows from the feed- tank to the RPB via the feed pump and valves. Gas flows via a high-capacity blower. The inlet and outlet gases were analyzed using a Horiba NDIR CO2analyzer. Liquid samples are analyzed using the standard titration method. A gas cooler controls the outlet gas temperature and condenses the moisture and amine entrainment, if any. This study uses a 30 wt.% aqueous MEA solution as a solvent. A $CO_2$ concentration of 8 - 12 volume% is considered as it represents most industrial combustion exhaust gases. It would take around 10-15 minutes to reach steady state operation. During the steady state condition, liquid samples were collected periodically and analyzed for $CO_2$ loading in the rich solvent. The solvent is regenerated in a stripper and used, known as the lean solvent, which flows the system in a continuous operation.

Authors have studied the post-combustion $CO_2$ capture through chemical absorption using different solvents viz. mono-ethanolamine (MEA), di-methanolamine (DEA), N–methyl diethanolamine (MDEA)[4], 2-amino-2-methyl-1-propanol (AMP), blended amine AMP and piperazine, etc.,[5]. in the conventional column.

**RESULTS AND DISCUSSION**

In this study, Pilot plant analysis for RPB, which has counter-current gas-flow mode, was experimentally tested for CO2 capture using aqueous monoethanolamine (MEA) solutions within a newly constructed RPB. The rotational speed (600-1200 RPM), liquid flow rate (8-11 lpm), gas flow rate (1200-2900 lpm), inlet $CO_2$ concentration (6-10 %), liquid-gas (L/G) ratios, and MEA concentration and temperature of solvent were varied within typical industrial ranges for $CO_2$ scrubbing from flue gas in pilot plant, and the gas phase was saturated to simulate industrial

conditions. A few experimental results are presented here in **Figures 4–7**. **Figure 4** shows the effect of gas flow rate on $CO_2$ absorption efficiency. Here the gas flow rate was changed without changing the liquid flow rate, hence a decrease of liquid to gas ratio. As the gas flow rate increases at a constant liquid flow rate the % capture of $CO_2$ decreases. It is due to the decrease of liquid to gas ratio. **Figure 5** describes the effect of rotational speed on % $CO_2$ capture efficiency. It is found that the % $CO_2$ capture efficiency is maximum at about 1000 RPM. **Figure 6** illustrates the effect of the liquid-gas ratio on $CO_2$ absorption efficiency. **Figure 7** represents the effect of inlet $CO_2$ concentration on $CO_2$ absorption efficiency. As the $CO_2$ concentration in the inlet gas stream increases the % $CO_2$ capture also increases.

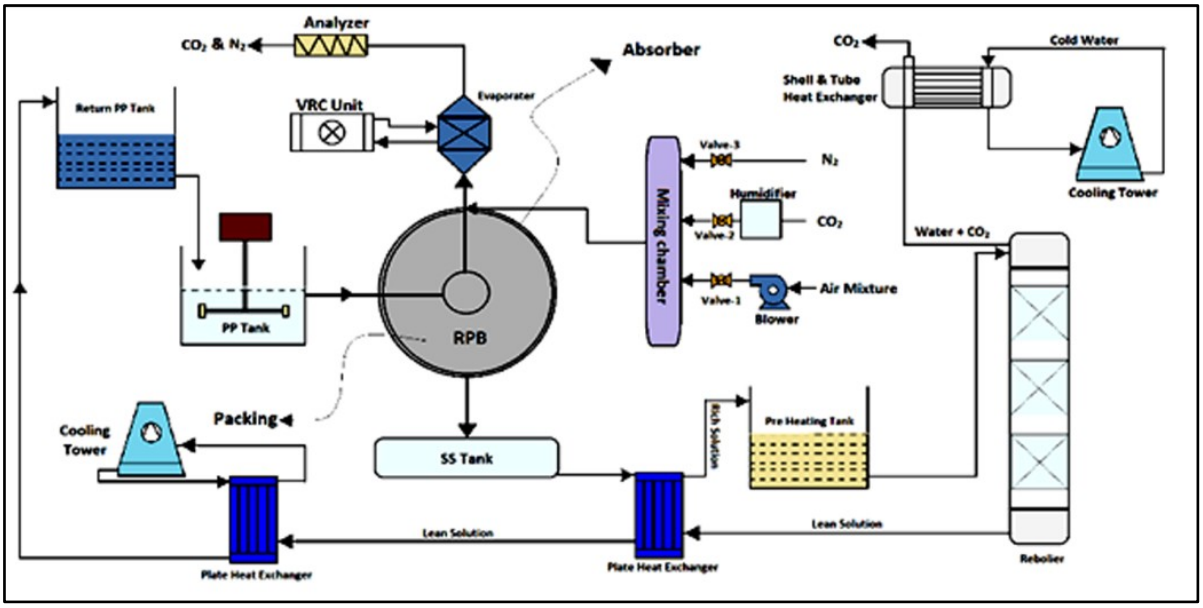


**Figure 3** Process flow diagram of the 1 TPD RPB pilot plant for $CO_2$ capture

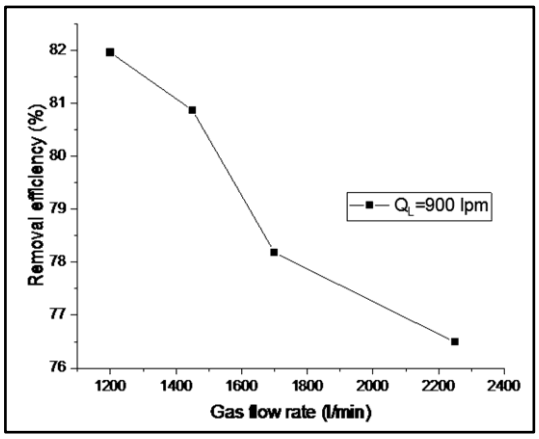


**Figure 4** Effect of gas flow rate on $CO_2$ absorption efficiency

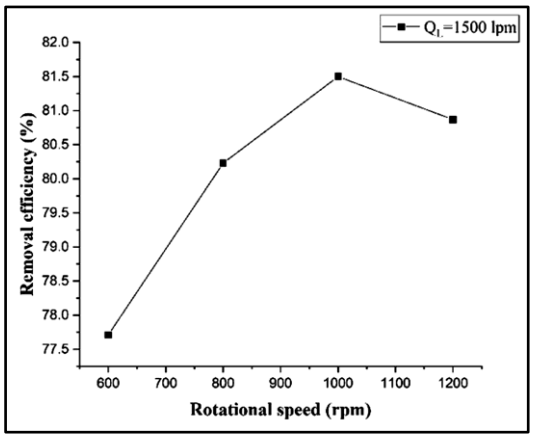


**Figure 5** Effect of RPM on $CO_2$ absorption efficiency

Hence the key parameters of the operating conditions suitable for $CO_2$ removal using an RPB absorber are the solvent flow rate, $CO_2$ concentration in the lean solvent, $CO_2$ concentration in the inlet gas and the rotational speed. Again, the improvement of the whole power plant's efficiency is due to the slight improvement in the $CO_2$ capture unit utilizing this technology over the conventional packed column-based absorption and regeneration system. Further, there are more efficient solvents are being used for further improvisation and these experimental results will help to compare the results with the base solvent (MEA) process.

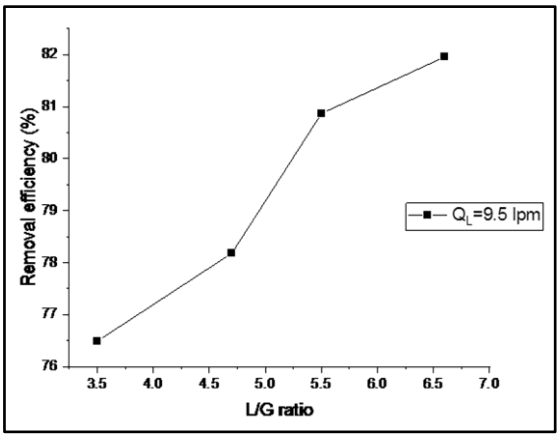


**Figure 6** Effect of liquid-gas ratio on $CO_2$ absorption efficiency

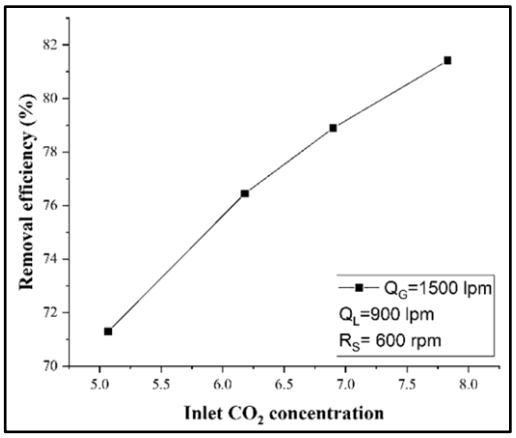


**Figure 7** Effect of inlet $CO_2$ concentration on $CO_2$ absorption efficiency

## CONCLUSION

Fossil fuels are expected to play an important role in the future global energy system; however, technical solutions are needed to reduce the $CO_2$ emissions from fossil fuel combustion. Carbon Capture, utilization and sequestration (CCUS) is one option that can be implemented in fossil fuel power plants and hard-to-abate industries. These plants can use either a conventional column-based $CO_2$ scrubbing system or processes intensified rotating packed bed absorbers. Compared to conventional absorption columns, the RPB offers significant advantages, such as the ability to design more compact absorbers for $CO_2$ capture due to mass transfer enhancement by promoting micro-mixing. This work demonstrated the effect of rotational speed, inlet $CO_2$ concentration, Gas flow rate, and liquid gas ratio on $CO_2$ removal efficiency in a one TPD pilot plant. The gas flow mode significantly impacted the liquid flow properties and effective contact between the liquid and gas, affecting mass transfer performance. The RPB provides the most significant driving force for better liquid-gas contact and mass transfer through counter-current contact. Overall, this study highlights the potential of the RPB for efficient and cost-effective industrial carbon capture. The present study is helpful for the designing and scale-up study of new effective solvents for $CO_2$ capture application and combined study of power plant integration with an improvement of efficiency and carbon footprint reduction.

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208_IEC4195

# Leveraging AI and Continuous Improvement for Zero Defects and Sustainability in the Automotive Industry: A Digital Transformation Study

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***Abstract:*** *For the automobile sector to achieve zero defects and maintain sustainable business processes, artificial intelligence and continuous improvement are essential. This study examines the gradual adoption of kaizen principles and the changeover from a manual inspection procedure to a fully digital, artificial intelligence-integrated. An analysis is conducted on the digital tracking and inspection system at a multivariant automobile production factory. By Utilizing electronic devices like tablets, barcode scanners, and integrated car monitoring systems, the business was able to successfully lower errors, boost productivity, reduce lead time and use less paper, supporting both environmental sustainability and operational excellence. The application of the use of PDCA (Plan-Do-Check-Act) and statistical quality tools, among other continuous improvement approaches, improved problem-solving and process optimization. This paper provides an information about how adopting AI-powered technology can promote manufacturing sustainability.*

***Keywords:*** *AI-integrated Inspection; Digital Transformation; Continuous Improvement; Operational Excellence; Environmental Sustainability*

## INTRODUCTION

In the fiercely competitive automobile sector, maintaining quality and attaining zero faults is crucial. Quality control has always been upheld via manual inspection procedures. However, because traditional manual inspection procedures require a lot of resources and are prone to human mistake, it is difficult for automakers to maximize sustainability initiatives while maintaining high quality standards. This paper presents a case study of a multivariant car manufacturing factory that used a kaizen strategy [1] to dramatically improve quality and sustainability by switching from a manual inspection system to an AI-driven digital inspection [2] and interlock the result with vehicle tracking system.

An inspector was in charge of verifying the features and operational characteristics of more than 200 distinct vehicle variations during the initial visual examination phase. A master check sheet that went through the inspection process with each car was used to conduct this examination. At every level, the inspector verified the inspection by stamping on the inspection check sheet.

Unfortunately, the intricacy of multi-variant checks along with the dependence on memory and training resulted in inspection errors. As a result of these mistakes, internal customers identified flaws including inaccurate specifications and malfunctioning components in later phases, at Pre-Delivery Inspection (PDI) stage or the GCA (Global Customer Audit) room. Defects have occasionally even made it to the ultimate consumer, which has left them unhappy. It was determined that achieving zero defects at the customer's end was essential.

## LITERATURE REVIEW

### Kaizen

The Japanese word "kaizen" (Ky "Zen") means "continuous improvement" and is a compound word made up of the words "Kai" (continuous) and "Zen" (improvement). Translations of the term's "kai" and "Zen" indicate "change" and "good" or "for the better," respectively [3]. American physician Dr. W. Edwards Deming, created the concept of kaizen, or continuous improvement, as a statistician. According to the Kaizen principle, "Do it better, make it better, and improve it even if it is not broken," because if we don't, we can't compete with those who can [4]. Kaizen

encompasses many of the characteristics of Japanese businesses that are recognized for their success. [5]

**The role of AI in Manufacturing**

AI technologies have been widely adopted in manufacturing to enhance quality control, streamline operations, and facilitate real-time decision-making. Kamble et al. (2020) highlights the growing influence of AI in reshaping production processes by automating key tasks like defect detection, predictive maintenance, and real-time monitoring. In the automotive sector, AI applications are especially beneficial, ranging from robotic assembly to advanced analytics that predict and prevent defects before they impact production lines (Wang et al., 2021). AI's ability to analyze vast datasets allows manufacturers to detect patterns, optimize operations, and enhance product quality [6]

**Sustainability in automobile industry**

Digital tool optimization becomes an ongoing endeavor. Industry 4.0 actively refines its usage of digital technologies through the use of Kaizen principles [7]. In the larger goal of continuous improvement, the emphasis is on increasing productivity, reducing waste, and getting the most out of digital tools. Industry 4.0 demands adaptability, and Kaizen's flexible methodology satisfies this need admirably. Businesses that embrace integration adapt swiftly to shifts in the technology environment, having an open mind for experimenting, taking lessons from past mistakes, and continuously improving procedures and tactics. [8].

**METHODOLOGY**

This study focuses on a multi-variant vehicle manufacturing facility that implemented a shift from manual inspection processes to a fully digitized, AI-integrated inspection and tracking system. The facility was selected based on its prior challenges with maintaining quality control and its desire to improve both operational efficiency and sustainability.

Steps in Implementation

1. Assessment of Current Processes: The study began by analyzing the existing manual inspection processes to identify inefficiencies, sources of defects, and areas for improvement.
2. Integration of Digital Tools: The facility introduced AI-powered tools including tablet-based data entry, barcode scanning systems, and real-time vehicle tracking to streamline the inspection process [**Figure 1**].
3. Application of Continuous Improvement Tools: Continuous improvement tools such as Fishbone Diagrams and PDCA cycles were applied to identify root causes of defects and improve process optimization.
4. Training and Workforce Involvement: Employees were trained in using the new digital systems, ensuring smooth adoption and fostering a culture of innovation.

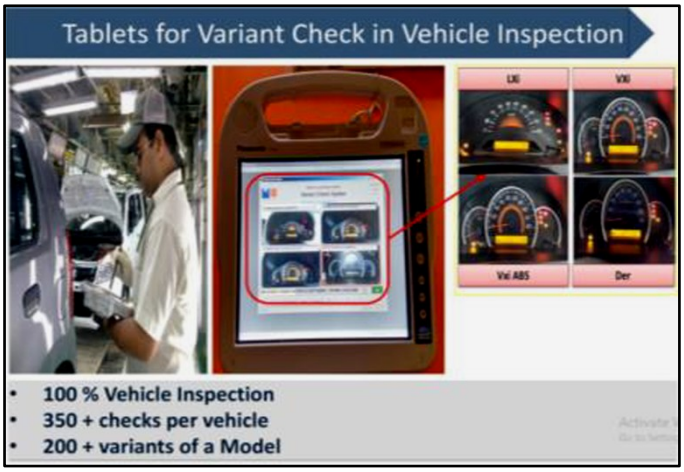


**Figure 1** Inspector inspecting the vehicle with Digital Tool

## DATA COLLECTION

Data was collected through direct observations, structured interviews with employees, and analysis of key production metrics before and after the implementation of the AI-integrated system. Metrics such as defect rates, production efficiency, and sustainability indicators e.g., A4 paper sheet (saving approximately 2 million A4 sheets annually) and energy usage) were measured. [**Figure 2**].

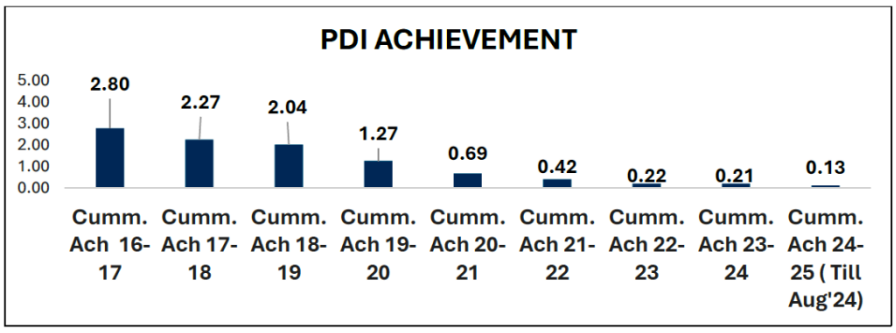


**Figure 2** Figure showing year wise trends of PDI cumulative defect percentage of an automative company

## THE IMPACT ON SUSTAINABILITY

The incorporation of digitalization powered by AI produced following remarkable outcomes:

### Defect Reduction

There were no faults at the final customer's end as a result of the digitalized inspection procedure, which removed inspection errors.

### Process Efficiency

By streamlining procedures, the vehicle tracking system made sure that every car satisfied quality requirements before it was let out of the inspection line.

### Environmental Impact and Sustainability Contribution

By eliminating paper waste, the switch from paper-based to digital checklists saved around 2 million A4 sheets yearly, making a substantial contribution to environmental sustainability.

### Resource Optimization

By cutting down on pointless vehicle movements for maintenance, the facility was able to save time, labor, and energy.

### Gain in Operational Efficiency

Notable gains in operational efficiency were obtained through the integration of digital tools and AI systems. For instance, shorter inspection cycle times allowed for a higher throughput of products. Real-time tracking also made it possible to make better decisions and respond to new production problems more quickly.

## DISCUSSION

### AI is a Driver for ZERO Defects

AI's ability to automate and enhance quality inspections has proven to be a significant factor in reducing defects. By applying machine learning algorithms to production data, here for example integrating tablet out to vehicle tracking

system, manufacturers can detect even the smallest deviations in product quality and adjust processes in real-time, moving closer to the goal of zero defects.

**Continuous Improvement for Sustained Gain**

The kaizen methodology ensures that improvements are not one-time events but are sustained and built upon. By continuously applying PDCA cycles and engaging workers in problem-solving, the facility maintained a culture of continuous learning and innovation.

**Sustainability through Digital transformation**

The shift from manual to digital processes not only improved operational efficiency but also contributed to environmental sustainability. By reducing paper usage and optimizing energy consumption, the facility aligned its operations with broader environmental goals, enhancing its corporate social responsibility.

## CONCLUSION

This case study shows how digitalization and AI-driven technology can decrease environmental impact, increase efficiency, and reduce defects in the car manufacturing industry. A completely integrated digital inspection system replaced human inspection procedures, which resulted into noteworthy enhancements in terms of sustainability and quality. The application of instruments for continuous improvement further ensuring that the solutions were reliable and flexible. The knowledge gained from this case study can help other manufacturing sectors that aim to adopting the newest AI-driven technologies to improve quality, cut waste, and accomplish sustainability goals.

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278_IEC59702

# The Selection of Optimal Biocomposite by Utilizing a Multi-Criteria Decision-Making Technique

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**Abstract:** This research focusses on selection of a suitable bio-composite sheet using a Multi-Criteria Decision-Making (MCDM) technique, specifically Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for its desirable applications. Nonwoven reinforcements consisting of Sunnhemp and Dhaincha fibres were used to create the bio-composite sheets, with polylactic acid (PLA) as a matrix material. Bio-composite density, flexural and tensile strength, and flexural and tensile modulus were used to assess the performance of bio-composites. Each characteristic was given a unique desirability weight. The PLA-300GSM Sunnhemp bio-composite was identified as a best material based on the highest TOPSIS score; it was followed by the PLA-300GSM Sunnhemp-Dhaincha biocomposite. This rating provides insightful information on the potential of environmentally friendly, sustainable materials for an array of industrial uses.

**Keywords:** Eco-friendly Composites; Sustainability; TOPSIS; Sustainable Materials; Polylactic Acid

## INTRODUCTION

Advancements in material science and engineering have historically been driven by the need to improve cost efficiency, sustainability, and overall performance. Traditional materials such as metals, plastics, and ceramics have long played a crucial role in various industries, facilitating the creation of structures, machinery, and products that have shaped modern society. However, the growing demand for lighter, stronger, and more environmentally friendly materials has sparked a shift towards composites. These materials, which incorporate high-strength fibres such as glass, carbon, and aramid into polymeric matrices like epoxy and polyester, have gained significant prominence in sectors like aviation, automotive, sports, leisure, and construction (Singha and Thakur 2009; Rabe et al. 2019). Despite their advantages, synthetic composites pose environmental challenges due to difficulties in recycling and biodegradability after their service life. This has led to the development of eco-friendly composites, including bio-composites and green composites, which utilize sustainable reinforcement and matrix materials (Lau and Cheung 2017).

The utilization of Multi-Criteria Decision Making (MCDM) methodologies, namely the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), has become an essential strategy for the determination of ideal bio-composites. TOPSIS technique is favoured for its ability to rank choices based on their closeness to an ideal solution, making it particularly useful in situations where multiple contradictory criteria must be considered (Koona & Himagireesh, 2022; Mahajan et al., 2024). Numerous researches have shown how well TOPSIS works for assessing bio-composites in terms of mechanical attributes as impact resistance, tensile strength, and environmental factors (Sanjay et al., 2019). For instance, studies have demonstrated that TOPSIS may be effectively used to determine whether carbon fibre reinforced polymers (CFRPs) are appropriate for use in structural applications by taking into account factors such as impact resistance, tensile strength, and compression strength, among others (Ahmed, 2023). To increase the dependability of the criterion weights used in the TOPSIS analysis, this study developed a hybrid weighting approach that included the Analytic Hierarchy Process (AHP) with Shannon entropy (Salwa et al., 2020).

Dhaincha (Sesbania aculeta) and Sunnhemp (Crotalaria juncea) are the green manuring crops mainly employed for

the improvement of soil health and its stabilization in the agricultural fields. Rather being used in green manuring, these crops also yield high strength lignocellulosic fibres which can be employed in the various technical textile applications. Since these bast fibres have very courser fineness, it is hard to spin and produce suitable yarn for apparel construction. In this light, these fibres, better fits into technical textile arena, that too for fabricating bio/green composite materials. Hence, in this study nine different needle punched nonwoven fabrics from Dhaincha and Sunnhemp fibres were produced. These developed nonwovens were further utilized as reinforcing material for the development of biocomposites. The best developed bio-composites were selected using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), a multi criteria decision making technique using various mechanical performances of the composite materials.

## METHODOLOGY

Sunnhemp and Dhaincha fibres were mechanically softened and carded to construct cross-laid and needle punched nonwoven materials with the different variations in fabric weight and fibre blend proportions. nine different needle punched nonwoven fabrics from Dhaincha and Sunnhemp fibres by varying material density (200, 300, and 400 g/m$^2$) of the fabric and blend proportion of fibres (100% Sunnhemp; 50:50 Sunnhemp: Dhaincha; 100% Dhaincha fibre) were developed.

Bio-composites were developed using hot compression moulding method. The Taguchi experimental design was employed to create various bio-composites. Constant parameters such as 325g of PLA, temperature of 175°C, and pressure of 30 kg/cm$^2$ were determined through experimentation with varying levels to achieve the optimal bio-composite, ensuring an even dispersion of PLA throughout the reinforced fabric. Later, in the development of bio-composites two metal plates and HDPET sheets (60 × 60 cm) were coated with wax and used to create the composite. Oven-dried PLA pellets (325g) were divided into three portions, layered with fabric, and placed in a wax-coated mould. The assembly, covered with an HDPET sheet and metal plate, was then hot-pressed at 175°C with 30 kg/cm² pressure for 40 minutes, with degassing at intervals. After cooling overnight, the bio-composite was removed, labelled, weighed, and measured. The developed bio-composites were assessed for flexural and tensile characteristics along with their individual densities.

The TOPSIS approach incorporates multiple phases to choose the best bio-composite based on flexural & tensile strength (0.25 desirability), flexural & tensile modulus (0.2 desirability), and composite density (0.1 desirability). Firstly, criteria and options (bio-composites) are compiled into a decision matrix. After normalizing the results, the desirability weights of each column are multiplied. The best and worst values for each criterion are represented by the ideal and negative-ideal solutions, respectively. The relative proximity to the ideal answer is produced by computing the distance between each alternative and these ideal solutions. In the end, the bio-composites are ranked, and the best biocomposite is indicated by the one with the highest closeness coefficient (Kabir & Hasin, 2012).

**Table 1** Ranking developed biocomposites based on the scores of Dj and normalized Dj (TOPSIS score)

| Ranks | Bio-composite | Degree of differntiation (Dj) | Normalized Degree of differntiation (TOPSIS Score) |
|---|---|---|---|
| 1 | SH 300 | 0.574 | 0.185 |
| 2 | SH-DH 300 | 0.509 | 0.164 |
| 3 | SH-DH 400 | 0.489 | 0.158 |
| 4 | SH 400 | 0.366 | 0.118 |
| 5 | DH 300 | 0.356 | 0.115 |
| 6 | DH 400 | 0.297 | 0.096 |
| 7 | SH-DH 200 | 0.233 | 0.075 |
| 8 | DH 200 | 0.185 | 0.060 |
| 9 | SH 200 | 0.094 | 0.030 |

## RESULTS

In this study, nine PLA-based bio-composites were developed using the compression molding technique. These bio-composites were evaluated for their physical and mechanical properties, including density, tensile strength, tensile modulus, flexural strength, and flexural modulus. Based on these characteristics, the composites were ranked using the MSDM-TOPSIS method. **Table 1** and **Figure 1** illustrates the ranking and corresponding TOPSIS scores. The analysis identified the PLA-300 GSM Sunnhemp (SH 300) bio-composite as the top performer, followed by PLA-300 GSM Sunnhemp Dhaincha (SH-DH 300). SH 300 demonstrated superior mechanical properties, making it suitable for various industrial applications.

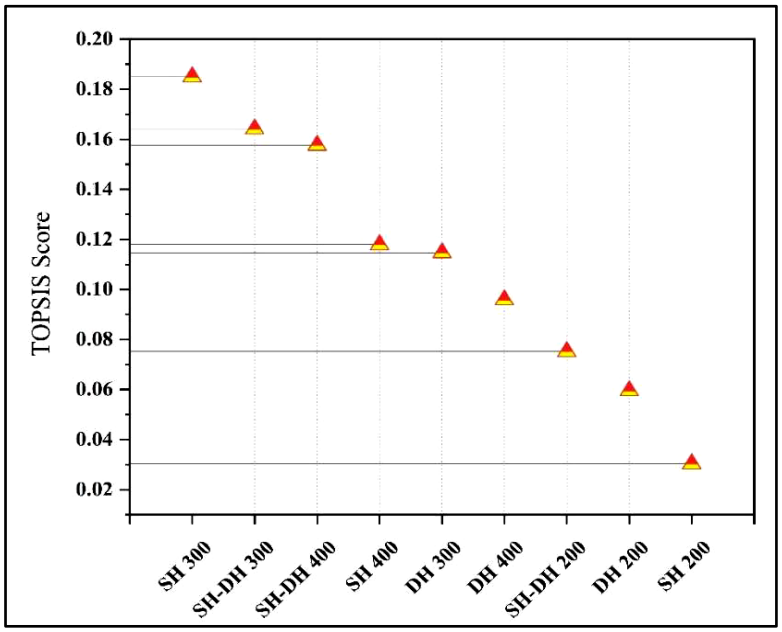


**Figure 1** Ranking of various developed PLA based bio-composites using TOPSIS score

## CONCLUSION

In this study, nine PLA-based bio-composites were fabricated from Sunnhemp and Dhaincha fibres based nonwovens, and their mechanical and physical properties were assessed. The MCDM-TOPSIS approach was used to rank the composites, and PLA-300 GSM Sunnhemp (SH 300) shown higher performance than other bio composites. The high mechanical qualities demonstrated by SH 300, make it a viable option for industrial use and highlight the potential of sustainable materials in composite industry.

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308_IEC11665

# Standardization of Sustainable Surface Modification Protocol of Nonwoven Jute Fabric with Dry Heat Treatment for the Development of Biocomposite Products

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***Abstract:*** *Jute nonwoven fabric can be utilized for development of biocomposite with 18-21 percentage volume of reinforcement; however, it can be improved by prior suitable surface modification of jute fibre with reduction in the processing void. In this work, Jute nonwoven fabric was exposed to dry heat at 100℃, 110℃, 120℃, 130℃, 140℃, 150℃ & 160℃ for 2 h to modify its surface for improving its compatibility with unsaturated polyester resin (USP). Dry heat-treated jute fibre and fabrics (DHJF) were evaluated for their physical, chemical, mechanical and morphological properties and then used for the development of biocomposite with USP by conventional brush dabbing cum compression moulding method. Results inferred that dry heat treatment modified the physio-chemical, mechanical and morphological properties for the improvement of interfacial adhesion with USP resin. The enhancement of fibre properties is positively correlated with the dry heat temperature up to 140℃ and then declined due to reduction in mechanical properties. Among biocomposites, DHJF (140℃): USP based bio-composites shown higher tensile, flexural and Interlaminar shear strength properties than other biocomposites. It is concluded that jute fibrous reinforcement can be modified with dry heat at 140℃ for 2 hours for improvement its compatibility with the hydrophobic resin. It could also be a sustainable surface modification protocol for the benefit of natural fibre based composite industry by achieving SDG-06.*

***Keywords:*** *Jute, Biocomposite; Sustainable Goal; Dry Heat; Surface Property; FTIR*

## INTRODUCTION

Jute fibre based biocomposites have great attention in the field of structural, automobile, electronics and furniture application due to their cost and renewability for the replacement of glass-fibre based composites. The automobile sector of India has started to develop lignocellulosic fibre-based car accessories to enhance the sustainability as well as increase the fuel efficiency. The main problems exist in the development of biocomposite is poor interfacial adhesion between the hydrophilic fibre and hydrophobic resin. Among plant fibers, jute fibre is preferred for composite products due to its stiffness and spirally oriented micro-fibrils bound together. It has also very good modulus with lower elongation at break. Many chemical modifications were carried to enhance the reinforcing ability of plant fibers like alkali treatment, acetylation, graft copolymerization and coupling agents; however, those treatments involve high volume of effluents.

To sustain out water resources to achieve sustainable development goal SDG6, a cleaner surface modification protocol of jute fibrous reinforcement without affecting its inherent properties for the development of greener composite products is the need of hour. An attempt has been made to modify the surface of the jute nonwoven fabric with dry heat at 100, 110, 120, 130, 140, 150 & 160°C for 2 hours followed by their assessment of properties in terms of physical, chemical, morphological and mechanical properties as per standard methods. After characterization, those modified jute nonwoven fabric were used in three layers for the development of biocomposite with unsaturated polyester resin by the conventional hand laying cum compression moulding method. Then biocomposite sheets were evaluated for their mechanical properties for standardization of the pretreatment protocol.

## EXPERIMENTAL CONDITION

### Materials

Unsaturated polyester resin (Density 1.2 g/cc) purchased from local market of Kolkata and used without purification;

all other chemicals used elsewhere were AR grade. 300 GSM jute nonwoven fabric was taken as reinforcement.

**Dry Heat Treatment**

Jute non-woven fabrics of 60 × 60 cm dimension were kept in a relaxed vertical position in a hot air oven and exposed to dry heat of temperature 80 (control), 100, 110, 120, 130, 140, 150 & 160°C for 2 hours. After dry heat treatment, the samples were kept in a desiccator for 24 hours (25°C / 25% RH) in order to stabilize the moisture content. The physico-chemical, morphological and mechanical properties of heat-treated jute fibre were assessed by FTIR spectroscopy, XRD spectroscopy, SEM and TGA spectroscopy as per standard protocols.

**Preparation of Biocomposite**

The unsaturated polyester resin was thoroughly mixed with required amount (2%) of accelerator (cobalt naphthenate) and catalyst (2 %, MEK peroxide). The mixed resin was coated on the fabrics (60 cm × 60 cm) by brush dabbing followed by rolling technique. Three such fabrics were super imposed and were consolidated in a hydraulic press under a pressure of 5 kg.cm$^{-2}$ at room temperature for 30 minutes. The bio composites were trimmed to cut the edges; kept at room temperature for 3 days followed by curing in an oven at 80°C for 3 hours; conditioned for testing

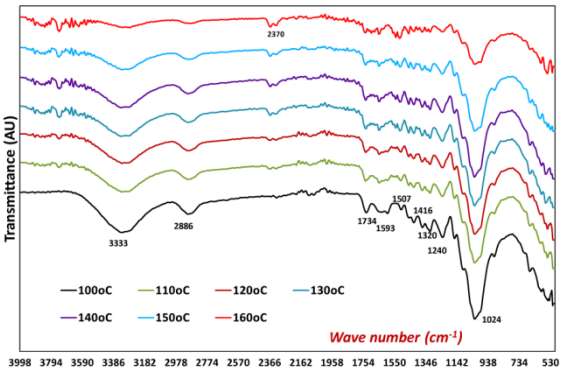
**Evaluation of Mechanical Property**

Tensile tests (TS) were evaluated with a 30 kN load cell as per ASTM D-3039 standard. Three-point bend tests were performed in accordance with ASTM D7264 / D7264M-07 to measure the flexural strength (FS) and modulus (FM) of the composites. The interlaminar shear strength (ILSS) of the composites was calculated in the stress units based on the area of the sheared edge and it evaluated as per standard ASTM D2344-76.

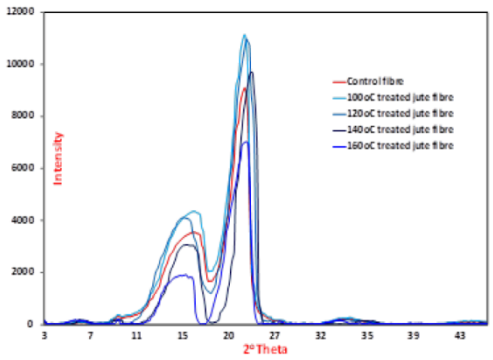
**RESULTS AND DISCUSSIONS**

**Characterization of Dry Heat-Treated Jute Fibres**

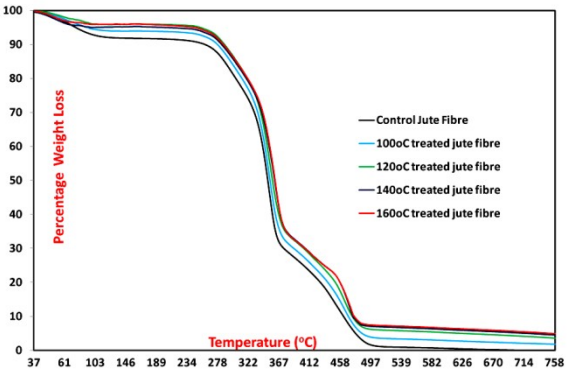
Jute is a lignocellulosic fibre and majorly composed of cellulose, hemi-cellulose and lignin. Cellulose polymer of jute fibre is reinforced by continuous the lignin polymeric matrix and this natural composite structure is cemented by low molecular weight hemicellulose. These polymers are linked together through β-O-4 aryl ether or by carbon–carbon linkages. A possible mechanism for the physiochemical changes occurred on jute fibre during heat treatment described as follows.



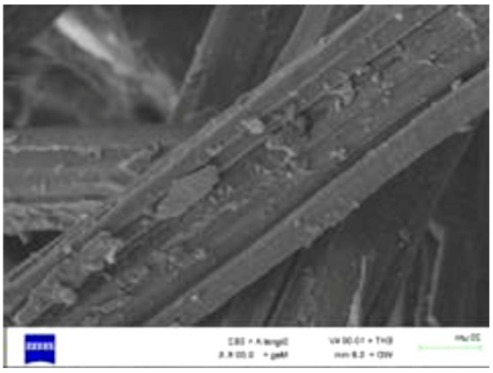

*(2a) FTIR spectra of dry heat-treated jute fibres*




*(2b) XRD spectra of dry heat-treated jute fibres*




*(2c) DTA Spectra of dry heat treated jute fibres*



*(2d ) SEM image of dry heat treated jute fibres*

Properties of dry heat-treated jute fibres

During controlled dry heat treatment, amorphous cellulose can be re-crystallized at 140°C and formed new crystallites within the amorphous region of jute fibre. It also led to a realignment of cellulose chains on crystalline region or at their ends and increased the crystallization of jute fibre. Dry heat treatment can also partially decompose the lignin polymer due to the presence of various oxygen functional groups, i.e., at aryl–ether linkages and formed highly reactive and unstable free radicals. These active groups further react with neighbour cellulose/ lignin polymer and form products with increased thermal stability. The physico-chemical changes are witnessed from FTIR spectrum, XRD spectrum, SEM and TGA spectrum as per above figures.

**Properties of Biocomposites**

The interface adhesion between the jute fibre and the polyester resin and the mechanical properties of the fibre and resin can influence the mechanical properties of the biocomposite. It is well known that composites based on stiff and strong fibres have low strain to failure. It is attributed that dry heat treatment can modify the jute fibre. The tensile, flexural and ILSS properties of dry heat-treated jute nonwoven fabric-based composites are tabulated. Results inferred that load required to break the physically modified JNWBC are higher than control composites. The improvement in load bearing also leads to improve in modulus of the composite through increase in its stiffness both through physical modifications.

***Table : Mechanical properties of control and dry heat treated nonwoven based biocomposites***

| *Property* | *Tensile Strength (MPa)* | *Tensile Modulus (GPa)* | *Tensile Strain (%)* | *Flexural Strength (MPa)* | *Flexural Strain (%)* | *Flexural Modulus (GPa)* | *ILSS (N/mm2)* | *Strain (%)* |
|---|---|---|---|---|---|---|---|---|
| 80°C | 35.6 | 3.42 | 2.5 | 53.3 | 1.7 | 3.9 | 7.2 | 2.6 |
| $100^0$ C | 41.6 | 3.95 | 2.3 | 56.5 | 1.3 | 4.5 | 8.8 | 2.0 |
| $120^0$ C | 49.9 | 4.55 | 2.3 | 67.9 | 1.8 | 4.7 | 9.3 | 2.3 |
| $140^0$ C | 55.3 | 4.85 | 2.7 | 80.5 | 1.6 | 6.0 | 11.2 | 2.9 |
| $160^0$ C | 42.4 | 4.22 | 2.1 | 60.8 | 1.4 | 5.3 | 8.6 | 2.6 |

Results also inferred that dry heat treatment influenced the performance of the biocomposite up to 140°C and then there will be drastic reduction in the properties which may be due to drastic change in mechanical properties of the jute fibre properties. It also indicated that the 140°C treatment might be a standard condition for improvement in mechanical properties of the biocomposite.

## CONCLUSION

An eco-friendly surface modification protocol i.e. controlled dry heat treatment on jute fabric reinforcement at 80-160°C for 2 hours for the development of biocomposite by hand laying cum compression molding method was developed. Controlled dry heat treatment modified the surface morphology, fine structure and physical properties of the jute fibers. The defibrillated and micro-ruptured jute fiber at 140°C improves the mechanical interlocking / anchoring with the matrix. Dry heat-treated jute based biocomposite shows higher tensile strength, flexural strength and inter-laminar shear strength than control jute fabric-based biocomposite. It is also well known that good interfacial adhesion can increase mechanical interlocking, chemical bonding and inter-diffusion bonding between fibre reinforcement and polymer matrix. Fracture morphology also visualized that there is a better interfacial adhesion between the dry heat-treated jute fiber reinforcement at 140°C and the unsaturated polyester resin matrix than untreated jute fibre in biocomposites. It is also observed that lesser fiber pull-outs, lesser matrix cracks, better uniform fracture of fiber reinforcement and lesser porosity/ voids between the fiber reinforcement and polymer matrix in dry heat-treated jute nonwoven based biocomposites than control jute nonwoven based biocomposites.It is concluded that the controlled dry heat treatment at 140°C could be a standard surface modification protocol for jute nonwoven reinforcement to improve its compatibility with a thermosetting resin for the development of rigid biocomposites.

## ACKNOWLEDGEMNET

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# Environment & Sustainability

# Waste Management and Circular Economy

25_IEC55364

# A Small-Scale Pilot Project on Vermicompost Enriched with STP Sludge: An Opportunity to Recycle the Organic Waste into Organic Fertilizer

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***Abstract:*** *The present paper addresses the opportunity of Wealth creation from Waste in Mejia Thermal Power Station, DVC. There are different types and substantial amounts of bio waste generated in thermal power stations and some of the sources are sludge of Sewage Treatment Plant (STP), dry leaves, dry grasses and dry branches of leaves etc. The study discovered two 'waste' items, that is, STP Sludge and dry grass that are convertible manually into organic fertilizer for plant growth through Vermicomposting method. Result shows that a good quality vermicompost can be produced economically from the STP sludge, dry grass and cow dung with an optimum bed layer ratio as 5:1:1, respectively. Vermicompost is enriched with Nitrogen, Phosphorous and Potassium whose values are about 9076.92mg/kg, 3883.48 mg/kgand 1461.35 mg/kg, respectively which is helpful for effective plant growth. Cost-benefit analysis discloses that the production cost of vermicompost is about Rs. 22.57 /kg which comparatively lower than the market prevailing rate (Rs. 50 /kg). About 400kg of developed and tested vermicompost is distributed among the forestry department of DVC filed formations and successful plant growth is found.*

***Keywords****: Dry Grass; Economic; Sewage Treatment Plant; Sludge; Vermicompost*

## INTRODUCTION

Waste is the any kind of discarded substance after primary use mostly. Waste segregation is one of the greatest concerns for its probable use in different ways like production of valuable product, energy etc. For achieving Circular Economy, efforts are being done for the transforming Waste to Wealth [1]. There are different types and substantial amount of bio/food waste generated in thermal power station and some of the sources are plant canteen waste, colony canteen waste, sludge of Sewage Treatment Plant (STP), dry leaves, dry grasses, dry branches of leaves etc. At present, only STP sludge is being used for plant gardening as manure but most of the other biodegradable wastes are disposed of in unsafe ways – unscientific dumping and causing indoor air pollution. Bio-waste has the potential to be harnessed as energy, fuel, and fertilizer. Vermicomposting is basically a managed process of worms digesting organic matter to transform the material into a beneficial soil amendment. It is defined as organic matter of plant and/or animal origin consisting mainly of finely divided earthworm castings, produced non-thermophilically with bio-oxidation and stabilization of the organic material, due to interactions between aerobic microorganism and earthworms, as the materials pass through the earthworm gut. It is helpful for sustainable agricultural production without causing pollution of soil, water, and environment [2]. There are different studies for vermicomposting from different sources of waste materials [3]

There are several benefits of Vermicompost as follows [4]:

(i) It is enriched in plant growing nutrients i.e. mainly Nitrogen, Phosphorous and Potassium.

(ii) It also contains growth promoting hormone 'Auxins', 'Cytokinin' and flowering hormone 'Gibberellins' secreted by earth worms.

(iii) It contains some antibiotics and actinomycetes which help to protect from pests and diseases.

(iv) Due to its high porosity, aeration, drainage, and high holding capacity which will help soil health.

## METHODOLOGY

Following conventional process are followed for the project of vermicomposting [5, 6]:

(i) First, non-biodegradable items like plastic, glass and etc. are to be removed from bio-degradable waste.

(ii) The vermi bed should be placed under the roof and maintained at the temperature within 35°C.

(iii) Chop the organic waste into convenient size and kept in shade for drying for few days,

(iv) Put 5-inch layers of the shaded dried STP sludge into the bottom of the bed.

(v) And then, put 01-inch layer of shredded dry cutting grasses on the layer of STP sludge.

(vi) After that, sprinkle 01-inch layer of cow dung over it. [As in literature, the effective bed layer of organic residue and cow dung volume ratio was found of about 6:1].

(vii) Over this layer, another layer of STP sludge is spread and then followed by spraying of dry grass and cow dung slurry as per above mentioned layer thickness.

(viii) The above said process will be repeated till the spread of the organic residues 06 inch above the top of the pit.

(ix) Wait for partial decomposition of organic residues for about 15 days. The confirmation of partial decomposition is to be confirmed by the reduction of C/N ratio < 30 and PH > 6.

(x) After confirming, the earthworms are added as per defined rate by making holes at the top of the bed on four corners and centre of the pit. [@ 1kg (around 1000 worms)/ bed having 01 ton organic residue].

(xi) The filled pit is to be covered by jute bag or mat to protect earthworms from birds and insects.

(xii) Water needs to be sprinkled daily on the vermin bed to keep them moist (about 40-50% moisture).

(xiii) Watering is stopped for at least 05 days before final harvest from top layers.

(xiv) The black granular crumbly vermicomposting on the top of bed confirms the maturity of compost.

(xv) It is preferred to check the physiochemical parameter of the compost. In general, plant nutrients contain in the compost as Organic carbon: 9.15 to 17.98 %; Total Nitrogen: 1.5 to 2.1 %; Total Potassium: 0.6%; Total Phosphorous: 1-1.5 %; Sulpher: 128 to 548 ppm; Calcium and Magnesium 22-70 me/ 100gm; Copper: 100PPM; Iron:1800ppm and Zinc: 50PPM. The C/N ratio comes down below 10.

(xvi) Layer wise scraping of vermicomposting is required followed by sieving. Sieving is required for separation of earthworms, eggs and cocoons from the compost.

(xvii) After sieving, the compost should be dried for a few hours.

(xviii) After that, as per the required amount, it will be packed and stored in shade.

## RESULTS AND DISCUSSION

**Figure 1** shows the details design of the Vermicompost project having capacity of 400 kg. At the bottom bed, no plastering is required, and it will be made of only brick and cement. The side wall is made of Brick and Cement with intermittent gap. Plastering may be done. For washing the bed, a drain pipe with isolating valve is made. Pit should be made at 06 inch above the ground level. For the present project, existing similar bed is used for the study.

**Figure 2** also shows the details design layout of the shed over the vermicompost bed. **Figure 3** shows that the layer wise distribution of cow dung and dry grass over the STP sludge. **Figure 4** shows the Earthwarm addition as per the procedure mentioned in section 3. In general, it is placed at 04 corners and 01 Centre position.

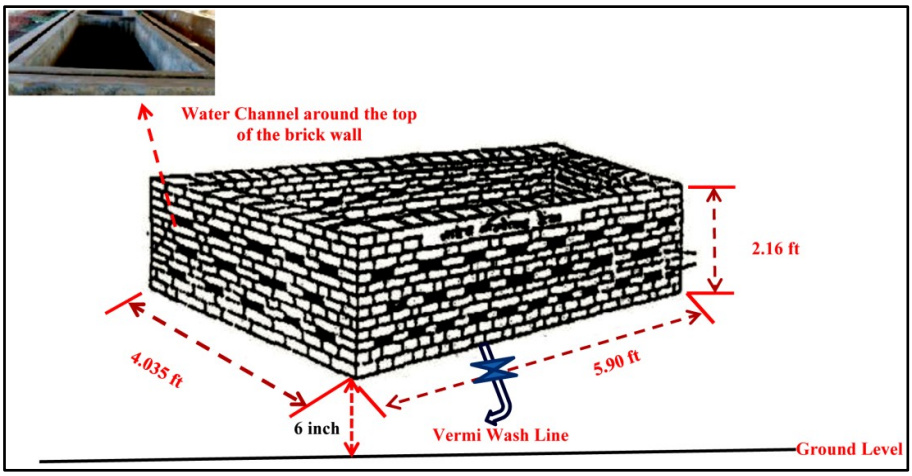


**Figure 1** Design layout of vermicompost pit ( length & width dimension are in inner side)


**Figure 2** Design layout of vermicompost shed

**Figure 3** Vermicompost bed filled with organic residue and cow dung layer wise

**Figure 4** Earth worms addition into the partial decomposed organic residue

**Table 1** Physiochemical analysis at different stages of project

| Description | pH | Carbon ( C ) | Nitrogen (N) | Phosphorus (P) | Potassium (K) |
|---|---|---|---|---|---|
| Fresh STP Sludge | 8.84 | 14634.15 mg/kg | 3360 mg/kg | 156.14 mg/kg | 1230 mg/kg |
| 10 days old STP sludge | 6.99 | 34.04% | 0.75% | - | |
| Final Product of Vermicompost (after 45 days from the start of project) | 5.77 | 0.31% | 9076.92mg/kg | 3883.48 mg/kg | 1461.35 mg/kg |

Physiochemical analysis of the fresh STP sludge, 10 days old STP sludge (dewatered sludge) and final product (vermicompost) is shown in **Table 1**. **Figure 6** also shows the variation in important physiochemical parameter with time of project. It is found that the fresh sludge is enriched with carbon and nitorogen along with different microbacteria as per fresh sludge analysis. The carbon % increases with time as it is found in **Figure 5** if it is kept in open area. During the start of pilot project, it is about 33% and after the vermicomposting, it is reduced to 0.31% which witnessed the decompostion of sludge. Moreover, the constituent namesly, Nitrogen, Phosphorous and Potassium are both increased which is helpful for plant growth. **Figure 6** shows the final physical appearance of the final product which has been distributed among gardner for use in the plant.

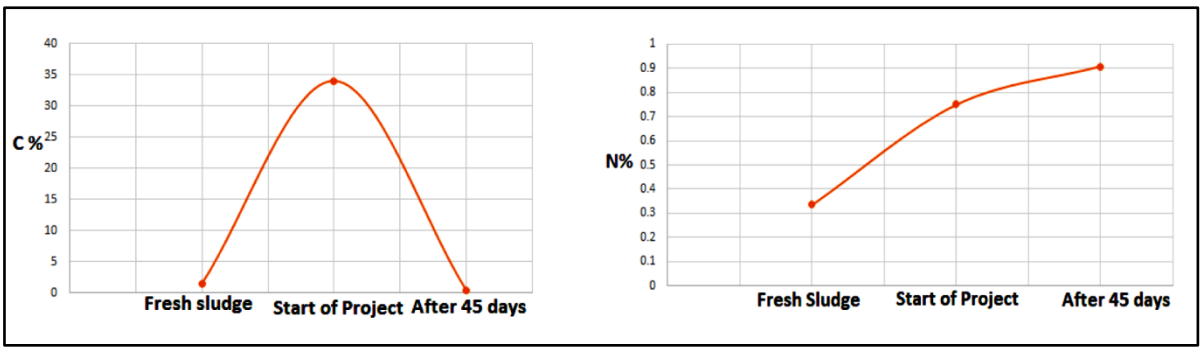


**Figure 5** Variation of Carbon (c) and Nitrogen (N) with different stages of project


**Figure 6** Final vermicompost product

**Cost-Benefit Analysis**

**Table 2** shows the cost-benefit analysis of the executed project. The cost of the STP sludge is not considered as it is collected from the MTPS Sewage Treatment Plant. Cow dung used in the project was collected from the local area at the rate of Rs. 1 /kg. The cost towards physiochemical analysis of the samples in totality are also shown in **Table 2**.

**Table 2** Cost benefit analysis of the pilot scale vermicompost project

| Sl.No. | Descriptions | Rate (Rs/kg) | Cost (Rs) |
|---|---|---|---|
| 01. | STP sludge cost-300kg | From STP plant | 0.00 |
| 02. | Cow dung cost-150 kg | 1.00 | 150.00 |
| 03. | Physiochemical analysis | --- | 6077.00 |
| 04. | Packaging cost-20 no. of bora capacity 20 kg each | 50.00 | 1000.00 |
| 05. | Separating screener-04 nos. | 100.00 | 400.00 |
| 06. | Earth worms cost (red tiger worms) | 500gm | 399.00 |
| 07. | Others | ---- | 1000.00 |
| 08. | Cost towards Vermicompost bed | Existing waste collection cemented bed is used | 0.00 |
| Total cost incurred for the project | | | **9026.00** |
| Vermicompost Product- 400kg Market cost | | 50 | **20000.00** |
| Probable Profit from the Pilot scale vermicompost project | | | **10974.00** |

From **Table 2**, it is found that total cost involvement to produce 400 kg vermicompost enriched with STP sludge is about Rs. 9026.00 which is about Rs. 22.57 /kg of Vermicompost. The developed product cost is compared with market available cost i.e. Rs. 50/ kg and it is derived that about Rs. 10,974.00 is saved for the gardening from the 400kg of developed product used.

**CONCLUSIONS**

From the above pilot project study, it is concluded that the STP plant waste i.e. Sludge can be converted into the value added Vermicompost which can used for the growth of plant as organic fertilizer. Result shows that a good quality vermicompost can be produced economically from the STP sludge, dry grass and cow dung with an optimum bed layer ratio as 5:1:1. Vermicompost is enriched with Nitrogen, Phosphorous and Potassium whose values are about 9076.92 mg/kg, 3883.48 mg/kg and 1461.35 mg/kg, respectively which is helpful for effective plant growth. Cost-benefit analysis discloses that the production cost of vermicompost is about Rs. 22.57 /kg which comparatively lower than the market prevailing rate (Rs. 50 /kg). About 400 kg of developed and tested vermicompost is distributed among the forestry department of DVC filed formations and successful plant growth is found. Hence, this kind of

project will help to achieve the circular economy of the country and making it possible for transformation of Blunder (STP Sludge as Waste) into Blessings (Wealth).

**ACKNOWLEDGMENT**

R&D department are indebted to the DVC management for funding the pilot project.

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# Just Transition of NTPC Badarpur Power Plant — a Leap towards Sustainable Future

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***Abstract:*** *Over the past two decades, as the urgency to build a low-carbon society has gained momentum, the question about the fate of the fossil fuel industry workers and the communities dependent on such industries have gained prominence.*

*Just transition highlights the need for social justice in the shift towards a zero-carbon world. It reinforces the fact that ending our dependence on fossil fuel should not be a trade-off between the environment and economy. It compels us to think and plan alternative economic and social systems that are sustainable and thriving.*

*For India, the question to move away from coal is complex given the country's coal dependency and the social fabric of fossil fuel supply chain ecosystem. But Just Transition can be "good economics and good politics", if a shift away from coal-economy is planned and managed well. A well-managed just transition will not only help to mitigate the impacts of climate change but also ensure a growth trajectory that is sustainable and equitable and is less vulnerable to social and economic disruptions. The advancements in renewable energy and other innovative technologies give us a perfect opportunity to transition to clean energy; we must seize it. At the same time, we must ensure that fossil fuel related industry workers and the local communities do not shoulder the burden of such energy transition. NTPC, through its engagement on climate change mitigation is working towards a just transition through a collective approach of fulfilling both environmental and social obligation.*

*At 705 MW Badarpur Thermal Power Station (BTPS) of NTPC Limited was fully decommissioned from operations in October 2018. The plant was successfully sold through e-auction for a sum of Rs. 266.75crore higher than its asset's book value. The challenges of resettlement of its employee and contract labor were met as per present industrial practices and laws. The plant had been fully dismantled and disposed-off following environmental guidelines of DPCC, CPCB, NGT & CAQM. The timelines could be maintained despite hurdles posed by COVID'19 and countrywide lockdown, GRAP orders in various categories during Oct. to Feb. each year affecting construction & demolition works and vehicular movement in NCR. The development of Ecopark on the ash dyke also have challenges of matching technologies, product, designs suitable for harsh and corrosive nature of ash, creating conducive working conditions for labor and handling strict compliance of NGT and Forest department, continual liaison with state and central bodies e.g. DJB, UPID, MoP, DDA, Forest Department, NGT, DPCC, BRPL.*

*In the case of BTPS, the land had been leased to NTPC Limited by the central government for fifty years at an annual rental lease of 52 million. Land was handed over to MoHUA (Ministry of Housing and urban affairs) in June 2023. Challenge of huge amount of ash in dyke was coped up through intervention of central government who decided to redevelop the ash pond area into an EcoPark as the company was required to return the land fully levelled, remediated and 're-grassed'.*

*BTPS and Ecopark are leading examples of Just transition of coal-based power plant for the country and globe at large imbibing adherence to all aspects of a coal plant's end-of-life, from retirement to decommissioning to remediation and redevelopment, adherence to legal and regulatory requirements.*

***Keywords:*** *Just Transition; BTPS; NTPC-EcoPark; Decommissioning and Dismantling; Badarpur; Coal Plant; I-Forest*

## LIST OF ABBREVIATIONS

| | |
|---|---|
| BTPS | Badarpur Thermal Power Station |
| DPCC | Delhi Pollution Control Board |
| CPCB | Central Pollution Control Board |
| EC | Environmental clearance |
| NGT | National Green Tribunal |

| | |
|---|---|
| CAQM | Commission for Air quality Management |
| GRAP | Graded Response Action Plan |
| MoHUA | Ministry of Housing and urban affairs |
| CEA | Central Electricity Authority |
| CERC | Central Electricity Regulatory Commission |
| DDA | Delhi Development Authority |
| CPCB | Central Pollution Control Board |
| CTE | Consent to Establish |
| CTO | Consent to Operate |
| R&M | Renovation and Modernization |
| RPO | Renewable purchase obligation |
| GNDTP | Guru Nanak Dev Thermal Plant |
| SOP | Standard Operating Procedure |
| TPP | Thermal Power Plant |
| MoP | Ministry of Power |
| PPA | Power Purchase Agreement |
| DTL | Delhi Transco Limited |
| DISCOM | Distribution Company |
| EPCA | Environment Pollution (Prevention & Control) Authority |
| FSNL | Ferro Scrap Nigam Limited |
| BoQ | Bill of Quantities |
| ANPR | Automatic number plate reader |
| UVSS | Under Vehicle surveillance system |

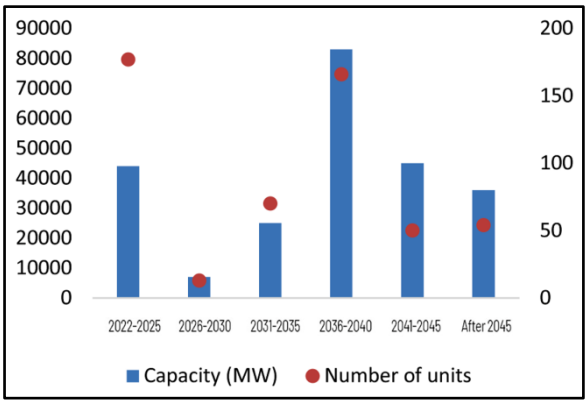
**JUST TRANSITION OF COALBASED POWER PLANT**

INDIAN SAGA

India's coal fleet is fast ageing. About one-fifth of the current capacity is primed for decommissioning as their average age is more than 35 years. If the Ministry of Power's advisory to retire coal-based generation units of more than 25 years old is implemented, then as much as 50-60 GW capacity will retire in the coming ten years. Decommissioning a coal-based thermal power plant (TPP) in a just transition context entails a complex set of technical, environmental, social, and economic interventions. The objective is to ensure that the plant site is fully remediated, the economic loss of dependent workforce and communities compensated, and new economic opportunities and environmental outcomes are created for communities to benefit from.

According to the Central Electricity Authority (CEA), 126 coal-based power generating units aggregating a capacity of 11,995-Megawatt (MW) have been retired from operations between March 2016 and June 2021 due to techno-economic and commercial considerations. Of the 12 GW of coal-based capacity Decommissioned since 2016, most retired units await further decision and action. Whereas BTPS and GNDTP are examples of power plants being fully dismantled and sites being remediated for alternate reuse.

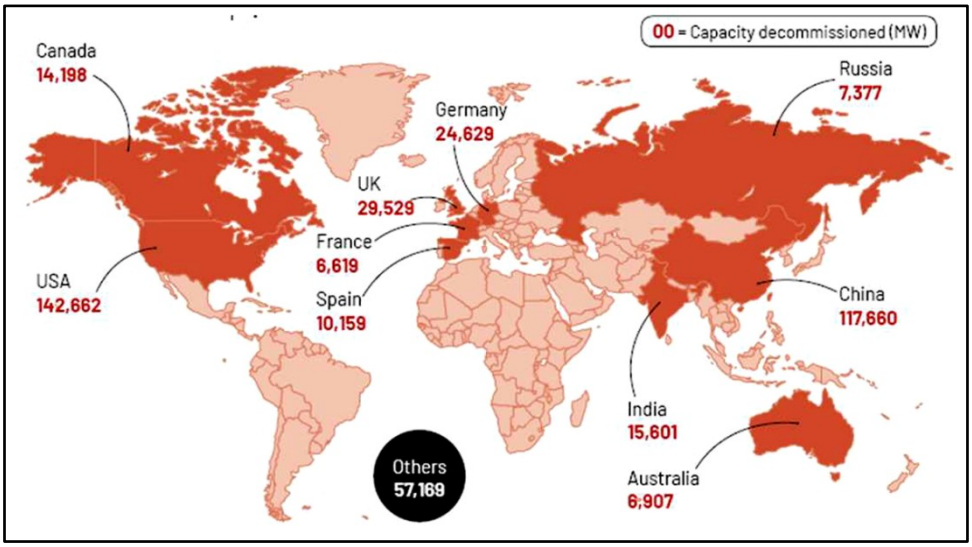
In case the Ministry of Power (MoP) advisory to retire coal-based generation units over 25 years old is implemented, 44 GW of capacity across 177units will have to be retired in India by 2025. This category includes 27 GW of capacity across 112 units which are over 30 years old. In the next decade, between 2026 and 2035, 32 GW across 100 units will need to be retired from operations. Maximum retirement will be witnessed between 2036 and 2040 when 83 GW of capacity across 166 units will need to be retired. Post-2041, 45 GW of capacity across 80 units will be retired by 2045, and another 36 GW across 54 units will be retired after 2045.




**Graph 1** Retirement schedule of India's coal-based power plants--- Source: CEA; Global Energy Monitor

## GLOBAL SCENARIO

Substantial coal-based power generation capacities have been retired globally in the past two decades. According to the Global Energy Monitor platform, 432.5 GW of coal capacity has been retired since the year 2000, which amounts to one-fifth of the capacity currently operating. The retired capacities have been gradually increasing, from 20.5 GW during 2000-05 to 64.2 GW during 2006-10, 139.2 GW during 2011-15, and 218.1 GW during 2016-20. Sixty per cent of the retired capacity is located in the United States (US) and China, followed by 7 per cent in the United Kingdom (UK), 6 per cent in Germany, 4 per cent in India and 2 per cent in Canada. While closures in the US, China and India have been driven by techno-economic concerns, European countries have been pushing voluntary retirements of coal power plants as climate mitigation action.




**Map 1** Source-CEA; Global Energy Monitor (Source: Global Energy Monitor 2022)

Retired TPPs have either been repurposed for energy or non-energy use or abandoned, depending on the business decision of plant/ landowners.

The compliance requirements during repurposing depend on the specific end-use planned for a retired power plant. Generally, if the power plant is being repurposed for alternate use, new environmental clearance (EC), Consent to Establish (CTE) and CTO need to be obtained, depending on the nature of the new activity. If the repurposed sector falls within the EIA Notification, 2006, new EC, CTE and CTOs are required. Due to the pre-existing transmission and other support infrastructure, there is a strong case for utilizing these sites for energy-related end-use such as for solar power generation and battery or other storage technologies. Some decommissioned plants have been repurposed

with small retrofits or significant replacements to operate as energy generation assets on alternate fuels such as natural gas or biomass. For example, several coal power plants in European countries are planned to be repurposed with biomass, natural gas or waste pellets. In China and India, most decommissioned small sub-critical units have been replaced by larger supercritical efficient units.

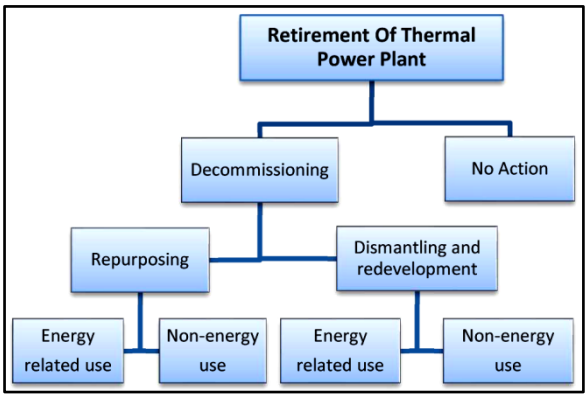



**Chart 1** Post closure treatment of power plant

**BADARPUR THERMAL POWER STATION-CLOSURE**

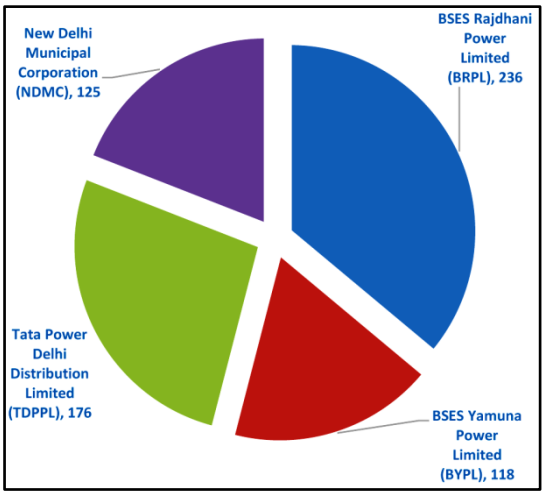
BTPS had an installed capacity of 705 MW. The original ownership of NTPC, Badarpur vested with Government of India and was operated and maintained by the Central Electricity Authority (CEA) till March 1978. On April 1, 1978, the management was transferred to NTPC Ltd. NTPC operated and maintained the station from April 1978 to May 31, 2006, on an annual management fee basis. On June 01, 2006, ownership of the station was transferred to NTPC Ltd.

**Table 1** Unit capacity and Commercial Operation Dates

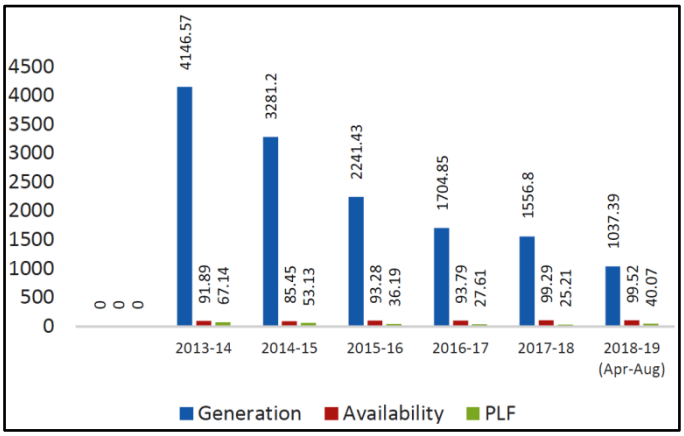
| Stage | Unit | MW | Date of synchronisation | Commercial Operation Date |
|---|---|---|---|---|
| Stage-I | Unit-1 | 95 | July 26, 1973 | Nov 01, 1973 |
| | Unit-2 | 95 | August 5, 1974 | Sep 01, 1974 |
| | Unit-3 | 95 | March 29, 1975 | Apr 01, 1975 |
| Stage-II | Unit-4 | 210 | December 2, 1978 | Mar 17, 1980 |
| | Unit-5 | 210 | December 25, 1981 | Apr 01, 1982 |

Plant, township and ash dyke are spread over 517.08 hectares. Out of this, Plant area is 99.82 hectares, Township area is 59.26 hectares and Ash dyke area is 358 hectares.

As per Gazette notification No 110 dated 31-05-2006, the title of the land of Badarpur Thermal Power Station vested in the Government of India on lease to NTPC for an initial period of 50 years at an annual lease rent equivalent to 10% of the book value of the land. The annual lease rent NTPC is presently paying is 6.87 Cr. including property tax. 100% power from BTPS had been allocated to Delhi. An initial PPA was signed with DTL. On transfer of Bulk Power purchase function to DISCOMs in Delhi w.e.f. 01.04.2007, NTPC signed PPAs with all the five DISCOMs of Delhi.




**Graph 2** MW share of Beneficiary




**Graph 3** Plant performance before closure

## CHRONOLOGICAL DEVELOPMENT REGARDING THE CLOSURE OF BTPS

### Submission made to the department related to the parliamentary standing committee on Science and Technology, Environment & Forests

The Parliamentary standing committee on Science and Technology, Environment & Forest called a meeting regarding Environmental pollution in Delhi, where the submission made by NTPC on 12.02.2016 that all the five units of Badarpur Station are complying with the emission norm of 150 mg/Nm$^3$ as given in consent order No. DPCC/PLG/2014/33457 dated 02.01.2014 which is valid till 31.01.2018. However, in the overall interest of reducing pollution levels in Delhi, NTPC Ltd. agreed to consider shutting down Badarpur Thermal Power Station as per the timeline which may be decided by Government of India & Government of NCTD subject to commercial settlement with all stakeholders.

### EPCA Meeting on 12.05.2017

A meeting of reconstituted EPCA for NCR region was held on 12.05.2017 under the chairmanship and it was decided that BTPS will be permanently closed in July 2018, post commissioning of Tuglakabad Substation.

### Meeting of LG on 25.05.2017

Chaired by Hon'ble LG Delhi on the subject of post closure land issues of the Badarpur plant. Secretary (power) of

GNCTD informed that, in view of EPCA directions and Delhi Govt's own commitment to reduction of air pollution in Delhi, Badarpur Thermal Power Station is planned to be closed as soon as the Tughlakabad Inter State 400 KV substation, then under construction by PGCIL, could be commissioned.

NTPC assured it is fully on board with this decision and has already internally started planning for closure after June 2018.

**Hon'ble LG Directed**

(i) DTL may take necessary action regarding the smooth takeover of the 220 KV switchyard.
(ii) While the plant area may take time to be handed over to the successor agency, DDA may coordinate with NTPC to determine the detailed layout and present status of the entire area of the plant as well as the township and undertake the holistic as well as phase wise planning of the entire area accordingly.
(iii) iii. Chief Secretary (Delhi) may take up the ministry of human resource development to decide the issue of future funding for the Kendriya Vidyalaya.
(iv) The private school may be permitted to operate, and the Director of Education would take the necessary action for the same.
(v) The Director of Education would take up the DDA for future allocation of land for government schools.
(vi) A follow-up meeting on the subject will be held by the Chief Secretary in about a month's time.

**Consent to Operate Order of DPCC Dated 25.07.2018**

As per the order issued by DPCC on 25.07.2018, the consent to operate BTPS units has been extended till 15.10.2018 or Up to the date of enforcement of GRAP provisions w.r.t shutting down of BTPS as per decision of EPCA or Up to the date of commissioning of Tuglakabad substation, whichever is earlier.

**Meeting of JS(Thermal), MoP on 28.08.2018.**

A meeting was held on 28.08.2018 at MOP, chaired by JS(Thermal) to discuss the issues related to closure of Badarpur Thermal Power Station. NTPC was directed to complete the hand-over plan / formalities of transfer of substation to DTL as per decisions of Hon'ble LG Delhi meeting.

**METHODOLOGY CRAFTED FOR TRANSITION IMMEDIATE MEASURES**

After Decision regarding closure of BTPS following steps were taken for a smooth closure:

- All stake holders including employees, contracting agencies, Statutory authorities, State and Police administration, Schools, Shop keepers were informed in writing in advance.
- Open house communication meetings were organized for briefing all employees.
- Union and Association were taken into confidence with continuous meetings and communications.
- The action plan was chalked out for tapering off deployment of contract labor so that there will be minimum number of contract laborers only as per requirement.
- Facilitation centers were opened for contract labors for availing themselves of their statutory benefits.
- Payment of retrenchment benefit to all contract laborers was ensured through contracting agencies.
- Employees were given the option of transferring to other locations of NTPC Projects / Stations and transferred as per their order of preferences for relocation.
- The Special Medical board was constituted to consider the medical requirement of employees.
- Differently abled employees were given a choice for relocation in NTPC projects of NCR.
- Closure permission was obtained as per section 25(O) of Industrial Dispute Act 1947.
- An injunction was obtained from Delhi High court for restraining any strike / dharana at BTPS.

**MAIN PLANT-STRATEGY**

- Approval of NTPS Board of Management was sought for

  - BTPS shut down,
  - Asset transfer to other stations
  - Handover of Switchyard to DTL
  - Authorization of CMD for all future decisions reg Dismantling and Disposal.
- An Internal Committee was constituted including members from BTPS, Regional-HQ, Corporate-Commercial, Corporate -Finance, Corporate -C&M and Corporate -Engineering and made responsible for -
  - Method of disposal.
  - Identification of spares and equipment for disposal.
  - Fixation of reserve price.
- Net assets value of plant and township as on 31.10.2018 was Rs. 238.52Cr.
- Till July 2019 assets valuing Rs. 84.13Cr. had been transferred to other NTPC stations.
- Revised value based on scrap weight basis (Present Fair Market Value) received from valuation agency M/s FSNL was Rs. 247Cr. which was considered as "Reserve Price" for auction.
- E-auction was conducted successfully on 30.08.2019 with H1 bid as Rs. 266.75Cr.
- The H1 bidder successfully dismantled and disposed-off the main plant area with land remediation through backfilling and levelling in scheduled time.

**DISMANTLING AND DECOMMISSIONING**

- The plant's systems, areas, equipment & buildings were divided into 10 segments.
- The criterion of segmentation at BTPS was finalized on equal sale value. However other sites /plants may consider segmentation on the following basis –
  - Equal or ascending or descending value of each segment
  - Area/system wise
  - Interdependency of segments
- Payments from the agency were received in installments. Installments were linked to performance to w.r.t. successful dismantling, disposal and site levelling. Lifting of (N-1)th segment allowed only after payment of Nth segment.
- Order of decommissioning, dismantling and disposal was based on following key factors –
  - Balance between lifting, dismantling and clearing areas of debris.
  - Cash flows to agencies resulting from permitting lifting of dismantled segment assuring further sustenance of work.
  - Plant owner's interest in timely clearing of site/area/segment.
- **Safety**
  - An Emergency Response Plan was prepared by the Safety department in consultation with other related functional heads.
- **Environment**
  - The hazardous items e.g. batteries, Oils, e-waste were identified and returned to stores. Disposal of such hazardous wastes accomplished by stores through e-auctions. Auction terms and condition mandated participation of agencies having valid license of disposal under respective environmental rules and regulation.
- **Standard Operating Procedures & Guidelines**
  - 20 nos. of SOPs were prepared covering contract labor, gate control, isolation, safety, function and role of C&M, HR & O&M teams.
- **Regulatory Compliances**
  - Communication to CEA & CERC
  - Surrender of Factory License
  - Surrender of Licenses e.g. PESO, Telecom Authority
  - Environmental Rules and Regulations
- The following major Items were kept under exclusion list -
  - Items under Store buildings (Capital nature, Spare parts, high value etc.)

- STP & RO Plant
- Street poles, High Masts and Watch Towers
- MBOA Items
- CCTV system
- Batteries
- Transformer Oils

- The C&M functions were retained at BTPS for subsequent disposal of the above items through either transfer to other stations or e-auctions.

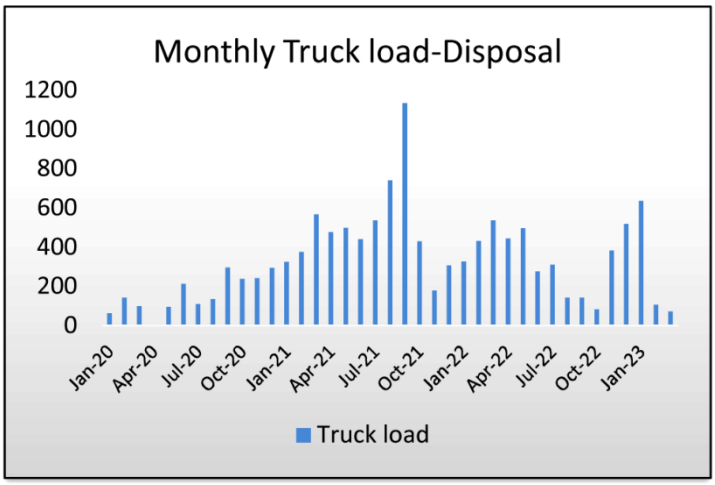



**Chart 2** Pattern of Monthly No. of trucks for plant disposal

**Chart 2** clearing shows effects of imposition of GRAP orders. GRAP restrictions are based on the Air Quality Index. Stage-III and IV call for stopping construction and demolition work. Diesel trucks are banned during this period October. to January. Sharp dip in numbers of trucks can be seen in Nov.21 and Oct. 22.

## TOWNSHIP MONETISATION

- BTPS has three townships, common buildings, KV and Notre Dame school, National Power Training Institute, PGCIL, and MTNL withing premises. Approval from Competent Authority was sought for its Monetization after site civil survey by third party.
- The third party was hired for valuation to assist in fixing reserve price for e-auction.
- Valuation objective should be clear to ascertain true market figure –
  - Re-use of buildings
  - Dismantle and disposal.
  - Replacement value
- Making/dividing township(s) into lots considering –
  - The physical and separable boundaries.
  - Sequence of availability for said purpose.
  - Interdependency of system/ Common system (Sewage, water, underground cables, water network etc.)
  - Quantum of Monetary value for realization

## CHALLENGES AND MITIGATIONS

In the first township's auction had failed multiple times. The earlier valuation was based on Net Replacement Value which resulted in high reserve price. This price was not commensurate with what market was ready to provide. NTPC management again hired third party and got revised valuation with purpose of dismantling and disposal of township as SCRAP basis. Subsequently BTPS got successful bid for auction through MSTC Ltd.

**REPURPOSING: NTPC ECOPARK**

**Concept and Theme**

- The concept of Ecopark was first discussed during a meeting chaired by Hon'ble LG Delhi on 28.05.2017.
- Meeting chaired by Principal Secretary to Prime Minister-24.02.2018 wherein MoP was entrusted a state-of-the-art park on Ash dyke after plant closure.
- MoM dated 01.05.2018 chaired by Secretary power (MoP), DDA, NTPC, Govt of NCT freezed decision for Ecopark.
- NTPC CSR & sustainability Committee had, in its 78th Meeting held on March 12, 2018, approved allocation of Rs. 116 lacs under SD budget for FY 18-19 for appointment of a consultant for Ecopark.
- A consultant was hired, and it submitted DBR (Design basis Report) and Preliminary Cost estimate and concept drawing.
- In 461st Board Meeting Rs. 300crores were sanctioned under Sustainable Development Initiative of NTPC. With rider that expenditure shall be met first Ash fund then from SD budget.

The Ecopark area spread over 884acres has been divided into four phases. Attractions in Phase-1 are one Butterfly Park, two numbers of Arid Conservatories, Fish shading structures, Lotus Pond, Herbal gardens, Ash Mound, Reflective pool, Yoga & Meditation Centre, Cafeterias, Administration building and a 50kW functional ground mounted solar plant. Phase-II encompasses grand entrance gates and arches, Visitor centres meant for entry and exit to park with ticketing etc., Boating Lake, Golf Course, Maze Garden, Kids play area, Clover Cafe, Lotus Park with theme lighting, an amphitheatre, Haat Area and a 1000kW of solar plant mounted on solar tree structures. Phase-III encapsulates Jungle Safari wherein both carnivores and herbivores has been envisaged. Phase-IV shall have boundary area development along the park. Entire Park shall have state of the art security and surveillance system e.g. Access control system (UVSS & ANPR), Command and control system, Visitor management system, GPS, Large displays for information, Public Address system, Gardon speakers, Smart poles.

**Map 2** NTPC Ecopark


**Map 3** Phase-1 Proposed Structures


**Map 4** Phase-2 Proposed Structures

## CHALLENGES

- As the initial survey of ash pond was done by drones, the right levels could not be marked because of thick vegetation across the dyke. This has led to deviation in estimated earthwork quantities leading to delays in execution and rise in cost. Enormous quantity variation surfaced out between the drawings and BOQ. The items and the quantity required could not be truly reflected in the BOQ. Also, there were mismatches in BOQ vis-à-vis approved drawings. Estimates by the third party consultant came out to be unrealistic.
- The work of different contractors was envisaged in the serial order. Agencies had to start the work after the handover of site/s from the previous agency. Packages could have well been staggered w.r.t. time had the estimates be matching ground reality.
- Permission to set up the Batching plant at Ecopark was denied, as a result RMC (ready mix concrete) transportation could happen only during night hours (citing the usual ban of entry and exit of commercial trucks in Delhi).
- GPC (Geo-polymer concrete) pavers design mix for mass scale workability was finalized in Dec'21. Agencies are unwilling to take up this work as it's a loss-making proposition for them.

- Agencies faced challenges of working in coalashes.
- Initially labor was unwilling to take up the work because of dust and ash.
- Difficult working conditions in ash w.r.t. dusts due to winds and slush formation in rainy seasons.
- Tree-felling permission from the forest department could not be granted despite follow-ups leading to a location change of the entire parking area from the original layout.
- COVID, NGT ban, heavy rains in year 2023 hampered the civil foundation works and the work below ground level.
- The NTPC Ecopark shall be supplied with treated water from Okhla STP. The laying of supply pipeline is delayed as it has to cross land under UPID, NHAI and GAIL.

**Figure 1** BTPS Main plant dismantling snapshots

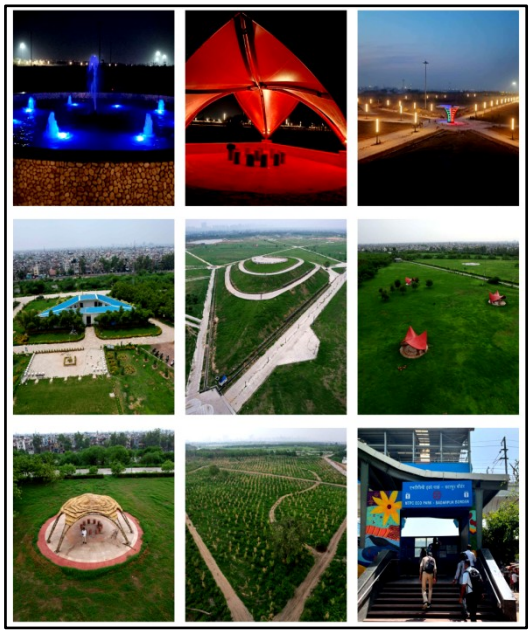


**Figure 2** Remediated land in form of NTPC Ecopark

## WAY FORWARD

The Main Plant has been successfully disposed-off, townships demolition and disposal is to be completed by Mar. 2025. Land of Badarpur including NTPC EcoPark has been handed over to MoHUA on 15 June 2023 with rider that running works of townships & NTPC Ecopark shall be completed. Total realization from monetization of plant and townships shall be to the tune of 450crores. As responsible corporate entity Just transition of BTPS and development of NTPC Ecopark shall be a boon to residents of NCR breathing a little more fresh air for years.

BTPS has definitely set an example of successful transition and remediation with the development of its NTPC EcoPark. But it's just the debut in this power sectorial dimension. Comprehensive framework for Just transition though single window approach is need of the hour. The decision on retiring a thermal power plant should be planned at least 5 years in advance along with site's land reuse, as decommissioning planning and execution is dependent on it. Decommissioning of TPPs should be mandated by a new law, or an amendment to an existing law. 25nos. Indian districts need to undertake integrated just transition planning over the next few decades due to high dependence on coal economy. The New Environmental Act needs to consolidate all the environmental related provisions and remove multiplicity in clearances and permit procedures. Dismantling, remediation, and redevelopment are interrelated concepts, and must be clearly defined in guidelines. All existing labor laws and Codes need to be reviewed and revised from a just transition perspective. Reforms should happen for managing the financial aspect of closure e.g. Corpus funds for decommissioning, Institutional set-up to administer the fund, report on decommissioning cost in

financial statements through SEBI, Bankruptcy and decommissioning.

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89_IEC85694

# Packaging Box for Transport of Fruits and Vegetables from Jute Stick Particle Board

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***Abstract:*** *A formal dehyde free board was developed from jute stick particles. The jute stick was chopped into particles of 6 mm size. About 24% polyvinyl alcohol of the weight of the dry jute stick was taken and mixed with the jute stick particles. The adhesive coated particle was subjected to a constant pressure of 100 kg/cm$^2$ in the hot press 20 min at 140°C and. After pressing, the particle boards were taken out, cooled and kept at 65 ± 5% humidity and 25 ± 2 °C for seven days to stabilize the particleboards before their evaluation of properties. The modulus of rupture was 15 MPa which satisfies the minimum criterion for the MOR in the Japanese Industrial standard (8 MPa) for particle boards. The two hour water absorption ranged between 30-40%. The weight of the box varies between 1-2 kg and has the capacity to hold about 5 kg fruits like mango or apple. Each box cost around Rs 200-250 and is a reusable, environmental friendly alternative to plastic crate popularly used for transport of fruits and vegetables. The box comply by IS 9590: 1980 (non-returnable wooden boxes for horticultural produce — Type 1 — non-returnable wooden box with corner posts, of nailed or stitched construction The box has high compression strength (3967 kgf) (determined as per IS 7028-1987 (Part 6) RA 2013). The box has bending strength of 30.15 kgf/60 mm (as per guidelines of IS:6219:1989 RA 2014). Can withstand incline impact at a speed of 4 km/h (as per guidelines of IS 7028-1987 (Part 3) RA 2017). Can with stand vibration of 200 cycles and 2.54 cm amplitude for 1 h (as per guidelines of IS 7028-1987 (Part 4) RA 2018).*

**Jute stick particle board boxes for transport for fruits and vegetables**

102_IEC26914

# Eco-Friendly Handmade Paper from Jute

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***Abstract***: *The golden fibre jute is widely known for its eco-friendly and bio-degradable properties in the packaging industry. Additionally, jute is an air-purifying plant, contributing to its environmental benefits. It offers a sustainable alternative to plastics (particularly single-used) due to its cost-effectiveness, strength and durability. The study explores jute slivers, jute caddies and corn husks to produce handmade papers for sustainable applications. The produced paper was evaluated for various performance parameters, including tearing strength, tensile strength, bursting strength, abrasion resistance and antifungal activity. The results showcase the potential of jute waste as a sustainable material for various applications.*

***Keywords***: *Antifungal; Corn husk; Eco-friendly; Jute; Handmade; Paper*

## INTRODUCTION

Jute, the golden fibre and one of the most important cash crops is a natural lignocellulosic bast fibre. It is a strong, shiny, long, rough fibre that can be spun into fine or coarse yarn. Jute is composed of primarily cellulose (64.4%), hemicellulose (12%), lignin (11.8%), pectin (0.2%), water-soluble matter (1.1%), wax (0.5%), and water (10%) [1]. Jute is widely used in the packaging industry due to its eco-friendly, biodegradable nature, offering a sustainable alternative to plastic. Jute plants clean the air by consuming large quantities of $CO_2$ gas, and it is reported that one hectored of jute plants can consume about 15 tonnes of $CO_2$ from the atmosphere and release about 11 tons of oxygen in the 100 days of the jute growing season.

It is cost-effective, strong, and durable, making it ideal for packaging heavy goods like agricultural products. Jute's breathability helps preserve perishable food items, while its recyclability and aesthetic appeal enhance its suitability for both industrial and premium packaging. The eco-friendly and biodegradable nature of jute has created a new domain in applying non-traditional diversified products. Different researchers have reported the diversified use of jute by modifying its mechanical and chemical properties. The product innovation of making green bags made of jute has been reported in the literature [2]. Some other researchers tried to incorporate the used jute sacks into recycled polyethylene to make composites, which may be used as alternative materials for low-strength conventional composites [3]. The Central Pulp and Paper Research Institute reported that plants with good cellulose content can produce paper [4].

## MATERIALS

### Raw Material

The present work used jute slivers and jute caddies from the carding process, and corn husks to produce handmade paper.

## METHODS

### Papermaking from Jute Sliver

Jute sliver was treated with 18% (w/v) sodium hydroxide solution at boiling temperature for 90 min to remove hemicellulose. Thealkali-treated jute sliver was neutralised with acetic acid and ground using an electrical mixer grinder. After that, following the traditional method of papermaking, all the processed jute slivers were mixed with soluble starch and a paper sheet was formed with the help of a screen. The screen was dipped into the pulp mixture, allowing a thin layer of pulp to settle on the screen. As the water drains away, the fibres bond together to form a sheet of paper. A paper-thin sheet was extremely soft and lightweight, but its strength was low. This paper can be used for

lightweight fashionable bags. **Figure 1** shows the flow chart for producing handmade paper from jute slivers.


**Figure 1** Flowchart of papermaking using jute sliver

**Papermaking from Jute Caddies and Corn Husk**

Jute caddies and corn husk in equal proportion were treated with 18% (w/v) sodium hydroxide at boiling temperature for 90 min to remove hemicellulose. After alkali treatment, acetic acid was used to neutralise alkaline residues. The mixture was rinsed thoroughly with water to remove excess acid and impurities. This mixture was then ground with an electric mixer to produce a pulp. The traditional screen method was used to form the sheet of paper from this pulp. The pulp was evenly spread by hand onto a screen, allowing a thin layer to settle. The fibres bonded as the water drained to form the paper sheet. The wet sheet was transferred onto cotton fabric and pressed with a sponge to absorb excess water. Once air-dried, a thin, solid sheet of paper was formed.


**Figure 2** Flowchart of papermaking from jute caddies and corn husk

## TESTING AND CHARACTERISATION

### Measurement of Areal Density

The mass per unit area of handmade paper produced from jute caddies and corn husk was measured as per ISO 3801-1977.

### Measurement of Tearing Strength

The tear Strength of handmade paper in both horizontal and vertical directions was measured following the method described in IS 6489-1993 (Superceding standard: IS 6489-1: 2011. This method is based on the ballistic pendulum Method (Elmendorf).

### Measurement of Tensile Strength

The breaking strength of handmade paper in both horizontal and vertical directions was measured following the ASTM D-5034 standard. The ASTM D5034 uses a grab method to determine maximum force and elongation at maximum force, gripping only the specimen's centre in jaw faces.

### Measurement of Bursting Strength

The bursting strength of paper measures the pressure required to rupture or burst a paper sample. It is an important parameter for evaluating the durability and performance of paper, particularly in packaging applications where the material must withstand significant pressure and stress without failing. The bursting strength of handmade paper produced from jute and corn husk was measured following ASTM D-3786.

### Measurement of Abrasion Resistance

The abrasion percentage of paper refers to the measure of the paper's resistance to surface wear caused by friction or rubbing. The abrasion of handmade paper was measured following IS 12673-1989. This standard prescribes methods for the determination of the resistance to flat abrasion and flex abrasion.

### Assessment of Antifungal Activity

The hand-made paper made from jute and corn husk and jute, corn husk and neem (Azadirachta indica) leaves were subjected to AATCC 30: Part 3-2017 Test Method to assess Antifungal activity. For the evaluation of the relative resistance of two different handmade papers, the percentage of surface growth of Aspergillus niger was rated according to the table mentioned below.

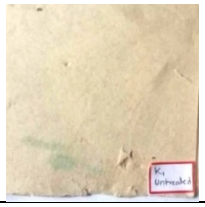
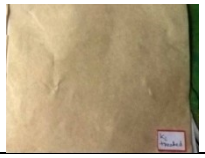
| Growth on specimen | Rating |
|---|---|
| No growth | 0 |
| Trace of Growth (<10%) | 1 |
| Light Growth (10 to 30%) | 2 |
| Medium Growth (30 to 60%) | 3 |
| Heavy Growth (60% to complete coverage) | 4 |

## RESULTS AND DISCUSSIONS

### Antifungal Activity

**Table 1** shows the antifungal activity of untreated and treated paper. The controlled paper shows no zone of inhibition andfungalgrowthpresentonthepaper.Therating3signifiesmediumgrowthof fungus (30 – 60%) on the paper made from jute and corn husk. It implied that jute and corn husk is not a fibre with inherent antifungal activity i.e., antifungal activity is absent. However, the same paper when produced by the addition of neem leaves during pulp formation shows no fungal growth below or above the sample. This suggests that neem acts as an antifungal agent on paper and this paper can be used in various applications where anti-fungal activities are of important requirements.

**Table1** Antifungal activity of untreated and treated paper

| Sample Identification | Zone of Inhibition | Rating | Interpretation |
|---|---|---|---|
| 1. Controlled  | No zone of inhibition. Fungal growth present on the paper | 3 | Antifungal activity absent |
| 2.Treated with neem  | No zone of inhibition but no fungal growth below or above the sample | 0 | Antifungal activity present |
| Whatman Filter Paper Viability Control | | 4 | Antifungal activity absent |

**Measurement of Different Mechanical Properties**

The handmade paper produced from jute caddies and corn husk was tested through different parameters: tensile and tear strength, bursting strength, and abrasion resistance. The test results are shown in **Table 2**.

**Table 2** Different mechanical parameters of handmade paper from jute and corn husk

| GSM | Source Material | Tensile strength (kgf) | | Tear strength (N) | | Bursting Strength (psi) | Abrasion% |
|---|---|---|---|---|---|---|---|
| | | Horizontal | Vertical | Horizontal | Vertical | | |
| 114 | Jute and corn husk | 11.08 | 13.13 | 1.93 | 2.07 | 10.08 | 5.4 |

## CONCLUSION

Jute waste can effectively be utilised to produce handmade paper, which may be used to make packaging in diverse fields. These eco-friendly alternatives will undoubtedly improve the environment by reducing the use of plastic products, particularly single-use plastic. The antifungal result also encourages using natural antifungal agents for producing packaging, which requires antifungal properties. This study has also analysed and reported the mechanical properties of handmade paper made from jute caddies and corn husks. Plenty of scope exists for using natural waste to convert it into handmade paper.

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133_IEC70372

# Sustainable Textiles through Natural Dyes — a Shift from Fast to Slow

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***Abstract:*** *The global environmental impact of human activities, particularly in the textile industry, has reached a critical stage due to toxic chemicals, effluent release on water bodies and many other practices. Fast fashion is fuelling this issue by contributing to pollution and waste generation through overproduction and overconsumption of cheap synthetic fibres. The study highlights the pressing need for a shift towards a slow fashion model by exploring techniques of fabric colouration with natural dyes and innocuous mordants free from heavy metals. This paper emphasises the importance of adopting a sustainable slow fashion model by incorporating natural dyes and traditional techniques.*

***Keywords****: Fashion; Fast; Mud-Resist; Slow; Textile*

## INTRODUCTION

Human activities adversely impact the environment in various ways; textile production, processes, and disposal are some of the key contributors to this phenomenon. The environmental impacts of textiles can be categorised at every stage, including raw material collection and production, transportation, fabric manufacturing, dyeing, finishing, use, and disposal. From the extraction of fibres to the final product, it consumes significant energy, water, and chemicals. Moreover, processes including dyeing and finishing release toxic effluents to water bodies, affecting the ecosystem. In addition, the disposal of textiles, especially synthetic textiles (non-biodegradable materials like polyester), plays a significant role in polluting the environment by accumulating in landfills for ages [1]. Fast fashion trends further fuel overconsumption, which leads to excessive production of cheap polyester clothes and waste generation. At this juncture, it is essential to slow down and think about the environment by introducing and adopting green and resource-efficient products and processes. Slow fashion as a business model emphasises ethical production and sustainable practices [1]. It reduces overproduction, encourages conscious consumerism, durable clothing, and fair labour practices, and minimises environmental degradation. This study promotes a slow fashion model by exploring natural dye on natural fibres alongside different printing applications to broaden consumer acceptance. The natural dye application extends beyond traditional colouring; it also improves functional properties such as UV protection and antimicrobial properties of the fabric. Natural dyes require mordants that fix them to the fibres and enhance their fastness properties. Metal mordants are widely used, but some of them generate toxic effluents. Researchers are trying to replace these heavy metals with eco-friendly, bio-inspired mordants.

## MATERIALS

### Fabrics and Yarn

In the present study, cotton fabric with an areal density of 100 gsm, 2/28 NM wool yarn, and 2/20 Ne organic cotton yarn were used.

### Natural Dyes

Indian Madder (Rubia cordifolia L.), Lac (Laccifer lacca), Khayer (Acacia Catechu), Myrobalan (Terminalia chebula), Natural indigo (Indigofera tinctoria) were used for dyeing and printing purposes of textile substrates as mentioned.

### Mordants

Myrobalan, alum,iron rust and citric acid were used as mordanting agents.

## METHODS

### Masking the Dye Penetration through Clay

The penetration of dye is restricted through a mechanical resisting technique, which is deeply rooted in traditional practices. One such age-old technique is Daboo, practised in the Indian state of Rajasthan for centuries. This study focuses on traditional Daboo printing, with a special touch of West Bengal. The process began with preparing the clay paste; the clay used was sourced from the local area of Birbhum, West Bengal. Next, this clay was combined with other ingredients (insect-eaten wheat flour, gum arabic, and calcium oxide) to increase the resisting and binding properties of clay [2]. Once the paste was prepared and meticulously transferred into fabrics using wooden blocks and paintbrushes. After applying these resisting agents, the sawdust was sprinkled over the fabric, which helped it quickly dry. Next, the fabric was immersed in the indigo vat; then, it was washed thoroughly to remove the resist paste and excess dye present in the fabric. The dyeing of fabric with indigo was performed following a standard process using hydrosulphite and alkali.

### Application of Clay as Bio-Mordant

This study included another experiment where clay performed the role of bio-mordant instead of resisting material. The experiment combined the basic process of mud resist, but only the application was performed on a pre-dyed fabric with myrobalan. Once the fabric dried, it was dipped into a natural dye bath (Manjistha) and washed.

### Reversible Woven Stole with Natural Dyed

This study explored the realm of weaving utilising naturally dyed (lac and Indian madder) organic cotton and wool to produce a reversible stole.This study follows a 1/3 twill weave structure as it possesses some distinct surface texture, which adds visual depth to the fabric and a different functional value.

## RESULTS AND DISCUSSION

The main purpose of these three experiments is to produce different textile products that align with consumer needs. Most importantly, this study emphasises slow fashion. The former experiment produced traditional mud-resist printing, resulting in an impressive pattern. However, the final product showed a slightly reddish tone due to using red soil sourced from the Birbhum district of West Bengal. The second study resulted in a unique surface pattern, as only the areas printed with clay darkened, providing a tonal surface pattern on the fabric. The final experiment produced an interesting stole that can be used on either side.

## CONCLUSION

Textile plays an essential part in expressing individuality. However, this industry has significantly contributed to the overproduction of cheap clothes, fuelling the fast-changing trendy market. This study demonstrated the potential of natural dyes, traditional techniques, and new explorations in the same field. Although it is crucial to remember that natural dyes may not be a complete alternative to synthetic dyes, they can contribute to sustainability.

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205_IEC55108

# Cradle-to-Gate Life Cycle Assessment of Perlite Based Composite Plaster Developed with Upcycled Material

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***Abstract:*** *This study examines the environmental performance via cradle-to-gate life cycle assessment (LCA) of perlite based composite plaster developed with upcycled flue gas desulfurization (FGD) gypsum as replacements for cement in plaster production. A novel laboratory-scale assessment is performed using openLCA software and ecoinvent database. Three distinct formulations are developed and subjected to physical, chemical, mechanical and environmental assessments. Present analyses confirmed the advantageous effects of using FGD gypsum and perlite by significantly reducing the dry bulk density of the developed composite plaster, notably achieving 687kg/m$^3$. To enable broader applications of developed composite plaster, LCA is performed on five categories; climate change, energy resources, water use, human health and ecosystem quality. GPP3 mix presents a promising environmentally sustainable lightweight composite plaster. In the composite plaster production, the minimum contribution and maximum benefit is from the non-renewable energy resource consumption (-24.916MJ) along with -1.897$CO_2$-Eq climate change impact. Gypsum plaster production creates the highest impact of ecosystem quality as 0.212PDF m$^2$yr. Present study upcycles the by-product FGD gypsum from coal fired power plants for development of lightweight interior single coat plaster. This work will solve the problem of industrial waste disposal and help in reducing the environmental impacts of construction sector.*

***Keywords:*** *Perlite; FGD Gypsum; Composite Plaster; Life Cycle Assessment*

## INTRODUCTION

The swift advancement of urbanisation and population growth, coupled with the environmental repercussions of human endeavours, necessitate substantial demands for the innovation of new construction materials. From an environmental standpoint, industrial waste-based processes are recommended for the production of plaster. Sustainable developments represent an essential part of modern building materials design. In this regard, one of the goals of the performed study consists of mitigation of the environmental burden related to plaster mix production [1]. The relevance of resource consumption in the construction sector leads to consider materials and energy resources as a relevant factor, both for ecological reasons and for the need of suitable technical tools and organizational measures to reduce the costs of construction. Therefore, it is necessary to consider the resource consumption with deep attention within a comprehensive environmental sphere. Life cycle assessment (LCA) is a methodology derived from environmental impact assessment, which is widely applied in a critical analysis of industrial systems using materials and energy resources. The main goal of LCA is to assess the effective use of materials and energy and their relative environmental impacts [2].

One of the preeminent waste which is obtained from the coal-fired power plants is flue gas desulfurization (FGD) Gypsum. The problem of discarding FGD gypsum has become a crucial factor [3]. A siliceous volcanic rock called perlite is found in nature and is an amorphous metastable aluminium silicate. When heated quickly to its softening temperature, which ranges between 900°C and 1200°C, perlite generally expands between 5-20 times its original volume, which distinguishes it from other volcanic glasses [4]. This expansion is brought on by the combined water in the raw perlite rock [5]. Perlite has long been utilized as a lightweight alternative to cement and mortar. Expanded perlite has several other desired physical characteristics for industrial usage, including low bulk density, high surface area, low sound transmission, low thermal conductivity, superior heat resistance and chemical inertness [5, 6].

Compared to cement-based materials, the scientific knowledge regarding the use of alternative materials in the manufacturing of construction materials is currently limited [7]. This paper introduces a novel approach, calculating

laboratory scale inventory through literature and experiments, bridging theory and practical implications. Most of the existing research focuses primarily on the characterization stage, neglecting the critical importance of the environmental performance phase [5].

In the present work, we proposed to develop perlite based plaster with FGD gypsum for construction application. Three mixes of β-hemihydrate gypsum and perlite were envisaged in different proportions to develop gypsum perlite plaster (GPP). The GPP were cast into cubes and studied for their compressive strength. GPP samples were investigated for their physical, chemical and environmental assessments. LCA allows the analysis of the process, from cradle-to-gate using openLCA software and ecoinvent database.

## MATERIALS AND METHODS

### Materials and Mixes

The samples of FGD gypsum were collected from NTPC-Vindhyachal, Super Thermal Power Station (VSTPS), Singrauli, Madhya Pradesh and perlite used in the present study was procured from market. Raw FGD gypsum was calcined at 150°C to obtain β-hemihydrate form. Formulations of GPP are shown in **Table 1** with 0.05% of DTPA as retarder.

**Table 1** Mix compositions of gypsum perlite plaster (GPP)

| Mix Designations | Hemihydrate plaster (%) | Perlite (%) |
|---|---|---|
| GPP1 | 96.0 | 4.0 |
| GPP2 | 95.0 | 5.0 |
| GPP3 | 94.0 | 6.0 |

### Life-cycle Assessment (LCA)

This study employed LCA methodology, specifically following the International Organization for Standards 14040 (2006) guidelines to calculate the environmental impact over the life cycle of the developed plasters. The approach followed is consistent with an attributional LCA, where the inputs and outputs were attributed to the functional unit (FU) of the system by linking the unit processes of a system under procedure [8]. Four main steps are performed: goal and scope, inventory analysis, impact analysis and interpretation of results [7]. The FU adopted in this study is the production of 1kg composite plaster with 687kg/ m3 bulk density. In the cradle-to-gate production stages, all impacts arising from the extraction of raw materials and procedure of production of plaster until the gate of the factory (i.e., composite plaster ready for use) are accounted. The analysis was conducted using openLCA 2.2.0 software and ecoinvent v3.10 database. The IMPACT World+ v2.0.1 technique was utilised, specifically emphasising impact categories: climate change, energy resources, water use, human health and ecosystem quality. **Figure 1** depicts the system boundary used in the present study.

## RESULTS

### Properties of Developed Plasters

Physical properties of the developed gypsum perlite plaster (IS:2542-1978) and gypsum (ß-hemihydrate) plaster (IS: 2547-1976) are expressed in **Appendix 1** and **2**, respectively.

### Environmental Life Cycle Impact Assessment (LCIA)

The environmental life cycle impact assessment is performed via cradle-to-gate analysis which focuses on the production process of the plaster mix to compare the impacts of the gypsum plaster with the perlite based composite plaster. Mix composition GPP3 with maximum perlite content and minimum dry bulk density is used for the present LCA study. **Figure 2** explains the LCIA results of plaster production. The results exposed that gypsum plaster

without perlite was a major contributor in all the impact categories of production. The LCIA results of developed plaster samples are obtained as negative values, which shows the environmental benefits of production. This means that the assessed production of composite plaster is overall decent for the environment as this reduces emissions and provides resources as raw materials [9,10].

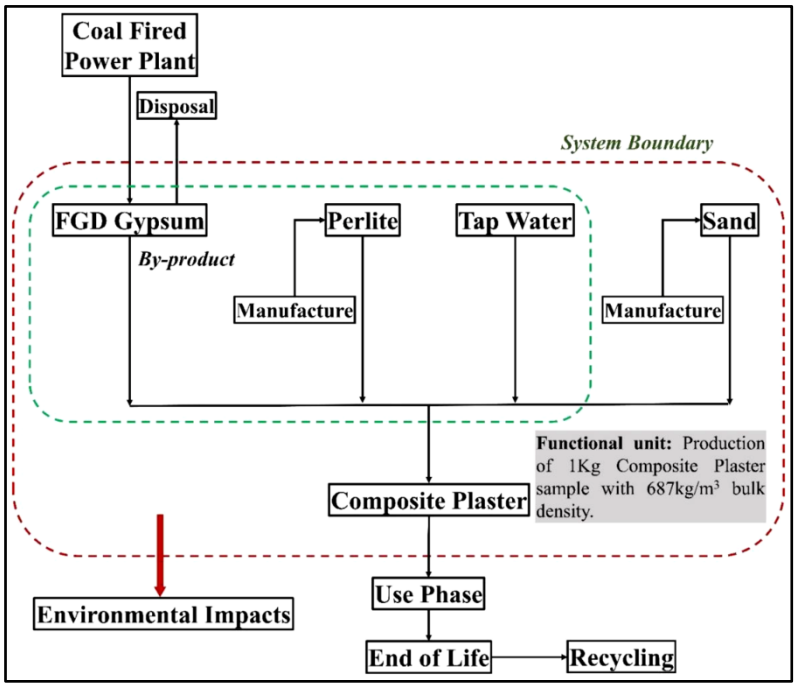


**Figure 1** System boundary used in the present study

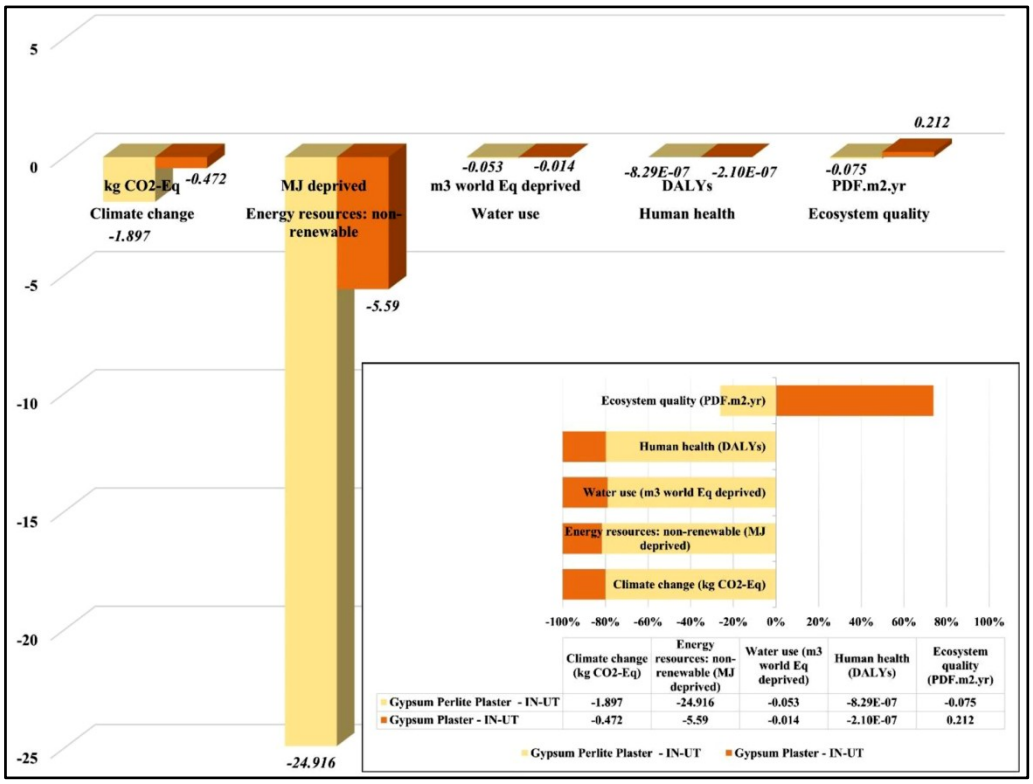


**Figure 2** LCIA results of developed plasters

In the composite plaster production, the minimum contribution and maximum benefit is from the non-renewable energy resource consumption (-24.916MJ) along with -1.897$CO_2$-Eq climate change impact. Gypsum plaster production creates the highest impact of ecosystem quality as 0.212PDF.$m^2$.yr. The literature on LCA of cementitious plaster systems is scarcely available and results are very dispersed [11-14]. The struggle of comparing existing results has also been earlier exposed in other research studies [15].

## CONCLUSION

A comparative LCA of composite plaster and gypsum plaster system based on IMPACT World+ method is presented. Five environmental impacts categories, climate change, energy resources, water use, human health and ecosystem quality, were assessed for both the plasters using cradle-to-gate approach. Based on the results, it has been observed that on increasing the percentage of perlite from 4-6%, compressive strength and dry bulk density decreases. Mix composition GPP3 with maximum perlite content and minimum dry bulk density (687kg/$m^3$) is used for the present LCA study. The Cradle-to-Gate analysis shows that composite GPP plaster production leads to around 80% resource savings and reduced $CO_2$ emissions compared to gypsum plaster. LCA results indicated that developed GPP is more environmentally sustainable than gypsum plaster due to its lower emissions and avoidance of excessive processing stages. The LCIA results of developed plasters are obtained as negative values, which shows the environmental benefits of production. Moreover, the developed composite plaster is operative in fortifying and alleviating industrial waste-based plaster for possible application in civil infrastructure. It is recommended to conduct further research that specifically examine the structural reactions and life cycle assessment of composite plaster-based structures in various applications.

## ACKNOWLEDGMENT

The authors are grateful to the CSIR-CBRI for granting the permission to publish this work. The financial support provided by CSIR for supporting project MLP12002 is also gratefully acknowledged. The first author is thankful to CSIR-India for providing the Research Associate Fellowship.

**Appendix 1** Physical properties of Gypsum Perlite Plaster (IS:2542-1978)

| **Parameters** | | **Values** | |
|---|---|---|---|
| | **GPP1** | **GPP2** | **GPP3** |
| Colour | Creamy white | Creamy white | Creamy white |
| pH | 7.30 | 7.28 | 7.26 |
| Loss on ignition (LOI) | 9.47% | 9.23 % | 8.90 % |
| Dry Bulk Density (powder) | 740 kg/m3 | 717 kg/m3 | 687kg/$m^3$ |
| Set Bulk density of cube (dried at 42oC) | 1100-1120 kg/m3 | 1010-1030 kg/m3 | 1000-1010 kg/m3 |
| Specific gravity | 1.96 | 1.86 | 1.76 |
| Consistency | 55.00% | 57.00% | 60.00 % |
| Fineness: RetRetention on 45 µm sieve | 10.0- 15.0 % | 10.0-15.0 % | 10.0-15.0 % |
| Setting time | 20-25 min | 20-25min | 20-25 min |
| Compressive strength (2.5 x2.5x2.5$cm^3$)<br>7 days<br>28 days | <br>11.72 MPa<br>11.59 MPa | <br>10.93 MPa<br>10.83 MPa | <br>10.08 MPa<br>10.08 MPa |
| Flexural Strength<br>7 days<br>28 days | <br>4.50 MPa<br>4.50 MPa | <br>4.05 MPa<br>4.05 MPa | <br>3.6 MPa<br>3.6 MPa |
| Soundness (Max. 5. As as per IS:6909- 1990) | ~1.5 mm | ~1.5 mm | ~1.5 mm |

**Appendix 2** Physical analysis of ß-hemihydrate plaster (IS: 2547-1976)

| Parameters | Values | IS: 2547-1976, Part I requirements | IS: 8272-1984 requirements |
|---|---|---|---|
| Colour | Off white | ---- | ---- |
| pH | 7.5 | ---- | ---- |
| Normal Consistency | 50.0-52.0 % | ---- | ---- |
| Setting time (without retarder) | 5 min | 20-40 mins | 20-30 min |
| Compressive strength (retarded plaster) DTPA (0.05 %) | 12.50 MPa | ---- | Min.: 7.6 MPa |
| Transverse strength DTPA (0.05 %) | 5.25 MPa | Min. 0.50 MPa | ---- |
| Soundness | Set plaster does not show any sign of disintegration, popping or pitting | Set plaster shall not show any sign of disintegration, popping or pitting | ---- |
| Residue on 90 µm sieve | < 3.0 % retained | Max. 5.0 % retained | Max.: 1.0 % residue on 600 µm sieve |
| Expansion of set plaster | 0.0040 mm | Max. 0.20 at 24 hours (applicable to final coat plaster) | ---- |
| Dry bulk density | 880-920 kg/m$^3$ | ---- | ---- |
| Dry bulk density at 42°C (cube) | 1400-1450 kg/m$^3$ | ---- | ---- |
| Dry bulk density at 105°C (cube) | 1305-1355 kg/m$^3$ | ---- | ---- |

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297_IEC77354

# Waste Management and Circular Economy

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***Abstract:*** *The conception of waste has changed into the new area of raw materials used for the next process to convert in the form of Circular Economy to help the mankind in various ways. The wastages are of different in in nature i.e. Organic, solid waste, liquid waste, recyclable and hazardous . Today's idea of refuse, reduce, reuse, repurpose, repair is very common among the domestic and industrial Circle. The whole concept of those 5 R is to save energy , environment, to generate energy, and to be economical. However, the hazardous wastes, in general, are non- recyclable . More and more wastages are generated from the Industries, households, eateries, hospitals, prisons, school & colleges are controlled by local municipalities and most of them are being recycled to create biogas, electricity, and composed for using fertilizers. There are limitations in waste management system because of the lack in knowledge , equipment, and skilled manpower in the municipal bodies. The Circular economy is to create energy from all types of wastages through suitable designs and Technology. It is now-a-days started by various organizations, all over the world to produce electricity, biogas and Gobar gas.*

***Keywords:*** *Recycle; Energy; Environments; Control of Waste; Technology*

## INTRODUCTION

What is a waste? It means to throw away the remaining's finding as if of "No use" which is derived from the regular production Process. It is treated as 'unnecessary' and hence sold out to an out sider at a throw-out rate just to get rid as a burden. When there is no taker of these unwanted residue, some manufacturers throw it in barren land or nullah, or river making them polluted. But today, the situations are changed drastically. Nothing is considered as 'waste' but it is considered as a raw material for the further process to make the industries to be more economical.

The conception of Refuse, Reduce, Reuse, Recycle and repurpose has started thereafter.

There are in general, Five types of waste:

- Organic waste: Generated from food, fruits, and vegetable (**Picture 1**).
- Liquid waste: Includes dirty water, wash water, organic liquids, waste detergents, and sometimes even rainwater derived from rusted pipes (**Picture 2**).
- Solid waste: It is generated from the household materials such as torn out plastic items, trash, and that of factory's unuse items. Pl refer **Picture 3**
- Recyclable waste: Which are possible to recycle in various ways i.e. Papers, card boards, metals, glasses, biodegradable plastics, textile materials, tyres, batteries, and electronic items. Please refer **Picture 4**
- Hazardous waste: which are having harmful effects on human, animal, and creatures. They are not recyclable. For example, paints and burnish, pesticides & chemicals, used oils removed from the cars, dyes and chemicals. Please refer **Picture 5**

**Picture 1** Organic waste

**Picture 2** Liquid waste

**Picture 3** Solid waste

**Picture 4** Recyclable waste


**Picture 5** Hazardous wastes

**OTHER TYPES OF WASTE INCLUDE**

- Municipal solid waste: they are household wastages, food related wastages generated from the hotels and restaurants, schools and hospitals, Offices, prisons etc.
- Industrial non-hazardous waste: It is generated from the industries though not directly harmful for the human. But if decomposes, create methane emissions, and must be managed in proper way. In the Cotton Textile Mills, the cotton dusts are thrown away which are creating problems for the natures nearby trees. Now a days it is absolutely recycled.
- Agricultural and animal waste: Agricultural and animal wastes (faces, urine etc) are significant environmental burdens that may lead to ground and water pollution if not utilized properly. For example, the burning of agricultural wastes results in air pollution and emission of the GHG.
- Medical waste: It all ranges from used needles and syringes to soil dressings, body parts, diagnostic samples, blood, chemicals, pharmaceuticals, medical devices, and radioactive materials.
- Radioactive waste: It generated as a by-product of producing or using radioactive materials by industries such as mining, nuclear power generation, defense, medicine, and certain types of scientific research.
- Construction and demolition debris; It is very common thing found in the cities which are Improper disposal of waste which can lead to issues like pollution, health risks, and resource depletion. It is a big nuisance also for the road users.

**WHAT IS WASTE MANAGEMENT?**

To control and monitor all the above hazards, semi hazards and non – hazardous in the scientific ways are known as waste management.

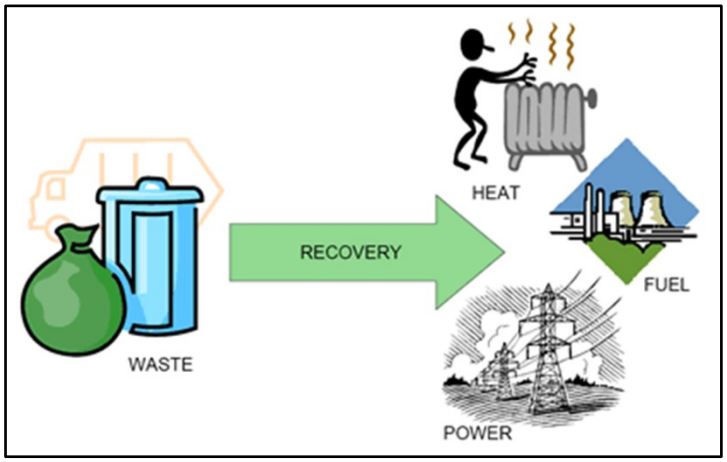
It is to streamline the processes to follow the theories of dispose, to prevent the formation of any waste and to create the environment clean. The waste disposal system should be a very much scientific and with friendly atmosphere. The waste disposal includes collection from the sites, to transport to the proper area and to treat the waste following the methods of waste related laws and technologies.

The more effective waste Management can be controlled by 7 R — (i) Refuse (ii) Reduce (iii) Re use (iv) Repair (v) Repurpose (vi) Recycle and (vii) Recover.

The point no (i) and (ii) indicates non – creation of waste i.e refuse, for example avoid crackers, inflammable, toxic or corrosive. Reduce (ii) for example to carry cloth bags instead of Plastic, instead of purchasing so many small items, purchase a large size that will reduce the usage of the hazardous items. Please refer **Picture 6**. (iii) reuse: For example, the cotton waste is reused in formation of pillows, and making coarser yarns. It means to use the same item again and again, say torn cloths, books, kitchenware, empty food container etc. (iv) repair means despite of throwing out the broken items, it can be repaired instead of purchasing a new one. (v) Repurpose means it is just to use the separate purposes like metal cans, Buckets etc. Please refer **Picture 7** for this example. (vi) Recycle: It involves huge examples i.e. polyester waste, plastic bottles to fabric and so on. (vii) Recover: It means to transform wastages into another resource, composting of the materials – say formation of biogas, go bar gas, from human excreta, animal slugs, organic wastages etc. Please see **Picture 8**.

**Picture 6** One big can reduce wastage


**Picture 7** Repurpose




**Picture 8** Waste recovery

**THE PROBLEMS WITH THE WASTE MANAGEMENTS**

Most of these are managed by the local municipalities, where there is large scale apathy in work cultures, shortage of

the machineries and skill work force. Times, Mumbai 30.9.24 published (i) “Sewage sent to Ulhas River, NGT fines TMC Rs.102cr.(ii) ‘Dues unpaid' garbage piles left at Thane energy plant. (iii) State's legacy waste at 1.42 Cr. Ton, threat to soil & ground water, times, Mumbai, 2.10.24. Such problems are much more at several places.

**CIRCULAR ECONOMY**

What is that? The circular economy can help tackle challenges such as waste gestion, pollution, biodiversity protection and climate change, by reusing production waste and by-products to reduce consumption of resources and safeguard the needs of future generations. The circular economy is defined as a system to minimise the wastages, closing the energy leakages and to renovate something new that helps the mankind through the biodiversity, stopping pollution at every level. These can be achieved through proper design, maintenance, by using 5-R policies. it should use as a cheaper raw material to manufacture any value-added products.

The **Picture 9** describes in short, the mode of Circular Economy. Which is explained in point no 5.


**Picture 9** Circular Economy

**Another Unique Example of Circular Economy**

Several ‘Waste to Energy" Project are initiated Ministry of New and Renewable Energy. One such Energy Plant is recently set up in Maharashtra at Pune area.

In this Plant the Dry and wet wastages are segregated , then the dry waste is burnt in furnace at a temperature of 1000-1100 degree centigrade , water is passed through pipes , forming steams , goes to turbine and generates electricity. It has the capacity to recycle 700 mt of waste per day and generates 14-megawatt electricity per day. Hence from the dry waste , 100% electricity is generated , and from the wet waste composed / fertilizer is made. It is a totally pollution free industry. **Picture 10** and **Picture 11** are showing the energy plant.


Picture 10


Picture 11

## DISADVANTAGE OF CIRCULAR ECONOMY

- Lack of infrastructure: There may not be enough infrastructure to recycle and reuse different types of materials.
- Technical challenges: Some products and materials may not be technically feasible for circular solutions. For example, recycling is not completely environmentally friendly and not all waste can be recycled.
- Data issues: Monitoring data is complex, especially for environmental impacts.
- Implementation challenges: Transitioning to a circular economy is complex and faces barriers to scaling.
- Limited availability: Circular products and services may be limited.
- Cost: Products designed for circularity may have a higher upfront cost.
- Limited choices: Circular economy may limit the range of products available to customers.

## CONCLUSIONS

- 'The waste is a waste' is no more an acceptable criterion to anyone. It is changed to the new theories. Of again and again usable by adopting various processes. In our Textile Industries, almost every place is waste free zone.
- Sometimes the waste is the cheapest raw material for the further productions.
- The hazardous wastes are not always recyclable.
- The waste Management is not always manageable status by some municipal authorities because of lack in technologies, shortage of equipment's and that of skilled work force.
- The conception of Circular Economy is creating electricity, biogas, Gobar Gas is nice to accept into the society. More and more plants are coming up in various states under the 'Ministry of New and Renewable Energy'.

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318_IEC429

# Smart Waste Management: A Community-Driven Revenue Generation Model for Small Townships

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***Abstract:*** *The increase in population has surge the demand of all essential services. The increasing demand and supply, change in lifestyle and march towards a cosmos life has led to and poor management in various sectors. Among these, waste management stands out as one of society's most pressing challenges. Traditional methods of waste disposal are increasing the burden on land and contributing to land pollution, hampering the environment. Due to Change in life style the change in waste generation has also changed. It has given a rise to an urgent need to develop sustainable and effective waste management strategies. The existing literature highlights the problems encountered in pre and post waste managing services. In response, to manage the waste at the source and to encourage the people's participation a revenue generation model is proposed and applied to a small residential area, colony. This model is designed is to generate revenue through awareness and implement "3 R's" (Reduce, Reuse, Recycle), making the residential colonies self-sufficient. A comprehensive study on revenue generation and its management is presented, demonstrating the effectiveness of this approach.*

***Keywords:*** *Revenue Generation; Smart Waste Management; Reduce; Recycle; Reuse; Community Engagement*

# Information & Communication Technology

## 5G/6G Communication

152_IEC74748

# Design and Analysis of Compact Antenna for 5G Advanced mm Wave Bands for V2X Wireless Telemetry Applications

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***Abstract:*** *This paper presents a compact, wideband antenna designed for modern mm-wave communication systems, particularly 5G applications. The antenna employs a combination of meander line and ring-loaded structures to enhance current density and performance across multiple frequency bands designed on a Roger substrate measuring 28 mm by 42 mm, with a height of 1.6 mm, and the antenna achieves a peak gain of 8.4 dBi with 20 dB front to back ratio and –2.4 dB isotropic sensitivity and features wide band capabilities, with notches around 34.9 GHz and a minimum reflection coefficient of -35.4 dB. Covering frequencies from 34.4-38.8 GHz, it supports 5G bands n259, n260, V2X wireless telemetry, and ground-based navigation systems, making it ideal for advanced 5G applications.*

***Keywords:*** *Wireless Telemetry; Fractals; Microstrip Patch Antenna; Wireless Communication*

## INTRODUCTION

In wireless technology, antennas are becoming more and more important Advancements in fractal antenna technology have led to innovations in antenna design, such as multiband and wideband fractal antennas, which can operate across multiple frequency bands with improved efficiency [1-4]. Integrating three-way hybrid power dividers enhances antenna systems' efficiency and adaptability in wireless tech [5-7]. These dividers optimize signal distribution across multiple frequency bands by combining fractal antenna technology with multiband and wideband capabilities [8-13]. Such innovation elevates antenna performance in various applications, including mobile communication, Wi-Fi, and satellite links. A comprehensive literature survey reveals a spectrum of research [14-16], methodologies, and advancements in this field as follows:

In 2021, Bharti, and Sivia proposed ‘a multiband nested square-shaped ring fractal antenna’, showcasing the potential of fractal geometries in wireless applications [1] and Ullah and Tahir's (2020) ‘snowflake fractal antenna for dual-beam applications’ at 28 GHz [2]. In the realm of emerging technologies, Raj et al. (2023) presented ‘a high-gain Sierpinski carpet fractal antenna’ [3-4], contributing to the ongoing efforts to develop advanced antenna arrays for 5G communication. Furthermore, Raj and Mandal (2024) conducted ‘experimental analyses of fractal antennae’, showcasing their potential for 6G and 5G mm-wave communication [12]. Recent works by Verma et al. (2023) and Kumar et al. (2023) continue to ‘advance fractal-based antennas for 5G and millimeter-wave communication’ [13][14]. Raj and Mandal (2023) proposed ‘a novel substrate cylindrical cavity 4x4 fractal-inspired MIMO antenna for 5G - n258 satellite communication’, exploring innovative designs for satellite communication in the 5G era. Moreover, the literature survey underscores the diverse applications and ongoing advancements in fractal antennas for wireless communication. Researchers are actively exploring novel designs, array configurations, and experimental validations to meet the evolving requirements of 5G and future communication technologies, demonstrating the effectiveness of integrating fractal geometries in antenna design [15-16].

## NUMERICAL ANALYSIS

In the design of ‘microstrip patch antennas’, key parameters such as ‘patch width’ and ‘length’ are determined using mathematical formulas: The ‘patch’s width’ is accounted by:

$$\left( (W) = \left(\frac{(C)}{(2f\sqrt{\frac{\varepsilon r+1}{2}})}\right) \right) \quad (1)$$

Where, 'c' – Light's speed in free space = 3×108 $ms^{\wedge}$, $f_r$ – 'Operational freq.' , $\varepsilon_r$ – 'Relative permittivity'

Actual patch length calculated as:

$$\left(L = \left(\frac{1}{2fr\sqrt{\varepsilon}}\right) \times \left(\frac{1}{\sqrt{\mu\varepsilon}}\right) - (2 . \Delta L)\right) \quad (2)$$

($L^1$ = (L + 6.h)' and '($W^1$ = (W + 6.h))' as 'effective length & width'

$$\left(\text{Band width Percentage} = \frac{2(f2-f1)}{(f1+f2)} \times 100\right) \quad (3)$$

For '50 Ohms', the 'feed point Position' can be accounted by,

$$\left(('\text{Rin}(y = y0)') = (\ '\text{Rin}(y = 0)') \cos\left(\frac{\pi}{L} y0\right)^2\ \right) \quad (4)$$

Where ''$R_{in}$' '(y = y0)'' as '50 Ohms', Then ''$R_{in}$' '(y = 0)'' is roughly accounted as, ('$Z_{in}$') = ('$1/Y_{in}$') = ('$R_{in}$') = ('$1/2G_1$')

$$\left((G1) = \begin{cases} \left(\frac{1}{90}\left(\frac{W}{\lambda}\right)^2\right) & (W \ll \lambda) \\ \left(\frac{1}{120}\left(\frac{W}{\lambda}\right)\right) & (W \gg \lambda) \end{cases}\right) \quad (5)$$

**ANTENNA DESIGN**

The proposed antenna design follows a systematic four-step process to achieve enhanced multi-band performance and compactness. In Step 1, the bare kite-shaped patch is introduced, serving as the foundation for further modifications.

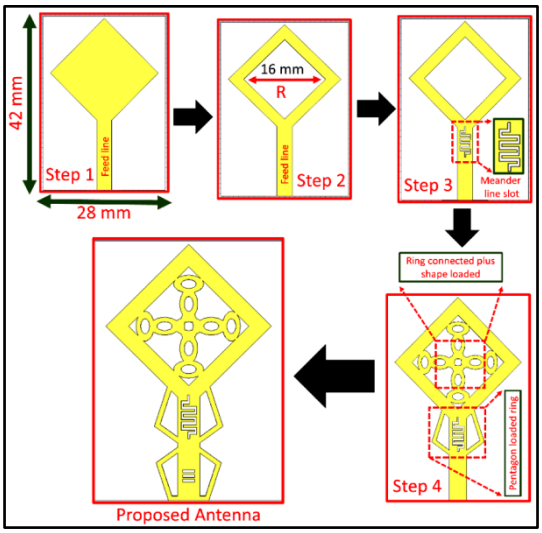


**Figure 1** Stepwise evolution of the proposed kite-shaped antenna design with meander line and ring-loaded structures

In Step 2, a circular ring with a 16 mm radius is added at the center, effectively improving the current distribution and enhancing resonance at higher frequencies. In Step 3, a meander line slot is incorporated, which increases the surface current path, thereby improving the antenna's impedance matching and return loss performance. This step is crucial for widening the operating frequency range and achieving better resonance at specific notches.

Step 4, the final stage, optimizes the antenna's performance by integrating ring-connected and shape-loaded structures. This modification enhances the bandwidth and radiation characteristics, allowing the antenna to cover a wide frequency range from 10-40 GHz, particularly for mm-wave and 5G applications. The ring-loaded structure aids in minimizing reflections and improving the antenna's gain, which reaches a peak of 8.4 dBi while maintaining optimal performance across several critical bands.

## RESULTS AND DISCUSSION

The comparative analysis of the proposed antenna through its development stages, as depicted in **Figure 2** (Step 1 to Step,4) and **Table 1** reveals notable improvements in key parameters, such as bandwidth and return loss. In Step 1, the antenna resonates between 32.3 GHz and 38 GHz with a return loss reaching up to 29.7 dB but with limited bandwidth (0.2-0.4 GHz). Progressing to Step 2, we observe a more comprehensive frequency range (21.6 GHz to 39.5 GHz) and an improved return loss up to 38 dB, though bandwidth improvements remain moderate. However, parametric analysis performed in **Figure 2** Step 3 demonstrates further optimization, particularly at 34.1 GHz, with a modest bandwidth of 0.3 GHz and a return loss of 21 dB.

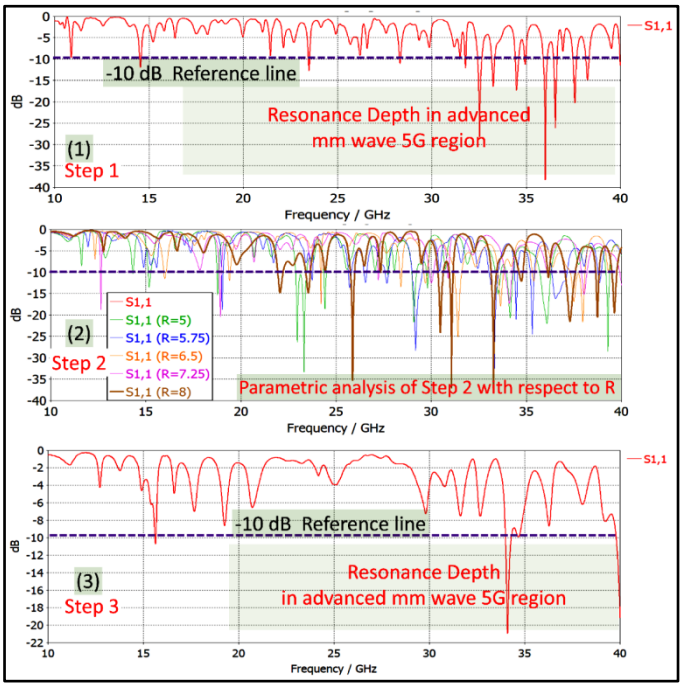


**Figure 2** Performance analysis of the step1, step2, step3, featuring Reflection Coefficient including parametric analysis

**Table 1** Comparative analysis of different parameters of proposed antenna concerning step1,2,3, and 4, respectively

| Figure 1 | F1 (GHz) | F2(GHz) | Bandwidth (GHz) | Return loss (dB) |
|---|---|---|---|---|
| Step 1 | 32.3 | 32.6 | 0.3 | 29.7 |
| | 33.1 | 33.3 | 0.2 | 16 |
| | 34.2 | 34.6 | 0.4 | 16.3 |
| | 36.1 | 36.3 | 0.2 | 37 |
| | 36.6 | 36.8 | 0.2 | 26 |
| | 37.1 | 37.3 | 0.2 | 20 |
| | 38 | 38.2 | 0.2 | 15 |
| Step 2 | 21.6 | 21.8 | 0.2 | 15 |
| | 22.8 | 23.2 | 0.4 | 15 |
| | 26.2 | 26.5 | 0.3 | 35 |
| | 30.7 | 30.9 | 0.2 | 24 |
| | 31.6 | 31.9 | 0.3 | 37 |
| | 33.1 | 33.5 | 0.4 | 38 |
| | 37.2 | 37.7 | 0.5 | 21.3 |
| | 38.6 | 38.8 | 0.2 | 20.2 |
| | 39.3 | 39.5 | 0.2 | 19.6 |
| Step3 | 34.1 | 34.4 | 0.3 | 21 |
| Step4 | 34.4 | 38.8 | 4.4 | 34.5 |
| **Proposed Antenna** | **34.4** | **38.8** | **4.4** | **35.3** |

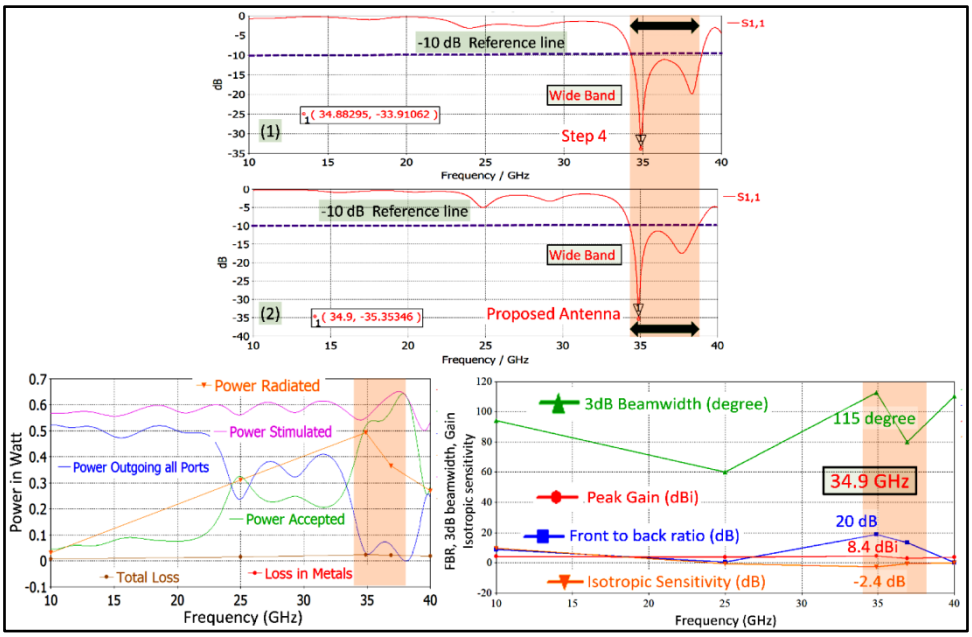


**Figure 3** Performance analysis of the proposed antenna design, featuring S11, FBR, Gain, Power, and Isotropic Sensitivity

In Step 4, notable improvements are observed: the bandwidth increases to 4.4 GHz, and the return loss enhances to 34.5 dB, signifying improved impedance matching and reduced signal reflection. The finalized antenna further refines this with a return loss of 35.3 dB. These advancements position the antenna as an excellent candidate for high-frequency applications requiring wideband coverage. Figure 3 details the antenna's performance from 10 to 40 GHz,

showing dominant power radiated at higher frequencies and a peak gain of 8.4 dBi at 34.9 GHz, with a 3dB beamwidth of 115 degrees, ensuring adequate coverage.

## CONCLUSION

The antenna performs effectively from 10 to 40 GHz, achieving a peak gain of 8.4 dBi at 34.9 GHz with a 3dB beamwidth of 115 degrees, ensuring sufficient coverage. Designed for modern mm-wave communication systems, particularly 5G, it utilizes meander line and ring-loaded structures on a compact Roger substrate, featuring a minimum reflection coefficient of -35.4 dB. It supports 5G bands n259, n260, V2X wireless telemetry, and ground-based navigation systems, making it ideal for advanced 5G applications.

## ACKNOWLEDGMENT

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188_IEC36941

# Selection of a Suitable Filter to Reduce ISI and Improve BER for 5G Links

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***Abstract:*** *The interference between the two consecutive symbols, received in two successive clock periods in a data communication receiver is a very common phenomenon. It happens mainly due to the fact that the waveforms generated corresponding to a symbol takes certain time to die down. This slow decay again has a role to play in the stability of the system. It is known from theory that filters can help to reduce this problem. However, theory also states that the effectiveness of different types of filters varies quite a lot. In this work, we have experimented with three types of filters- Butterworth, Chebyshev-I and Raised Root Cosine (RRC) filters. We have generated the comparisons in two formats –*

*(i) constellation diagrams to explain the ISI performance and*
*(ii) BER graphs. The objective is to show quantitatively the differences among the three filters in respect of their efficacy to reduce the effect of Inter Symbol Interference (ISI).*

*The definite way to compare the results is with the help of Bit-Error-Rate (BER) in all the three cases. We have derived results to prove that RRC type is the most efficient to reduce ISI.*

***Keywords:*** *BER; Butterworth Filter; Chebyshev Filter; ISI; RRC Filter*

## INTRODUCTION

The wireless communication has seen phenomenal improvements in the last two decades- both in terms of speed as well as in terms of reliability. Here, one has to remember that the vulnerabilities of wireless or radio communication has not decreased over time. Rather, with so many wireless networks working simultaneously, the chances of interference and thereby, fading has increased manifold [4,5,6]. In the realm of digital communication, this transferred to measuring the Bit Error Rate (BER) for a received file. If the BER was high, the file was requested for a second time or third time through the Repeat Request command. With improved technology- 2G-3G-4G or LTE-5G, the demand for speed and reliability of data kept on increasing. With higher speed, the time slots allocated to read bits is less and therefore the chances of erroneous bits is much more. As the operating frequency is shifting to UHF and SHF ranges, the phenomena like scattering, diffraction are also increasing. These integral problems are caused partly by the physical properties of the medium and partly by the lack of perfection in the design of the transmit filters and the receive filters.

A practical example is the radio channel, in which the transmitted signal reaches the receiver along multiple paths through reflections, diffractions and dispersion. The delayed components are equivalent to echoes that cause time dispersion of the transmitted signal. If time dispersion is greater than a pre-set fraction of the signaling period, the channel responses to the different data signals overlap. This effect is called the inter symbol interference (ISI) [1,2,3,11].

As a consequence, the signal observed at the receiver input in such a condition is a superimposition of a certain number of data signals. Therefore, ISI is a major impairment introduced by the channel. Our objective was to examine various well-known filters for their capacity to control the ISI. With this in mind, we compared, first, theoretically a few filters and tabulated their key parameters relevant to our exercise in the **Table 1**.

The next task was to analyze the filters and think of some simulation to bring out the results. We developed the simulation software in Python script.

**Table 1** A comparison of filters

| Filter Type | Characteristics | Roll-off Factor | ISI Performance | Applications | Notes |
|---|---|---|---|---|---|
| **Butterworth** | Maximally flat frequency response in the passband. No ripples. | No explicit roll-off factor | Moderate ISI. Does not provide steep transitions, so it allows some overlap. | General-purpose filtering, analog signal processing. | Good for basic applications, but does not minimize ISI as well as others. |
| **Chebyshev Type I** | Steep roll-off with ripples in the passband. | Depends on ripple and order | Improved ISI reduction, but the passband ripples can introduce slight distortion. | High-performance filtering, especially in communication systems. | Offers better transition than Butterworth but with passband ripples. |
| **Chebyshev Type II** | No passband ripples but allows ripples in the stopband. | Depends on ripple and order | Better ISI reduction than Type I, but potential distortion due to stopband ripples. | Applications requiring controlled passband response with fast roll-off. | Less distortion in passband but risk of stopband ripples affecting performance. |
| **Raised Root Cosine (RRC)** | Ideal for minimizing ISI in communication systems, particularly in digital communication. | Explicitly defined (α) | Excellent ISI performance due to controlled roll-off and flat passband. | Widely used in digital modulation schemes like QAM and PSK to minimize ISI. | Best filter for ISI minimization, especially in digital communication. |

**ANALYSIS**

Butterworth filters are known for their maximally flat frequency response in the pass band, meaning they introduce no ripples in the pass band, ensuring smooth signal transmission. This characteristic makes Butterworth filters suitable for applications where signal amplitude preservation is important. However, they have a relatively slow roll-off, which can allow some overlap between adjacent symbols in a communication system, leading to ISI. Therefore, while they help reduce ISI to some extent, their slow roll-off limits their effectiveness in very high-data-rate systems where sharper filtering may be needed.

Chebyshev filters, particularly Chebyshev Type I filters, offer a steeper roll-off compared to Butterworth filters at the expense of introducing ripples in the pass band (Type I) or stop band (Type II). The steeper roll-off helps better confine the signal within the bandwidth, reducing the overlap of neighbouring symbols and thus mitigating ISI more effectively in scenarios where sharper transitions are critical. However, the ripples in the pass band (in Chebyshev Type I) could distort the amplitude of the signal, which might lead to issues with signal integrity, depending on the system's requirements. SRRC filters pre-shape the pulses to reduce ISI [7,8,9,10]. The received signal with SRRC pulse shaping can be expressed as: $rSRRC(t) = pSRRC(t) * h(t) + n(t)$ , where pSRRC(t) is the pulse shaped raised cosine filter and is convolved with the channel response h(t), n(t) is the time-dependent AWGN factor. One tries to shape the SRRC pulse with a known roll-off factor.

The roll-off factor shouldn't be too high as then the spectral bandwidth (BW) is lower and spectral energy at the higher ends of the spectrum can cause severe ISI.

On the other hand, a lower value spreads the BW and as a result, the interference with the adjoining symbol periods is less. Usually a value of 0.5 is a common choice for the roll-off rate.

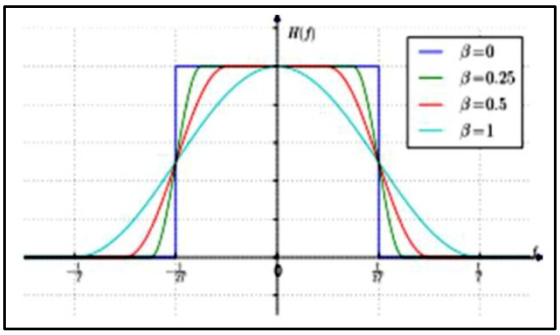


**Figure 1** The effect of roll-off factor on interference

Communication systems specifically targeting ISI reduction, roll-off filters like the Root Raised Cosine (RRC) filter are often preferred because they are designed to minimize ISI by controlling the bandwidth and phase response of the system. RRC filters offer a controlled roll-off factor, providing a trade-off between bandwidth efficiency and ISI mitigation. They ensure zero ISI at the symbol sampling points, making them a common choice in digital communication systems such as QAM.

**Key Differences**

Butterworth filters provide a smooth response, but do not suppress ISI as effectively due to their slower roll-off.

Elliptic and Chebyshev Type I/II filters offer faster roll-offs, which help reduce ISI but may introduce passband or stopband ripples that affect signal quality.

Raised Root Cosine (RRC) filters are specifically designed for digital communication and are the best at minimizing ISI, especially with their carefully controlled roll-off characteristics.

**RESULTS AND ANALYSIS**

We focused on the resultant BER since BER value is the most visible parameter to prove change or improvement in ISI. We carried out simulations increasing the modulation order from four to eight. The reason behind this is the fact that when the modulation order increases, the number of bits in the system automatically increases. It leads to more interference and degradation of Signal-to-Noise Ratio (SNR). Since, BER is inversely proportional to SNR, the BER increases.

These observations were established in the results of experimentation, which are shown in the figures. **Figure 2** shows that the performance of the RRC filter is the best. **Figure 3** proves that the BER increases even form RRC filter , when the modulation order is doubled from 4 to 8.

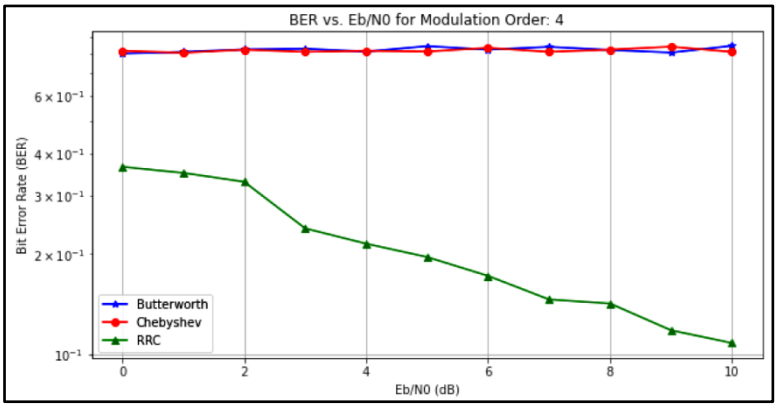


**Figure 2** The variation of BER when modulation order=4

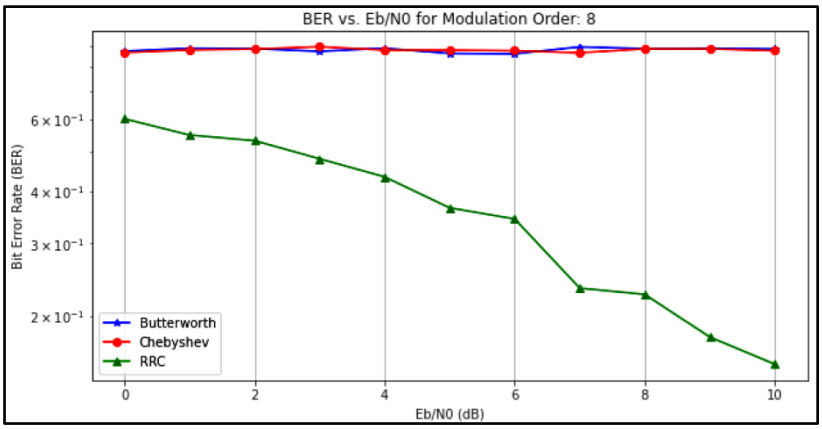


**Figure 3** The variation of BER when modulation order =8

## CONCLUSION

As we could find, there are many more combinations which can be tried to make the solution sturdier. We intend to try those along with other filter types also to improve the communication quality more.

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217_IEC56673

# Far Field Radiation Pattern Synthesis of Elliptical Antenna Array for 5G and 6G Communication Systems

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***Abstract:*** *This paper introduces a novel design strategy for a 12-element Time-Modulated Asymmetric Elliptical Antenna Array (ATMEAA) aimed at optimizing far-field radiation patterns for 5G and 6G communication systems. The design focuses on minimizing interference by reducing sidelobe levels (SLLs) and sideband levels (SBLs), both of which are critical for enhancing signal quality in high-frequency communication environments. To achieve ultra-low SLLs and SBLs, an optimal combination of switch-ON time sequences and progressive phase delays is employed. These parameters are fine-tuned using advanced metaheuristic optimization techniques, namely Grey Wolf Optimization (GWO) and Sail Fish Optimization (SFO) techniques. The practical implementation of ATMEAA is analyzed at a fundamental operating frequency of 2.4 GHz. Key performance metrics such as SLLs, SBLs, feed network efficiency, and directivity are evaluated using the GWO and SFO methods. The results demonstrate significant improvements in reducing unwanted radiation components and boosting antenna performance. This approach ensures the antenna array is well-suited for high-performance applications in next-generation 5G and 6G wireless communication networks, where minimizing interference and maximizing efficiency are paramount for reliable and high-speed data transmission.*

***Keywords****: Elliptical Antenna Arrays; Feed Network Efficiency; GWO; Sidelobe Level; Sideband Level; SFO*

## INTRODUCTION

The rapid advancements in wireless technology have revolutionized communication, providing consumers with faster and more affordable services. This surge in demand has fuelled the growth of the wireless communication industry, particularly in the transition to 5G and the development of 6G. However, to meet this increased demand, there is a need to enhance capacity, improve efficiency, and reduce interference. High directivity and real-time beam-steering antennas, which boost gain and spectral efficiency while minimizing multipath propagation, offer a promising solution [1]. One of the techniques being explored for this purpose is time modulation switching in antenna arrays. The concept of time-modulated antenna arrays was first introduced by Shanks and Bickmore [2], who proposed using "time" as a fourth dimension alongside space to control radiation patterns. This approach offers superior radiation pattern synthesis compared to traditional antenna array methods by adjusting Switch-ON time sequences. However, time modulation can also introduce sideband signals that transfer electromagnetic energy, causing interference. To mitigate this issue, sideband levels (SBLs) are incorporated into optimization procedures and evolutionary optimization techniques are applied to minimize these unwanted effects while achieving the desired antenna performance [3].

This research focuses on applying the time-modulated concept to elliptical antenna arrays [4], specifically analyzing key performance metrics for 5G and 6G applications. A 12-element, uniformly spaced elliptical antenna array is used to evaluate feed network efficiency (FNE), directivity (DIR), sidelobe levels (SLL), and sideband levels (SBLs). Through this approach, the study aims to optimize antenna design for next-generation wireless networks, improving signal quality and reducing interference.

The remainder of this paper is organized as follows: Part II describes the general framework for the mathematical modeling of the Time-Modulated Asymmetric Elliptical Antenna Array (ATMEAA). Section III provides a brief summary of the optimizer used to manage design variables, while Part IV discusses the development of the cost functions. Section V presents the numerical results, including the radiation pattern, convergence curve. Finally, Section VI concludes with a summary of the research findings.

## MATHEMATICAL MODELLING

The pattern multiplication concept suggests that the array factor and the radiation pattern of a single element at a chosen reference point can be multiplied to produce the overall field of an antenna array. Instead of using actual elements, isotropic point sources are often employed to calculate the array factor (AF). consider an elliptical array (EA) with N isotropic sources in the far field, focused on a point P. The array is defined by a semimajor axis of length 'a' and a semi-minor axis of length 'b' in the X-Y plane, as shown in **Figure 1**. If the components are isotropic sources, the radiation pattern of the elliptical antenna array (EAA) in the azimuthal plane (θ = 90°) can be modeled by **Equation (1)**.

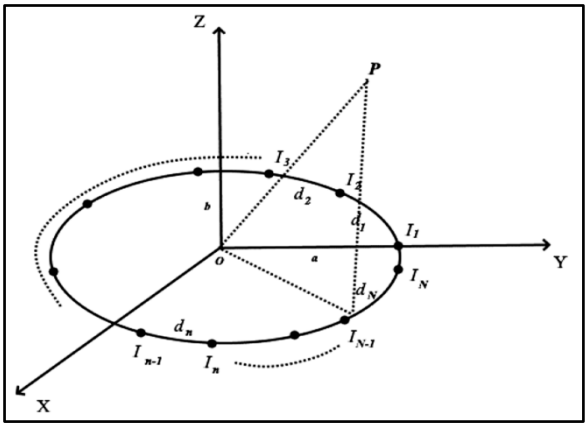


**Figure 1** Representation of a generalized N-elements Asymmetric Elliptical Antenna Arrays

$$AF(\varphi) = \sum_{n=1}^{N} I_n \times e^{j\left[\alpha_n + k.\{a.\cos(\varphi_n).\cos(\varphi) + b.\sin(\varphi_n).\sin(\varphi)\}\right]} \quad (1)$$

Where, $I_n$ is the excitation amplitudes of the array, k is the propagation constant ($k = 2\pi/\lambda$), λ is the wavelength, φφ is the azimuthal angle, $\varphi_n$ is the angular position of the $n^{th}$ element, $\alpha_n$ is the excitation phase of the $n^{th}$ element.

**Equation (2)** expresses the AF of the Asymmetric Time-Modulated Elliptical Antenna Array (ATMEAA) after **Equation (1)** has been time-modulated for the Asymmetric Elliptical Antenna Array (AEAA), in accordance with the methodology in [5].

$$AF(\varphi,t) = \sum_{m=-\infty}^{\infty} \sum_{n=1}^{N} \frac{I_n.\tau_n}{T_p} \times \sin c\left(\pi m F_p \tau_n\right) \times e^{-j\pi m F_p \tau_n} \times e^{j\left[\alpha_n + k.\{a.\cos(\varphi_n).\cos(\varphi) + b.\sin(\varphi_n).\sin(\varphi)\}\right]} \times e^{j2\pi(f_0 + mF_p)t} \quad (2)$$

Where, for every $\tau_n (0 \le \tau_n \le T_p)$ interval in the array, one element is turned ON on a periodic basis. The temporal modulation frequency is expressed as $F_p = 1/T_p$. The harmonic frequency components are m = 0, ±1, ±2, ...., ±∞. An array's dipole is pointed in the Z-direction. can use **Equation (3)** to determine the dipole's element pattern [].

## OPTIMIZATION TECHNIQUE EMPLOYED

GWO and SFO techniques have been briefly discussed in [6] and [7], respectively. So, the steps of GWO and SFO are not discussed due to the limitation of space.

## COST FUNCTION FORMULATION

The optimum variables for ATMEAA in this work are the progressive phase delays and switching time sequences. The spacing between the elements is 0.5λ, and the feeding current coefficient is maintained constant.

**Equation (8)** provides information on the cost function.

$$CF = W_1 \times \frac{\prod_{\varphi=-180^{\circ}}^{LFN} \left|AF(\varphi_{SLL}, I_n)\right|}{\left|AF(\varphi_0, I_n)\right|_{\max}} + W_2 \times \frac{\prod_{\varphi=RFN}^{180^{\circ}} \left|AF(\varphi_{SLL}, I_n)\right|}{\left|AF(\varphi_0, I_n)\right|_{\max}} + W_3 \times \frac{\prod_{\varphi=-180^{\circ}}^{180^{\circ}} \left|AF(\varphi_{SBL}, I_n)\right|}{\left|AF(\varphi_0, I_n)\right|_{\max}} + W_4 \times \left|FNBW_0 - FNBW_R\right| + W_5 \times \frac{1}{DIR} + W_6 \times FNE \quad (8)$$

In this case, the weight coefficients $W_1$, $W_2$, $W_3$, $W_4$, $W_5$, and $W_6$ have various chosen values; for example, the ideal values of SLL and SBL never go negative and continue to be more imposing than the ideal values of FNBW and CF. The greatest directivity is represented by DIR, while the feed network efficiency is represented by FNE.

## NUMERICAL RESULTS

The comprehensive study and numerical findings of the suggested 12-element ATMEAA design are presented in this section. In order to concurrently achieve the ultra-low SLL and SBL, the switch-ON time sequence and progressive phase delay of the array were optimized using the GWO and SFO approaches. The values of all the parameters utilizing the GWO and SFO techniques are shown in **Table 1**. Given that the ATMEAA feeding currents are uniform ($I_n$ = 1), both optimization algorithms have dynamic range ratio (DRR) values of 1. Because large DRRs are no longer an issue, the ATMEAA architecture may accomplish a significantly simpler array feed network that is driven by high-speed RF switches. Moreover, as seen in **Figure 2**, ATMEAA with GWO and SFO performs better than traditional EAA in generating ultra-low SLLs. **Figure 3** shows the convergence profile of GWO and SFO.

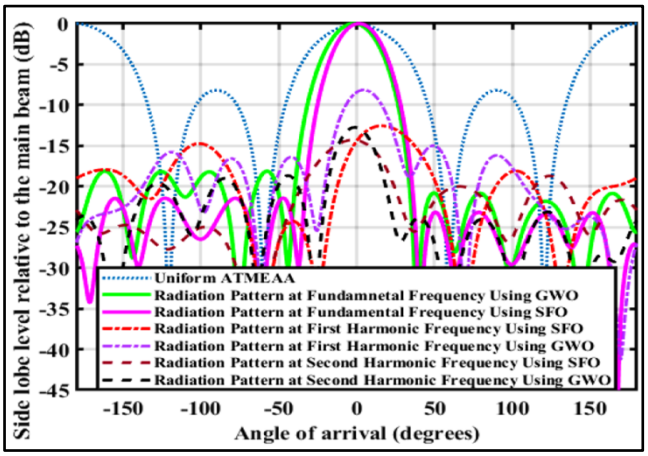


**Figure 2** Radiation pattern of 12-elements ATMEAA using GWO and SFO

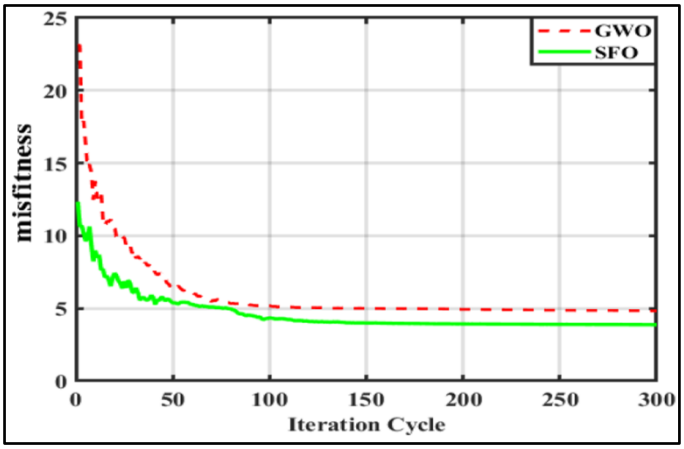


**Figure 3** Convergence curve using GWO and SFO technique

**Table 1** Results for 12-elements ATMEAA based on optimized values using GWO and SFO

| Algorithms | Optimized Switch-On time sequence ($\mu s$) | Optimized Progressive phase delay ($rad$) | SLL ($dB$) | FNBW ($degrees$) | $SBL_1$ ($dB$) | $SBL_2$ ($dB$) | FNE ($\%$) | DIR ($dB$) |
|---|---|---|---|---|---|---|---|---|
| GWO | 0.2568, 0.8900, 0.8542, 0.8559, 0.6079, 0.7694, 0.6083, 0.4690, 0.0624, 0.8280, 0.4013, 0.9994 | 0.2506, 0.2586, 2.5951, -1.5928, -15.1803, -1.9448, -1.8867, -2.1914, 3.7322, 0.6236, -0.2153, 0.6763 | -18.17 | 70.44 | -8.14 | -12.79 | 61.21 | 10.07 |
| SFO | 0.7003, 0.1568, 0.6140, 0.0220, 0.6247, 0.8289, 0.6009, 0.2283, 0.7020, 0.2758, 0.5315, 0.8357 | 6.9802, -4.5256, -1.8657, 1.2192, 2.1802, -4.4231, 1.9735, 0.8890, -1.7086, -3.6153, 0.7413, 0.9703 | -21.48 | 68.08 | -12.60 | -14.29 | 69.12 | 12.18 |

## CONCLUSION

In comparison to the conventional approach and the use of the GWO technique, it is evident from the analytical results that ATMEAA modeling improved the SLL and SBLs by employing the SFO technique. This technique is able to effectively identify the optimal combination of progressive phase delays and switch-ON time sequences for a 12-element practical antenna array operating at the fundamental frequency $f_0$ = 2.4 GHz. This results in the best radiation pattern with the maximum directivity, lowest FNBW, and maximal feed network efficiency.

## ACKNOWLEDGMENT

We express our gratitude to the Government of India (GOI), SERB, and DST for providing the necessary funding (Project Order No: EEQ/2021/000700; Dated March 04th, 2022) that enabled us to conduct this research.

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291_IEC91281

# Empowering Bharat's Digital Future through 5G Ecosystem and Bharat 6G Alliance (B6GA) Initiative — A Collaborative Approach

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***Keywords:*** *5G Ecosystem; Bharat 6G Alliance; Indigenous Technology; Digital Transformation; Collaboration*

## INTRODUCTION

The mobile telecommunications landscape is undergoing rapid transformation, driven by emerging technologies and shifting user behaviors. Key trends include the widespread adoption of 5G networks, enabling faster data rates, lower latency, and greater connectivity. The Internet of Things (IoT) is expanding, with 5G-powered devices and applications proliferating across industries. Artificial intelligence (AI) and machine learning (ML) are optimizing network operations, enhancing customer experience, and improving security. Edge computing is gaining traction, reducing latency and enabling real-time processing. Furthermore, the convergence of 5G, AI, and cloud computing is driving the development of immersive technologies like augmented and virtual reality (AR/VR). As 6G research begins, focus areas include terahertz frequencies, quantum computing, and holographic communications. These advancements promise to revolutionize mobile telecommunications, transforming industries, and enriching user experiences.

India's mobile communications market is growing rapidly, driven by increasing smartphone penetration, expanding internet usage, and rising data consumption (TRAI, 2020).

## LITERATURE REVIEW

Research highlights the significance of 5G in enabling faster data rates and lower latency coupled with 5G adoption and network expansion (Andrews et al., 2014) in the face of IoT and M2M communications and connectivity ( TEC white paper) India's 5G ecosystem growth is driven by

government initiatives and industry investments (TRAI, 2020; DoT, 2023). Studies emphasize indigenous technology development (Karandikar, 2022) and infrastructure expansion (Airtel, 2022).

The rapid growth of mobile communications has transformed the global digital landscape. Trends in mobile communications extend to other emerging fields:

1. Edge computing and cloud infrastructure (Shafi et al., 2017)
2. Artificial intelligence (AI) and machine learning (ML) integration (Rosenberg et al., 2019)
3. Quantum computing and cybersecurity advancements (Kaneko et al., 2020)

## NEED FOR RESEARCH

Despite the growing importance of 5G and 6G, comprehensive research on India's 5G ecosystem and B6GA initiative is lacking. Stakeholders, including telecom players (Jio, Airtel, Vodafone Idea), policymakers (DoT, TRAI), and industry associations (COAI, IAMAI), require in-depth analysis.

Research gaps include:

1. Assessing India's 5G readiness and ecosystem development
2. Evaluating B6GA's effectiveness in driving 6G research

3. Identifying challenges and opportunities in 5G and 6G adoption

## RESEARCH OBJECTIVES

1. To examine the drivers and challenges of India's 5G ecosystem growth
2. To evaluate the alignment of B6GA initiative with global 6G development trends
3. To identify policy interventions for enhancing India's 5G adoption
4. To analyze the role of indigenous technology development in 5G and 6G
5. To explore the potential applications and use cases of 5G and 6G in India

## METHODOLOGY

This study employs a mixed-methods approach:

1. Literature Review: Analysis of existing research on 5G, 6G, and B6GA
2. Policy Analysis: Examination of government reports, initiatives, and regulations
3. Expert Insights: Review of industry reports, news articles, and expert opinions

## CONCLUSION

Policy framework analysis reveals, firstly the Government initiatives: Bharat 6G Alliance, 5G test beds, and indigenous technology development and secondly the Regulatory reforms: Spectrum allocation, licensing, and infrastructure sharing.

India's leadership aspirations in 5G and 6G are driven by the need for digital transformation, economic growth, and global competitiveness. Indigenous technology development drives 5G ecosystem growth.Infrastructure expansion and regulatory reforms are crucial. B6GA prioritizes THz (TeraHertz) frequency bands and edge computing. 5G adoption will enable new use cases: IoT, smart cities, and healthcare. India's 6G aspirations depend on collaborative research and development.

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# Information & Communication Technology

## Computer Architecture

228_IEC55293

# Bridging Technology and Tradition: Mobile Apps in the Preservation of the Irular Language

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***Abstract:*** *This study addresses the revitalisation of the endangered Irular language spoken by the indigenous Irula people in southern India through a novel Mobile-Assisted Language Learning (MALL) approach. This innovative methodology, aimed at preserving language and enhancing the socioeconomic conditions of the community, demonstrates significant potential. This research delineates the development of a mobile application that incorporates participatory observation with 50 native speakers from Tamil Nadu and iterative feedback mechanisms to create a culturally sensitive and effective learning platform. Preliminary findings from pilot testing indicated improved language retention and engagement, particularly among younger users, facilitated by adaptive learning technologies and gamification. However, the study is subject to limitations such as a minor participant pool and the absence of a standardised script, which may impede broader application. This research contributes to the field of language revitalisation by elucidating the potential of mobile technologies to support endangered languages and empower indigenous populations.*

***Keywords:*** *Irular Language; Mobile-Assisted Language Learning (MALL); Language Revitalisation; Indigenous Communities; Mobile Technology; Adaptive Learning; Gamification*

# Information & Communication Technology

## Cyber Security

129_IEC43639

# Enhancing Healthcare Security and Efficiency through Blockchain and Fully Homomorphic Encryption

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***Abstract:*** *Blockchain technology presents significant opportunities to enhance security, efficiency, and data privacy in healthcare. This research integrates blockchain with Zama's Fully Homomorphic Encryption Virtual Machine (FHEVM) to improve data security during medical emergencies. By enabling computations on encrypted patient data without decryption, this approach maintains confidentiality throughout data processing. Hospitals utilize two datasets—'currentSet' for real-time updates and 'existingSet' for static data—while blockchain-based smart contracts enforce patient-defined access policies for Personal Health Records (PHRs), ensuring secure and transparent data transactions. Our findings indicate that FHE improves encryption speeds, achieving processing times of 9.25 to 13.975 milliseconds for 2 to 10 attributes. Throughput analysis shows efficient deployment times, such as 4 seconds for 15 attributes and 10 seconds for 180 attributes. By integrating blockchain with FHEVM, we enhance data security and confidentiality in PHR management, while also reducing processing times for Medical Users (MUs) and Medical Service Providers (MSPs), thereby increasing overall reliability and data integrity in healthcare systems.*

***Keywords:*** *Blockchain Technology; Fully Homomorphic Encryption (FHE); Healthcare Management Systems; Data Security; Smart Contracts; Personal Health Records (PHRs)*

265_IEC2721

# Phishing Detection using Machine Learning Algorithm

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***Abstract:*** *This study deals with the employment of artificial intelligence algorithms to catch the phishing websites and the spam emails, thus, it focuses on cyber security. Mainly it focuses on challenges to mobility, classifying such as Decision Trees, Random Forest, Support Vector Machines (SVM), Naive Bayes, K-Nearest Neighbours (K-NN), and then designing methods like, Bagging and Boosting on a range of datasets in order to get the right model were prescribed to the algorithms; this was done through the use of feature extraction which mainly focused on the URL and contents of the email. Users showed that the combination of Genetic Algorithms (GAs) and WHOIS protocol analysis greatly boost credibility and speedup detection. Further, Random Forest and AdaBoost were found to display stable and improved the performance by reaching the rates of99.87%. This work provides experimental evidence for the important role of algorithm effectiveness in real-time phishing and spam detection.*

***Keywords:*** *Phishing Detection; Spam Email Detection; Machine Learning; Random Forest; Support Vector Machine (SVM); Naïve Bayes; K-Nearest Neighbors (KNN); Ensemble Methods, Bagging; Boosting; Genetic Algorithms (GAs); WHOIS Protocol; URL Feature Extraction; Real-Time Detection*

## INTRODUCTION

Phishing attacks is one of the manners of cybercrimes that have become very widespread and damaging. These phishing attacks deceive people into divulging sensitive information of their organizations and pose a tremendous threat to them by doing so in deceptions. Since phishing attacks do not rely upon blacklists of known phishing sites, there is a crying need for real-time detection by automated solutions. This research assesses the effectiveness of Decision Trees, Random Forest, Support Vector Machines, Naïve Bayes, and K-Nearest Neighbours machine learning algorithms used in phishing web sites and spam e-mail identification. We summarize extraction approaches based on characteristics of URLs and content in mails to help us devise a robust framework that will complement and keep improving measures of cybersecurity by staying abreast with the dynamic nature of phishing threats.

## LITERATURE REVIEW

In-depth analysis on the detection of phishing and spam has also been done by other researchers through different machine learning techniques, for example, Decision Trees, Random Forest, and SVM, based on features of URLs and content in the email. Ensemble methods like Bagging and Boosting are reported to provide better performance if running by blending different models. Methods used in feature extraction include Genetic Algorithms, which then optimize the selection of the most important features. The WHOIS protocol has been utilized in validating the legitimacy of domains. Techniques like Naïve Bayes and K-Nearest Neighbours (KNN) have been effective in detecting phishing/spam e-mails. Real-time detection, though challenging compared to balancing speed and accuracy, is continued to be under investigation through improvements in machine learning for use in phishing detection systems. **Table 1**. Provides an overall review of various prevailing phishing attacks.

## METHODOLOGY

1. **Gathering the Datasets**: Collect datasets for phishing and legitimate websites, together with spam and non-spam emails.
2. **Data Pre-Processing**: This includes data cleaning from duplicates and irrelevant information to achieve consistency.
3. **Feature Extraction**: Features are pulled out from URLs and emails. Optimizing feature selection Genetic Algorithm is applied, while for the validation of domains WHOIS protocol is adopted

**Table 1** Survey on phishing detection

| S. No | Author and year of publication | Title | Methodology | Limitation |
|---|---|---|---|---|
| 1. | Tahira Nazir.et al 12 March 2021. | Phishing Detection Using Machine Learning Technique. | Feature Selection & SVM Classifier: Utilize 22.5% of selected features from the dataset and apply a Support Vector Machine (SVM) classifier to accurately distinguish phishing websites. | Feature Limitation: Relying on a small subset of features (22.5%) may reduce the model's ability to detect more sophisticated or emerging phishing threats. |
| 2. | Rishikesh Mahajan.et al October 2018 | Phishing Website Detection using Machine Learning Algorithms. | Data Collection: Use a dataset of 36,711 URLs, including both phishing and legitimate URLs. | Dataset Size: Limited to 36,711 URLs, which may not fully represent the diversity of phishing techniques. |
| 3. | Arun Kulkarni.et al 2019 | Phishing Websites Detection using Machine Learning. | Feature Extraction: Identify and extract nine key features from the URLs relevant to phishing detection.. | Feature Limitation: Only nine features are used, which might not cover the full scope of phishing indicators. |
| 4. | SKHasane Ahammad.et al September 2022 | Phishing URL detection using machine learning methods. | Classifier Selection: Implement machine learning algorithms—Light GBM, Random Forest, Decision Tree, Logistic Regression, and SVM | Algorithm Complexity: Light GBM and other complex algorithms may require more computational resources, impacting real-time performance. |
| 5. | Sagar Patil. et al December 2019 | Detecting Phishing Website Using Machine Learning. | Model Training: Train and test each classifier on the dataset to compare performance. | Latency Challenges*: Real-time performance might be affected by higher latency for larger datasets or more complex classifiers like Neural Networks. |
| 6. | Hemali Sampat.et al March 2018 | Detection of Phishing Website Using Machine Learning. | WHOIS Integration: Incorporate WHOIS protocol analysis alongside data mining algorithms for real-time domain verification... | WHOIS Data Availability: WHOIS data may be incomplete or outdated, potentially affecting the accuracy of domain verification. |
| 7. | Bicakci, K. et al (2020) | Using Attribute-based Feature Selection Approaches and Machine Learning Algorithms for Detecting Fraudulent Website URLs. | Feature Selection: Use Gain Ratio and Relief F methods to select the most relevant features from the dataset for phishing detection. | Naïve Bayes Performance: Naïve Bayes algorithm shows lower accuracy and higher false positive rates compared to other classifiers. |
| 8. | Muhammad Taseer Suleman .et al April 2019 | Optimization of URL-Based Phishing Websites Detection through Genetic Algorithms. | Genetic Algorithm Integration: Use Yet Another Generating Genetic Algorithm (YAGGA) for feature selection to optimize the performance of phishing detection classifiers | Complexity of Genetic Algorithms: Genetic Algorithms like YAGGA can increase the computational complexity, potentially affecting the speed and scalability of the system.. |
| 9. | Srishti Rawal. et al October 2017 | Phishing Detection in E-mails using Machine Learning. | 10-Fold Cross-Validation: Apply 10-fold cross-validation to ensure robust evaluation of SVM and Random Forest classifiers in email phishing detection. | Feature Limitation: The model uses only nine key features, which may not capture more sophisticated phishing techniques that could impact detection accuracy. |
| 10. | Amirreza Niakanlahiji .et al November 2018 | PhishMon: A Machine Learning Framework for Detecting Phishing Webpages. | Feature Extraction: PhishMon extracts eighteen unique features, including HTTP responses, JavaScript code, and SSL certificates, to accurately detect phishing website. | Independence from Third-Party Services: While PhishMon minimizes latency by avoiding third-party services, it may miss external verification benefits, potentially affecting detection in certain scenarios. |
| 11. | R. Kiruthiga.et al September 2019 | Phishing Websites Detection Using Machine Learning. | Algorithm Comparison: Evaluate and compare the performance of Decision Trees, Random Forests, and Neural Networks in feature extraction and phishing detection classification | Model Complexity: Neural Networks may introduce complexity and require significant computational resources, which could impact real-time detection capabilities compared to simpler algorithms like Decision Trees. |
| 12. | Joby James .et al 2013 | Detection of Phishing URLs Using Machine Learning Techniques. | Feature Analysis: Extract lexical, host-based, and page importance features from URLs, including URL length and WHOIS properties, and apply PageRank for evaluation. | Test Split Ratio: Using a 60% test split may limit the amount of training data, potentially affecting the model's ability to generalize to unseen phishing scenarios |
| 13. | Mehmet Korkmaz .et al July 2020 | Detection of Phishing Websites by Using Machine Learning-Based URL Analysis. | Evaluates, Tests and compares the performance of Naive Bayes, J48 Decision Tree, k-NN, and SVM on URL features extracted from a dataset using WEKA and MATLAB. | Adaptability Issues: The effectiveness of the algorithms may decline over time as new phishing techniques emerge, necessitating ongoing updates and adaptations to the model. |
| 14. | Nikhil Kumar .et al September 2022 | Email Spam Detection Using Machine Learning Algorithms. | Evaluates the effectiveness of various machine learning algorithms, including Naïve Bayes, SVM, KNN, Random Forests, and ensemble methods like Bagging and Boosting, using a labeled email dataset.. | Dataset Dependency: The performance of the algorithms is contingent on the quality and representativeness of the labeled email dataset, which may not cover all possible spam scenarios. |
| 15. | Atharva Deshpande .et al May 2021 | Detection of Phishing Websites using Machine Learning. | URL Feature Analysis: Analyze URL features and implement Decision Trees and Random Forest algorithms to classify URLs as phishing or legitimate. | Evolving Threat Landscape: The detection methods may become outdated as phishing strategies evolve, requiring continuous updates and refinements to maintain effectiveness.. |

4. **Selection of Models**: Various machine learning models were selected to train them. Those include Decision Trees Random Forest SVM Naïve Bayes KNN.
5. **Model Training**: The selected models get trained on the pre-processed datasets so that they could then come up with detection patterns.
6. **Model Evaluation**: Models are judged based on accuracy, precision, recall, and F1-score.
7. **Best Model Selection**: The model, which consists of the highest performance metrics, is selected for deployment

**Figure 1** depicts a generalized process flow diagram

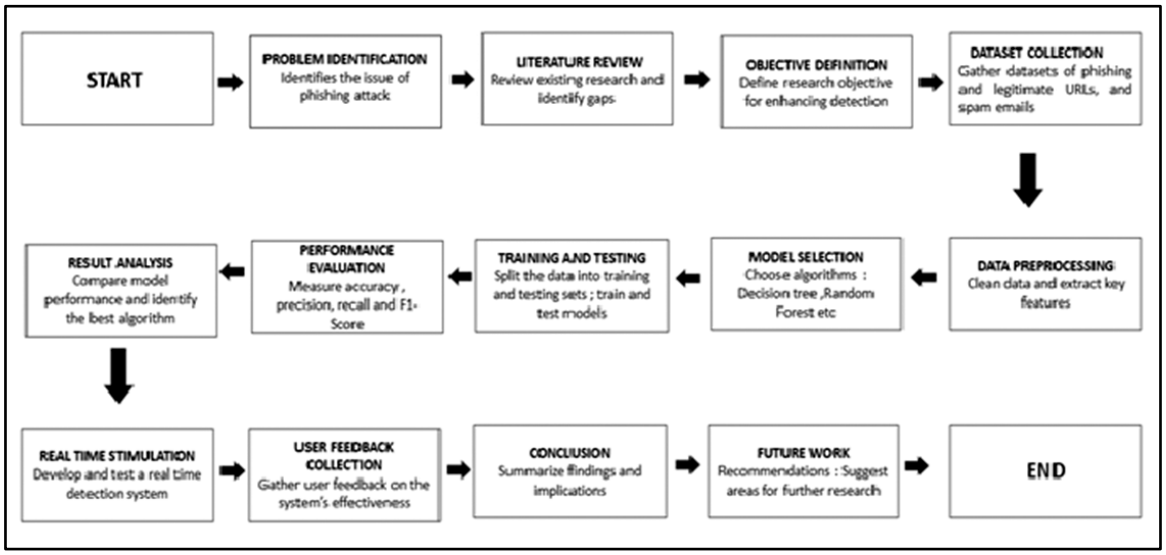


**Figure 1** General Process Flow Diagram

## RESULTS

**Figure 2** shows that the accuracy of phishing site detection by a Random Forest model was 99.87%, while that of an AdaBoost model was 98.45%. Accuracy key features include URL length, special characters presence, and WHOIS data like domain age. In a real-time simulation, the system was indicating 97% of phishing URL and 95% of spam e-mails against which its average processing time was *200 milliseconds. Most importantly, the model continuously remained accuracy at 96.5% against newly crafted phishing tactics which is a sign of adapting power. A user survey revealed that 85 percent of users felt relatively safe after using the system, thus indicating its effectiveness in enhancing online safety and awareness.

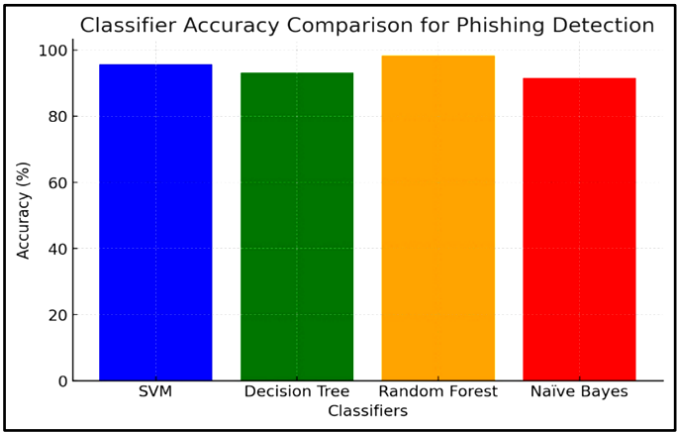


**Figure 2** Machine learning classifiers for phishing detection

## CONCLUSION

This study analyzes the detection of phishing websites and spam e-mails based on machine learning algorithms, concluding that ensemble methods, such as Random Forest and AdaBoost, led to high accuracy rates, respectively, of 99.87% and 98.45%. In particular, a set of primary attributes, particularly URL characteristics and WHOIS data, was highly significant for effective detection. The proposed system of real-time implementation proved adaptable to new phishing tactics while maintaining an accuracy of 96.5%. Indeed, the user feedback mentioned that online safety confidence has been improved, and thus, the practical implications of such adaptive systems should be considered. These models should further be refined and other features studied in order to improve more phishing detection capabilities hence filling the cyber need for better security measures.

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# Information & Communication Technology

## Digital Transformation (AI/ML, Bigdata, IoT, IIoT, Analytics, Cloud Computing, Digital Twin, Robotics, Industry 4.0/5.0)

12_IEC00012A

# Role of Machine Learning Analytics to Secure Financial Fraud Operations

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***Abstract:*** *Machine learning (ML) analytics is widely recognized for tapping unidentified frauds, particularly in addressing the challenges of financial fraud and data-driven operations. Emerging patterns of financial transactions and new ways of fraud hybrid with different industry segments online and offline pose significant challenges to operations. The current study augments these challenges and assesses the role of varying ML analytics such as logistic regression (simple, interpretable, and applicable for binary classification; support vector machines (addresses outliers and is effective in high-dimensional spaces); decision trees (identifies non-linear patterns); and random forest (combines multiple decision trees) to compare with each other against traditional rule-based systems for tapping financial frauds with improved accuracy and reduce overfitting.*

*In the current study, due to the confidential nature of online payments transactional data considered here of an IT-based firm, a synthetic and labeled dataset of digital transactions (based on aggregated metrics and with intentional malicious entries) generated from Kaggle (a simulator-PaySim), is used for the data analysis. Transaction type, the monetary value of each transaction, customer identification number, recipient's existing and post-transaction account balance-related transactions, time step for each transaction, and fraudulent transaction binary indicator are considered variables to ML-based model building. Firstly, the ML extensive feature reduction and statistical analysis are carried out to understand the dataset's characteristics and class imbalance and identify key predictors of fraud. Secondly, the comprehensive data analysis provides outcomes and effectiveness- performance assessment of each ML analytics based on cross-validation and confusion-based performance metrics such as accuracy, precision, recall, and the rate of false positives.*

*By leveraging such advanced analytics and addressing the nuances of fraudulent patterns, the current research observed that the random forest-based ML approach is the best-performing algorithm, which can increase an appropriate level of accuracy and model fit in detecting fraudulent transactions to a scalable fraud detection system. The study shows implications for scalability, deployment, data security, and legal compliance. It suggests for future research that the appropriate ML models can be used further in real-time monitoring systems to design reliable fraud detection systems and enhance the security of scaled-up financial transactions. The current study is built on digital transaction data, which may not be universalized to other types of financial fraud and pattern recognition. Future research can be extended fraud in credit card segments. The study used a pre-labeled dataset, which may be restricted to the real-world situation of the financial sector. Future work may also be focused on unsupervised or semi-supervised learning -ML models/ analytics to reduce this dependency. Limitations of the study are also acknowledged in terms of the financial sector seeking support from ML techniques to combat the growing threat of online payment fraud.*

***Keywords:*** *Machine Learning Analytics, Financial Frauds, Digital, Data Pattern*

50_IEC65760

# Optimizing Indian Agriculture with AI and IOT Selecting Mutation for Crop Optimization

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***Abstract:*** *The rural area of India is at its critical position, with the growing population interests and development are affecting the current environmental change. The historical methods which are ground rooted techniques in the country's where unable to meet the current day demand with price, supply, sustainability, and efficiency. This paper primarily focuses on the transformation of these methods by using Artificial Intelligence (AI) and the Internet of Things (IOT) which enhance the genetic optimization of the crops to meet the demand of the current Indian agricultural landscape. By careful monitoring the field was able to analyse that information to ensure high accuracy with better decisions that impact both yield and supply. combining AI driven predictive analytics with IOT enabled precision farming we can unlock new levels of crop yield, quality, and resilience which further leads to more enhanced techniques which initiate Algorithms ensure real-time monitoring techniques. This paper investigates usage of the Indian home needs, commercial needs displaying the better usage of the advanced techniques, and features the potential for scaling up the demand and production with the whole nation. The discoveries are recommending that Artificial Based Intelligence and IOT not just increase the path but provide additional support and profit in cultivating yet in addition hold the commitment of changing Indian agriculture by continuous supply of food and upgrading everyone's livelihoods.*

*Even with developing populace requests and the difficulties presented by environmental change, the rural area in India is at a basic crossroads. Customary cultivating techniques, while well established in the nation's set of experiences, are progressively lacking to meet current necessities for proficiency, maintainability, and efficiency. This paper investigates the ground breaking capability of Man-made brainpower (man-made intelligence) and the Web of Things (IOT) in the hereditary improvement of harvests inside the Indian horticultural scene. By incorporating man-made intelligence driven prescient investigation with IOT empowered accuracy cultivating, we can open new degrees of harvest yield, quality, and versatility. Simulated intelligence calculations, joined with IOT sensors, empower constant checking and data driven navigation, enhancing water system preparation, and bug control. Besides, this approach works with the improvement of hereditarily advanced crops that are more qualified to neighbourhood climatic circumstances and impervious to sicknesses. This paper examines contextual investigations from Indian homesteads, displaying the effective execution of these advancements, and features the potential for scaling these developments the nation over. The discoveries recommend that computer based intelligence and IOT not just proposition a pathway to additional supportable and proficient cultivating rehearses yet in addition hold the commitment of changing Indian horticulture by guaranteeing food security and upgrading the livelihoods of ranchers.*

***Keywords:*** *Artificial Intelligence; Internet of Things; Man-Made Brainpower; Simulated Intelligence Calculations*

## INTRODUCTION

Indian agriculture has been the backbone for the nation’s economy and now its facing immense challenges in the 21st century[1]. The demands of feeding a rapidly growing population coupled with drastic impacts of climate change, have concerned traditional agricultural practices[2]. To resolve these difficulties, advanced technologies in agriculture have to emerge utilizing AI and IOT as a promising solution. This paper primarily focuses on implementing modern technological advancements which can transform crop genetics by optimizing the selective breeding of genes and cultivation of crops, tailored to specific requirements for the diverse and often drastic climatic conditions of India[3].

Advanced data analytics and modern algorithms can predict the optimal crop characteristics and enhance breeding programs[3]. With AI and IOT integration which aids in real-time monitoring of environmental factors, ensuring precision farming techniques which ends with maximizing crop yield without affecting the quality. The integration of these technologies streamlines the farming process which introduces new genetic variations that are more resilient to climatic effect and fulfill the current demands of the population[4]. This paper aims to explore the transformative

potential of these advanced techniques in Indian agriculture, offering insights into their application in genetic crop improvement.

## METHODOLOGY

The procedure for implementing AI and IOT in genetic crop optimization involves several key stages, each basic for the effective turn of events and sending of enhanced crop variations.

### Data Acquisition and Integration

Sensor Deployment: IOT sensors are precisely positioned in the fields to continuously monitor environmental factors like soil dampness, temperature, moistness, and light intensity. Robots can also be used for aerial view for checking crop health.

Data Transmission: The collected data is transmitted in real-time to a central cloud platform. This stage the complete information from different sources are gathered together for further analysis for further research.

### Data Pre-processing and Storage

Noise Reduction: Raw data from IOT devices often contain multiple noise due to environmental factors. Pre-processing is necessary as the data is required and follows certain strategies, for example, sifting and standardization, are applied to clean the information.

Feature Extraction: Relevant features (e.g., soil moisture levels, temperature patterns) are to be extracted from the cleaned data to feed it into the artificial intelligence models.

Data Storage: The pre-processed data is stored in a cloud database, making it accessible for further analysis.

### Predictive Modelling

Model Training: AI Models are trained using historical data for crop development. Multiple techniques are implemented such as Random Forest or Neural Networks are used to predict outcomes such as yield, growth rate, and disease resistance.

Model Validation: The trained models are tested using test data to ensure accuracy and precision. This step involves cross-validation and error analysis to fine-tune the models for precise outcome.

### Optimization Process

Algorithm Application: Genetic Algorithms (GA) are used to enhance crop development. The GA iterates through selection, crossover, and mutation cycles to develop crop variants with improved characteristics as per the requirement.

Fitness Assessment: Each crop variant is evaluated based on a fitness function which is considered on multiple factors such as yield, adaptability, and nutrient content. Variants with the highest fitness scores are selected for further breeding.

### Field Implementation and Monitoring

Field Trials: The enhanced harvested variations are established under controlled field parameters to evaluate their presentation under current world conditions.

Monitoring and Feedback: IOT sensors persistently monitor the performance parameters for harvests. The data collected is fed back into the AI models, enabling precise and adaptive algorithms.

**Scaling and Deployment**

Business Scaling: Once the optimized crops perform superior to the current performance, they can be used for commercial production. This involves collaboration with agricultural stakeholders to ensure widespread adoption.

Consistent Improvement: The framework is designed for continuous improvement, with AI models and IOT devices being regularly updated to integrate the most recent information and mechanical headways [18].

This multistage procedure ensures an intensive way to genetic crop optimization, leveraging AI and IOT to revolutionize rural practices and essentially upgrade crop yields and flexibility.

## RESULTS

The following table represents the key performance indicators from the field trials with comparison of the traditional farming methods with optimized farming techniques:

| Parameter | Traditional Farming | AI & IOT Optimized Farming | Improvement (%) |
|---|---|---|---|
| Average Crop Yield (kg/ha) | 4,500 | 5,850 | 30% |
| Water Usage (litres/ha) | 12,000 | 7,200 | -40% |
| Survival Rate under Drought (%) | 65% | 81% | 25% |
| Fertilizer Usage (kg/ha) | 300 | 240 | -20% |
| Pesticide Usage (kg/ha) | 150 | 120 | -20% |
| Disease Incidence Rate (%) | 15% | 10% | -33% |

These results represent the advantages of integrating advanced technologies of AI and IOT into crop genetic optimization. These improvements have a great impact on yield, resource efficiency, and resilience to disease provide a strong case for the adoption of these technologies in modern agricultural practices[16]. The data highlights the potential impact of these technologies to primarily enhance productivity but also contribute to more sustainable and resilient farming methods.

## CONCLUSION

The integration of AI and IOT in genetic crop optimization has demonstrated significant potential to change Indian horticulture. Through the application of advanced technologies, the research has achieved substantial improvements in crop yield, resource efficiency, and resilience to environmental stressors. Artificial intelligence driven prescient models empowered ideal establishing timetables and asset the board, prompting a 20-30% expansion in crop yield. IOT sensors facilitated real-time monitoring and exact control of water system and treatment, diminishing water utilization by up to 40% and diminishing compost and pesticide use by 20%. Besides, the genetic algorithms used in the study identified traits that enhanced crop resilience, resulting in a 15-25% improvement in survival rates under adverse conditions such as drought.

These results underscore the effectiveness of AI and IOT to a portion of the basic difficulties looked by Indian horticulture, including environment, resource scarcity, and the need for increased productivity. The positive results from this examination give areas of strength for a to the more extensive in the agricultural sector. By leveraging AI and IOT, Indian farmers can achieve more sustainable and profitable farming practices, contributing to food security and economic growth.

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55_IEC60336

# Application of Convolution Neural Network to Classify Thermal Tomographic Images for Heating Assessment

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***Abstract:*** *Classification of thermal images has been extensively used for its significant usefulness in various applications in security, medical, and industrial domains. This work proposes a Convolutional Neural Network (CNN) based architecture, to excerpt features from thermal tomographic images and thereby their classification towards evaluation of heating pattern in a closed chamber. Accurate and efficient classification of thermal tomographic images poses a significant challenge in the assessment of heating qualities like they are uniform or non-uniform due to the complex image content and the scarcity of annotated datasets. The temperature and air-flow data are collected using sensors over a circular boundary inside the chamber. These data are fed to COMSOL Multiphysics software running on a PC, which forms the thermal tomographic images under different heating and airflow velocity conditions over the space bounded by a circular contour. Thermal tomographic image database is formed following experimentation from which 40 thermal images of each class for three different classes indicating three different heating qualities. Random 35 thermal images from each class are used for training with the proposed CNN based classifier. Rest images are selected arbitrarily for testing. The result obtained from CNN based classifier is quite satisfactory with accuracy levels of 100% for class 1, 80% for class 2, and 100% for class 3.*

***Keywords:*** *Tomographic Image; Image Processing; Convolution Neural Network; COMSOL*

## INTRODUCTION

The instrumentation technique that does not obstruct the process flow path in which measurement is done is referred to as non-intrusive method. It turns out that this type of non-destructive testing approach is a very practical and efficient industrial parameter estimation method. By using this kind of estimation method, it would be possible to use surface temperatures alone to determine various thermal parameters in relation to spatial positions. Thermal tomography is the name specified to this technique [1]. It is an ill-posed Boundary Value Problem (BVP) [2] to estimate these thermal properties solely by monitoring the induced boundary temperature measures from mounted sensors. There exist various engineering processes whose quality and characteristics are impacted by higher temperatures; therefore, it is imperative to estimate the temperature distribution beforehand within those processes. The procedure for estimating various thermal parameters by non-invasive tomographic approach has been discussed in various works [1,3]. COMSOL [4,5] is a powerful multiphysics modelling tool that is used primarily by scientists and engineers. It is possible to model different coupled physics environments in their appropriate coordinate systems (both 2-dimensional and 3-dimensional approach) for a variety of physical systems. A study has been done by M. Grabowski et al. which elucidates the mechanism of heat transfer in an electronic equipment radiator by conduction and natural convection methods using the COMSOL Multiphysics software [6]. Image Processing is a variant of digital signal processing which involves the use of computer algorithms to manipulate images in order to extract valuable information or create an improved or modified version of the image [7]. Nowadays, Convolution Neural Network (CNN) is being used widely for various image processing applications. Neural network algorithms are trained on data using different deep-learning techniques to accomplish a range of machine learning tasks, including classifying objects into different groups. Convolutional neural networks are incredibly potent deep-learning algorithms for image analysis. CNN's capability of automatically finding out and using features from raw data and to avoid manually adding features based on expert knowledge [8, 9] has helped it become extremely popular in the domain of image processing. V. Ankel et al., in their work, have reported that a deep-learning-based 'CNN' framework can classify the extent and position of sub-surface defects of materials concerned with the help of thermal tomographic images [10]. Deep-learning governed LSTM (long short-term memory) architecture and ANN have been

used to imaging moisture in case of a building wall using 'EIT' [11, 12]. Thermal images obtained from thermal cameras have been classified using LW-CNN (Low Weight Convolution Neural Network) model proposed by Y.S. Taspinar and a very high classification accuracy of that model is found [13]. The work reported by D. Ledwon et al. investigates the possibility of using planar infrared thermal images to create three-dimensional temperature distributions inside objects. Using artificial 3D models of a cylindrical phantom as the basis for a heat transfer model, the researchers trained an autoencoder deep neural network. Five metrics were used to assess the performance of the deep model [14]. Here, analysing the accuracy and other performance metrics of the CNN-based approach for classifying thermal images created from a sensor-based thermal tomographic imaging approach is the crux of our current work.

## EXPERIMENTATION

A basic set-up has been constructed to generate and classify thermal tomographic images within a specified closed volumetric space that resembles a chamber, specifically a rectangular wooden box that has been heated by hot-air blowing into and out of it [15, 16]. Moreover, a thermistor-based temperature sensor arrangement and a flex sensor type air-flow velocity arrangement mounted on a PVC made ring like structure followed by an embedded microcontroller unit interfaced with a PC, are used in the design of a data-acquisition circuit to measure the boundary point temperatures and various point-wise 2-dimensional air flow velocities. The following **Figure 1** depicts the workflow process. Inside the set-up, a desired fluid i.e. air flow rate has to be maintained. Due to this, on one face of the chamber, a universal motor operated blower has been attached. Now, inside the chamber, a circular ring hung from the upper lid, with a 15cm diameter houses a temperature measurement system consisting of 8 negative temperature coefficient bead-type thermistors, each with a nominal value of 10kΩ at 25°C. These thermistors are placed with an angular gap of 45° between each pair. The element, which is heating the internal air of the chamber is a ceramic heater of 200W. Due to the amalgamated actions of the heater and air blower, the boundary temperature values induced are recorded using a data acquisition system governed by an embedded microcontroller system. Double-axis air velocities at strategic boundary points are also measured using flex sensors. These sensors are interfaced with Arduino Mega unit through instrumentation op-amp based amplifier circuitry. The measured temperature and air velocity data are fed to the COMSOL Multiphysics programme as the boundary values for the system modelling. The measured boundary temperature values were entered into a 2-dimensional circular geometric contour that was designed for this purpose. A similar incorporation of the fluid i.e. air-flow velocity profile has also been made in the aforementioned model. The unsteady heat transfer equation [17] provides the following governing domain equation:

$$\rho C_P \frac{\partial T}{\partial t} + \nabla.(-k\nabla T) = Q - \rho C_P \vec{u}\nabla T \qquad (1)$$

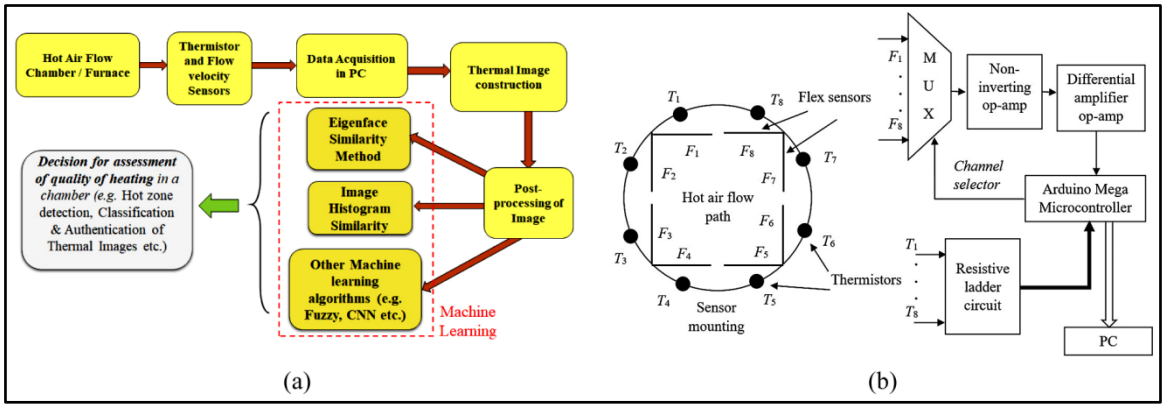


**Figure 1**(a) Work flow illustration & (b) block diagram of the sensor mounting and the data-acquisition circuitry

Both the boundary temperature profile and the air-flow velocity profile have been altered concurrently in this ongoing work. ρ, $C_\rho$ and k values have been taken to be of temperature-independent type. The equations are strategically

approximated and the problem has been discretised. In essence, these discretisation procedures aid in the approximation of the PDE, or heat flow equation, using numerical model equations. Numerical techniques can then be applied to solve these model equations. As a result, the estimated solutions to the aforementioned equation are fairly close to the actual ones. Since it depends on finite element analysis, COMSOL Multiphysics software can solve the whole computation with the aid of the finite element method (FEM) [15-17]. In tackling the unsteady heatflow problem, a medium-sized FEM mesh was employed for analysis utilising the COMSOL [16]. The problem was effectively addressed to ascertain the temperatures at all nodal points within the internal domain of the specified contour. Following this, the outcomes were depicted using a colour-mapping technique, resulting in the formation of thermal images. Three sets of tomographic images were created, each illustrating different levels of heating quality characterised by spatial temperature variations within specified contour. These categories encompass Non-uniform heating (NUH), Uniform heating (UH), and Highly non-uniform heating with zero air velocity (HNZAV) [17].

## THE PROPOSED CNN BASED CLASSIFIER

In this section, the suggested CNN-based methodology is discussed for the classification of the obtained tomographic images. **Figure 2(a)** portrays the development and utilisation of the CNN based classifier. First, the tomographic experimentation is carried out and an image database is developed. The image database consists of colour images for three categories: NUH, UH and HNZAV. Training and test subsets are prepared by selecting the images at random. The images that are present in the training subset do not appear in the test subset. Second step entails choosing a suitable configuration for CNN and its training. CNNs are extensively employed to deal with tasks containing unstructured data i.e. image and video classification, object detection, localisation of defects in constructions etc. [18-20]. CNNs can automatically extract features from images by using a set of specialised layers. The configuration of a CNN model is depicted in **Figure 2(b)**.

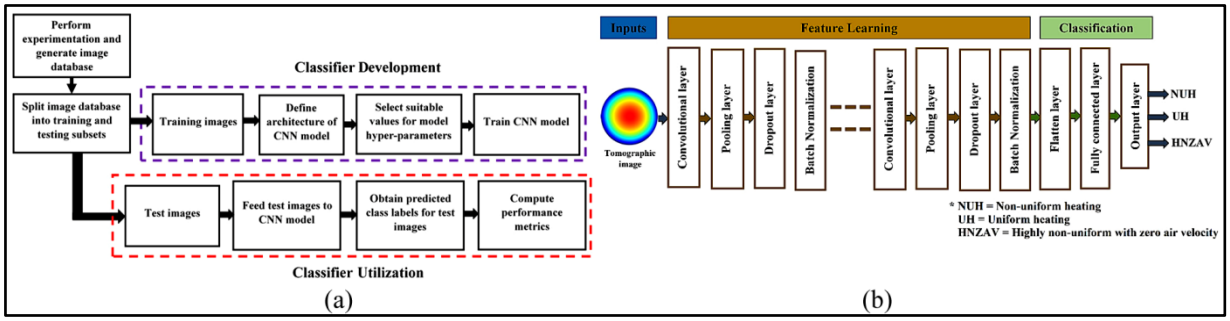


**Figure 2** (a) The proposed methodology & (b) the structure of CNN model

## RESULTS AND DISCUSSIONS

The image database obtained from the tomographic experimentation contains images for the 3 classes. There were 40 images for each class. Out of the 40 images of each category, 35 images were randomly selected for learning, and the remaining was utilised to assess the classification performance of the classifier. In **Figures 3(a)** and **3(b)**, the representative images of the three classes for training and testing are given **Table 1** provides training details and hyperparameters of the CNN based classifier. The weights of the kernels in the Convolutional Layers (CLs) and the weights of the Fully connected Layers (FLs) were optimally determined using Adam optimisation algorithm. After the classifier was trained, it was tested using the test images in order to verify its ability to classify unseen tomographic images.

The classification results are bestowed in **Table 2**. In addition to the accuracy, two other performance metrics: sensitivity ($S_e$) and positive-predictivity (+P) were also computed. It can be noticed from the obtained results that the proposed CNN based classifier demonstrated satisfactory classification performance with low misclassification rate (overall accuracy: 93.33%).

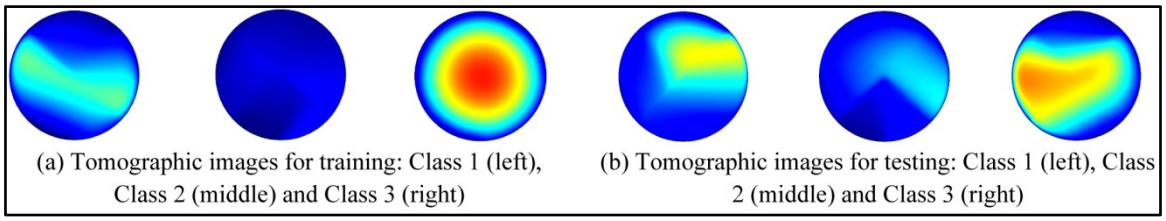


**Figure 3** Tomographic images used for (a) Training & (b) Testing

**Table 1** Hyperparameters and training details of CNN based classifier

| Specification | Values /Functions/ Method | Specification | Values /Functions/ Method | Specification | Values /Functions /Method |
|---|---|---|---|---|---|
| No. of CLs | 2 | Size of a filter in CL | 3×3 | No. of neurons in FL | 128 |
| No. of Pooling Layers | 2 | Size of a filter in Pooling Layer | 2×2 | Training algorithm | Adam |
| No. of dropout layers | 2 | Pooling operation | Max Pooling | Initialisation | Normal |
| No. of batch normalisation layers | 2 | Dropout rate | 0.2 | Size of input images | [75×75×3] |

**Table 2** Comparative table of actual and detected tomographic images along with Sensitivity and Positive predictivity indicators for the testing set

| Actual tomographic images | Detected tomographic images | | | Total | No. of True Positive (TP) obtained | No. of False Positive (FP) obtained | No. of False Negative (FN) obtained | $S_e$ | $+P$ |
|---|---|---|---|---|---|---|---|---|---|
| | Class 1 | Class 2 | Class 3 | 15 | | | | (%) | (%) |
| Class 1 | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 100 | 100 |
| Class 2 | 1 | 4 | 0 | 5 | 4 | 0 | 1 | 80 | 100 |
| Class 3 | 0 | 0 | 5 | 5 | 5 | 0 | 0 | 100 | 100 |

## CONCLUSION

It can be concluded that the proposed Convolution Neural Network framework has successfully abled to classify the given thermal tomographic images with considerable accuracy mark. The proposed classifier sensitivity and positive-predictivity values were also found satisfactory. However, the performance of the proposed algorithm classifying the test images are to be further critically assessed using a greater number of constructed training and testing images. This kind of indirect assessment of heating may perhaps be supportive for scheming further curative measures. With the right choice of sensor arrangements, these kinds of studies can be used to obtain highly accurate measurements of the temperature distribution inside any real-world engineering processes, such as closed-conduits transferring liquid or gas, inside industrial furnaces, and so forth.

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58_IEC22427

# Business Growth with AI/ML

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***Keywords:*** *Data Analytics; Automation; Cyber Security*

## INTRODUCTION

This paper looks in to the various ways in which AI/ML can be used to drive the growth of businesses and their potential area of application.

The information technology and services sector in India is getting into an exciting phase with huge growth and opportunities across diverse segments. Since the last couple of decades, India's technology service industry is at the forefront and driving technology-enabled business transformations across the world. With initiatives like Aadhar, Aatma Nirbhar Bharat and Digital India along with technologies like Data Analytics and AI, India is not just transforming but leading the global market in digital transformations.

AI & ML is one of the emerging technologies in digital transformation that help businesses deliver unforgettable digital customer experiences. They enable the emergence of new business innovations.

The use of data and AI is the central point for organizations and management, driving their digital transformation journey. Digital transformation coupled with AI & Machine Learning can deliver best results and help in transforming core areas like BFSI, healthcare, citizen services, MSME, agriculture and manufacturing, with speed and scale.

Organizations can build predictive models to bring a great deal of efficacy in digital optimization and automation and it can help scale processes much faster, allowing results to be delivered in seconds as compared to months

AI (Artificial Intelligence) and Machine Learning (ML) is projected to achieve a CAGR of 52% by 2025, indicating its rapid adoption by worldwide businesses.

Collectively, they augment growth prospects for businesses focused on customers and striving to leverage the extended possibilities of digital transformation fully. The integration of AI is currently permeating and being put into action across diverse industries, including but not limited to national security, healthcare, logistics, and education.

## METHODOLOGY

### India AI Mission Pillars

This mission aims to promote inclusive growth of AI ecosystem through the following seven pillars.

1. IndiaAI Compute Capacity
2. IndiaAI Innovation Centre
3. IndiaAI Datasets Platform
4. IndiaAI Application Development Initiative
5. IndiaAI FutureSkills
6. IndiaAI Startup Financing
7. Safe & Trusted AI

The basic element needed for AI to thrive is the availability of data and computing power. Advancement in

technology has helped both areas; availability of greater computing power and large amounts of data. Businesses today are trying to harness data to gain a competitive edge over their counterparts.

The various ways in which AI/ML can propel Business growth is outlined below.

1. **Process automation**

   The primary advantage businesses can derive from AI/ML is the comprehensive automation of processes. By automating diverse processes, it allows the businesses to allocate their attention to other essential responsibilities.

2. **Smart market analysis**

   Most companies focus on innovative market analysis to grab a competitive edge in their domain. But now, thanks to the emergence of AI-influence, it has become pretty easy to stack and identify market data effectively. This software is designed to help businesses understand the sales matrix and conversions of customers.

3. **Streamlined sales process**

   To create an advanced sales process, organizations can utilize AI-powered CRM platforms. They can build and manage customer databases, allowing business stakeholders to see how different leads can be materialized through proper strategies.

   These sophisticated multitasking platforms empower businesses to handle customer data effectively and enhance sales processes.

4. **Personalized customer experience**

   It becomes the primary obligation of all stakeholders to elevate the customer experience by utilizing all accessible resources.

   In alignment with present trends, the method of choice for capturing people's interest is through personalized customer experiences.

   By harnessing robust systems integrated with machine learning algorithms, companies can present tailor-made services to customers based on their specific requirements.

   Achieving this necessitates understanding their preferences, and machine learning technology excels at delivering such solutions with exceptional precision and accuracy.

5. **Better decision making**

   Artificial Intelligence and Machine Learning can be used to analyse large volumes of data and show insights that might elude human observation. This allows businesses to enhance their decision-making processes.

   It encompasses tasks like recognizing emerging market prospects or refining the efficiency of supply chain operations.

6. **Cyber security monitoring**

   Utilizing AI and ML enables the real-time monitoring of cyber security threats and the identification of anomalies, effectively mitigating the potential for data breaches and other security breaches.

7. **Profitable growth**

   Digitalization has helped organizations to expand and generate income by utilizing advancements in Artificial

Intelligence. The incorporation of AI contributes to revenue growth for companies in diverse ways.

It enables enterprises to identify areas of vulnerability and generate precise forecasts concerning potential opportunities, competition, and shifts in market trends.

8. **Improved productivity**

Leveraging Artificial Intelligence to automate distinct manual tasks empowers organizations to achieve heightened productivity. This assertion is substantiated by numerous studies indicating that AI contributes to productivity growth of 40% or higher.

Artificial intelligence effectively enhances productivity through various avenues. It can swiftly gather and compile information, thereby saving valuable employee time that can be channelled toward core objectives.

Furthermore, AI can execute intricate computations, recognize patterns, and automate repetitive tasks. Consequently, organizations gain a competitive advantage by efficiently obtaining insights that facilitate well-informed decision-making.

**RESULTS**

The transformation that a business can undergo by deploying AI/ML is enormous and this will help to grow a business in a very competitive way

This paper presents as a result the areas in which AI/ML can be deployed to fuel the business growth

1. AI can help convert Smart Cities into Intelligent Cities by meeting the rapidly increasing demand of the urbanised population and providing them with a better quality of life, better traffic control to reduce congestion and enhance security using improved crowd management.
2. AI in E-Pathshala by providing text-to-speech and text translation systems to aid easy availability of learning material in the many Indian languages as well encourage interoperability of teachers across states.
3. AI in E-Prison using video analytics platforms to identify violations and illegal activities and flag them for swift action.
4. AI in Farmer Portal using image-recognition software, drone technology and machine learning to monitor crops, predict yields, encourage precision farming, stabilise yield, analyse soil quality, predict economic gains from future yields and predict advisories for weather, sowing, pest control, input control to help increase farmers' income.
5. **Telecom**

The Telecom industry is one of the fastest adopters of AI and Machine learning in multiple areas of business, from improving network reliability to better customer experience to predictive maintenance. The most common AI applications in Telco are:

(a) Predictive Maintenance and Network Optimization
(b) Customer Satisfaction and experience
(c) Better Customer Targeting

6. **BFSI Sector**

This sector is gradually opening up to adopt innovative solutions to transform the banking system with initiatives like Jan Dhan Yojana, UPI, and the BharatNet mission which is driving internet adoption across India. Areas, where AI can play a crucial role, are:

(a) Digital Services to gain a competitive advantage, drive efficiencies and improve customer experience.
(b) Robotics and Natural Language Processing (NLP) to enhance on-demand customer experience and satisfaction.

(c) Adoption of algorithms in Investments to increase portfolio returns and reduce risks, both for institutional and retail investors.
(d) AI-based financial management tools to deliver personalized financial management advice and alerts to customers.
(e) Smart transaction analysis programs and tools to detect fraud and money laundering transactions.

## CONCLUSION

The adoption of AI/ML has become order of the day and as it can be seen from this paper presented that businesses stand to gain immensely by deploying them to stay on competitive track.

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74_IEC74268

# Exploration of Relative Permittivity as a Marker for Moisture Content in Bamboo Samples

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***Abstract:*** *In present times, ethanol is used as an alternative to fossil fuels globally. Bamboo is an important source of producing ethanol. The moisture present in the bamboo determines the efficiency of ethanol production. Hence, accurate moisture measurement in bamboo is important. Gravimetric measurement is gold standard for determination of moisture content in any solid fuel (i.e. coal, biomass etc.). However, this method is time consuming and not suitable for onsite or field testing. On the other hand, other available methods for onsite moisture measurement are primarily applied to woods. Bamboo being one of the tallest grass shows significant different characteristics than woods. Here, as an initial exploration, we attempt to measure moisture content in Bamboo through capacitance sensing, which is simple, compact and thus field deployable. Our work shows promising result where relative permittivity of bamboo sample, when measured through capacitance sensor, well correlates with its moisture content.*

***Keywords****: Ethanol, Capacitive Sensor, Bamboo Moisture Measurement, Relative Permittivity*

## INTRODUCTION

Access to affordable and renewable energy is an important aspect to be achieved by 2030 as a part of United Nations SDGs [1]. Ethanol is less pollutant than conventional petroleum sources as it has low carbon and Sulphur content [2,3,4]. This is produced from biomass extraction of various plant based sources like sugarcane, corn, bamboo etc. [5,6]. In developing countries, bamboo (Bambusa Vulgaris) is used as one of the most important source for ethanol production [6].The mechanical and other physical properties depends heavily on the moisture present in bamboo [7]. It has also been observed that the quality and efficiency of ethanol production depends heavily on the moisture content present in bamboo [7,8]. That's why it is imperative to measure the moisture content present in bamboo before it can be used for Ethanol production.

At present, gravimetric measurement is used for determination of moisture content in any solid fuel like coal, biomass etc.[9,10,11]. In this technique, oven dry weight of the sample under test has to be determined which requires heating the sample uniformly (without burning) until entire moisture evaporates from the sample [9,10,11]. Thus this method is time-consuming and is entirely based on laboratory facilities.

To overcome such laboratory dependencies, other techniques such as microwave, ultrasound, resistive sensing, infrared thermography etc. may be explored. This is to note that indeed many of the mentioned techniques have been explored for determining moisture measurement in various types of woods over a few decades [12-16]. For example, in [17], a method to detect moisture in wood by measuring the speed of ultrasound is reported. Similarly, microwave based technique (as a non-contact and non-invasive modality), for moisture content determination in wood is reported in [18]. Also, resistive sensor (FHA 636-MF) may be used to determine moisture content in wood [19] with some limitation. For example, it is reported in [19] that with resistive sensor one can measure moisture content in wood in moisture range of 7% to 30%. Additionally, there is reliability issues with these resistive sensors to predict moisture level above 20% and below 9% [9]. Apart from resistive sensor, capacitive sensor is also used to measure the amount of water in wood [20, 21]. However, it is reported that it can only measure moisture level up to 50%.

We would like to highlight the fact that bamboo is different from wood and it belongs to the family of grass -in fact the tallest grass in the world [22]. Thus significant differences in properties among wood and bamboo are evident and they are highlighted in [23,24]. To best of our knowledge, we couldn't find any single work specific to bamboo that attempts to develop moisture content sensor that is simple, compact and field deployable. Thus our novelty lies in

developing simple capacitive type measurement on bamboo sample to extract the relative permittivity that effectively tracks the moisture content in a wide range (0% to 100%).

The paper is organized as follows — section II describes working principle. After that, experimental setup is discussed with figures. Results are discussed in section IV, followed by conclusion and acknowledgment.

**WORKING PRINCIPLE**

Our method measures the impedance of a sample (through capacitive sensing) - which is a function of the capacitance value for a fixed frequency. Thereafter we calculate the relative permittivity from the capacitance value. We hypothesize that the relative permittivity is a function of the moisture content in the sample. Mathematically speaking, the magnitude of impedance (Z) of a capacitor (C) can be written as

$$|Z| = \left|\frac{1}{j\omega C}\right| = \left|\frac{1}{\omega C}\right| \quad (1)$$

Where, ω (= 2πf) is called angular frequency (rad/sec) with f in Hz. Now, capacitance (C) of a parallel plate capacitor can be expressed as :

$$C = \frac{\varepsilon_0 * \varepsilon_r * A}{d} \quad (2)$$

Where, A is the area of each plate in parallel plate capacitor, d is the distance between two plates, $\varepsilon_0$ is permittivity of free space and $\varepsilon_r$ is the relative permittivity of the sample as depicted in **Figure 1**. Substituting the value of C, in (1), one obtains,

$$|Z| = \left|\frac{d}{2\pi f * A * \varepsilon_0 * \varepsilon_r}\right| \quad (3)$$

From (3), it can be written

$$\varepsilon_r = \left|\frac{d}{2\pi f * A * Z * \varepsilon_0}\right| \quad (4)$$

Using (4), relative permittivity can be determined and may be explored for different moisture levels.

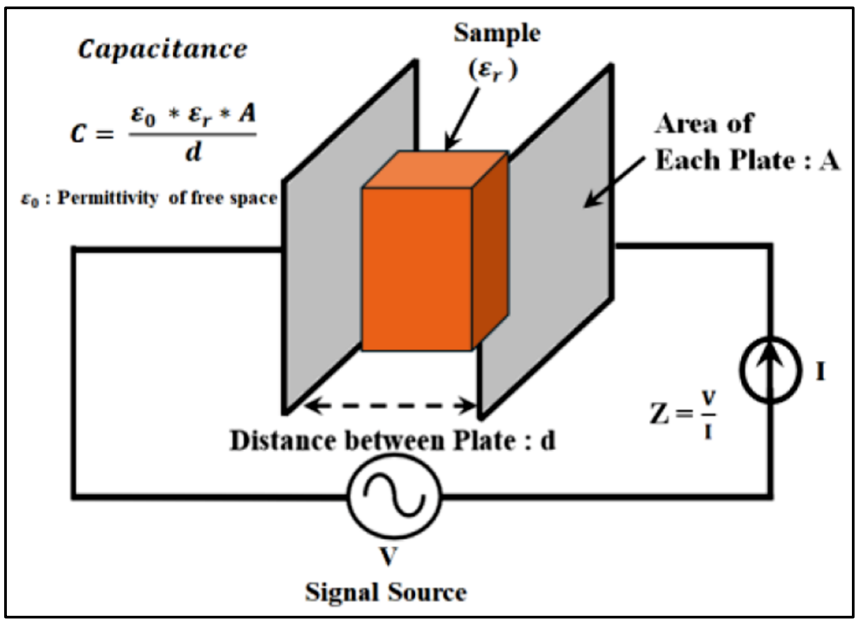


**Figure 1** Schematics of parallel plate capacitor

## EXPERIMENTAL SETUP

### Sensor Design and Experimental Setup

An experimental setup is depicted in **Figure 2**. The plates are made up of copper. The length and breadth of the sensors are 13.15 mm and 12.01 mm respectively. A clip is used to hold the parallel plates tight across the sample as shown in **Figure 2(b)**.

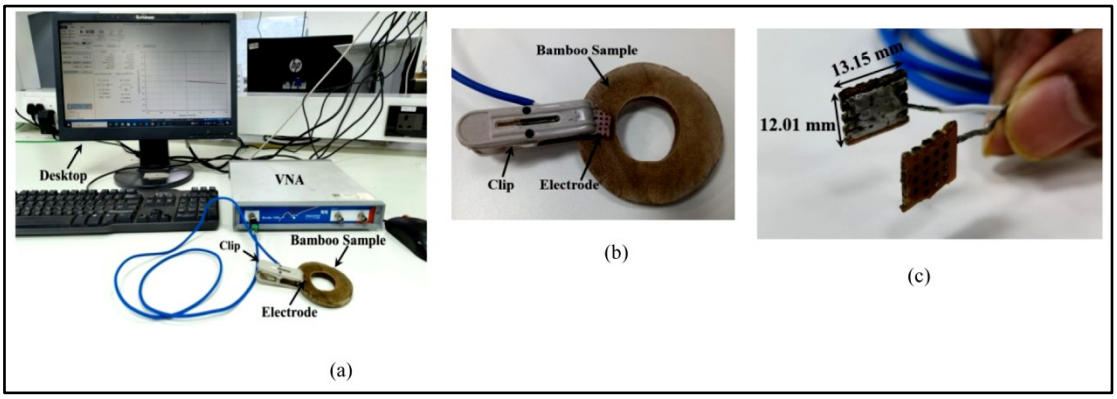


**Figure 2** (a) Experimental setup; (b) Electrode with Sample; (c) Electrode design.

### Mositure Level Estimation

Bamboo is considered for this experiment. Three slices are cut from a large bamboo to obtain different samples (samples A, B and C respectively). The picture of bamboo slice is shown in **Figure 2(b)**. To obtain different moisture levels, these samples are fully immersed into water in a beaker for 18 hours. After that, a sample is placed into a hot air oven one at a time and dried at 103 ±2°C as per standards [25,26]. This drying is carried out every 15 minutes after which the sample is placed inside the desiccator to cool down at room temperature.

This also prevents absorbing moisture from the environment while cooling phase. The weight of the sample is measured with a weighing machine (K. Roy Scientific, resolution 1 mg) to produce gravimetric based ground-truth. Then, impedance (Z) of the bamboo sample is recorded using VNA (Bode 100) at 1 kHz excitation frequency (5V pp). After this step , the same sample is placed inside the hot air oven for oven drying for another 15 minutes and same procedure is repeated until the complete moisture is evaporated. If completely dried sample (i.e. no moisture) weight is m0 ; intermediate moist sample weight is m, then the moisture content of the moist sample is calculated as:

$$\text{Moisture content} = \left(\frac{m - m_0}{m_0}\right) * 100\% \qquad (5)$$

The instrumentation for each of this experimental steps are depicted in **Figure 3**. As mentioned earlier, this whole process is carried out for 3 bamboo samples.

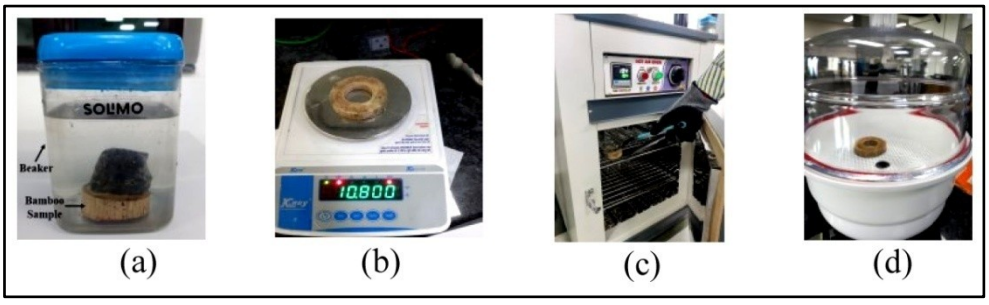


**Figure 3** Bamboo sample (a) immersed in water (b) weighing the sample, (c) oven drying of sample, (d) sample placed inside desiccator

## RESULTS

First, the ground-truth data is presented (obtained through over drying process). Here, the moisture level (through the oven dried process) is plotted for each sample in **Figure 4**. Each data point on the graph indicates that weight is taken at that point and moisture level is calculated from the weight through oven drying principle and capacitive measurement is taken on the sample to find out the relative permittivity at that moisture level. It can be seen that the moisture evaporates as the process continues and the moisture almost completely evaporates around time= 120 mins for all the samples. The complete oven dried weight $m_0$ (i.e. with no moisture in sample) of sample A, B and C are found to be 13.84 gm, 14.8 gm and 10.8 gm respectively. It is to note that bamboo samples, when immersed in water for long periods may absorb water that is more in weight than the sample itself and thus moisture level over 100% is achieved in the beginning (i.e., at time =0 or before drying process is started).

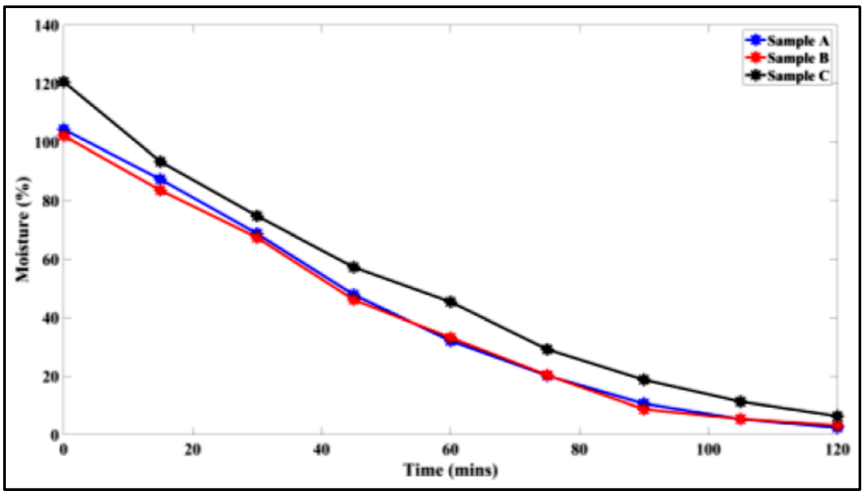


**Figure 4** Variation of moisture content (%) with time for Sample A, B and C

**Figure 5** shows the relative permittivity vs moisture level plot for each of the sample A, B and C. The moisture levels and corresponding relative permittivity values for each sample are tabulated in **Tables I**, **II** and **III** respectively.

It can be seen from **Figure 5** that a second order polynomial suitably fits these data points. Thus, from **Figure 5**, it is clear that the relative permittivity of bamboo increases with the moisture level and follows a second order polynomial. Thus, the relative permittivity may serve as a marker for measuring moisture level in bamboo samples and may be measured through simple capacitive measurement technique.

**Table I** Physical properties of bamboo sample A

| Time (Min) | Moisture free Weight (gm) $m_0$ | Moist Sample Weight (gm) m | Moisture level (%) | Rel. Permittivity ($\varepsilon_r$) |
|---|---|---|---|---|
| 0 | 13.84 | 28.78 | 104.32 | 9.1787 |
| 15 | | 25.92 | 87.28 | 9.5707 |
| 30 | | 23.35 | 68.71 | 7.6831 |
| 45 | | 20.46 | 47.83 | 4.8219 |
| 60 | | 18.28 | 32.08 | 3.0130 |
| 75 | | 16.63 | 20.15 | 1.9634 |
| 90 | | 15.31 | 10.62 | 0.7970 |
| 105 | | 14.58 | 5.34 | 0.5254 |
| 120 | | 14.18 | 2.45 | 0.4732 |

**TABLE II** Physical properties of bamboo sample B

| Time (Min) | Moisture free Weight (gm) $m_0$ | Moist Sample Weight (gm) m | Moisture level (%) | Rel. Permittivity ($\varepsilon_r$) |
|---|---|---|---|---|
| 0 | 14.8 | 29.92 | 102.16 | 10.4832 |
| 15 | | 27.16 | 83.51 | 11.4293 |
| 30 | | 24.77 | 67.36 | 9.1912 |
| 45 | | 21.62 | 46.08 | 7.9342 |
| 60 | | 19.71 | 33.17 | 5.6667 |
| 75 | | 17.81 | 20.33 | 3.2337 |
| 90 | | 16.09 | 8.7 | 0.8878 |
| 105 | | 15.60 | 5.4 | 0.7134 |
| 120 | | 15.27 | 3.17 | 0.7088 |

**TABLE III** Physical properties of bamboo sample C

| Time (Min) | Moisture free Weight (gm) $m_0$ | Moist Sample Weight (gm) m | Moisture level (%) | Rel. Permittivity ($\varepsilon_r$) |
|---|---|---|---|---|
| 0 | 10.8 | 23.83 | 120.64 | 12.7312 |
| 15 | | 20.88 | 93.33 | 14.3061 |
| 30 | | 18.87 | 74.72 | 12.3936 |
| 45 | | 16.98 | 57.22 | 8.9919 |
| 60 | | 15.7 | 45.37 | 7.8388 |
| 75 | | 13.95 | 29.16 | 4.3646 |
| 90 | | 12.82 | 18.74 | 1.3936 |
| 105 | | 12.02 | 11.29 | 0.7270 |
| 120 | | 11.49 | 6.38 | 0.5286 |

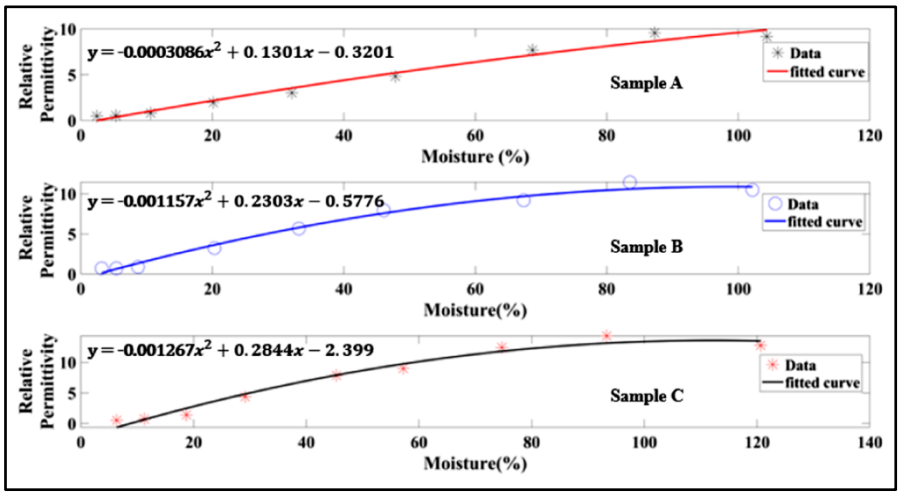


**Figure 5** Variation of relative permittivity against moisture level

## CONCLUSION

In this work, a preliminary study on variation of relative permittivity with moisture level in bamboo is presented using simple capacitive sensing technique. Our result shows clear correlation of permittivity with the moisture content over a wide moisture range. Thus, our results shows the possibility of developing compact field deployable sensor for on-spot moisture content determination for bamboo to aid sorting bamboos for ethanol production. As a future scope, we are planning to do experiments on more samples to come up with a calibration curve (i.e. training phase) and then applying it on unknown samples (i.e. testing phase) to actually measure the moisture content through our proposed method.

## ACKNOWLEDGMENT

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88_IEC89694

# Quantum Speedup of Machine Learning Algorithms

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***Abstract:*** *Quantum machine learning is a burgeoning field that leverages the unique properties of quantum computing to accelerate traditional machine learning algorithms. By exploiting quantum parallelism and interference, quantum computers have the potential to dramatically outperform classical computers on certain machine learning tasks. This research investigates the quantum speedup achievable for several fundamental machine learning algorithms. We observe significant improvements in the computational efficiency of:*

- *k-means clustering: A popular unsupervised learning algorithm used for data segmentation.*
- *Support vector machines (SVMs): A supervised learning algorithm widely used for classification and regression.*
- *Principal component analysis (PCA): A dimensionality reduction technique used to extract the most important features from data.*

*The findings reveal that quantum algorithms can offer exponential speedups compared to their classical counterparts for these tasks. This is due to the ability of quantum computers to explore a vast number of possible solutions simultaneously and to exploit quantum interference to amplify the probability of finding optimal solutions. These results highlight the promise of quantum computing for revolutionizing machine learning and enabling the analysis of larger and more complex datasets than is currently possible with classical approaches. As quantum hardware continues to advance, it is anticipated that quantum machine learning will play a crucial role in addressing a wide range of challenges in fields such as artificial intelligence, drug discovery, and materials science.*

***Keywords:*** *Quantum Machine Learning; Quantum Speedup; Machine Learning Algorithms; Quantum Computing; Computational Complexity*

## INTRODUCTION

Quantum machine learning is a rapidly emerging field at the intersection of quantum computing and machine learning. It leverages the unique principles of quantum mechanics, such as superposition and entanglement, to accelerate and enhance traditional machine learning algorithms. By exploiting these principles, quantum computers can explore a vast number of possible solutions simultaneously, potentially leading to exponential speedups compared to classical computers.

The convergence of quantum computing and machine learning has significant implications for a wide range of fields, including artificial intelligence, drug discovery, materials science, and finance. Quantum machine learning has the potential to address complex problems that are intractable for classical computers, such as optimizing large-scale combinatorial problems, simulating quantum systems, and developing new materials with desired properties.

This research delves into the potential quantum speedup achievable for several fundamental machine learning algorithms, including k-means clustering, support vector machines, and principal component analysis. Our aim is to demonstrate the advantages of quantum computing in these domains and to identify areas where quantum algorithms can offer significant improvements over classical approaches.

By understanding the capabilities and limitations of quantum machine learning, we can explore its potential applications and develop strategies to harness its power effectively.

## METHODOLOGY

Theoretical analysis and simulations of quantum algorithms vis-à-vis their classical counterparts for:

1. k-means clustering

2. Support Vector Machines (SVMs)
3. Principal Component Analysis (PCA)

**RESULT**

k-Means Clustering

- Classical algorithm: O(nkd) due to iterative distance calculations.
- Quantum algorithm: O(log n) using quantum parallelism and interference.
- Speedup: Exponential (O(n^kd) → O(log n)).

Support Vector Machines (SVMs)

- Classical algorithm: O(n^3) due to matrix operations.
- Quantum algorithm: O(log n) using quantum support vector machines.
- Speedup: Exponential (O(n^3) → O(log n)).

Principal Component Analysis (PCA)

- Classical algorithm: O(n^3) due to matrix operations.
- Quantum algorithm: O(log n) using quantum principal component analysis.
- Speedup: Exponential (O(n^3) → O(log n)).

The results are summarized in **Table 1**.

**Table 1** Summary Table

| Task | Classical | Quantum |
|---|---|---|
| k-Means Clustering | O(nkd) | O(log n) |
| SVM Training | O(n^3) | O(log n) |
| PCA | O(n^3) | O(log n) |

**CONCLUSION**

This research demonstrates the potential of quantum machine learning to revolutionize data analysis by leveraging quantum computing's unique properties. Our investigation has shown that quantum algorithms can achieve exponential speedups for fundamental machine learning tasks, including k-means clustering, support vector machines, and principal component analysis. These results suggest that quantum computing can potentially enable the analysis of larger and more complex datasets than is currently possible with classical approaches.

**Implications**

Faster Data Analysis: Quantum machine learning can enable real-time insights from large datasets.

Improved Accuracy: Quantum algorithms optimize model performance and feature extraction.

New Applications: Quantum-inspired machine learning models tackle complex problems in AI, drug discovery, and materials science.

**Current Limitations**

Quantum Hardware: The current state of quantum hardware is still relatively immature, with limited qubit numbers and high error rates. These limitations can impact the application of quantum machine learning algorithms.

Noise and Error: Quantum noise and errors can degrade the accuracy and reliability of quantum computations. Use of effective error correction techniques is crucial for achieving practical gains.

Quantum Algorithm Development: While significant progress has been made, there is still a need for more efficient and versatile quantum algorithms for various machine learning tasks.

Scalability: Scaling quantum machine learning algorithms to handle large datasets and complex models remains a work in progress.

Quantum Control: Maintaining control over scaled up quantum systems.

**Future Directions**

Scaling Quantum Machine Learning: QML implementations involving larger datasets and more complex models can solve hitherto intractable problems.

Noise Resilience: Developing robust quantum algorithms and error correction techniques.

Quantum-Classical Hybrids: Optimizing integration for practical applications.

Quantum machine learning has the potential to transform data analysis, enabling faster, more accurate, and more efficient processing of complex datasets. As quantum hardware advances, we anticipate significant breakthroughs in AI, healthcare, and materials science. Our research provides a foundation for further exploration of quantum machine learning's capabilities and limitations.

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103_IEC43935

# Revolutionizing Healthcare: A Comprehensive Survey on Large Language Models

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***Abstract:*** *Large language models (LLMs) are enabling a revolution in artificial intelligence, particularly in the healthcare industry. These models enable a more customized approach to healthcare analytics, which raises the relevance and accuracy of results when they are customized to specific disorders. Specialized LLMs improve their ability to respond to inquiries unique to their area of expertise by building on basic models and being trained on extensive datasets spanning a wide range of subjects. The increasing prevalence of tailoring LLMs for medical applications is exemplified by applications such as MedAlign, MedLM, and MediPalm, which are instances of generative AI solutions created with the healthcare sector in mind. The countless opportunities that LLMs have to improve the working conditions of healthcare personnel and, consequently, the caliber of patient care, are evidenced by the continuous advancement of novel approaches and applications in this domain. This research attempts to showcase the most recent developments in cutting-edge LLMs in the medical field, with an emphasis on personalized models that address particular medical requirements.*

***Keywords:*** *Large Language Model; Artificial Intelligence; Generative AI; Healthcare*

## INTRODUCTION

The creation of foundation models has prompted a revolutionary wave in the field of artificial intelligence over the past few years. Their success can be attributed mostly to large model sizes and extensive pre-training on massive datasets, particularly to their remarkable ability to generalize across a wide range of downstream tasks [1]. Large language models have evolved remarkably in the Natural Language Processing community as a result of this growth, marked by a number of groundbreaking developments some models like BERT [2], T5 [3], and the most recent popular model GPT4 [4]. The transformer architecture, which was first introduced in the Google article "Attention is all you need" in 2017 [5], is the brains behind innovative models like ChatGPT [6], which have generated fresh enthusiasm in the AI world. LLMs are a subset of AI created especially to produce text-based material, and they are closely related to the term "generative AI". Text generation and manipulation in LLMs are achieved through the use of transformer architecture and deep learning. More importantly, LLMs basically use unsupervised learning which calculates probability from previous words and modifies its parameter settings with an optimization system via a back-propagation technique and this kind of technique predicts the next word in a sequence depending on the text that came before it.

Due to the popularity of LLMs, AI technologies now have an unparalleled chance to significantly advance the medical field through the development of Medical Large Language Models. With the potential to revolutionize healthcare and biomedical applications, Med-LLMs such as ChiMed-GPT [7], MedicalGPT [8], HuatuoGPT-II [9], and ChatMed [10] have attracted increasing interest from the academic and industry communities. Most recently, studies on Med-LLMs have covered a wide range of topics, from enhancing patient care quality and outcomes to assisting physicians in making more correct judgments. Med-LLMs have the potential to improve healthcare in many ways, such as through better understanding of medical information, more accurate diagnosis, tailored therapy suggestions, etc. On the United States Medical Licensing Examination, for example, MedPrompt can do better than expert-level humans. HuatuoGPT-II is capable of passing several Chinese medical certification exams.

### What LLMs can do for Healthcare?

Strong capabilities are shown by the Medical Large language model in a number of medical domains, including as drug design, radiography, dentistry, nuclear medicine, and clinical settings. It is a collection of medical records and medical documents efficiently by using specialized models such as Bidirectional Encoder Representations from

Transformers for Biomedical Text Mining (BioBERT) and Generative Pre-trained Transformerfor Biomedical Text Generation and Mining (BioGPT), which outperform traditional models in processing intricate biomedical terms. Particularly, BioBERT demonstrates significant gains in tasks like biomedical query ranking, entity recognition, and relationship extraction. Because they improve patient outcomes, operational efficiency, and individualized care, LLMs have the potential to completely transform the healthcare industry. But these developments also bring with them new ethical problems that need to be resolved within the parameters of conventional healthcare ethics. These problems include algorithmic bias, data privacy issues, decision-making openness, and the possibility of dehumanizing healthcare.

It is essential to investigate the uses, constraints, and future developments of LLMs in the medical field. The goal of this review is to provide a comprehensive overview of the benefits, challenges, and recent advancements related to the application of LLMs in medicine.

By reviewing the corpus of literature and previous research, we hope to evaluate different methods, provide information about the state of Large Language Model in medicine field today, and identify areas that require more research and improvement. The following is a summary of the study's contributions:

(a) Our comprehensive and current evaluation of medical large language model covers the latest developments in theory, practice, and applications.
(b) We thoroughly analyzed the latest advancements in the medical model, looking at the prospect and paths it gives for further study in adjacent domains.

**EARLY WORK**

We have discovered a few recent survey papers that offer an extensive summary of the research conducted on large language models in the medical field. The survey [11] demonstrates both the excitement and the reservations over the growing use of large language models (LLMs) in the medical domain. It follows their evolution from traditional Pretrained Language Models (PLMs) and examines their benefits and drawbacks. Among the key areas of concern are the training methods used by LLMs in the healthcare industry, as well as the challenges pertaining to justice, ethics, accountability, and transparency. The survey indicates a move from model-centered to data-centered approaches, from discriminative to generative AI, and PLMs to LLMs. It also identifies accountability, transparency, and ethics as the primary obstacles to their adoption in the healthcare industry. With their human-like linguistic abilities, large language models (LLMs) such as the GPT series have drawn a lot of interest and are currently revolutionizing the healthcare industry. With an emphasis on their effects on clinical decision support, report creation, and medical education, this paper examines the development of Medical Large Language Models (Med-LLMs) from general to specialized medical applications. It highlights sophisticated algorithms that improve LLM performance in intricate medical settings and talks about how important it is to handle moral issues like accountability, privacy, and justice. The evaluation also looks at Med-LLMs' potential futures, with a particular emphasis on responsible innovation and legal frameworks [12].

This paper [13] examines the creation and use of large language models (LLMs) in the medical domain, emphasizing the range of applications that these models can have. It talks about the difficulties encountered throughout the development of LLMs as well as the advances in LLMs brought about by increased computing power and resources. The article highlights the benefits of medical LLMs, offers a brief overview of current models, and makes recommendations for future study to improve how well they integrate into medical practice.

As indicated in **Table 1**, we compare and contrast this study with previous review papers on the same topic in order to better understand our contribution, improve the paper's contributions, and offer additional information for future research.

**Table 2**, which attempt to provide a development road map for some Med-LLMs, is arranged chronologically.

**Table 1** Gaps of existing papers

| Paper Name | Application | Threat Issues | Thread Solution |
|---|---|---|---|
| The future landscape of large language models in medicine (2023) [14] | X | Ethics and data security | NA |
| Large language models in | Chatbot | Ethics, accuracy, | Yes |
| medicine (2023)[15] | | interpretability | |
| Large language models encode clinical knowledge (2023)[16] | X | Ethics, extension of evaluation data, clinical accuracy, human evaluation framework | Na |
| Embracing large language models for medical applications: Opportunities and challenges (2023)[17] | X | Ethics, accuracy, cost, privacy, regulatory framework | Na |
| A survey of large language models in medicine: Progress, application, and challenge (2023)[11] | Health Support, Report Generationmm, Medical robotics, Translation | Evaluation benchmarks, limitations of domain data, new knowledge adaptation, behavior alignment, ethics | Yes |

**Table 2** Lists of existing MED-LLMS

| Med-LLMs Model | Training Information | Assessment Information |
|---|---|---|
| MentalBERT(2021)[18] | Depression Stress, Suicide Detection | Reddit |
| PubMedBERT(2021)[19] | Literature on Medicine | Biomedical language Under-standing and Reasoning Benchmark |
| BioBART(2022)[20] | Literature on Medicine | CovidDialog, iCliniq etc. |
| GatorTron(2022)[21] | Medical Remarks | Multi-Query Attention, NER |
| KeBioLM(2022)[22] | Literature on Medicine | Biomedical language Understanding and Reasoning Benchmark |
| Galactica(2022)[23] | DNA sequence | MedMCQA, PubMedQA |
| Med-PaLM(2022)[24] | Clinical Datasets | HealthSearch question-Answers |
| ChatDoctor(2023)[25] | Doctor-patient | Conversations iClinic |
| MedAlpaca(2023)[26] | Questions-Answers and Clinical Conversations | Medical Meadow |
| PMC-LLaMA(2023)[27] | Academic Papers in Biomedicine | PubMedQA, MedMCQA |
| BianQue(2023)[28] | Clinical Question-Answers | PubMedQA |
| HuatuoGPT(2023)[9] | Data on Instruction and Conversations | webmedQA, and Huatuo26M |
| MedAGI(2023)[29] | Available Medical Pictures and Datasets | SkinGPT-4, XrayChat, PathologyChat |
| MedLSAM(2023)[30] | Medical image segmentation | MedBench, ELO |
| ChatMed(2023)[10 ] | Online Advise | - |
| EpiSemoGPT(2024)[31] | Estimating the epileptogenic zones | - |
| Qilin-Med(2024)[32] | Domain-specific continued pre-training, RAG | - |
| Apollo-7B(2024)[33] | Multilingual, Lightweight, Proxy | - |
| | tuning | |
| CancerLLM(2024)[34] | Diagnose 17th types of Cancer | - |

## DISCUSSION

On May 2024, China has launched its first AI hospital town, where patients will receive medical care from AI-generated doctors in a virtual environment. The concept of an AI hospital town, where AI doctors treat virtual

patients, is very important to both medical professionals and the general public. Through a simulated environment, the AI hospital seeks to train doctor agents so they can become more adept at treating illnesses on their own and evolve on their own. Researchers from Tsinghua University have just established the "Agent Hospital" in this virtual environment, where all medical staff, nurses, and patients are managed by intelligent agents with the ability to communicate independently thanks to extensive language models. 10,000 patients can be treated by AI doctors in a few days, an effort that would take at least two years for human doctors. During this survey, we find CancerLLM [35] where the paper introduced medical LLM for cancer domain and it gives better accuracy than the existing LLMs.

## CONCLUSION AND LIMITATION

In conclusion, this comprehensive analysis has offered a detailed overview of the constantly evolving field of large language models in healthcare, progressive advances, and trustworthy considerations. Here we demonstrate up-to-date assessment of l LLMs covers the latest developments in theory, practice, and applications.

Although large language models (LLMs) have been used in a number of healthcare domains, including drug discovery and diagnostics, their application is still restricted to a few specialized fields. These include specialized medical fields driven by ethical considerations, such as formal mental health diagnosis, sophisticated interventional treatments requiring prompt decisions, and uncommon genetic illnesses. Furthermore, the analysis of data from long-term research and healthcare policy and management do not yet make extensive use of LLMs. The difficulties arise from the difficulty of these assignments, the requirement for specialized knowledge, and the present shortcomings of LLMs in managing complicated medical data.

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113_IEC96381

# A Systematic Review and Experimental Analysis of AR based Simulator used for Maritime Training

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***Abstract:*** *This is a systematic literature review and experimental study on the integration of Augmented Reality (AR) based Training methodology within maritime training. The study focuses on systematic optimization the usability and evaluating the training effectiveness. AR Technology presents a promising AI tool bridging between the conventional training simulators and final proficiency acquisition by making the seafarers training environment a virtually real space. This preview analyses an abundance of data gathered from more than a hundred pre reviewed studies offering a clear understanding of how immersive technology can be effectively utilised to evaluate the training and watch keeping requirements (STCW).*

*The experimental study, involves application of AR based tailored training simulators to a group of aspiring maritime professionals allowing an immersive, hands-on practice with increased student engagement, and evaluation of competency, knowledge retention and skills without an associated risk.*

*To assess the impact of AR on skill acquisition, a series of experiments were conducted, wherein 80 students specializing in maritime engineering participated in a series of tests designed to evaluate the effect of augmented reality on skill learning. Two groups of participants were formed; one group trained conventionally, and the other group trained using*

*an augmented reality simulator. The purpose of the experiment was to assess how augmented reality (AR) impacted student practical skills, comprehension of marine operations, user engagement, flexibility, and overall training satisfaction. Comparing the students who trained with the AR simulator to those who received traditional training, the results showed that the former had significantly improved their ability to acquire new skills. In particular, the AR group performed better trouble shooting tests involving managing equipment, spatial awareness, and taking corrective action decisions.*

*Despite of these encouraging results, the study also pointed out certain challenges. A portion of students reported feeling uneasy or confused when utilizing the augmented reality simulator, suggesting that additional improvements to the technology are necessary to guarantee user comfort. Furthermore, the AR equipment's initial setup and maintenance required a significant amount of time and money commitment, which would prevent some organizations from adopting it. Finally, by providing an efficient, interesting, and adaptable learning tool, augmented reality (AR) has the potential to transform certain areas of maritime engineering education, as demonstrated by the experimental study and systematic literature review. The benefits of augmented reality (AR) in improving proficiency skill acquisition and offering a safer, more affordable training environment are evident, notwithstanding several obstacles to its broad adoption. Future research on addressing the technical and logistical barriers to AR adoption, as well as exploring long-term outcomes of AR-based training in maritime engineering will ease in its adoption as an effective tool.*

*This study intends to analyse and increase and constantly improve the application of augmented reality (AR) in maritime education, with a special focus on engineering equipment maintenance. The purpose of the study is to determine how well AR-based training may improve the practical skills, knowledge retention, and competency of maritime engineers.*

***Keywords:*** *Augmented Reality; Immersive Technology; Maritime Training; Education, Training Effectiveness; Simulators; Marine Engineering; Proficiency; STCW, MET*

### 1. Evaluate Theoretical Knowledge Retention and Competency

To evaluate and compare, the knowledge retention of individuals undergoing AR-based training with those undergoing traditional training methods, using pre- and post-test results.

**Figure 1** B. Tech Engineering trainee performing Single Butt Joint (3G) welding using Augmented Reality welding Simulator (Tolani Maritime Institute)

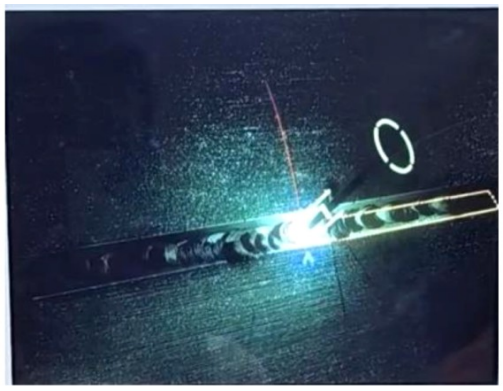


**Figure 2** The screen image seen through the headset (SOLDAMATIC Augmented Reality Simulator)

**2. Measure Maritime Proficiency Skill Acquisition**

Using performance metrics on given activities, determine how well the AR-based training simulator performs in comparison to traditional training in terms of improving participants' practical abilities in operating and maintaining equipment.

**3. Assess user Involvement**

Using surveys to assess motivation of participants and degree of involvement during AR-based training sessions in comparison to traditional training sessions.

**4. Assess Confidence Levels**

To look into how participants' confidence has taken a turn in using newly acquired knowledge and abilities before and after participating in conventional and AR-based training sessions.

**5. Assess user Satisfaction**

To understand satisfaction of participants with the AR-based training simulator in comparison to conventional training techniques, taking into account factors like user feedback, intuitiveness, and ease of use.

**6. Determine the Usability of Augmented Reality (AR) in Maritime Training**

To investigate opinions of trainers about how well AR fits into different maritime training domains and investigate their level of satisfaction with the training simulator.

**HYPOTHESIS STATEMENTS**

Hypothesis statements for a research study on the training effectiveness of an AR-based training simulator:

**Hypothesis 1: Knowledge Retention (Competency Development)**

Null Hypothesis (H0): There is no significant difference in knowledge retention between participants who undergo AR-based training and those who undergo traditional training.

Alternative Hypothesis (H1): Participants who undergo AR-based training will exhibit significantly higher knowledge retention compared to those who undergo traditional training. (Pre-test and post-test score comparison between AR-based and traditional training groups)

**Hypothesis 2: Skill Acquisition (Proficiency Development)**

Null Hypothesis (H0): There is no significant difference in skill acquisition between participants who undergo AR-based training and those who undergo traditional training.

Alternative Hypothesis (H1): Participants who undergo AR-based training will demonstrate significantly higher skill acquisition compared to those who undergo traditional training. (Measure performance on practical tasks to assess effectiveness.)

**Hypothesis 3: User Engagement**

Null Hypothesis (H0): There is no significant difference in user engagement levels between participants who undergo AR-based training and those who undergo traditional training.

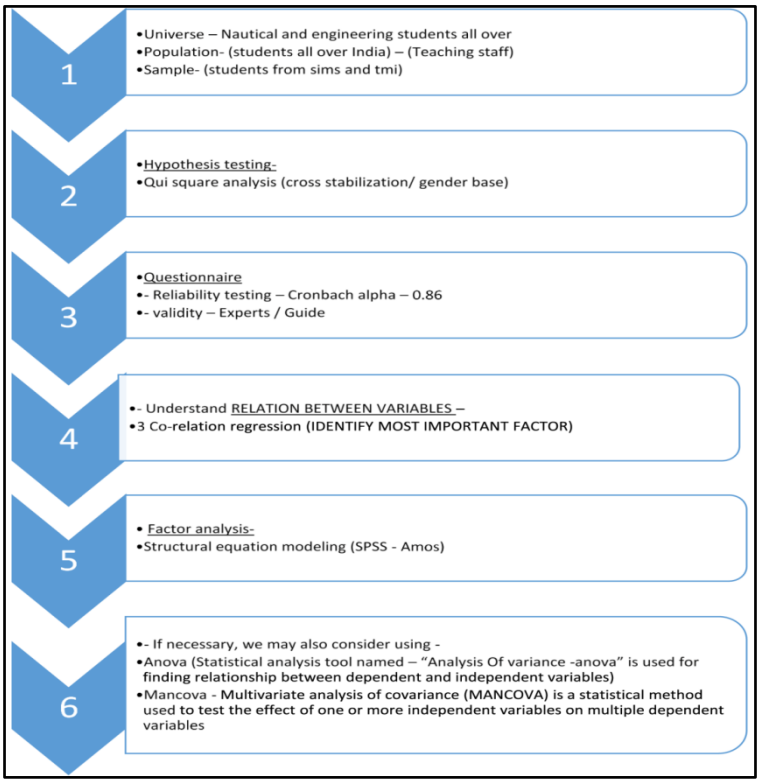
Alternative Hypothesis (H1): Participants who undergo AR-based training will report significantly higher levels of engagement compared to those who undergo traditional training. (Evaluate using surveys and interaction logs to measure engagement)

**Hypothesis 4: Return on Investment**

Null Hypothesis (H0): There is no significant difference in time or expenses incurred while training, between participants who undergo AR-based training and those who undergo traditional training.

Alternative Hypothesis (H1): There is significant reduction in training time or expenses while using AR-based training compared to traditional training. (Use surveys and interaction logs)

**METHODOLOGY**




**SUMMARY OF FINDINGS**

The quality of training has been greatly and more importantly positively affected by augmented reality technology, in

spite of having limited knowledge of its applicability in the MET setting. It is truly remarkable how openly and readily the cadets have accepted this new approach for their learning and training experience. The current research investigation supports the alternative proposed hypothesis, which can be validated, based on these data and inferences made from the analysis.

Smarter education methodologies have been explored and experimented for enhancing teaching learning experience. Approaches with AR and VR technology, in variety of domains; is maturing and widely getting accepted within upcoming avenues to address several emerging issues. There are phenomenal accomplishments of AR technology at the same time there are significant challenge that is beyond the scope of this paper.

Lot of advancements have been done in conventional training at the Maritime Training Institutes, but the shipboard training, which is done by a skilled and experienced mentors. But in future, due to reduced shipboard manning levels and tighter working schedules, the mentorship may not be effectively available to the learner.

The research retrospect, learner's process of understanding and ease of learning; is significantly upraised by supplementing simulations with VR and AR based real time training environment. Formative studies showed positive Impact of AR technology on learner's cognitive load, suggesting a strong case of AR based approach into training.

124_IEC35197

# Development of an IoT Based Simplex Wireless Communication Protocol for Smart Lighting Control

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***Abstract:*** *Due to the advancements in the field of electronics, the economical availability of varieties of sensors, microcontrollers and microprocessors have become a reality for the users. Recent trend of manufactured products include wireless transmission modules as well as microcontrollers with an integrated Wireless Fidelity (Wi-Fi) chip, the availability of which has prompted a surge in research and developmental studies in the field of wireless communication, wireless data monitoring and wireless controlling of electrical or mechanical appliances. Due to the availability of Wi-Fi, Internet of Things (IoT) sensor data transmission and wireless controlling has been steadily increasing. In the current paper a simplex wireless communication procedure has been presented, which has been developed and applied to an IoT based Pulse Width Modulated (PWM) lighting control of Light Emitting Diode (LED) luminaires. The working principle of the aforementioned developed system along with the performance evaluation of the LED luminaire has been presented. The performance evaluation includes both the electrical as well as illumination parameters. The LED luminaire chosen in the present work is a high voltage street luminaire.*

***Keywords:*** *Internet of Things (IoT); Light Emitting Diode (LED); Pulse Width Modulation (PWM)*

## INTRODUCTION

A considerable amount of work has been done in the field of application of wireless connectivity and controlling of luminaires , introducing automation, electrical and surrounding environment conditional monitoring and controlling as well as wireless lighting control of luminaires. Wireless lighting control of luminaires not only introduces ease of operation , but also provides flexibility for wireless control of various lighting parameters. The introduction of LED has revolutionized the concept of smart lighting by allowing the control of input current to LED for dimming . Thus, LED luminaires can be used as nodes of communication in a network ,similar to sensor networks in IoT. Digital switching as well as dimming control of luminaires using Bluetooth has been done in which a Bluetooth module has been used to provide connectivity . Shuangshuang et al [1] has utilized Bluetooth connectivity, for connecting to smartphone thereby providing an user friendly mobile Application (App), which provides machine – human interface. This enables lighting control of luminaire. The App dashboard has virtual soft switches for ON/OFF switching as well as virtual range slider for PWM dimming by certain degree. The communication of these data has been successfully executed. Cheng et al[2], has designed a Bluetooth communication App, consisting of three sliders for independent dimming control of three different led arrays of different colours. The concept of using Zigbee wireless communication protocol in lighting control and system monitoring has been introduced by Thattai et al [3] in which, the App dashboard has the options for controlling the dimming levels of different LED arrays. An option has been given for time monitoring so as to automatically adjust the lighting dimming levels for smart and intelligent energy conservation. B. C. Rolando et al [4], has developed a personal local network by incorporating different Zigbee modules attached to different luminaires enabling the wireless controlling of different luminaires at the same time using a mobile App. The usage of Wi-Fi for wireless transmission of an android based remote signal for lighting control of luminaires has also been done by K. -H. Teng et al [5]. The usage of various sensors and real time clock modules in controlling the dimming levels and monitoring the ambient surrounding light levels via Wi-Fi has been done by Tobiloba Somefun et al[6]. V. Rao Ch et al [7], has used ultrasonic sensors for the detection of obstacles according to which the dimming levels of luminaires are controlled.

The ease of availability of various Wi-Fi enabled microcontrollers and Bluetooth modules has provided the foundation for the exploration of automated control of multiple luminaires by creating a personal area network, consisting of multiple receiving stations attached to led luminaires. The availability of options for connecting a microcontroller to Wi-Fi and setting up a microcontroller itself as a Wi-Fi generating station has increased the

opportunities for connectivity to global as well as a personal local network for lighting control of luminaires. In the present paper a concept of a one way i.e. simplex communication protocol utilizing both wired and wireless data transfer protocol has been utilized. Universal Asynchronous Receiver Transmitter (UART) communication protocol has been utilized as a bridge between to two different IoT networks. One of the two IoT networks utilize the wireless connectivity to the user , providing the user with a Graphical User Interface (GUI) as well as wireless transmission and reception of sensor and controlling signal data.

## METHODOLOGY

### A. System Architecture

The heart of the entire system is the Main Controller Unit (MCU). The MCU is comprised of two parts i.e., MCU(2) and MCU(1). MCU(2) is responsible for providing a local Wi-Fi connection to the user. A webpage, consisting of a slider is available to the user. The webpage, which acts as the GUI, allows the user to control the dimming level of the luminaire. The user can select any duty cycle percentage from 0% to 100% , which are multiples of 10.MCU(1) is responsible for the wireless signal reception as well as the wireless signal transmission of data. It is also responsible for the wired reception of PWM duty cycle data from MCU(2).

Presence Detection Unit (PDU), detect the presence of any obstacle. The PDU consists of Transmitter Unit (TU) and Ultrasonic Sensors. The TU is responsible for the wireless transmission of sensor data to MCU(1).MCU(1) wirelessly transmits this data to each of the Signal Reception Unit (SRU)s. Each of the SRUs consists of two units i.e. Receiver Unit (RU) and Signal Amplification Unit. The RUs is responsible for the wireless reception of signals from the MCU while the Signal Amplification Unit is responsible for amplification of the received data from 5V to 10V, for driving the LED drivers. Each of the SRUs has been connected to a street led luminaire. The block diagram showing the operation of the entire developed system has been shown in **Figure 1**. In the Figure, the developed GUI has been shown. It consists of a range slider , which allows the user for selecting the PWM duty cycle % value. The GUI also shows the value of the selected PWM duty cycle % value, for the convenience of the user. This GUI is a webpage, which the user can access, once the user is connected the MCU local network.

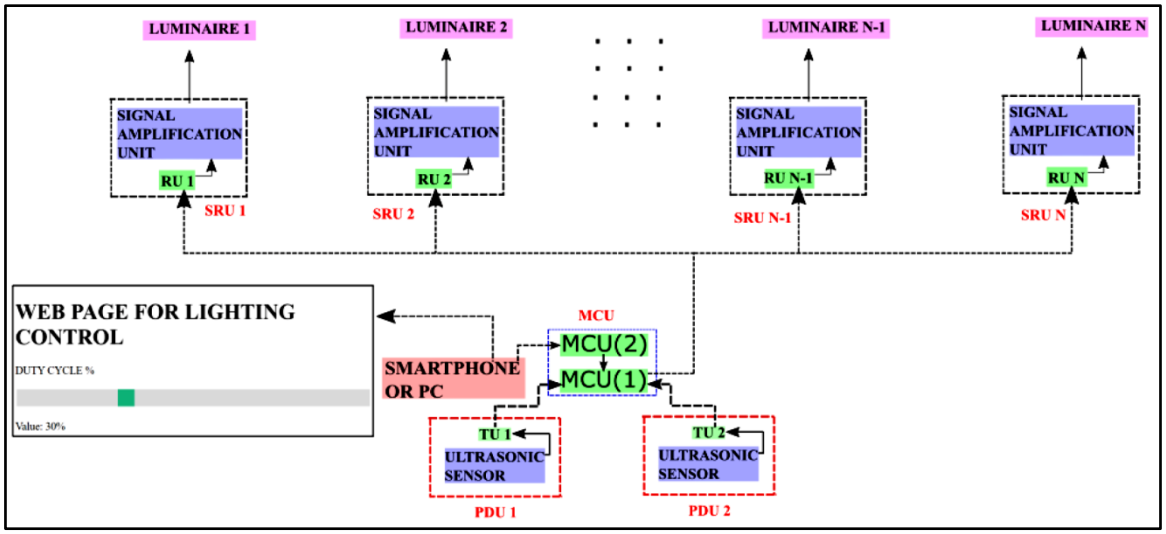


**Figure 1** Block diagram showing the operation of the entire developed system with the developed GUI

### B. Operational Algorithm

The algorithm for the operation of the entire system has been shown below.

Step I: Switch ON LED luminaire at low brightness level and set MCU (2) as Access Point.

Step II: if (occupancy = = true), then:

Step II a: Send occupancy data to MCU (1).
Step II b: if (occupancy <= range), then:
Step II b i: Constant brightness level.
Step II b ii: Update brightness level through SRU.
Step II b iii: RETURN to Step II.

Else:

Step II c: Set brightness level by user connection to Access Point network.
Step II d: Update brightness level through SRU.
Step II e: RETURN to Step II.

Else:

Step III: Wait for occupancy data
Step IV: RETURN to Step II.

**C. Reception Mechanism**

Control Algorithm:

Step I: Allocate output pins for PWM output.
Step II: Set PWM properties i.e. resolution and frequency.
Step III: Configure output pins with PWM properties.
Step IV: Receive dimming data from MCU (1).
Step V: Map received data to microcontroller bit range.
Step VI: Write data to allocated output pins.

The control algorithm for the SRU is uploaded into the microcontroller, which is brain of the SRU. Step I to Step III represent PWM initialization algorithm while Step IV to Step VI represents mapping algorithm for PWM generation. The concept of working mechanism of the SRU has been illustrated in **Figure 2**. The generated PWM control signals from the microcontroller is fed to Signal Amplification Unit, consisting of optocoupler and switching transistors which are biased to work in active region for amplification purposes. The amplifies signal is used to control a constant current LED driver which in turn drives LED arrays.

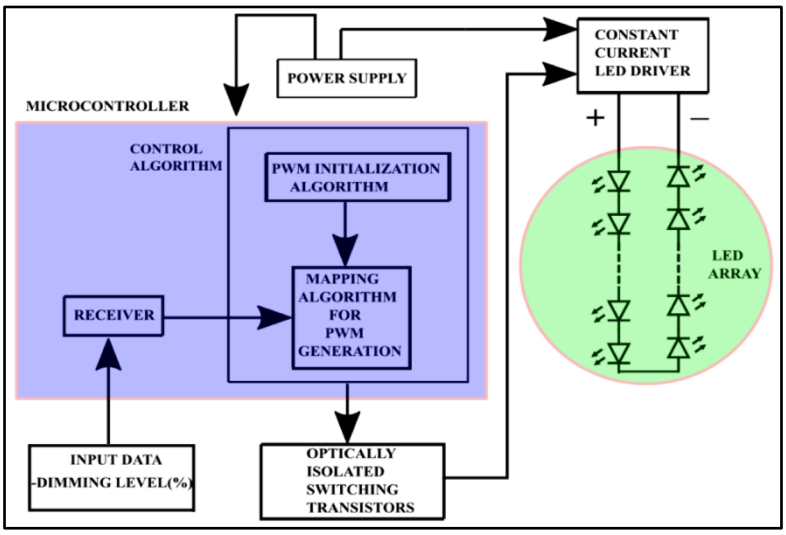


**Figure 2** Block diagram showing the concept for wireless dimming control of LED luminaire at reception end

## RESULTS

A street luminaire has been chosen for the experimental verification of the developed communication protocol. The illuminance of the luminaire has been controlled by the GUI, which is available to the user smartphone, after the user has connected to the local Access Point network. A graph, showing the variation of the output illuminance and the input current drawn with the variation in duty cycle % has been plotted as shown in **Figure 3**.

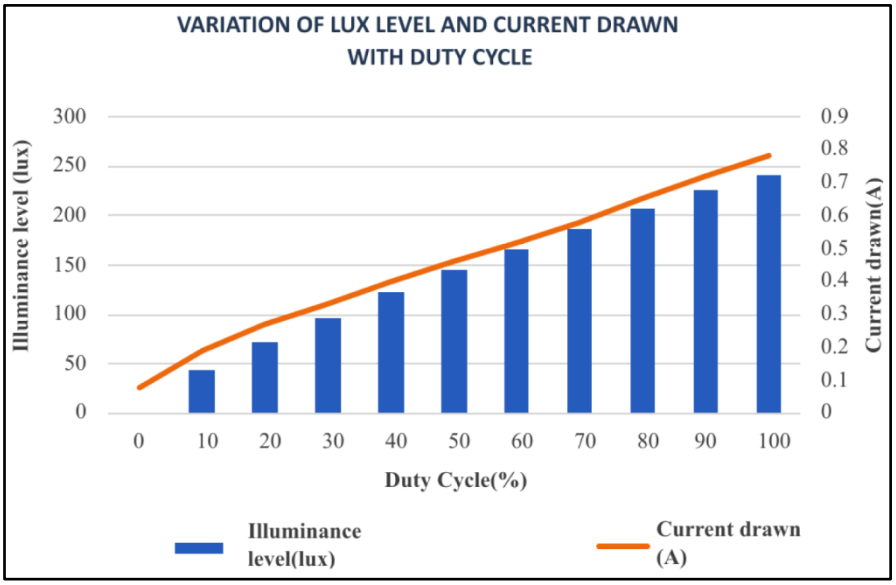


**Figure 3** Plot showing the variation of illuminance level and current drawn with variation of duty cycle percentages.

From the graph, it is evident that the system response is almost linear. The output illuminance and the input current drawn varies linearly, in accordance with the linear variation of dimming percentage. The initial jump in current drawn is due to the fact that initially at zero output illuminance condition, the Signal Amplification Unit draws some current for powering the system.

## CONCLUSION

The developed communication protocol has been tested for smart controlling of LED luminaire. The entire system has a linear response, paving way for IoT based wireless lighting control of LED luminaire. The wireless lighting control by user as well as the automatic lighting control with the help of sensors, justifies smart lighting. The user can control the dimming level so as to meet the lighting standards at any time of the night, ultimately leading to energy conservation as well as the fulfilment of aesthetics and lighting standard for mitigation of light pollution. This one way or simplex communication protocol has been developed without any feedback as feedback is not needed.

## FUTURE SCOPE

The developed communication protocol can be used for setting dimming levels for different luminaires for different times of night meeting needs for both lighting and energy conservation. The electrical parameters and the state of dimming level can be monitored for conditional monitoring purposes from a monitoring station located at a distant location. The data can also be recorded and be uploaded to cloud for future data analysis.

## ACKNOWLEDGMENT

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135_IEC29928

# Comprehensive Survey on Blockchain-based Identity and Access Management Systems in Mobile Networks

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***Abstract:*** *This paper provides a comprehensive survey of blockchain-based identity and access management (IAM) systems in mobile networks. Blockchain technology, due to its decentralized, secure, and transparent nature, has been a promising solution for addressing the limitations of traditional centralized IAM systems. This paper examines the key concepts, challenges, and future directions of blockchain-based IAM in mobile networks. It explores self-sovereign identity, zero-knowledge proofs, and smart contracts to bring security, privacy, and scalability. Lastly, it talks about integration with blockchain and IoT/next-generation mobile networks. By highlighting the challenges along with harnessing the strength of blockchain, we would be able to build stronger, efficient, and more user-centric mobile network ecosystems.*

***Keywords:*** *Identity and Access Management (IAM); Mobile Networks; Blockchain Technology; Self-Sovereign Identity (SSI); Decentralized Identity Management; Next-Generation Mobile Networks (5G)*

Identity and Access Management (IAM) systems are critical for ensuring security in mobile networks, particularly as the proliferation of mobile devices and services increases the complexity of identity management. Traditional IAM systems are centralized, which creates vulnerabilities such as single points of failure, scalability issues, and privacy concerns. In contrast, blockchain technology offers a decentralized approach to identity management, enhancing security and enabling user-centric solutions like self-sovereign identity (SSI). This paper provides a comprehensive survey of IAM systems in mobile networks that leverage blockchain technology, detailing current advancements, challenges, and future research directions.

IAM serves as the foundation for communication between users, devices, and network providers within evolving mobile networks and IoT environments. Centralized IAM frameworks are particularly susceptible to cyber-attacks and privacy risks, prompting the need for decentralized IAM systems. Blockchain technology is emerging as a promising solution due to its inherent characteristics of decentralization, security, and transparency. This survey aims to explore various approaches to blockchain-based IAM systems in mobile networks, assessing their strengths, limitations, and potential to address key challenges. Blockchain technology provides a distributed ledger that is transparent, immutable, and secure, making it highly suitable for identity management systems. Unlike traditional IAM systems, blockchain-based solutions allow for decentralized identity verification, where no single entity controls the identity information. This enables users to manage their identity and related data, allowing them to disclose only selected attributes to service providers without relying on a central authority, thereby reducing privacy risks. For instance, Gilani et al. (2022) propose a smart contract-based decentralized identity management system that enhances security and privacy, enabling users to maintain exclusive ownership of their identity attributes. Similarly, Bai et al. (2022) highlight the benefits of blockchain-based SSI systems in securing sensitive patient information within healthcare systems. In the context of IoT, identity management becomes increasingly complex due to the vast number of devices requiring secure, scalable, and low-latency solutions. Robust mechanisms for device authentication and secure communication are necessary. Integrating blockchain technology into IoT networks addresses challenges related to scalability, privacy, and trust, although it also introduces implementation complexity and storage overhead. Al Hwaitat et al. (2023) propose a permissioned blockchain authentication framework that optimizes data storage and enhances scalability while ensuring homomorphic encryption. Kettani and Carnley discuss the integration of blockchain with Public Key Infrastructure (PKI) and RFID to improve security and trust in IoT deployments.

The emergence of next-generation mobile networks, such as 5G, has increased the demand for sophisticated IAM solutions capable of managing greater complexity and scale. Blockchain-based IAM can significantly enhance the security, privacy, and flexibility of mobile network systems. Xu et al. (2020) introduce a dynamic identity management system that employs dynamic cryptographic key generation and chameleon hash functions to bolster security while minimizing storage burdens. Additionally, redactable blockchain technology allows for the removal of unauthorized user information without compromising the blockchain's integrity, thereby increasing system flexibility.

Despite the advantages of blockchain-based IAM systems, challenges remain, particularly concerning privacy and scalability. The transparency of blockchain can expose identity-related data to unauthorized entities, necessitating advanced cryptographic techniques like zero-knowledge proofs (ZKP) to mitigate these risks. Yang and Li (2020) propose a ZKP-based identity management scheme that enables users to verify their identity without revealing actual attributes, thereby enhancing privacy. Chia-Hung et al. (2022) present a blockchain-based identity and access control framework for open banking, utilizing smart contracts to ensure secure access control and safeguard user privacy.

Scalability and performance are critical issues for blockchain applications, especially in large systems like mobile networks and IoT environments. High storage demands and latency due to the growth of blockchain ledgers pose significant challenges. Proposed solutions include permissioned blockchains, optimized cryptographic techniques, and ledger pruning mechanisms. Xu et al. (2023) evaluate the scalability of their blockchain-based IAM system, demonstrating its capability to support numerous users while maintaining low latency through dynamic cryptographic key generation.

Conventional IAM systems in mobile networks are typically centralized, relying on trusted third-party entities for user authentication and authorization. This centralization introduces vulnerabilities and potential security breaches, as attackers may target central databases to steal sensitive identity data. Kumar and Sehgal (2020) note that the evolution of mobile networks has heightened the need for secure and efficient IAM solutions that can support both data and voice communication. While blockchain-based IAM systems offer numerous benefits, they also face significant challenges, including scalability and privacy concerns. Research is ongoing to develop scalable solutions, such as layer-two protocols and sharding, to address these issues. Additionally, as IoT devices become increasingly integrated into mobile networks, identity management must evolve to provide lightweight and energy-efficient authentication mechanisms. Overall, the potential of blockchain technology in enhancing IAM systems in mobile networks

## CONCLUSION

Blockchain-based IAM systems ensure solutions to several challenges in identity management for mobile networks by decentralizing identity storage and authentication. However, several issues remain to be resolved before these solutions can see generalized adoption, such as scalability, privacy, and interoperability. Future research should focus on improving blockchain scalability, developing privacy-preserving techniques, and integrating blockchain-based IAM systems with emerging technologies like IoT and 5G.

Blockchain technology may create opportunities to transform identity and access management in mobile networks into more secure, user-centric, and scalable systems. As one of the most promising approaches to decentralized identity and access management in mobile networks and IoT environments, blockchain-based IAMs can solve many of the challenges inherent in traditional systems by utilizing cryptographic techniques and smart contracts. However, challenges still remain, particularly around privacy protection and performance optimization.

Future research should address scalability issues in blockchain-based IAM systems, develop more efficient cryptographic techniques, and improve the integration of blockchain with existing mobile network and IoT infrastructures.

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151_IEC54034

# Wireless IoT-Based Soil Health Monitoring System by using Soil NPK Sensor for Crop Yield Optimization

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***Abstract:*** *Farming is important to our economic growth of a country. Crop productivity is mainly governed by soil fertility. Fertilizers are usually suggested based on the soil's nutrient content. To suggest an appropriate fertiliser amount, a soil nutrient analysis must be performed, which is normally done using laboratory procedures. Manual soil nutrient testing methods are time consuming. To implement precision Farming, a needle sensors based system has been proposed. A needle-based sensor has been developed to measure and identify the presence of Nitrogen (N), Phosphorus (P), and Potassium (K) in the soil. Such a sensor is used to estimate how much extra content of these nutrients should be given to the soil in order to boost soil fertility. The system collects data using an AVR micro-controller, so the sensor's output is converted to a digital display showing. The needle-based readings on many soil samples have been found to be capable of calculating the quantity of NPK content in the soil in mg/kg. This information is sent to the Amazon Web Services (AWS) cloud, and the resulting values are presented on a mobile app. The suggested Internet of things (IoT)-based application server has the knowledge to recommend the appropriate amount of Nitrogen (N), Phosphorus (P) and Potassium (K) fertilizer to improve the soil's integrity and assure the crop's optimal growth. All device are mounted into a Single PCB board.*

***Keywords:*** *Soil Sensor (NPK); Arduino IDE; RS485(TTL); NodeMcu ESP8266; OLED Dispaly; Battery*

## INTRODUCTION

In today's modern technological era, several kinds of technology have been developed to enhance the agricultural technology. A number of tools that have been developed to assist farmers in carrying out their agricultural operations and producing a healthy crop. Farming is the source of crop production, and soil is a valuable resource. In the production cycle, the physical and chemical characteristics of the soil have a significant impact. The majority of farming systems is dependent on the monsoon. when the monsoon is good, the entire economy succeeds and when the monsoon fails, everyone suffers to some extent. In the modern era, the green revolution came with the purpose of implementing a larger focus on farming. Soil assessment is one of the most useful tools for farmers to improve crop production. Farmers can feed the proper amount of organic or inorganic nutrients to the soil [1]. The soil Macro-nutrients Nitrogen (N), Phosphorus (P) and Potassium (K) content play a significant effect in maximizing production.

The plant's growth is boosted by these three nutrients in various ways. Nitrogen helps leaf and vegetative growth, phosphorus helps root and growth, and potassium helps blooming, fruiting, and nutrition and water management in plant cells. Fertilizer excess or absence may significantly reduce production efficiency and result in poor agricultural quality of product [2]. As the population grows, so does the demand for agricultural products. It is necessary to automated agricultural activities in order to boost productivity. The wireless sensor network used to analyse soil nutrients. The data from sensors and real-time measurements are transferred to the IBM Bluemix cloud [3]. The optical transducer, LEDs, and photo-diode with Arduino micro-controller have been tested as an alternate technique of determining deficit Nitrogen (N), Phosphorus (P) and Potassium (K) content in soil [4]. The soil moisture sensor is used to estimate the volumetric water content of the soil. These probes are inserted into the soil to detect the moisture value. Farmers can use the data generated from the sensor as a support system to better manage their irrigation system [5]. For site-specific applications in agricultural farm areas, soil factor assessment is important. The Internet of Things (IoT), which provides wireless technology to measure many soil properties, is changing traditional farming into modern agriculture [6]. Crop quality is assessed by continuous supervision of pH, temperature, humidity, and soil moisture, which allows farmers to boost their production [7]- [10]. To maximise the consumption of water for crops, an automated farming platform is designed. A decentralized wireless network of soil-moisture and temperature sensors is installed in the base of the tree as part of the system. A gateway unit also manages sensor data, triggers

actuators and sends data to the server application. Solar cells powered the device, which had a duplex network connectivity based on a cellular-Internet interface which allowing data examination and irrigation management to be configured via a web application [14]. A portable soil analysis tool that can assess soil health in less than 90 seconds was developed. It is the first type of technology, which is based on near Infrared Spectroscopy technique and gives a real-time soil investigation assessment on mobile phones through an embedded smartphone app [13]. Existing technologies just provide information for a small number of crops or fail to measure significant aspects.

## METHODOLOGY

The suggested technique needle based soil sensor continually assesses soil micro-nutrients such as Nitrogen (N), Phosphorus (P) and Potassium (K) content in soil by using hardware and software components. This suggests the appropriate amount of fertilizer to help farmers to improve crop productivity by guiding them along through best nutrient management selection and achieve effective crop production.

### A. Framework

The major goal is to examine the Nitrogen (N), Phosphorus (P) and Potassium (K) content in soil methodically. The RS485 TTL and ESP8266 Wi-Fi module are used to connect the soil NPK sensor. For sensor data transmission and reception, the Node MCU is interconnected to the RS485 TTL through Tx and Rx pins. The sensed data is transmitted to the Amazon Web Services (AWS) cloud. The data are transmitted from the Amazon Web Services (AWS) cloud to the smartphone devices. which are depicted in **Figure 1**.

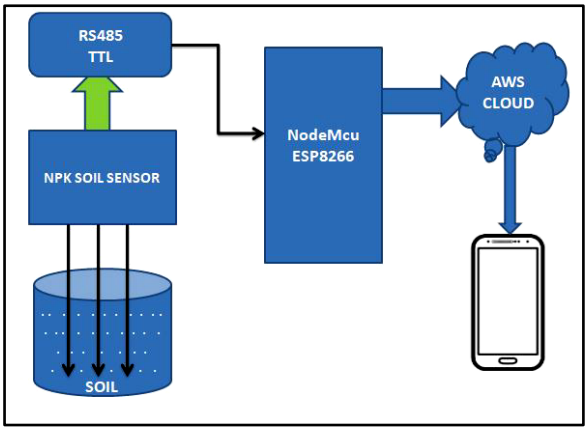


**Figure 1** The Proposed System's Block Diagram

**Table I** Soil NPK sensor configuration [13]

| PARAMETERS | TECHNICAL SPECIFICATIONS |
|---|---|
| Power supply | 9 - 24 V |
| Measuring Range | 0-1999 mg/kg |
| Operating Temperature | 5 - 45 °C |
| Resolution | 1mg/kg |
| Precision | ±2 % F.S. |
| Communication port | RS485 |
| Baud Rate | 2400/4800/9600 |
| Protection Class | IP68 |

### B. Procedure for Testing

- Choose the perfect location for the assessment.
- Avoid the rock, and make sure the steel needle does not come into contact with the hard object.
- Remove the topsoil to the appropriate depth as per the measurement.

- Maintain the original soil stiffness beneath the surface.
- Insert the sensor in the soil vertically and avoid moving it from side-to-side.
- Within a small range of one sample instant, several readings should be averaged.

**C. Precautions for Using a Soil NPK Sensor**

- Insert the sensors gently, not forcefully.
- Do not forcefully twist the steel needles of sensors, pull the sensor lead wire, or strike the sensor.
- Before measuring the data, clean and polish the needles' faces.
- Wait at least 30 seconds for stable data.

**D. Soil Sensor NPK**

A needle-based soil sensors detect the nutrient Nitrogen (N), Phosphorus (P) and Potassium (K) content of soil quickly, which save farmers time. It assess stable real-time data in less than 30 seconds. Farmers can analyze various samples in less time. The working model is shown in **Figure 2**.

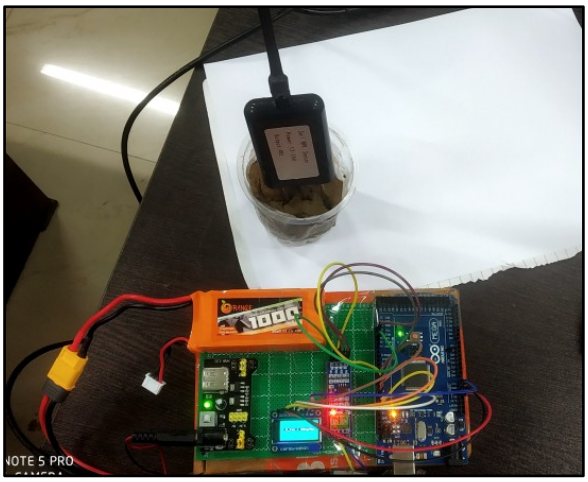

**Figure 2** Working model of soil NPK sensor

**E. Communication Protocol**

The Tx and Rx pins of the RS485 TTL are used for UART communication. Its gathers information from a needle based soil NPK sensor and communicates with the NodeMcu ESP8266 through the Tx and Rx pins.

**F. NodeMcu ESP8266**

The NodeMcu is a controller and a WiFi module in one package. It collects data from Rs485 TTL through UART communication and sends it to Amazon Web Services (AWS) cloud.

**G. Amazon Web Services (AWS) Cloud**

Its stores the data sent by users in an online database. Its secure platform to store any data or information. NodeMcu Esp8266 is used to send the sensors data in Amazon Web Services (AWS) Cloud.

**H. Samrtphone App**

Amazon Web Services (AWS) Cloud data retrieval to smartphone. The operating flow diagram for farmer assistance apps is shown in **Figure 3**.

1) Registration: It asks for the registration information which includes fields – User Name, Email Id, Password.

After entering these details and clicking the register button, the user would be registered in the agent database, as shown in **Figure 4**.

2) Login Page: It asks for the authentication details of the user, which are – Email Id and Password, as shown in **Figure 5**.
3) Register Farmer: It asks for the details of the farmer to be registered which include – First Name, Last Name, Address, Pincode and a Profile Picture. After entering these details and clicking on the save button the farmer would be registered in the farmer database. The crops could be added in the Farmer detail page, as shown in **Figure 6**.
4) All Farmers List: It includes a list of all the farmers registered to the specific user. There is a search button. This page lists all the farmers with at least one field which has low NPK first. Each card in the list contains – Farmer's name, Number of crops under the farmer, last NPK measurement date, Photo of farmer. There is an indicator at the left side of the card which shows the status of the field with the least NPK. This page also contains a button to register a new farmer from the app, as shown in **Figure 7**.
5) Farmers details: This page list all the crops under a farmer and they are sorted by their NPK level order. There is a search crop button. There is an add new crop button. Each card contains – crop name, crop photo, sowing date, recalibration button. There is an indicator at the left side of the card which shows NPK level (Red – low, Yellow – medium, Green-high), as shown in **Figure 8**.
6) Add New Crop: It contains 3 fields to be entered – Crop type, Sowing Date, Pincode of the farm. After entering the details, the user needs to calibrate the field by using the sensor. After clicking the save button, new crop would be added in the list, as shown in **Figure 9**.
7) Crop Detail Page: A card at the top shows your fields NPK level. Next all the individual levels of N, P2O5, K2O are shown in kg/ha, as shown in **Figure 10**.

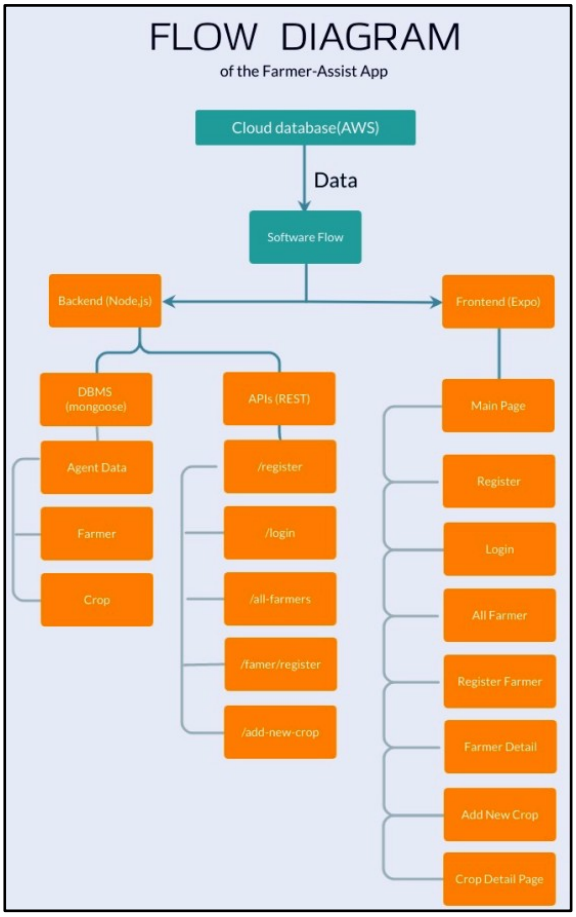


**Figure 3** Flow diagram of Farmer assist app

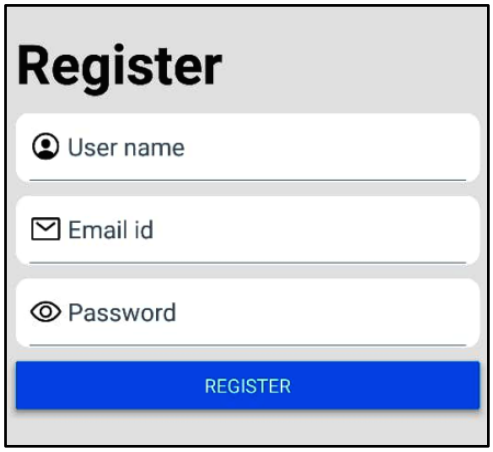


**Figure 4** Registration page

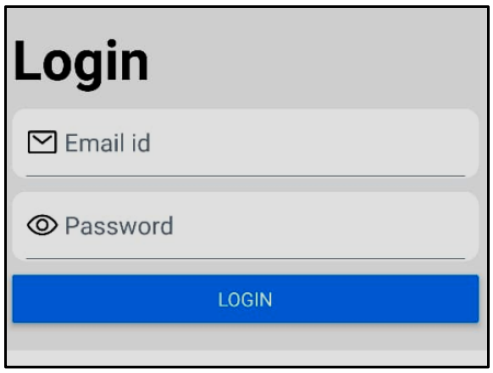


**Figure 5** Login page

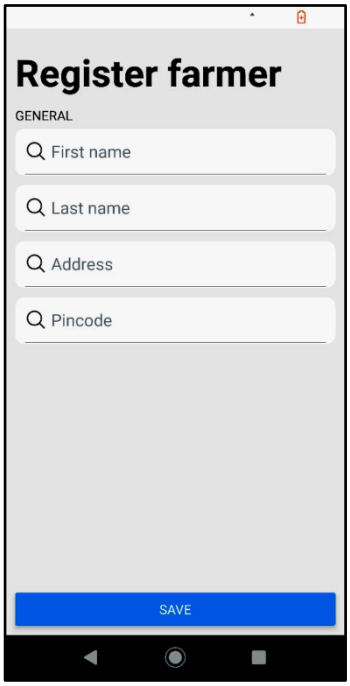


**Figure 6** Farmer register page

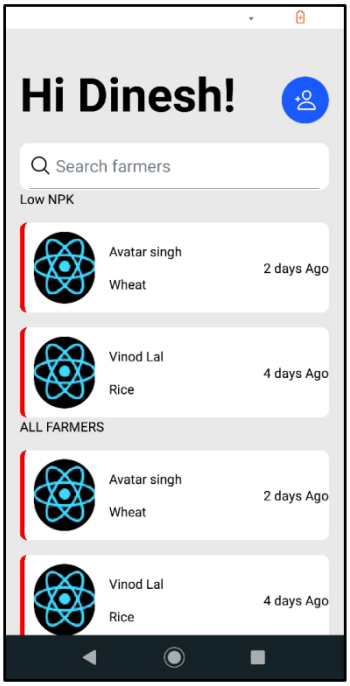


**Figure 7** Farmers list page

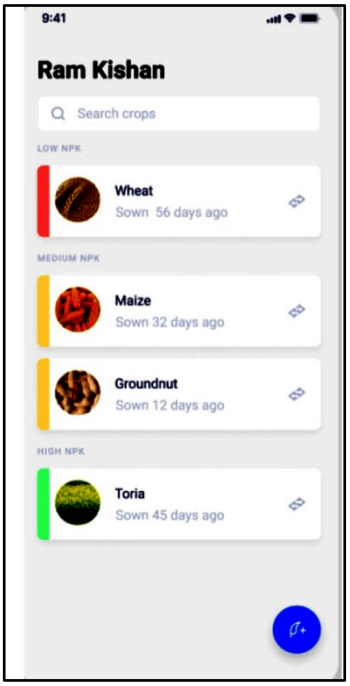


**Figure 8** Farmer details page

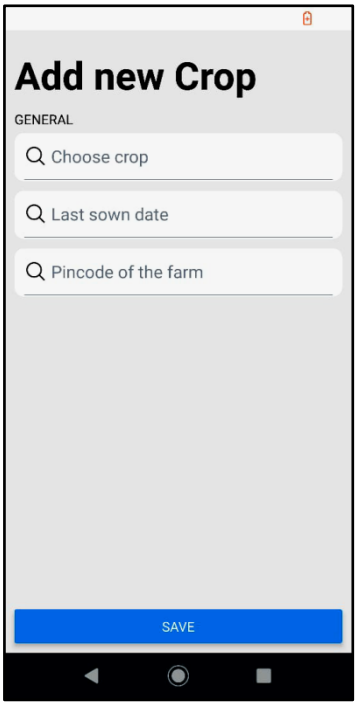


**Figure 9** New crop page

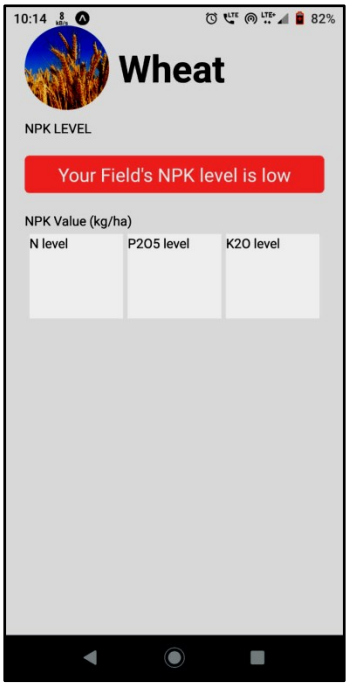


**Figure 10** Crop detail page

## RESULT

This system generates data for multiple soil parameters for various soil samples, as well as recommendations for fertilizer quantities, reducing the use of extra fertilizers and increasing productivity. Precise data are produced as technology advances, resulting in increased cultivation. As a result, precision agriculture improves farming

techniques by giving real-time data. **Table II** shows the lab data and sensor data for multiple soil samples, while **Table III** depicts the nutrient values of sensor data for various soil samples, and **Table IV** represent the NPK ranges, helping farmers to grow appropriate crops and enhance cultivation.

**TABLE II** Comparison of result

| Sample-1 | | |
|---|---|---|
| Content | Lab data | Sensor data |
| N (kg/ha) | 200 | 129 |
| $P_2O_5$ (kg/ha) | 27 | 80 |
| $K_2O$ (kg/ha) | 458 | 108 |

| Sample-2 | | |
|---|---|---|
| Content | Lab data | Sensor data |
| N (kg/ha) | 280 | 130 |
| $P_2O_5$ (kg/ha) | 30 | 83 |
| $K_2O$ (kg/ha) | 490 | 112 |

| Sample-3 | | |
|---|---|---|
| Content | Lab data | Sensor data |
| N (kg/ha) | 180 | 168 |
| $P_2O_5$ (kg/ha) | 22 | 105 |
| $K_2O$ (kg/ha) | 538 | 140 |

| Sample-4 | | |
|---|---|---|
| Content | Lab data | Sensor data |
| N (kg/ha) | 450 | 306 |
| $P_2O_5$ (kg/ha) | 80 | 195 |
| $K_2O$ (kg/ha) | 562 | 263 |

| Sample-5 | | |
|---|---|---|
| Content | Lab data | Sensor data |
| N (kg/ha) | 300 | 309 |
| $P_2O_5$ (kg/ha) | 30 | 190 |
| $K_2O$ (kg/ha) | 512 | 263 |

| Sample-6 | | |
|---|---|---|
| Content | Lab data | Sensor data |
| N (kg/ha) | 215 | 177 |
| $P_2O_5$ (kg/ha) | 49 | 112 |
| $K_2O$ (kg/ha) | 550 | 152 |

**TABLE III** Nutrient values for different samples of sensor data

| Sample | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|
| 1 | Low | Medium | Low |
| 2 | Low | Medium | LOw |
| 3 | Low | High | LOw |
| 4 | Medium | High | Medium |
| 5 | Medium | High | Medium |
| 6 | Low | High | Low |

**TABLE IV** Ranges of NPK

| FERTILIZER RANGE FOR $N$ IN SOIL | |
|---|---|
| Fertilizer Lvel | Range (kg/ha) |
| Low | upto 280 |
| Medium | 280-450 |
| High | more than 450 |

| FERTILIZER RANGE FOR $P_2O_5$ IN SOIL | |
|---|---|
| Fertilizer Lvel | Range (kg/ha) |
| Low | upto 45 |
| Medium | 45-90 |
| High | more than 90 |

| FERTILIZER RANGE FOR $K_2O$ IN SOIL | |
|---|---|
| Fertilizer Lvel | Range (kg/ha) |
| Low | upto 200 |
| Large Medium | 200-350 |
| Large High | more than 350 |

## CONCLUSION

This system continuously checks and reports the N, P, and k values. As a result, a software system is developed that shows various soil parameter values and suggests fertiliser for growing a specific crop. The proportion of fertiliser is recommended based on the sensor data, and the data are shown in the mobile application.

## ACKNOWLEDGMENT

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153_IEC69

# Leveraging AI and Digital Twin Technology to Shape the Future of 6G Wireless Communication Networks

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***Abstract:*** *The advent of 6G wireless technology heralds a new era of communication, with research focusing on emerging technologies to shape its landscape. Artificial intelligence (AI) and machine learning (ML) are poised to revolutionize 6G networks by optimizing processes, enhancing efficiency, and improving resource allocation. A key innovation is digital twin technology, enabling real-time simulations to refine designs. 6G promises higher data rates, greater spectrum efficiency, and improved performance metrics, including reduced latency and energy consumption. However, achieving these goals requires advancements in semiconductor technologies and AI-driven simulations. The integration of AI/ML will drive new approaches in semantic communications and resource management, crucial for future wireless systems.*

***Keywords:*** *6G Technology; Artificial Intelligence (AI); Machine Learning (ML); Digital Twin Technology; Wireless Communication*

## INTRODUCTION

The evolution of wireless communication is one of the most groundbreaking advancements in modern technology, revolutionizing how humans and machines interact. Since the foundational work of Claude Shannon in 1948, who developed information theory to describe how data is transmitted across channels and the limitations on communication systems, telecommunications [1] have progressed through multiple transformative phases. This theory has been the bedrock upon which the entire field of wireless communications has been built, enabling engineers to enhance the efficiency and capacity of communication networks [2].

Wireless communication has evolved through five generations (1G to 5G), each defined by significant technological breakthroughs. The first generation (1G) in the 1980s was pivotal in introducing analog voice transmission over cellular networks, though basic by today's standards. The second generation (2G) in the early 1990s saw the transition from analog to digital communication, enabling services like SMS and improving the security and quality of voice transmissions [3-6].

The introduction of the third generation (3G) in the early 2000s expanded the scope of wireless communication by greatly enhancing data transfer rates. This era saw the beginning of mobile internet usage, allowing users to access the web, multimedia messaging, and even video calling, effectively marking the start of a data-driven society.

The fourth generation (4G), launched in the 2010s, introduced faster speeds, lower latency, and more reliable networks, underpinned by technologies like Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input Multiple-Output (MIMO). This allowed high-definition video streaming, mobile gaming, and other data-heavy applications to flourish [7-10].

The fifth generation (5G) 's most recent advancement began its global rollout in 2020. This leap in wireless communication technology promises to deliver ultra-high speeds, minimal latency, and the capacity to connect a massive number of devices [8]. The deployment of 5G has unlocked revolutionary use cases, including enhanced mobile broadband, ultra-reliable low-latency communications (URLLC), and massive machine-type communications (mMTC), crucial for the Internet of Things (IoT), autonomous vehicles, and smart cities [9-10].

As wireless communication continues to evolve, its integration with artificial intelligence (AI) [11] and machine learning (ML) will further enhance future communication systems' performance, reliability, and intelligence. These technologies are poised to transform industries, enabling smarter, faster, and more responsive networks that shape the

future of human-machine interaction [12-14].

## COMMON OBSTACLES IN IMPLEMENTING DEEP NEURAL NETWORKS FOR WIRELESS COMMUNICATION

Integrating machine learning (ML) into modern computational paradigms has led to substantial discussions around its complexity and energy consumption. According to research from a team at MIT [6], as shown in **Figures 1** and **2** of their work, ML's complexity can be analyzed concerning Moore's Law across various computing eras. Initially, during the era of Dennard scaling, computing performance improved primarily through increased clock speeds, with power consumption in artificial intelligence (AI) mainly adhering to Moore's Law. **Figures 1** and **2** provide insights into the evolving landscape of AI in network management and computational complexity [6]. **Figure 1** illustrates the comparative analysis of AI4Net and Net4AI at both the link and network levels, highlighting these approaches' distinct roles and impacts in optimizing network performance. However, as computing evolved into the multi-core era, AI's power consumption began to outpace Moore's Law. Today, with the advent of deep learning (DL), this gap has widened significantly. The power consumption required for AI computations has increased dramatically, exceeding Moore's Law by at least a factor of 10^5. This escalation underscores the need to prioritize energy efficiency to ensure sustainable development. With addressing these energy demands, advancements in AI could be protected.

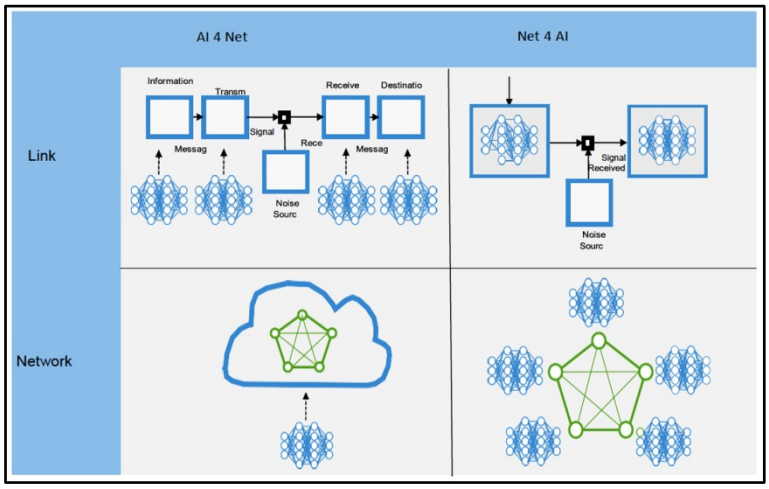


**Figure 1** A comparison between AI4Net at the link level and Net4AI at the network level [14]

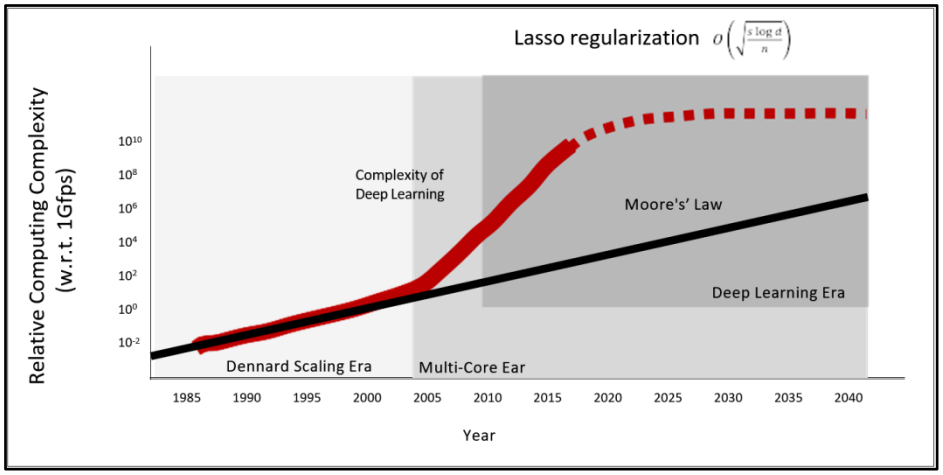


**Figure 2** Computational complexity across different generations, with performance measured where 'Gfps' represents 'gigaflops' per second [14]

A critical concern regarding the energy consumption of AI stems from the significant computational resources needed to achieve low error rates. Estimates suggest that lowering the error rate of machine learning models to approximately 5% could incur costs of around 100 billion US dollars and require an astonishing 10 quintillion program instructions. Given these staggering expenses, simplifying computational processes becomes vital for the future of AI. While strategies such as pruning, dimensionality reduction, reduced quantization levels, and smaller deep neural networks (DNNs) can help address some of these issues, the challenge of AI computing efficiency is expected to be a persistent engineering challenge for many years.

One potential solution to energy consumption challenges in AI-driven networks is distributed neural networks and learning. Energy use can be optimized by distributing computational tasks across multiple devices or networks. However, standardized methods for evaluating power consumption in computation and communication are necessary to identify the most energy-efficient solutions. **Figure 2** illustrates the increasing computational demands over time, measured in gigaflops per second (Gfps), highlighting the need for continuous advancements to effectively manage the growing complexity of AI systems. Regarding specific computational challenges, back-propagation, a fundamental process in training deep neural networks, poses significant hurdles for hardware acceleration. The iterative nature of gradient descent in back-propagation contributes to high power consumption. It affects latency in wireless transmissions, a critical factor in end-to-end communication systems. Numerous methods have been developed to address issues related to back-propagation. One common problem is the saturation of the sigmoid function [1], which leads to the disappearance of gradients. To mitigate this, functions like the rectified linear unit (ReLU) have been introduced, although the negative semi-axis of the ReLU function creates a dead zone where gradients become zero.

Consequently, variants such as Leaky ReLU and Parametric ReLU (PReLU) have been proposed to improve gradient flow. Moreover, exponential linear units (ELU) and scaled ELU (SELU) are used to stabilize further the gradient and weight distribution in deep neural networks [7]. However, gradient transmission becomes even more complicated when neural networks become too deep. To overcome this, highway and residual networks (ResNets) have been developed to simplify parameter usage and improve gradient flow [14].

Moreover, neural networks' memory capacity will likely play an increasingly critical role in future communication systems. For instance, semantic communication systems, which rely heavily on the memory capacity of neural networks, will require substantial storage to hold background knowledge. As a general rule, the larger the memory capacity of a neural network, the greater its potential to enhance communication efficiency [8]. **Figure 3** illustrates Shannon and Weaver channels, highlighting their application in traditional communications versus semantic communications, emphasizing how semantic models enhance information transmission and understanding. However, this raises an important question: how much memory can a neural network realistically have, and what is its maximum capacity? Understanding the relationship between memory capacity and network performance will be crucial as communication systems evolve.

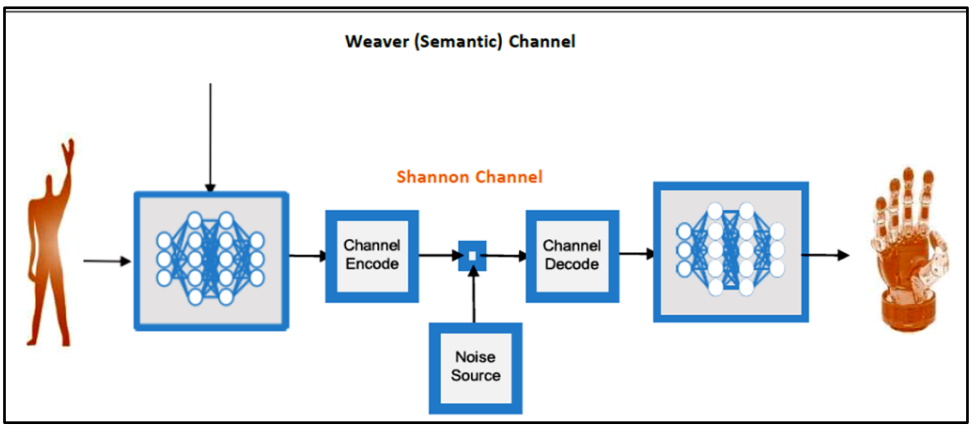


**Figure 3** Shannon and weaver channels for conventional communications and semantic communications [14]

The big data required to train deep neural networks is often collected via wireless communications, making developing more efficient and faster training methods essential. Reducing the demand for vast data while maintaining performance will be vital to minimizing the burden on wireless communication networks. Although the exact relationship between memory capacity and the size of deep neural networks remains unclear, it is known that networks with larger memory capacities typically require more parameters and significantly more data for training. There have been some promising efforts to address these challenges by [9] leveraging domain knowledge in communication systems. For example, model-driven deep learning for communication systems has been shown to reduce the need for training data. However, balancing domain knowledge, data requirements, communication performance, and system complexity remains complex. Moreover, determining the minimum amount of data needed for specific communication applications is an ongoing area of research.

Nowadays, most AI models are trained to assume that the environment, including the training data statistics, remains static during the training phase. However, real-world communication scenarios, particularly mobile communications, are highly dynamic. Thus, the essential characteristics of dynamic deep learning (DL) [2] for wireless communications require significant exploration. This challenge could be addressed through advancements in accretionary learning and meta-learning [10]. Accretionary learning [11], a theory initially proposed by cognitive psychologists, has recently been adapted for machine learning, particularly in classification tasks. **Figure 4** illustrates the robustness of the DeepSC semantic communication system, showcasing its performance relative to benchmark models. The comparison highlights DeepSC's superior resilience and effectiveness in maintaining communication quality under varied conditions, demonstrating its advancement over traditional systems [4]. This method addresses the limitations of traditional machine learning, which trains models using fixed recognition sets that fail when confronted with new features in the data. By incorporating accretion, fine-tuning, and restructuring, accretionary learning extends the capabilities of deep neural networks. Meta-learning, also known as learning-to-learn, is another promising area of research [5]. With continued development, dynamic learning systems for communication networks may eventually become a reality.

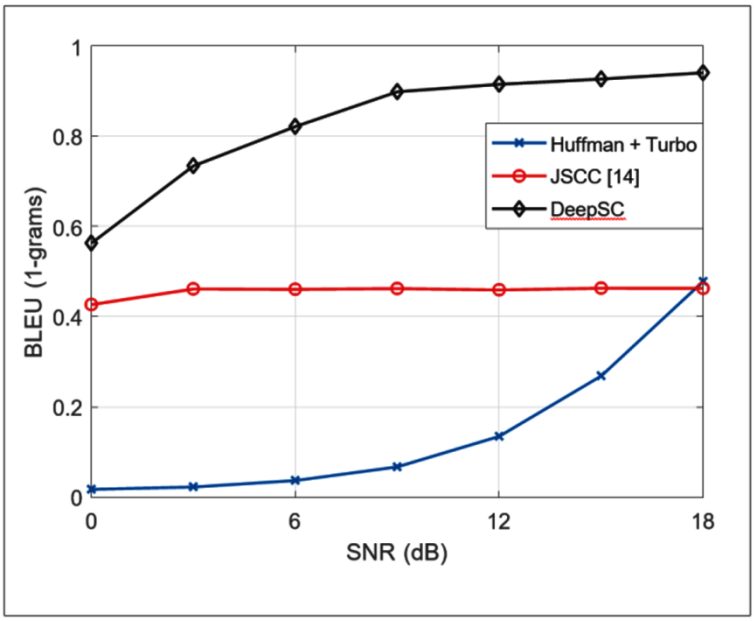


**Figure 4** Comparison of the robustness of the DeepSC semantic communication system against standard benchmarks[3]

Furthermore, looking back, Kolmogorov, a prominent mathematician, expanded upon Shannon's information theory, particularly regarding entropy. He introduced the concept of topological entropy, laying the groundwork for interdisciplinary applications between information theory, topology, and algebra. Shannon's foundational work remains highly relevant in the context of AI-driven communication systems [3]. However, there is also a growing need to develop a mathematical framework for post-Shannon or semantic communications. Entropy and capacity may

need to be redefined in semantic communication systems using logical rather than statistical probability. Recent research has begun to explore the concept of semantic source and channel coding [8], which is analogous to traditional Shannon theory but specifically adapted to semantic communications. While the theoretical tools to fully model and analyze semantics are still lacking, developing a semantic communication framework remains a critical goal. Since the implementation of semantic communications will rely heavily on AI, it makes sense to develop a theoretical foundation for semantic communications built on AI principles.

## CONCLUSION

In this review, we addressed key challenges for successfully deploying 6G technologies, including computing demands in deep learning (DL), communication complexities, distributed learning architecture, and DL-enabled semantic communications. The growing computational demands and energy constraints must be addressed to sustain progress in AI-driven communication systems. Innovative solutions will emerge to overcome these challenges, driving significant advancements and potential transformations in future communication technologies.

## ACKNOWLEDGMENT

Do not use the name of any persons in the Acknowledgment.

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155_IEC62341

# Electricity Power Defense Mechanism

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***Abstract:*** *Electricity theft emerged as a critical issue in modern smart grids, leading to substantial financial losses and jeopardizing grid stability. Traditional detection methods, such as manual inspections, audits, and rule-based algorithms, are increasingly ineffective in addressing the sophisticated techniques employed by modern electricity thieves. Though electricity consumption can be measured using a smart meter, a deviation exists between the actual and the current outcome that has not been identified properly. To address this challenge, we propose a deep learning-based data analytical model that can analyze the dynamic nature of cyber-attacks and detect a zero-day attack. Hence, it acts as a power defense mechanism.*

***Keywords:*** *Convolutional Neural Network; Deep Reinforcement Learning; Zero-Day attack; Cyber-Attack*

## INTRODUCTION

In recent years, electricity theft has been happening everywhere and it causes critical loss to the Government. Electricity theft accounts for approximately USD 96 billion (Electricity theft - Wikipedia) in yearly losses worldwide. Tamil Nadu and Punjab, two major Indian states with flourishing industrial and agricultural sectors, have faced numerous losses and power theft reports. In Tamil Nadu, 65 cases were evaluated in March 2024, resulting in fines totaling ₹9.26 lakh. In April 2024, 60 instances were assessed, leading to fines of ₹12.07 lakh. By May 2024, assessments were conducted for 73 cases, with fines amounting to ₹12.79 lakh. (Lenient Penalties Fuel Power Theft Surge in Tamil Nadu – Tamperfinder). The proposed model introduces a novel approach to electricity theft detection by leveraging cutting-edge machine learning techniques, specifically Convolutional Neural Networks (CNNs) and Deep Reinforcement Learning (DRL). We use Proteus simulation and design software to design and test electronic circuits including PCB layouts and embedded systems. It supports various microcontroller simulations, making it ideal for electronics engineers and students. We collect data through this simulation software as well as from data repositories. Data for the analysis is taken at the transformer level and not to any particular spot.

The major objectives of defense mechanisms are

- Data collection and preprocessing
- Feature extraction using CNN
- Decision-making and adaptive learning using DRL
- Training the model using Deep Q Networks (DQN) and Double DQN (DDQN) models
- Identifying the Zero Day Attack
- Validate the proposed defense mechanism

## EXISTING ELECTRICITY THEFT MODELS

O. A. Abraham et al. proposed a machine-learning model using XGBoost, Random Forest, and MLP for electricity theft detection in smart homes[6]. This model showed robust detection capabilities for electricity theft, outperforming traditional unsupervised learning methods, thus enhancing smart home security. W. Zhuang et al. proposed a novel dynamic graph-based method[4] with MixHop GCN for electricity theft detection. SMOTE oversampling and real-time adjacency matrix update to capture complex consumption relationships in the SGCC dataset. This method enhances model stability and classification accuracy by dynamically modeling consumption patterns and addressing class imbalance. S. Zhu et al. developed a detection model combining Omni-Scale CNN and AutoXGB[1]. The author used a SMOTEENN to balance class distribution and PCHIP interpolation to handle missing data. Integrating CNN with automated hyperparameter tuning in AutoXGB significantly improved detection performance and addressed data imbalance issues.

A. T. El-Toukhy et al. proposed a deep reinforcement learning (DRL)[2] approach using DQN and DDQN for detecting electricity theft, particularly focusing on real dataset training, consumption pattern changes, and zero-day attack defense. The DRL-based solution demonstrated adaptability and effectiveness in detecting dynamic theft patterns, outperforming traditional supervised methods. I. Elgarhy et al. evaluated DNN vulnerability[5] to evasion attacks and developed a cluster-based ensemble detector to enhance robustness. Cluster-based detectors are compared with global detectors, highlighting increased accuracy and defense strength. Clustering combined with ensemble learning significantly improved model resilience against evasion attacks while maintaining high accuracy in theft detection. S. Janthong et al. proposed multiclass imbalance solutions using ADASYN[7], anomaly models, and image data augmentation to classify energy theft and defective meters. Evaluated with six deep learning models and showed best performance with DenseNet121.

S. Abbas et al. utilized active learning[3] to iteratively select informative samples from the dataset, thereby reducing labeling costs, while improving detection accuracy in smart grids. It is applied to large-scale AMI data. Active learning showed promise in reducing the dependency on labeled data while maintaining high performance in electricity theft detection. M. T. Jibril et al. developed privacy-preserving machine learning algorithms[8] using differential privacy techniques to protect user data during theft detection. This model is tested on simulated smart meter data. The approach effectively balanced privacy and detection accuracy, ensuring minimal data exposure without compromising performance. K. T. S. Rao et al. introduced a hybrid model combining LSTM and CNN[9] to capture temporal and spatial patterns in energy consumption. Achieved high precision in theft detection from real-time AMI data. The hybrid model outperformed individual deep learning models by capturing spatial and temporal dependencies, enhancing detection accuracy in smart grid networks. R. Patel et al. proposed a blockchain and IoT-based system[10] for secure electricity theft detection. This model used smart contracts and decentralized data verification to prevent fraud and tampering. The blockchain-IoT framework provided enhanced security and transparency in theft detection, minimizing data manipulation risks in smart grid environments.

The major limitations of existing work are as follows.

- The Decision Tree and Support Vector Machine models are among the most commonly used methods for detecting theft.
- These methods use only historical consumption data to identify anomalies and flag potential theft.
- Fail to adapt to the dynamic nature of cyber-attacks and zero-day threats.

## METHODOLOGY

The proposed power defense mechanism is shown in **Figure 1** and its components are discussed below.

(a) Data Collection and Preprocessing: This module gathers data from smart meters, including historical consumption records, user profiles, and known instances of legitimate and fraudulent activities. The data preprocessing involves cleaning, normalizing, and preparing the data for feature engineering. Anomalous patterns such as spikes, drops, or inconsistencies in electricity usage are identified and marked for further analysis. Additionally, this module manages synthetic and real-world datasets used for testing and validation.

Any electronic design can be automated using Proteus Design Suite (https://proteus.soft112.com/). We used this tool to simulate the electricity board and its connection. **Figure 2** shows the simulated EB connection designed using this tool and some of the components are discussed below.

- LM35 Sensor: Measures temperature, which sends an analog signal to the Arduino for processing. The Arduino lights up LED bar graphs to visually represent the value based on the temperature.
- A 12V Battery: Powers the circuit, with a voltage regulator ensuring a stable 5V supply.
- Inductors, capacitors, and diodes: Smoothens the signals.
- MOSFETs: Control the LED outputs.
- Resistors: To limit the current flow and signal stability, enabling efficient temperature monitoring and display.

By simulating this circuit, we can gather data on the voltage consumed per household, the resistance changes with the wire's temperature and the consumption pattern observed through the oscilloscope.

(b) Model Development: Develop a hybrid model combining CNN for feature extraction and DRL (using DQN and DDQN) for dynamic learning. These algorithms learn dynamically by interacting with the environment, making real-time decisions based on the features extracted by the CNN. The DRL agent learns from a reward-based system, improving theft detection accuracy. This module handles various detection scenarios: global detection, customized detection for new customers, and adaptive detection for changing consumption patterns.

(c) Scenario-based Structuring: Implement four detection scenarios: a global model for all customers, customized models for new customers, adaptive models for changing patterns, and defense mechanisms against evolving cyber-attacks.

(d) Experimental Validation: Extensive testing on synthetic and real-world datasets is done here. Evaluate using metrics like detection rate, false positives, and computational efficiency to ensure robustness and effectiveness.

(e) Continuous Improvement: Establish a feedback loop for regular retraining with new data, allowing the system to adapt to new threats and changing consumption patterns.

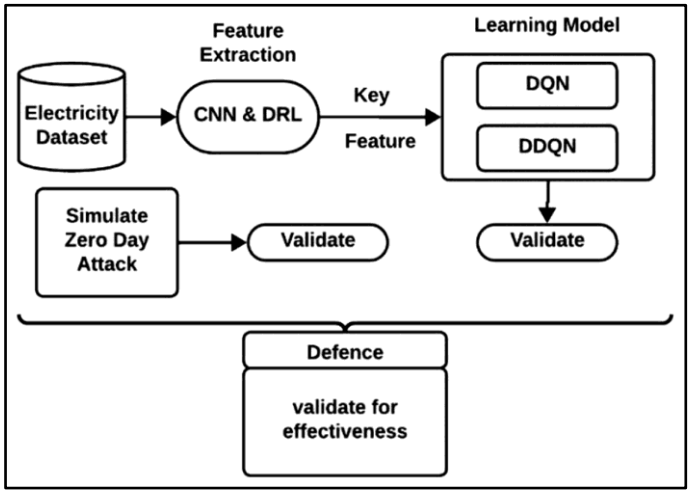


**Figure 1** Proposed power defense architecture

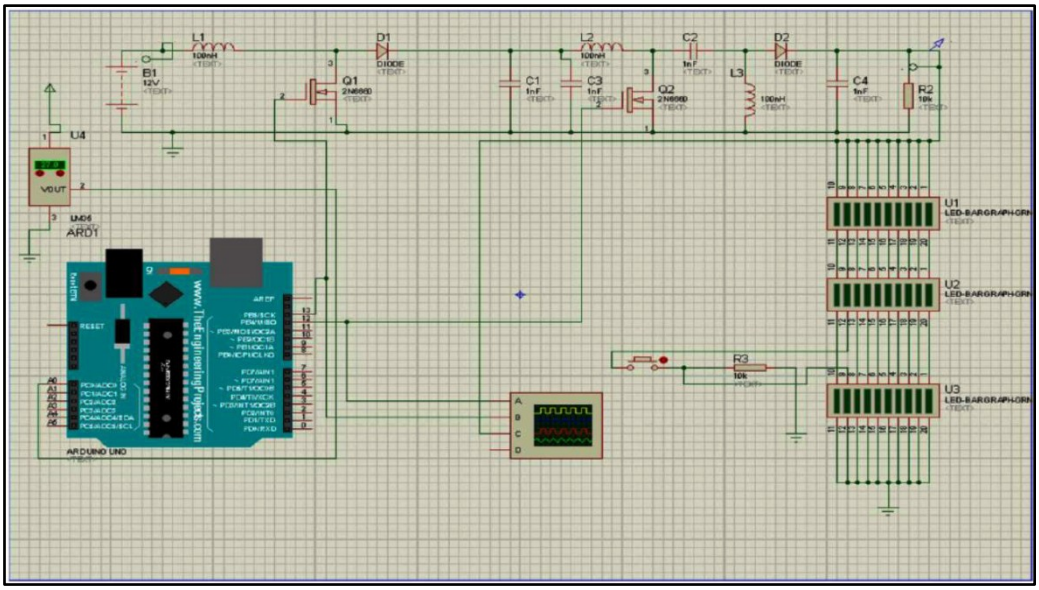

**Figure 2** Simulation model

## RESULTS

Following are the outcomes of the proposed power defense mechanism.

(a) Improved Detection Accuracy: The integration of CNN for feature extraction significantly boosted the accuracy of theft detection compared to traditional methods. The system achieved a higher true positive rate while reducing false positives.

(b) Enhanced Adaptability: The adaptive model successfully adjusted to changes in customer consumption patterns, maintaining high detection performance even as behaviors evolved. This flexibility ensures ongoing effectiveness in diverse scenarios.

(c) Effective Zero-Day Attack Mitigation: The customized detection model for new customers demonstrated strong capabilities in identifying zero-day attacks, ensuring timely responses to potential threats from unknown fraudulent activities.

(d) Robustness Against Cyber Threats: The defense mechanism implemented against new cyber-attacks showed resilience, enabling the system to counteract emerging threats effectively, thus reinforcing grid security.

(e) Positive Reward System Outcomes: The reward-based learning approach facilitated rapid training of the DRL agent, allowing it to quickly adapt and improve its decision-making process based on real-time feedback.

(f) Comprehensive Testing and Validation: Extensive experiments validated the system's overall performance, confirming its effectiveness in reducing electricity theft rates and enhancing security protocols within the power grid.

(g) Scalability Potential: The system was designed to be scalable, allowing for easy integration with existing grid infrastructures and the capability to handle large volumes of data.

## CONCLUSION

Using the CNN and DRL deep learning adaptive models, our power defense system adjusts the new customers, evolving patterns, and fraud strategies. Also, it ensures real-time adaptability to dynamic data, enhances cyberattack resilience, and provides grid operators with real-time alerts and actionable insights. Finally, the comprehensive validation will confirm its effectiveness in accuracy detection, adaptability, and threat resilience.

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# Robust Deep Learning Model for Plant Disease Identification and Management with Crop-Specific Precision

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***Abstract:*** *Effective and quick identification of plant diseases contributes significantly to farm production level as well as to the proper preservation of land and its resources. In case of overfitting in the previous models, they often misstated the crops, e.g., mistaking an apple leaf for a tomato leaf, or incorrectly identifying diseases etc. In this work, we propose a new system that deals with this problem by training and deploying different models for different crops resulting in an increase in accuracy and robustness. The model uses ResNet50 for image processing and disease detection, while a Nonet, a custom Nine-layered dense neural network is used for plant disease prediction. For training these models, an extensive dataset was used, which was gathered from various sources such as National Institutes of Health (NIH), Kaggle, and Research Gate, consisting of over 200,000 images per disease. The system is equipped with all functionalities to provide a seamless experience to the farmers with regards to management, a Flask-based backend and HTML/CSS based frontend. Machine learning elements employed include Tensor Flow, Keras, NumPy and Scikit-learn while the app is envisioned to be built with Buildozer. The objective of this system is to assist the farmers in the early detection of diseases and the subsequent management of the crops as per the given recommendations.*

***Keywords:*** *ResNet50; Transfer learning; Overfitting Mitigation; Buildozer; Precision Agriculture*

## INTRODUCTION

The health of crops is paramount to agricultural productivity, and diseases remain one of the major factors in improving the productivity of crops that must be dealt with. Early diagnosis of plant diseases can limit damage and prevent catastrophic outcomes, but the restrictions in most existing plant disease identification procedures are that they are long and centralized system often require expertise. In recent times, models based on machine learning (ML) and deep learning (DL) have been more frequently used in the field of plant disease recognition [1-2] in which images are used to assist in the automatic detection of such diseases. Even so, it is worth noting that many of these models, particularly ones targeting several types of crops, have challenges such as overfitting and misclassification bias [3]. For instance, crop's models may lead to error in agriculture practices, basically a misstep in classifying one's apple leaf as another's tomato leaf.

This document presents an innovative system that seeks to solve these problems through the use of a crop tailored approach. For each crop type, a specific model is trained on a dedicated large crop-specific dataset to diminish the confusion between the crops and better the predictions. The detailed models here are built internally for image classification using ResNet50 within large data sets. Using this transfer learning along with a custom Nine-layered dense neural network for Fine Tuning, ensures that the models transition smoothly from the training to the unseen images. More than 200,000 images for each of the disease class have been assembled for training purposes from credible sites such as National Institutes of Health (NIH), Kaggle, and ResearchGate.

The system is developed in such a manner that the user is able to interact with it through a web application built using Flask together with HTML and CSS technologies. It further suggests ways of controlling the specific diseases, thus offering the farmers for what they can do. In this regard, the paper outlines the design of the model, training of the model, and evaluation of the model in terms of performance.

## METHODOLOGY

### (a) DataSets

This work complements other repository databases by accumulating datasets from the National Institutes of Health

(NIH), Kaggle, and ResearchGate resulting in a database of over 200,000 images for each disease category. All of these include diseases of various crops, as well as healthy leaves of these respective crops. The dataset relied upon in this research is one of the largest and the most comprehensive ever compiled for the purpose of plant disease classification, as comprising over 200,000 images for each crop-disease pair. Every dataset has images of healthy leaves as well as infected leaves. For example, in apple crops, the common diseases are Apple Scab, Black Rot, and Cedar Apple Rust etc [5]. In potatoes it includes Early Blight and Late Blight, and for Tomato diseases the list is wider including Bacterial Spot, Early Blight, Late Blight and etc. The images of all these infected plant leaves along with the healthy leaf's images are trained in the model making it robust.

These images were acquired from various sources such as National Institutes of Health (NIH), Kaggle and ResearchGate[4] so as to make sure that the dataset includes a lot of conditions, lighting and angles which may have an impact in variations of how the images look like. The other reason for having such a large size of the dataset is that it also helps as a guard against overfitting which is a primordial risk in deep learning models when they are trained on smaller datasets.

**(b) Activation Functions**

The absence of non-linear activation functions in the LSTM (Long Short-Term Memory) network hinders the performance of the model further. This case specifies learning parameters with respect to the dynamic programming compiler hindering direct code optimization. Recognizing emotions from the coded information is taken on the last step in conjunction with the last perception of the deep learning neural network for this application. In LeNet-5 model, ReLU activation was used in all layers where applicable. ReLU is the most common non-linear activation used in deep nets, but many empirical cases omit it because of monotony. ReLU simply sets negative values to zero while leaving positive values unchanged. This process eliminates the need to shift the output and improvesmodel performance.

For disease prediction in particular, a SoftMax function may be utilized at the output layer to generate a probability distribution over out different disease classes. Recurrently, SoftMax is used for multi-class problems since it deals with raw outputs by converting them to probabilities only which enable classification by degree of confidence. SoftMax is a function which turns agent scores into probabilities for all actions available to the agent given all previously taken actions. The different components work in several instances where SoftMax is efficiently embedding the confidence on class assignments from the fused data of several previous models.

**(c) Entropies**

The training loss function has a very significant role of orienting the learning of the model. Categorical cross-entropy was employed as the loss function for this research work. The cross-entropy loss is mostly used for classification tasks since it finds the distance between the predicted and actual probability distributions. Cross-entropy loss is commonly used for classification tasks as it measures the difference between predicted and actual probability distributions, thus guiding the model to make more accurate predictions. This loss function was adopted to provide effectiveness on multi-class classification problems, and it did in this application as the model was of high accuracy with less error during validation.

**(d) Custom VGG19 Model Implementation**

At the beginning of this research, a modified VGG19 model was used to evaluate the accuracy of the model on plant disease dataset. VGG19 is an advanced deep repeater architecture that is best suited for classification of images. VGG19 proved to be very inefficient in managing the larger dataset employed in the study thus extending the training time and increasing chances of overfitting the model. While the VGG19 model offered some useful insights, in practice, its performance during feature extraction was significantly worse than that of the ResNet50 based model. The experience obtained from the VGG19 exercise was also particularly helpful in the construction of the final model architecture, especially with regards to volume and variability of the data set.

**(e) Transfer Learning Using ResNet50**

In this study, the primary model architecture is ResNet50, a deep convolutional neural network model [7] that has been pretrained using a dataset called ImageNet. The ResNet50 model achieved high performance without overfitting when the pre-trained model weights were fine-tuned with the plant disease dataset. To achieve even better classification results, a custom Nine-layer dense neural network was added to the functioning of the ResNet50 model. The dense layers in the model concentrates on fine-tuning the more detailed features present in the plant disease dataset as the ResNet50 layers only concentrates on the basic feature mapping of the images. Because of this approach of semi-supervised transfer learning, the model was able to perform very well on plant images that were not fed into the network development, thus solving real life problem of plant disease identification.

**(f) Metrics**

The performance metrics employed included accuracy, precision, recall and F1 measure amongst others. Cross-validation techniques were also employed to test the strength of each model. Accuracy levels in all crop models were observed to be above 90%, with ResNet50 models doing generally better than the custom VGG19 models [8]. Precision and recall measures in the diagnosis of diseases has shown very few false positives and false negatives even in high-risk situations [10].

**Figure 1** National Institutes of Health (NIH) and Kaggle Dataset [9]

**Table 1** Structural overview of the model

| LAYER (TYPE) | OUTPUT SHAPE | PARAMETERS |
|---|---|---|
| CONV2D (CONV2D) | (NONE, 222, 222, 32) | 896 |
| MAX_POOLING2D (MAXPOOLING2D) | (NONE, 111, 111, 32) | 0 |
| CONV2D_1 (CONV2D) | (NONE, 109, 109, 64) | 18,496 |
| MAX_POOLING2D_1 (MAXPOOLING2D) | (NONE, 54, 54, 64) | 0 |
| CONV2D_2 (CONV2D) | (NONE, 52, 52, 128) | 73,856 |
| MAX_POOLING2D_2 (MAXPOOLING2D) | (NONE, 26, 26, 128) | 0 |
| FLATTEN | (NONE, 86528) | 0 |
| DENSE | (NONE, 256) | 22,151,424 |
| DENSE_1 | (NONE, NO. OF CLASSES) | VARIABLE |

**Table 2** Various combinations of the activation function used and their respective observed accuracies

| Experiment | Activation Functions | Accuracy | Notable Changes |
|---|---|---|---|
| 1 | ReLU, SoftMax | low | Severe overfitting, struggled with modified testing images |
| 2 | ReLU, Leaky ReLU | moderate | Reduced generalization gap, better handling of augmented images |
| 3 | ReLU, Leaky ReLU, Sigmoid, Tanh | high | Highlighted the importance of removing mole size as a distinguishing feature |
| 4 | ReLU, Leaky ReLU, SoftMax | highest | Achieved highest classification accuracy, robust performance across activation functions |
| 5 | ReLU, Sigmoid, SoftMax | low | Decreased accuracy, illustrated the impact of size disparity |

**Table 3** Observed metrics for different training sets

| Train Size | Precision | Sensitivity | Specificity | F1-Score |
|---|---|---|---|---|
| 0.8 | 0.9756 (97.56%) | 0.9302 (93.02%) | 0.9859 (98.59%) | 0.9526 (95.26%) |
| 0.9 | 0.9833 (98.33%) | 0.9365 (93.65%) | 0.9907 (99.07%) | 0.9596 (95.96%) |

**Table 4** Observed metrics for different trained models for each crop

| Crop | Model Type | Accuracy (%) | Precision (%) | Recall (%) | F1 Score (%) | Specificity (%) | Loss (%) |
|---|---|---|---|---|---|---|---|
| Apple | ResNet50 (Transfer Learning) | 98.3 | 97.5 | 98.9 | 98.2 | 98.7 | 2.1 |
| Potato | CNN (Custom 7-Layer) | 96.8 | 95.2 | 96.5 | 95.9 | 97.1 | 3.5 |
| Tomato | VGG19 (Custom Architecture) | 97.6 | 96.9 | 97.3 | 97.1 | 98.1 | 2.9 |
| Wheat | InceptionV3 | 95.5 | 94.1 | 95.7 | 94.9 | 96.5 | 4.0 |
| Rice | EfficientNet | 98.9 | 98.4 | 99.1 | 98.7 | 99.0 | 1.6 |
| Maize | DenseNet | 97.1 | 96.5 | 97.2 | 96.8 | 97.5 | 3.2 |
| Soybean | AlexNet | 96.4 | 95.0 | 96.3 | 95.6 | 97.0 | 3.7 |

**Table 5** Observed confusion matrix for each crop

| Crop | Confusion Matrix |
|---|---|
| Apple | [[250, 5], [3, 240]] |
| Potato | [[320, 12], [7, 310]] |
| Tomato | [[200, 10], [6, 184]] |
| Wheat | [[300, 14], [11, 275]] |
| Rice | [[400, 5], [4, 385]] |
| Maize | [[280, 12], [9, 265]] |
| Soybean | [[350, 15], [12, 340]] |

## CONCLUSION

The system presented solves one of the most important concerns of former models, which is overfitting and cross-crop classification inaccuracies. As the proposal suggests building their models for various crops one after another, this issue was well addressed. Moreover, the fact that each disease category average around 200,000 images, which substantially adds strength to the model. Such variability ensures that the model is ready to face practical situations in which images can differ in quality, angles, or light exposure. Techniques for data's images alteration, like over-rotation or under-rotation helps in reducing the overfitting problem [4] making it easier for the model to generalize. Owing to the addition of ResNet50 as a feature extractor, the custom Nine − layer dense neural network showcased high accuracy of the system. With transfer learning and ResNet50, separation of deep signatures from complex leaf images is achieved.

The system is also built with usability at its front, yielding a very user-friendly Flask-based web interface. It guarantees easy uploading of images, disease prediction, and actionable recommendations to manage the diagnosed disease. Being a model that holds good real-world applicability, its value is immense for agricultural professionals as well as for farmers as a reliable solution to manage crop health. The systems can be expanded in the future to include more crops and diseases. In addition, further work in this direction includes integration of real-time environmental data for increasing the accuracy in the prediction of diseases to implement the proactive management strategy.

Therefore, in a nutshell, this research offers a crop-specific robust approach for identification and management of plant diseases and constitutes significant improvement over the generalized models that have been developed so far[5]. The focus on accuracy, ease of use, and practical application makes this system an extremely valuable resource in the field of agriculture.

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# Investigating the FSO Communication Way using Articulate Optical Sources in Visible Wavelength under Simulated Rainy Condition

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***Abstract:*** *Rain, fog, dust, snow, and other atmospheric dangers can impair the optical wireless communication channel established in free air in a free space optical communication system. Precipitation has a noteworthy effect on the Free Space Optical (FSO) communication system. Higher rainfall rates may have an unwieldy influence scheduled the system, particularly in the sultry and moderate regions. This article examines the investigational findings of different rain tariff that were manufactured artificially and how they affected the FSO communication channel. Using an artificial rain chamber with visible wavelength laser communication channels at 532 and 638 nm over a 20-meter connection range, the bit error rate (BER) and their attenuation levels have been determined for varying rainfall tariff.*

***Keywords:*** *FSO; BER; Optical Power Attenuation; Visible Wavelength; Rain*

## INTRODUCTION

Unlike fiber optics technology, which requires bulky wires or fiber cables, free space optical communication systems operate wirelessly. As a result, information can travel over open space and between nodes, as well as between many nodes. Line of vision is the critical or else necessary point that separates two nodes (transmitter and receiver). Since the dimension of raindrops is typically well-built than the wavelengths discussed in this editorial, geometric dispersal has taken place [1].This kind of arrangement might be accepted in different metropolitan cities where fiber wire mechanism is a difficult task. In those situations, this scheme might be very efficient. High wattage noticeable lights and analogous garnish like photodetectors, optics, etc. are readily available and cheaper than the IR wavelengths. Several applications, including LAN and MAN, can use this system [2]. Proper alignment between the transmitter and receiver is a critical problem since the line of sight between them is a fundamental aspect of the FSO communication system. For this system, alignment is simpler and more beneficial when using the visible spectrum as opposed to the NIR band, which is invisible to the human eye. It's also a cost-effective approach because there are no additional costs associated with the fiber connection or spectrum licensing. This conventional technique uses an optical beam that is transported via free air to confront various atmospheric precipitants. The modulated light source serves as the transmitter in this setup. The system's performance suffers as a result. This kind of study has been conducted all roughly the world due to the fact that rainfall tariff varies throughout nations. A selection of the reviews of the literature that have already been published are included in this section. An FSO communication channel was constructed in [11] by means of a 650 nm laser source. The specific attenuation for different rain rates — 0.5 mm/min to 3 mm/min — has been studied, also different uncovered rain simulation lengths — 0.7 m, 1 m, and 1.25 m—have been occupied keen on description. The probable FSO correlation can tolerate up to 19.79 dB/km of drizzle at a pace of 2.716 mm/min. Consideration is given to two noticeable wavelengths, such as 532 nm and 655 nm[12]. The particular attenuation of these wavelengths caused by rain. This article provides an analysis of it. A total of 3.5 meters has been calculated for the optical link, and several fake rain rates have been constructed, with 3 mm of rain per minute being the highest rate taken into consideration. This editorial claims that drizzle causes the attenuation altitude of 532 nm to be privileged than to 655 nm. Similar to [13], two wavelengths—the visible wavelength (532 nm) and the infrared wavelength (1064 nm) — have been considered for the investigational modeling of drizzle. After conducting an investigational scrutiny of the optical shrinking with transmittance, this study discovered with the intention of low rates of precipitation, each of the two wavelengths are equivalent, and the results from the

experiment is in line with the replicated statistics at most 5% distinction. The judgment of the ensuing optical dwindling exposed in a different work, by rain [14]. The trial has two wavelengths planned: 850 nm and 532 nm. According to this article, the 532 nm laser wavelength can tolerate a 15.37 dB/km attenuation level when it rains moving at 1.109 mm/min. The quantity of shrinking is greater on behalf of the wavelengths at 532 nm.

The following is a list of the intended work's main contributions:

- A laser source operating at visible wavelengths has been used to construct an affordable FSO communication link. Based on the rainfall patterns in Indian climates, the rain rates are provided using artificial rain simulation. Consequently, an atmospheric scenario for India has been used to evaluate the system's performance.
- Testing has been done on the optical power shrinking at poles apart drizzle tariff, commencing small to soaring, and the results have been compared to erstwhile models that are currently in use. It has been established that optical path constancy or dependability has been examine in conditions of real-time eye patterns, bit error rates, etc. using the necessary equipment (Mixed Signal Oscilloscope).
- According to the atmospheric rain rates in India, this study provides a detailed knowledge of the optical power shrinking and optical communication path presentation at different drizzle rates. Before putting this sort of equipment in the Indian atmosphere, this study will be helpful.

The format of the paper is as follows: Section I contains a brief description, advantages, disadvantages, and an application of the FSO communication system. Furthermore, a number of evaluations of pertinent literature are discussed here, along with the primary contributions of the suggested work. In section II, the effects of rain on various current models and the optical communication channel have been discussed. Both the artificial rain simulation setup and the FSO communication configuration (transmitter & receiver side) have been precisely shown in section III. The obtained grades are compared with the state-of-the-art rain attenuation models in section IV, which provides a detailed summary of the experimental data. A summary of the findings and the conclusion are presented in Section V.

## CONCEQUENCES OF RAIN ON COMMUNICATION CHANNEL

The rain's dewdrop mass or radius ranges from 200 to 2000 μm [3]. The standard power law may be used to anticipate the particular attenuation of the FSO communication channel caused by rain [4].

$$\sigma = k.r^{\beta} \quad (1)$$

where r = rain rate (mm/hr), σ Rain = rain attenuation (dB/km), and K, β = rain coefficient factor. The open space's temperature, the size of the raindrop, and other factors affect K and β values. **Table 1** provides a list of several common and useful rain coefficient factors.

**Table 1** Different attenuation model of drizzle

| Sl. No | Name of Model | Rain Rate (r) (mm/hr)/Region | Model of Rain |
|---|---|---|---|
| 1 | Japan Model [5] | Temperate | $1.58r^{0.63}$ |
| 2 | Charbonneau (France) [5] | Temperate | $1.07r^{0.67}$ |
| 3 | Malaysia [6] [7] | Tropical (r>145 mm/hr) | $2.03r^{0.74}$ |

**Equation (2)** [8] may be used to forecast the transmittance otherwise absorption coefficient of the laser ocular influence owing to varying drizzle tariff for a given link series (Z).

$$\tau(Z) = \frac{P(R)}{P(T)} = e^{-\sigma Z} \quad (2)$$

For a given connection range, P(R) = inward optical power and P(T) = Transmitted optical power. **Equation (3)** has

been used to forecast the signal to noise ratio [9].

$$SNR = P(R)/(NEP \times \sqrt{BW}) \quad (3)$$

where NEP is the photo detector's noise equivalent power and BW is its bandwidth. The photo detector's noise, which includes shot noise, f-noise, thermal noise, and dark current noise, is measured by something called the Noise Equivalent Power (NEP). (2) has been used to determine the received power P(R).

**Equation (4)** may be used to calculate the Bit Error Rate (BER) of the NRZ-OOK [9],

$$BER = \left(\frac{1}{2}\right) erfc\left(\frac{1}{2\sqrt{2}}\right)\sqrt{SNR} \quad (4)$$

## EXPERIMENTAL SETUP

### A. FSO Communication Setup

Three main components make up a free space optical system: a transmitter unit, a receiver unit, and a free space path. Once more, the transmitter part is made up of an arbitrary waveform generator, a modulator unit, and an optical source (a visible wavelength laser). Comparably, the photodetector with transimprdance amplifier and comparator circuit make up the receiver unit. **Figure 1** shows a typical transmitter device for a free space optical system. The MOSFET driver receives a TTL pulse and drives the MOSFET appropriately. The operation of the laser beam is determined by TTL pulses.

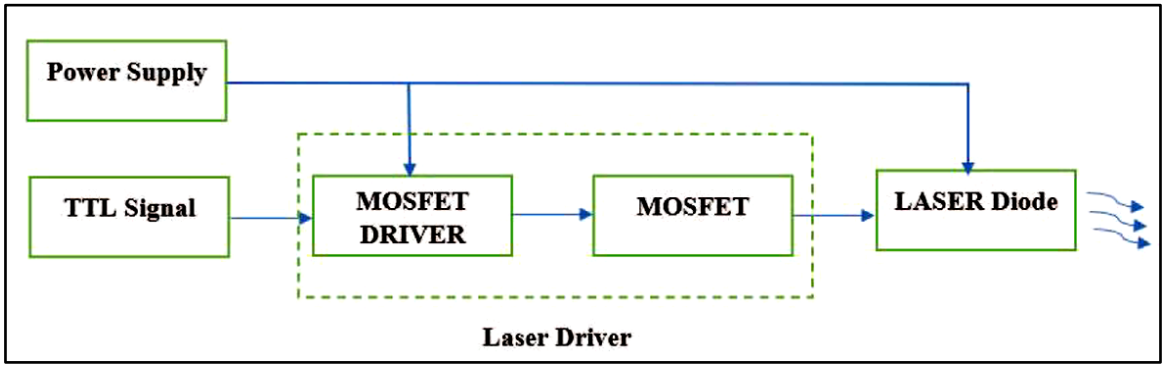


**Figure 1** Illustration of Transmitter Element of the Emblematic FSO Arrangement

Subsequently, the LASER grin that has been modified travels through the empty space before arriving at the photo detector. The photodetector's operational spectrum range, signal bandwidth, and noise equivalent power are 150 MHz, $9\times10^{-11}$ W/Hz$^{0.5}$, and 320 nm–1100 nm, respectively. The operation of the receiver unit is shown in **Figure 2**.


**Figure 2** Illustration of Receiver Element of the emblematic FSO Arrangement

### B. Rain Replication Arrangement

**Figure 3** shows a tripod-mounted FSO communication arrangement below fake drizzle replication conditions. Establishing a communication linkage requires a direct line of sight among the transmitter and receiver, since this graphic makes evident.

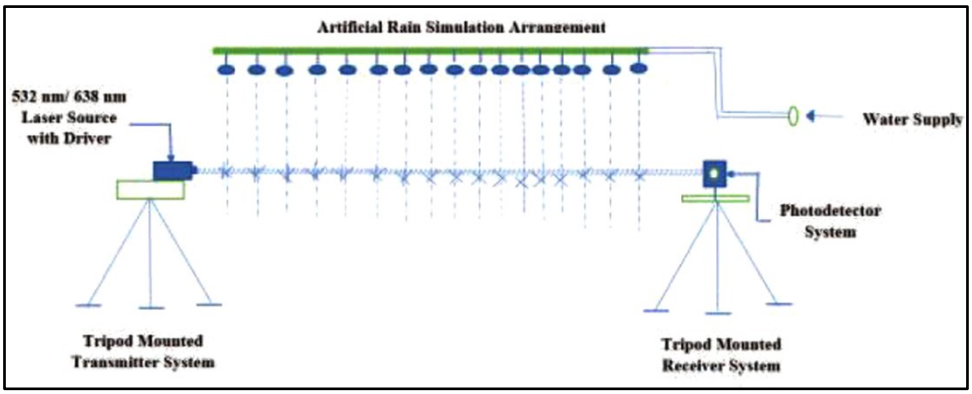


**Figure 3** Schematic rain simulation Arrangement

### C. Actual Experimental Arrangement

Dissimilar width pipelines, sprinklers, etc., create altering drizzle rates. The suitable valves legalize the rate of drizzle. There are now many rain rates available, ranging from extremely short (6 mm/hr) to incredibly towering (204 mm/hr). A motor-pump has delivered the irrigate to the pipe starting a tank, and a suitable rain gauge is used towards monitor the rate of rainfall. Both clear and variously generated rainy situations have been used to assess the optical power, eye pattern, etc. All of the characteristics, including optical power shrinking, eye pattern, BER, etc., are too tested for a duration of single minute into the diverse drizzle tariff. The rain rates have been measured during a one-minute time frame.

The Ophir Vega optical power meter was used to measure the optical power, while Keysight Technology's Mixed Signal oscilloscope was used to measure the eye pattern **Figure 4**. **Figure 5** shows the experiments being done in the artificial rain simulation setup utilizing 532 nm and 638 nm LASER. It also shows the produced artificial drizzle simulation arrangement with the transmitter and receiver setup.

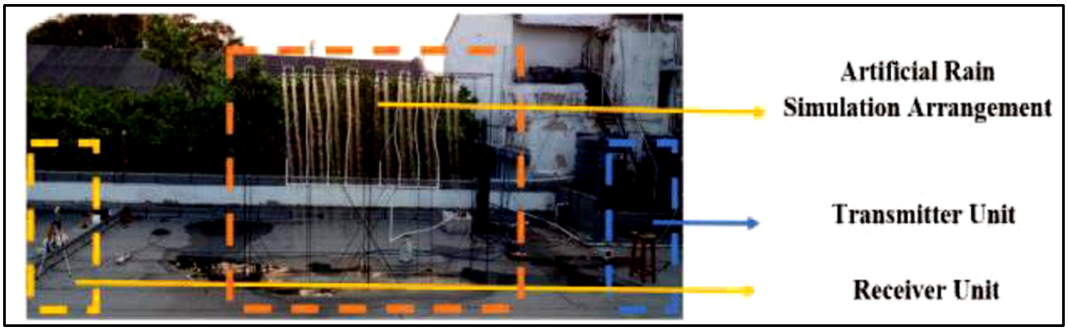


**Figure 4** Artificial rain simulation setup

**Figure 5** Testing is departing on in virtual drizzle replication arrangement using 532 nm and 638 nm LASER

The aerial unit's operation is previously momentarily covered in the FSO communication setup division, however into this segment, **Figure 6** provides a clear illustration of the hardware component of the transmitter unit. The image illustrates how the Arbitrary Waveform Generator (AWG) generates 5 MHz TTL pulses, which are then sent to the MOSFET Driver. The MOSFET is driven by the MOSFET driver's output. The MOSFET driver's output is supplied to the laser unit, which modifies the laser beam in accordance with TTL pulses.

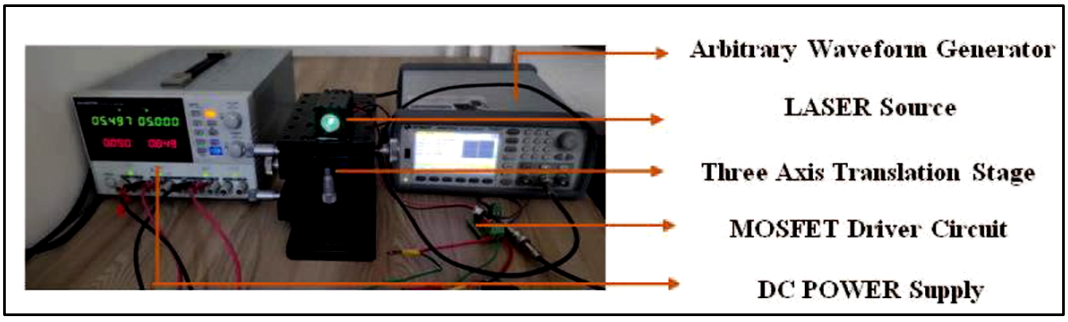


**Figure 6** Hardware ingredient of the aerial part

The modulated LASER ray is ultimately focused addicted to the photodetector part. The photodetector unit's gesture is a present indication, which is changed to a voltage gesture by the transimpedance amplifier. The comparator track is afterwards utilized to figure the waveform, acquiescent a quadrangle one. **Figure 7** displays the receiving unit's hardware.

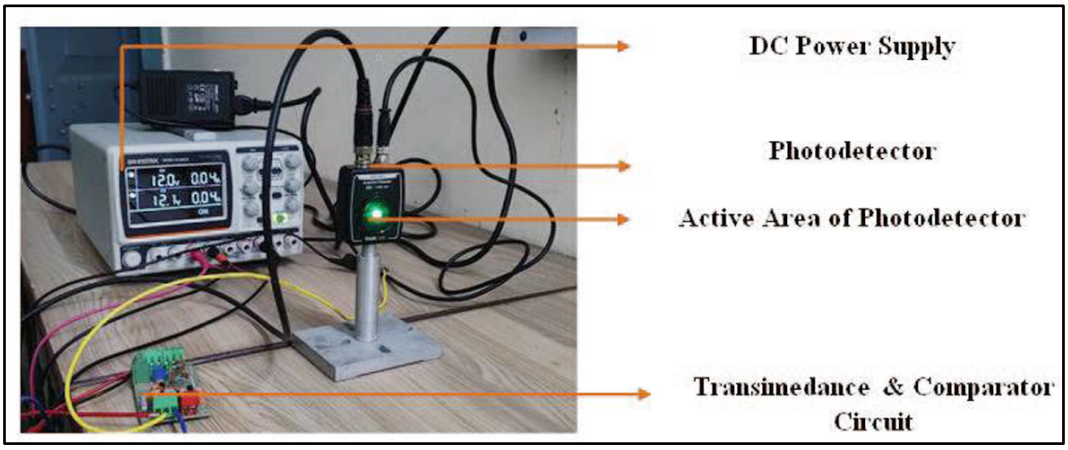


**Figure 7** Hardware arrangement of the recipient unit

## INVETIGATIONAL RESULTS

### A. Optical Power Attenuation

A communication link with a decreased bit error rate has been established using 230 μW optical power under clear weather conditions. As the rain rates rise, **Table 2** predicts that there would be a greater attenuation of the optical power, which is confirmed in every instance.

Because the rain particle size is greater than the optical wavelengths, the observed optical power attenuation for both wavelengths is almost equal. A country in a temperate zone, such as India, experiences rain at a rate of between 5 and 100 mm per hour. In a few exceptional instances, monsoon season maximum rain rates of 150–185 mm/hr are noted.

The International Telecommunication Union (ITU-R) has verified and approved the Japan model, which is suitable for assessing optical power attenuation for rain rates ranging from 5 mm/hr to 100 mm/hr [3][10].

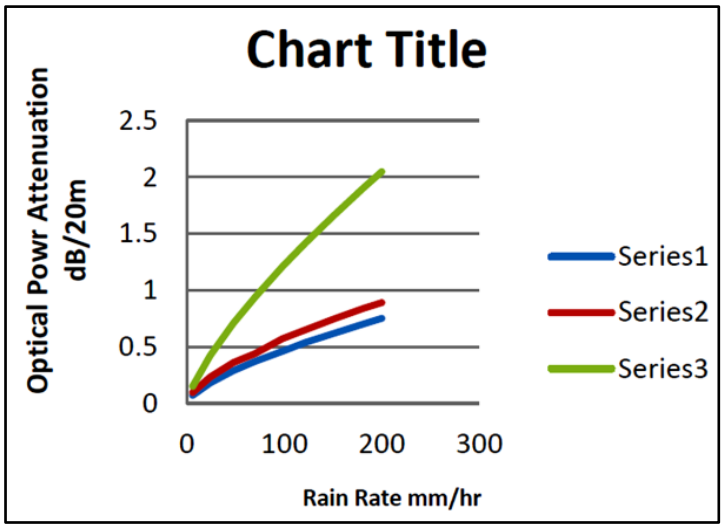


**Figure 8** Optical power shrinking at dissimilar drizzle rates at a linkage range of 20 with different model

For estimating the lower rain rates, the ITU-R recommends the Charbonneau model, which is likewise a viable model. In general, the Malaysia model is verified at rainfall rates higher than 145 millimeters per hour. According to the table, the precise optical power shrinking is found to be more accurate than the Japan model up to a drizzle pace of 122 mm/hr with a slip of about 5%. In contrast, the measured value of the error is found to be approximately 28% when compared to the Charbonneau model. Once more, the observed optical power attenuation is more in line with the Malaysia model with an error of around 2.7% at much higher rain rates of more than 150 mm/hr. **Figure 9** displays the optical power shrinking under various drizzle rates at a 20 m link range.

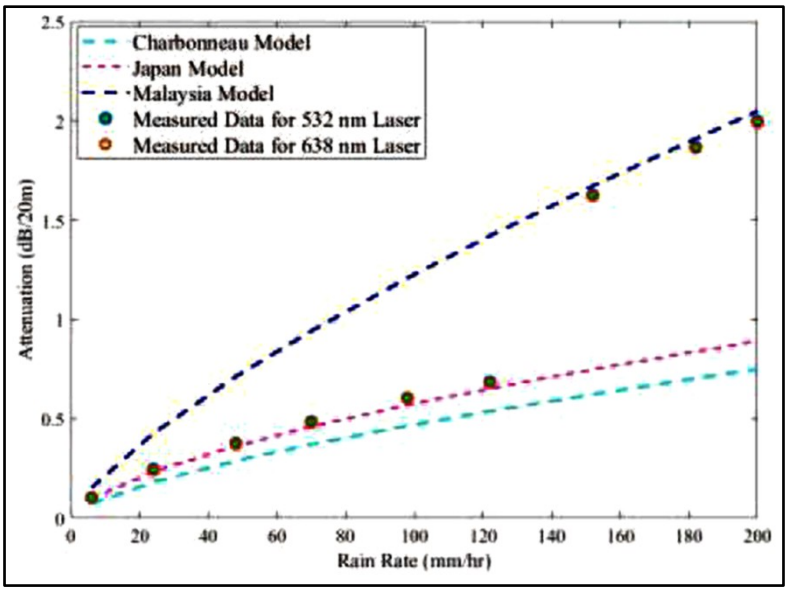


**Figure 9** Attenuation of optical power at dissimilar drizzle tariff at a link range of 20

**A. Communication Path**

In clear weather, **Figure 10** displays the augmented photodetector signal, comparator output gesture, and matching eye patterns. When the climate is clear, the comparator produces a spotless eye pattern because the entrance perimeter of the comparator is towering, and the amplified signal is around 1.2 V.

**Figure 11** shows the eye pattern of the photodetector gesture and matching comparator eye pattern after the system

was adjusted to a 6 mm/hr rain rate. With a rain rate of 6 mm/hr, there is very little attenuation of optical power, therefore the eye height remains high but is lower than in clear weather conditions. The comparator output produces a distinct signal since the comparator's threshold limit is high. The receiver end's signal intensity is the same for both wavelengths due to the same optical power attenuation, which causes the eye pattern to become almost identical for both wavelengths.

Similar to this, when the rain rate increases to 75 or 122 mm/hr, the photodetector signal's eye height decreases, but the comparator signal stays visible since the threshold value is still towering.

**Figure 10** and **Figure 11** display the photodetector gesture and matching comparator eye mould for drizzle rates of 75 mm/hr and 122 mm/hr, respectively. This study demonstrated that the optical channel operated correctly at visible wavelengths in the Indian atmospheric rain rate environment.

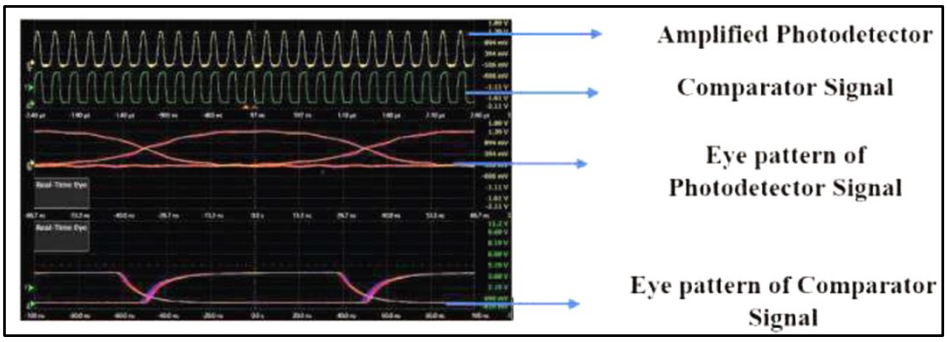


**Figure 10** Amplified photodetector, comparator gesture and their eye pattern at lucid weather condition

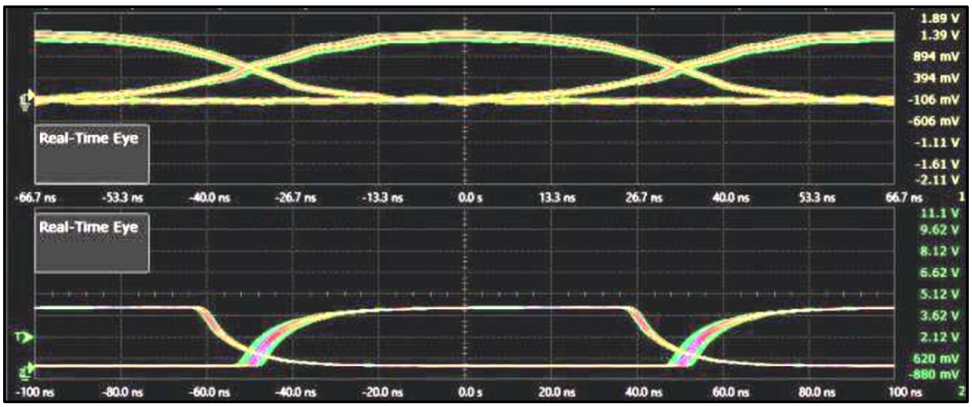


**Figure 11** Distinctive photodetector gesture and comparator eye pattern at a drizzle pace of 6 mm/hr

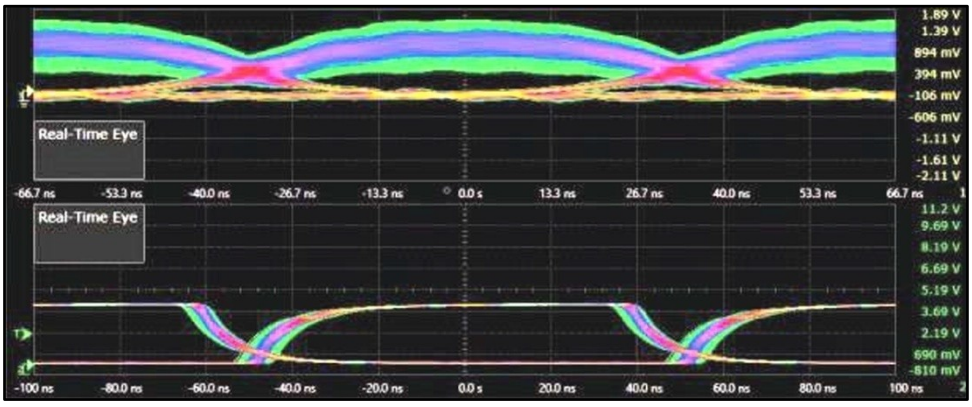


**Figure 12** Distinctive photodetector gesture and comparator eye pattern at a drizzle pace of 75 mm/hr

**Figures 13** and **14** show the photodetector and comparator gesture eye pattern at drizzle rates of 152 mm/hr and 185 mm/hr, respectively. In the case of 185 mm/hr, both the signal strength and the bit error rate are extremely low.

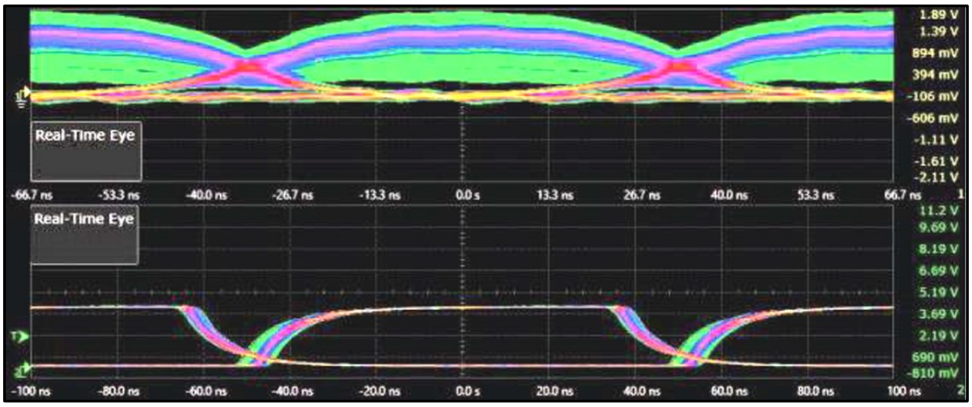


**Figure 13** Distinctive photodetector gesture and comparator eye pattern at a drizzle pace of 122 mm/hr

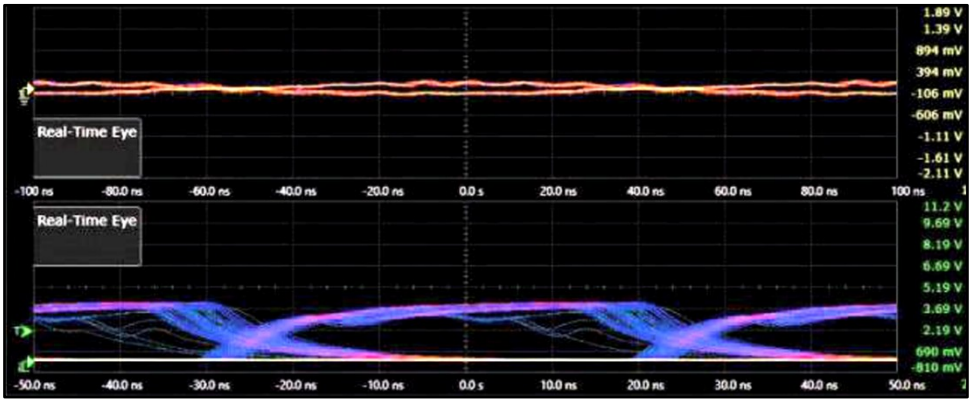


**Figure 14** Distinctive photodetector & comparator gesture eye pattern at a drizzle pace of 152 mm/hr

Because the comparator threshold limit (150 mV) is lower for both the 152 and 185 mm/hr rates, the optical power is too deteriorating, the comparator is malfunctioning, and since a outcome, the announcement connection is not formed correctly at the specific drizzle tariff.

The optical power attenuation has been found to be almost same for both wavelengths, which indicates that the signal intensity at the receiver end is nearly equal for both wavelengths under consideration. **Figure 16** displays the results of a comparison between the observed value and the signal to noise ratio, which was computed using various available models at varying rainfall rates. This table makes it evident that when the rain rate is less than 122 mm/hr, the observed SNR values are close to the Japan model; when the drizzle velocity exceeds 150 mm/hr, the measured SNR values are close to the Malaysia model. **Figure 15** shows the considered SNR value as well as the several models that were developed at a link variety of 20 m for varying drizzle tariff.

Similar to how the SNR value is used to estimate the Bit Error Rate, the MSO's vector signal analysis (VSA) program measures the BER.

**Figure 18** presents the BER values for varying rates of rainfall. Since the optical power attenuation at both wavelengths is almost equal, the SNR and BER values are correspondingly the same. Using various existing models with varying rates of precipitation, the Bit Error Rate (BER) has been computed and compared to the observed value. The findings demonstrate that, with an approximate 11% error, the observed BER value is slam to the Japan model up to a drizzle velocity of 122 mm/hr. The BER significance is about in the vicinity of the Malaysia model with 20% inaccuracy when the rain rate exceeds 150 mm/hr.

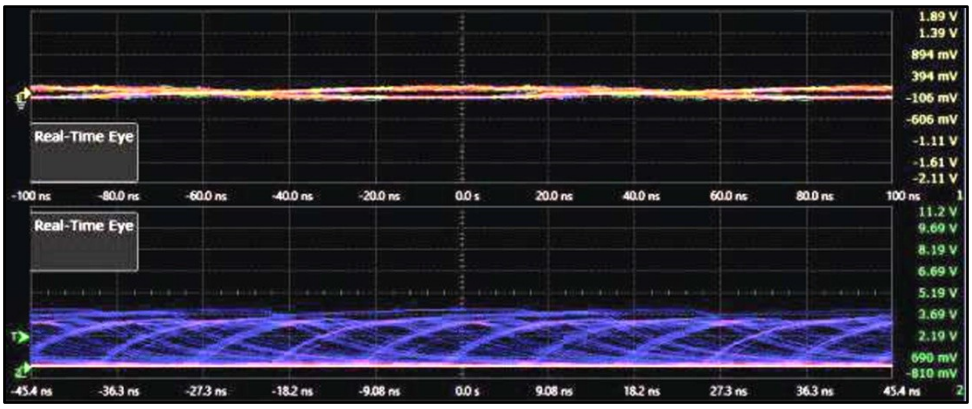


**Figure 15** Distinctive photodetector & comparator gesture eye pattern at a drizzle pace of 185 mm/hr

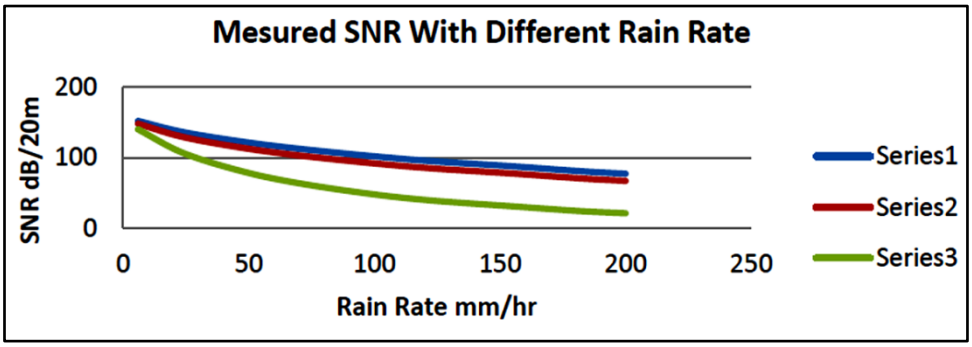


**Figure 16** Measured SNR for dissimilar drizzle tariff at a linkage variety of 20 m with different model

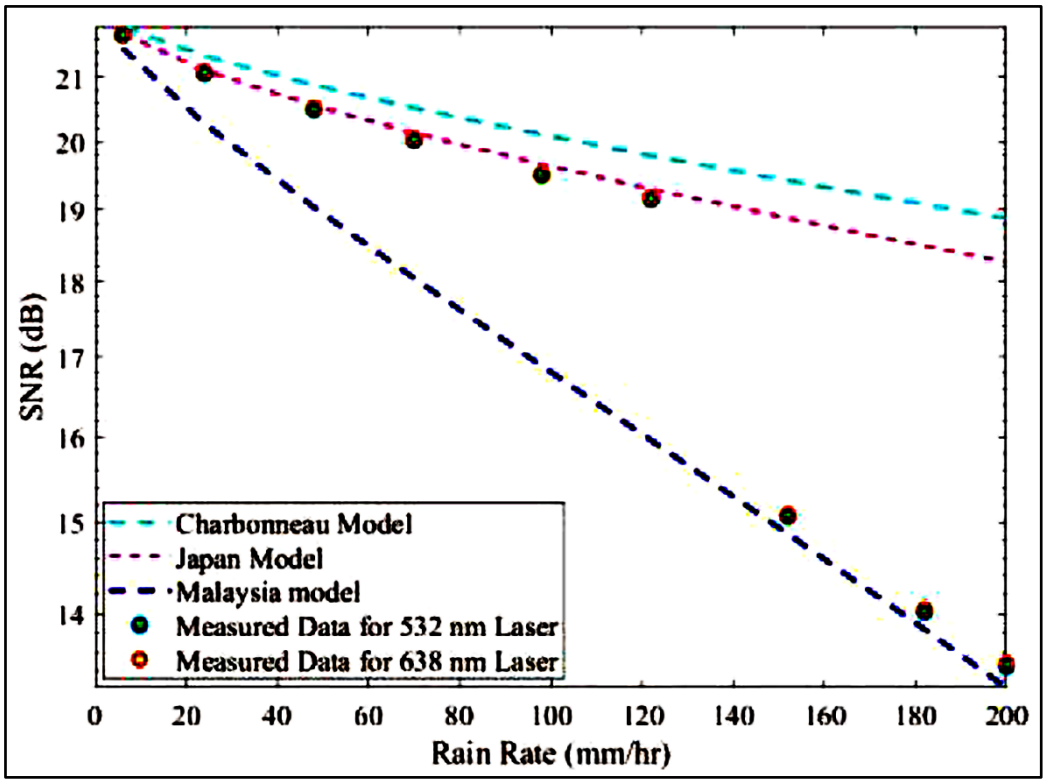


**Figure 17** SNR for dissimilar drizzle tariff at a linkage variety of 20 m

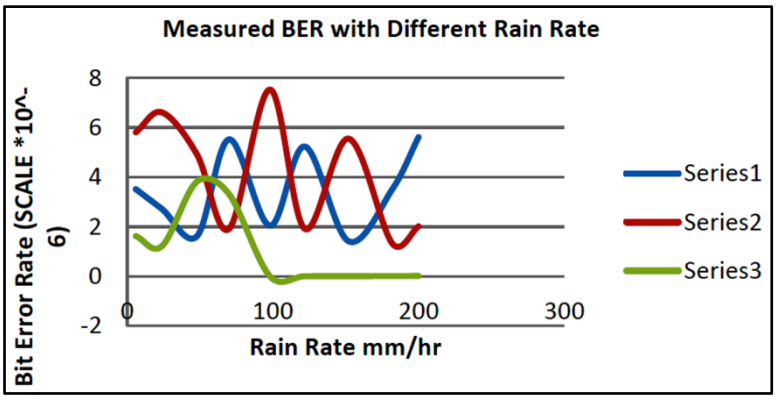


**Figure 18** Measured BER for dissimilar drizzle tariff at a linkage variety of 20 m

BER is displayed in **Figure 19** for various rain rates at a 20 m link range. The picture illustrates how BER increases when the rate of rain increases.

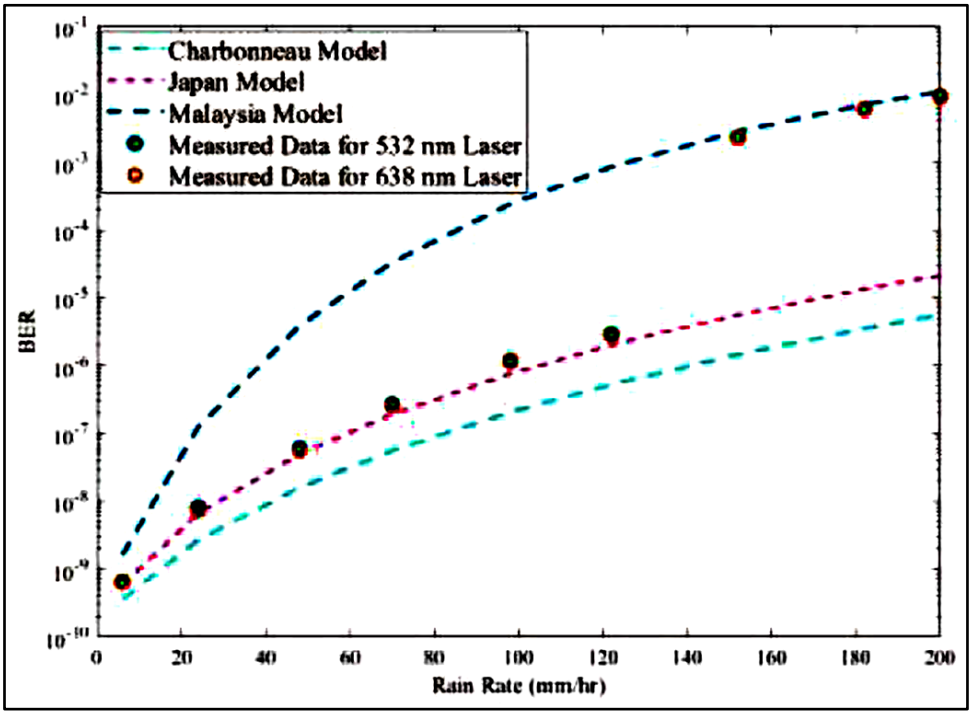


**Figure 19** BER for dissimilar drizzle tariff at a linkage variety of 20 m

## CONCLUSION

This article covers in-depth research on the impact of artificial rain simulation on communication connection channels with various visible wavelength lasers. This investigation makes it abundantly evident that the main variable influencing the communication link is the rain rate. Higher rain rates can cause the connection performance to deteriorate; in order to preserve the appropriate link performance parameter, such as signal strength, BER, etc., the optical power can be raised. The results also demonstrate that the geometrical scattering of rain causes about equal optical power reduction for both visible wavelengths. The SNR and BER values for the two wavelengths utilized are almost identical due to the nearly same optical power attenuation for both wavelengths. For Indian atmospheric conditions, this swot also offers a sympathetic of the optical power shrinking and the blow of the optical connection outlet utilizing visible wavelengths at varying rain rates.

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# Gen AI-Powered Distributed Asset Health Monitoring, Data Ops & Chat Interface by Presenter

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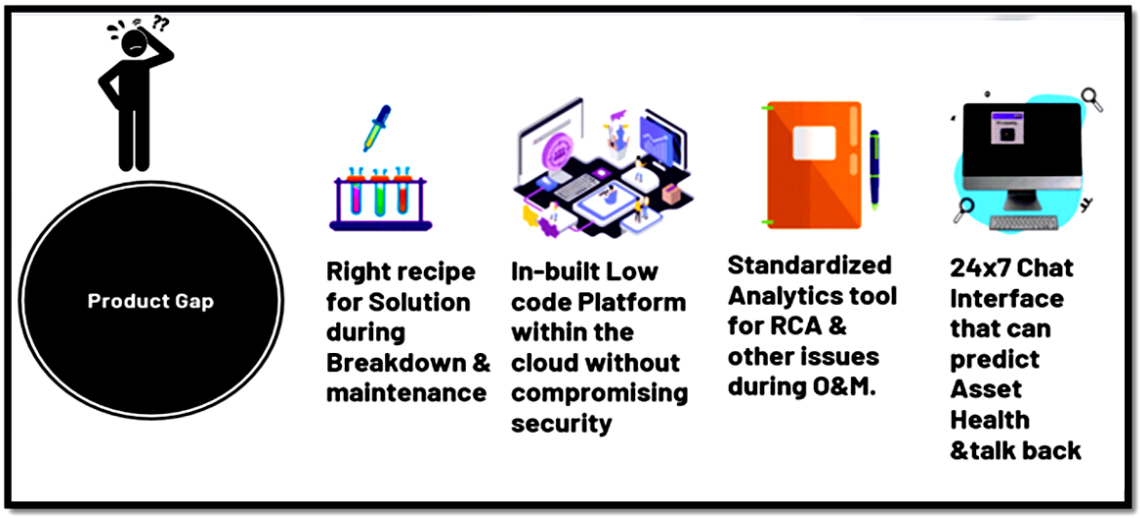
***Keywords:*** *Predictive Maintenance; Industrial DataOps; Gen AI; IIoT; Distributed AI; D2P2; Data Lake; ETL; Cloud Computing; AIML; Industry 4.0/5.0; Digital Twin*

## INTRODUCTION

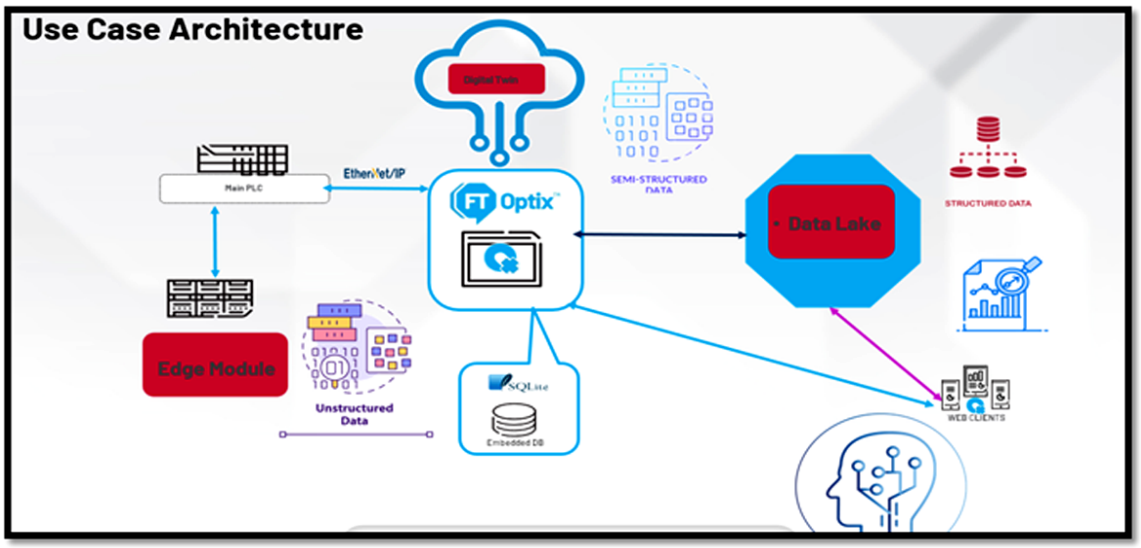
In the modern industrial landscape, organizations are facing an unprecedented influx of real-time data from sensors, machines, and Industrial Internet of Things (IIoT) devices. This data deluge poses significant challenges for traditional asset management approaches that rely heavily on human expertise and manual processes (Biggio & Kastanis, 2020). As industries strive for greater efficiency, reduced downtime, and improved decision-making, the limitations of these traditional methods have become increasingly apparent. Enter Generative AI, particularly Large Language Models (LLMs), which have emerged as powerful tools for transforming asset health monitoring and maintenance. By processing vast amounts of industrial data, LLMs can identify patterns, detect anomalies, and provide predictive insights that allow organizations to transition from reactive to proactive asset management. A critical component of this transformation is the Data Verse, a comprehensive data repository that serves as the foundation for AI-based analysis. The Data Verse can be deployed on 'cloud infrastructure' or 'on-premises', providing organizations with the flexibility to manage their data according to security and operational needs. This abstract outlines the transformative potential of generative AI-powered asset health monitoring systems and explores how LLMs, integrated with robust data pipelines, can reshape industrial maintenance strategies.

## PROBLEM / USE CASE

There's a significant gap when it comes to identify alarms & faults with utmost precision, therefore reducing production downtime in Plants. So there's huge gap when it comes to the right kind of RCA (root cause Analysis) & hence improve the OEE (Overall Equipment Efficiency).



## METHODOLOGY




### AI-Powered Maintenance

The integration of AI into maintenance strategies has broadened the scope of asset management significantly.

'Predictive Maintenance' and 'Anomaly Detection' are two key features enabled by generative AI that help industries to optimize their operations and avoid unexpected failures.

### Predictive Maintenance

Predictive maintenance leverages AI algorithms to analyze historical and real-time data from various assets. By monitoring key performance indicators (KPIs), such as temperature, vibration, and energy consumption, predictive models can forecast potential equipment failures. For instance, consider an industrial motor monitored through various sensors; the AI system can analyze the data and predict when maintenance is required, allowing for timely interventions. This approach shifts maintenance from a reactive stance — where issues are addressed only after they arise — to a proactive strategy that enhances efficiency and reduces operational costs. In practice, predictive maintenance can result in significant savings. According to industry reports, organizations implementing predictive maintenance strategies can reduce maintenance costs by 20% to 50% and extend equipment life by 20% to 30% (Doron et al., 2023).

### Anomaly Detection

Anomaly detection focuses on identifying deviations from normal operating patterns. In industrial environments, minor anomalies often precede significant issues. For example, a subtle increase in the vibration of a motor may not be noticeable to operators but could indicate impending failure. AI-driven anomaly detection systems can continuously monitor equipment data, flagging anomalies in real time. This capability allows maintenance teams to investigate issues before they escalate, thereby preventing unplanned downtime and improving overall reliability.

### Root Cause Analysis (RCA)

When failures occur, the ability to perform effective 'Root Cause Analysis (RCA)' is crucial. AI systems, equipped with vast amounts of historical data, can identify the underlying causes of equipment failures. For instance, if a sudden shutdown occurs, the AI model can analyze a range of data, including historical performance, maintenance logs, and real-time sensor readings, to determine what went wrong. By correlating data points, the system can pinpoint the cause of the failure more accurately than traditional methods. The benefits of AI in RCA are particularly valuable in complex industrial environments where multiple interconnected systems operate simultaneously. This

capability not only enhances operational efficiency but also supports informed decision-making for future maintenance strategies.

## ARCHITECTURE AND INTEGRATION

The architecture of an AI-powered asset health monitoring system is centered around the 'Data Verse', a structured data repository that organizes and processes industrial data. The effectiveness of this architecture relies on seamless integration of data sources, analytical tools, and AI models.

### The Data Verse: A Central Repository

The 'Data Verse' serves as a central repository for collecting and organizing data from various industrial sources. It enables data ingestion from IIoT devices, operational databases, and machine logs, all of which are crucial for effective asset management. The architecture of the Data Verse can be influenced by several factors, including the size of the organization, the volume of data generated, and specific industry requirements.

### Data Lakes vs. Data Warehouses

To better understand the role of the Data Verse, it is helpful to draw parallels with existing data technologies. Data lakes and data warehouses serve different functions within this ecosystem: - **Data Lakes**: Data lakes store vast amounts of raw, unstructured data, providing flexibility for data exploration and analysis. This is particularly valuable in industrial settings where data from various sources may be diverse and unstructured. Data lakes allow organizations to retain all data without the need for immediate processing, enabling future analysis as required.

### Data Warehouses

In contrast, data warehouses store processed, structured data that is optimized for analysis and reporting. This structured data can be easily queried and visualized, making it essential for business intelligence applications. In an industrial context, a combination of both data lakes and warehouses may be beneficial. Data lakes can capture raw sensor data, while data warehouses can store processed data for real-time analytics and reporting.

### ETL Processes and Data Pipelines

The ETL (Extract, Transform, Load) process is a critical component of the data pipeline that ensures data integrity and usability.

- Extraction involves gathering raw data from various sources, including sensors, machines, and operational databases.
- Transformation is where the data is cleaned and structured, making it suitable for analysis. This step is crucial for ensuring that the data used by the AI models is accurate and reliable.
- Loading entails moving the transformed data into the Data Verse, where it can be accessed by AI models for real-time analysis.

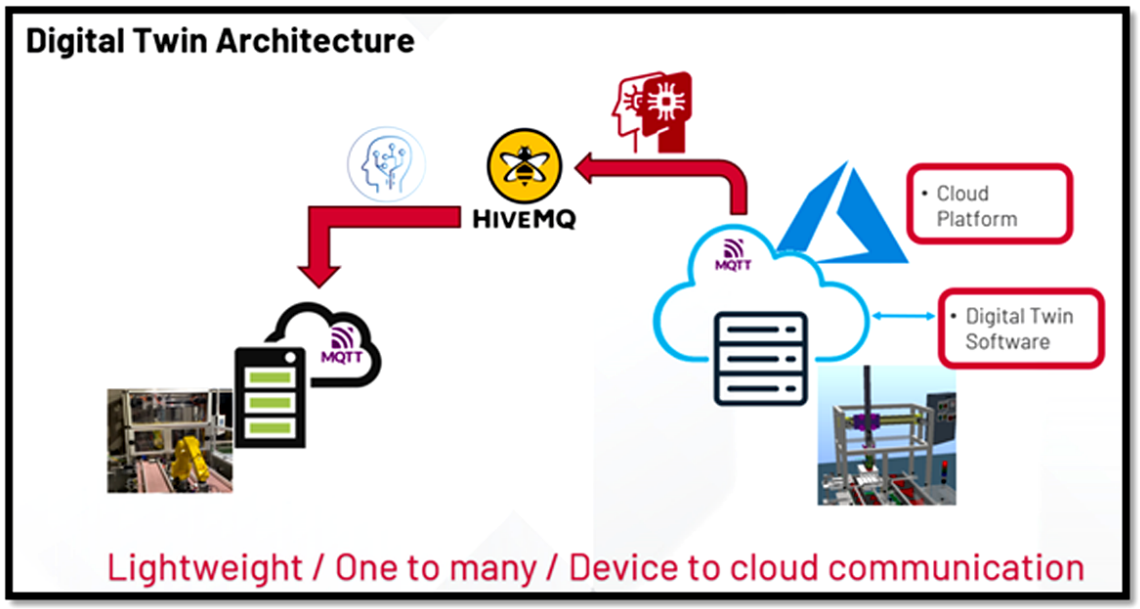
These data pipelines not only streamline the flow of data but also ensure that AI models receive timely and relevant information for predictive maintenance, anomaly detection, and RCA.

### Tuning the Digital Twin

We can use all the relevant data in the Data Verse & link it with the Digital Twin & create a Real time Soft ‘Thumbprint’ of the Plant wide infrastructure.

## OPTIMIZATION OF LLMS FOR REAL-TIME PROCESSING

At the heart of the AI-powered asset health monitoring system is the **Large Language Model (LLM)**, which processes the vast amounts of industrial data stored in the Data Verse.




**Training and Fine-Tuning**

LLMs are trained on extensive datasets that include not just operational data but also maintenance logs, equipment manuals, and historical performance records. This comprehensive training allows the models to understand the intricacies of industrial environments. Fine-tuning is an essential step where the model is adapted to specific industrial contexts. For instance, if an LLM is applied in a manufacturing facility, it will be fine-tuned with relevant data to improve its accuracy in predicting failures or providing maintenance recommendations.

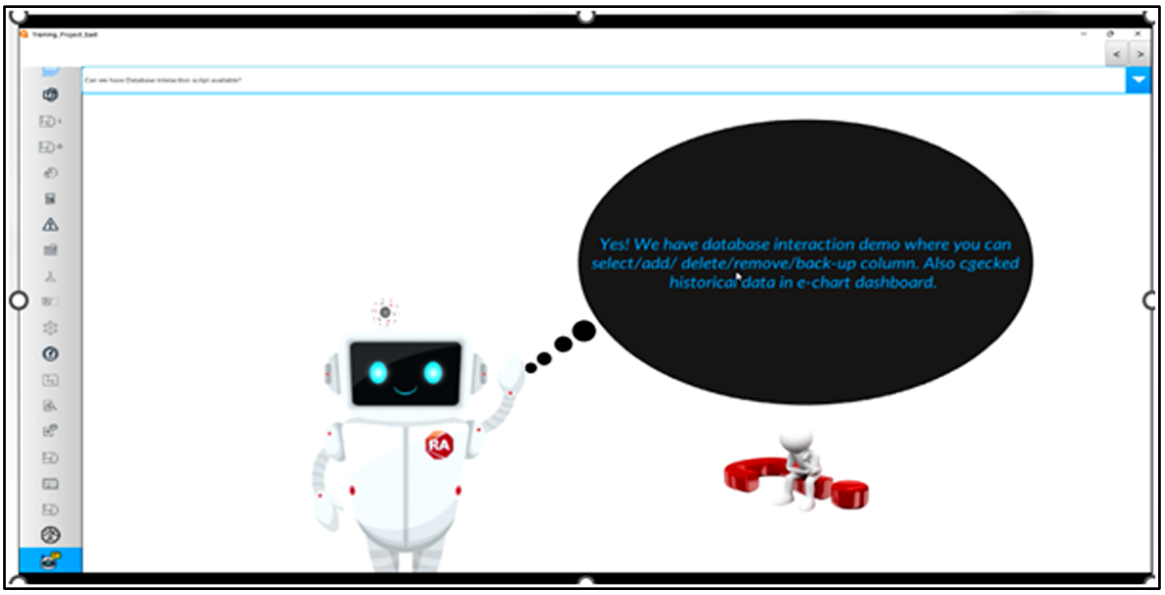
**Real-Time Processing Capabilities**

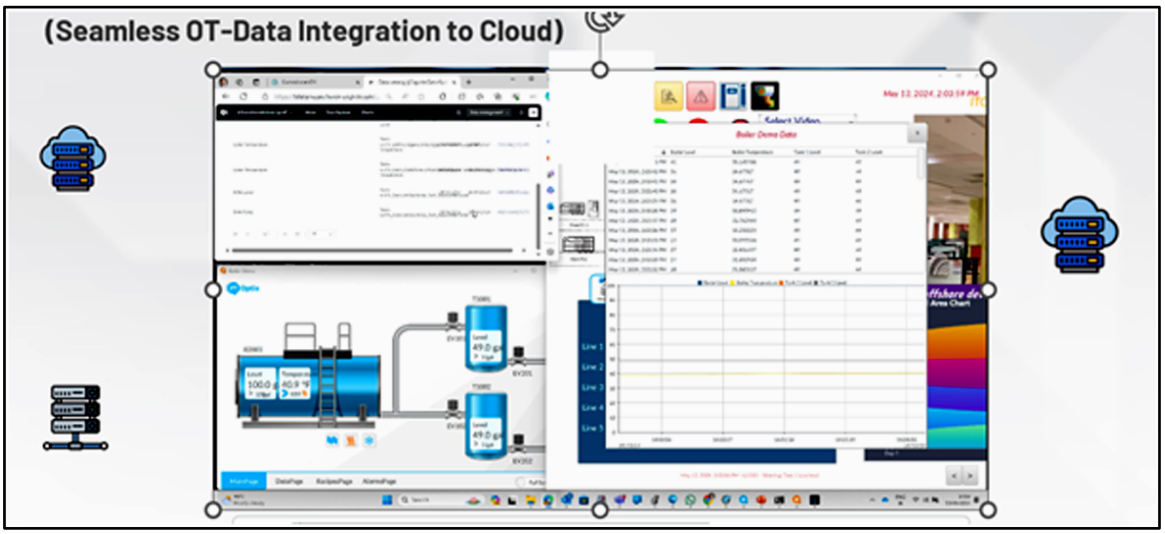
To handle real-time data efficiently, LLMs are optimized using various techniques, including **transfer learning** and **reinforcement learning**. These techniques enable the models to adapt to new data quickly and improve their predictive capabilities over time. Furthermore, leveraging **high-performance computing infrastructures** allows LLMs to process large volumes of data in real-time. This capacity is crucial for industries that require immediate insights to prevent downtime and ensure operational continuity.

**Chat Interface**

Simplifying Maintenance Tasks** One of the most user-friendly features of an AI-powered asset health monitoring system is the **chat interface**. This interface allows maintenance personnel to interact with the AI system using natural language, simplifying the process of accessing insights and data-driven recommendations. #### **User-Friendly Interaction** With the chat interface, technicians can pose questions like, “What are the current issues with the pump?” or “When is the next scheduled maintenance for the conveyor belt?” The AI processes these queries in real-time and provides actionable responses based on the underlying data. This natural language interaction eliminates the need for technical expertise in data analysis, empowering maintenance teams to make informed decisions quickly. The ability to query the system easily also promotes a culture of data-driven decision-making across the organization.

#### **Integration with LLMs** The chat interface is seamlessly integrated with the LLM, enabling it to handle advanced queries that require deeper insights. For example, when a technician asks about a specific fault that occurred recently, the AI can pull together data from various sources, analyze historical patterns, and present a comprehensive overview that includes potential causes and recommendations for corrective actions. ---




## CHALLENGES AND LIMITATIONS

Despite the numerous benefits offered by AI-powered asset health monitoring systems, several challenges remain that need to be addressed.

### Data Privacy and Security

Data privacy is a significant concern in industries that handle sensitive operational data. Ensuring the protection of data through stringent security protocols is essential. Measures such as **encryption**, **access control**, and compliance with industry regulations must be implemented to safeguard data integrity.

### Model Explainability

The explainability of AI models is another challenge that cannot be overlooked. While LLMs can deliver precise predictions, their decision-making processes are often complex and opaque. This lack of transparency can be problematic in regulated environments, where understanding the reasoning behind specific AI-generated insights is essential. Organizations must invest in strategies that enhance the explainability of their AI models, potentially through additional layers of analysis or user-friendly reporting tools that clarify how decisions are made.

**Real-Time Data Processing Challenges**

Processing massive volumes of real-time data presents technical challenges, including issues related to **latency** and **throughput**. In cloud-based systems, where data must be transmitted over networks, delays can occur, impacting the timeliness of insights. Ensuring high performance requires careful consideration of network architecture and data management practices.

## CONCLUSION

Generative AI, particularly through the integration of **Large Language Models (LLMs)** and a robust **Data Verse**, holds transformative potential for the field of industrial asset health monitoring. By enabling predictive maintenance, anomaly detection, and efficient root cause analysis, these AI systems facilitate a shift from reactive to proactive maintenance strategies, ultimately enhancing operational efficiency and reducing costs. However, the implementation of these systems is not without its challenges. Organizations must navigate concerns related to data privacy, model explainability, and the technical hurdles of real-time data processing. By addressing these challenges, industries can unlock the full potential of AI in asset management, leading to improved decision-making and greater overall productivity. As industries continue to evolve in the era of digital transformation, the combination of generative AI and data-driven insights will play an increasingly crucial role in shaping the future of asset health monitoring and maintenance practices.

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181_IEC36267

# Facial-recognition based Secured Cloud Voting System using Transfer Learning

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***Abstract:*** *The smooth and effective administration in a country requires the unbiased representation of people's mandate obtained through the Voting system. The traditional voting approach is prone to manipulation by non-state actors, thereby increasing the risk of proxy voting. To mitigate this issue, the conventional voting approach may be upgraded with the aid of advanced technologies of Cloud Computing to formulate an electronic, integrated, and unified citizen-centric voting mechanism. In this paper, a Cloud Voting System (CVS) based on a smart card namely, Multipurpose Electronic Card (MEC) has been proposed. This MEC provides multi-variate electronic services to citizens through the public cloud. Authentication of voters is one of the important aspects of the Cloud Voting System. One-shot learning-based facial recognition is a classification task that performs classification given one or a few instances of each class. The authors have addressed the One-shot Learning Facial recognition using the transfer learning technique of Deep Learning. Transfer learning works by applying a pre-trained model to a new problem. The input facial image could be verified successfully with that of the facial images stored in the repository dataset using ResNet and Xception pre-trained models. The accuracy obtained using the Xception model is 87.916%.*

***Keywords:*** *Cloud Voting; Facial Recognition; One-shot Learning*

## INTRODUCTION

The principal constituent of any democracy is its election system. The strength of a democracy lies in the freedom of its people to have the power to vote. The traditional voting approach is prone to manipulation by non-state actors, leading to proxy voting. The possibilities of duplicate votes, fake vote counts, and rigging Electronic Voting Machines are some of the drawbacks of the conventional voting system. The traditional voting approach involves high cost and time, which needs to be mitigated to prevent any delay in the process. A Cloud Voting System (CVS), based on advanced technologies like Cloud Computing, Computer Vision, etc., which will instil a sense of security in the mindset of the valid voter, has been proposed here. The proposed system is based on a Multipurpose Electronic Card (MEC) [1-3, 4]. This smart card provides an integrated and unified biometric interface for delivering different electronic services to the citizens.

The proposed system of Cloud Voting can leverage the proliferation of new and emerging Information and Communication Technologies (ICT) such as Cloud Computing to increase the overall efficiency of the voting process. This system intends to mitigate the problems of conventional voting approaches, particularly the unauthorized interference of non-state actors which intends to threaten and manipulate the actual mandate of the valid voter.

In the proposed system of Cloud Voting System, the election data is stored, recorded, and fetched as digital information. Voter authentication is a highly crucial element of online voting. Voter identification and authentication have to be performed in a reliable and accurate manner. The proposed system of Cloud Voting System incorporates multiple levels of authentication i.e. MEC-based authentication and biometric-based authentication. Here in this paper, the authors have enhanced voter authentication using Facial recognition. Facial recognition can be used to detect any fraudulent voting and prevent false votes, leading to a more robust and reliable system.

A huge number of contributions have been made in the domain of online voting systems using different biometric based authentication systems. In [8], iris detection in a voting system is performed by capturing the images of eyes, and by using the image processing technique, the iris is detected and subsequently compared with the image stored in the database. The system declares the voter to be eligible for voting after comparing with the voter's Aadhar details. After confirmation from the system, the voter is allowed to vote. This authentication approach involves less

manpower and is highly secure. Fingerprint recognition is another efficient technique of voter authentication. The fingerprint is recognized using a sensor and saved in the database. After the biometric image is fetched, the information will be sent to the web interface through the serial port of the microcontroller. The input image is compared with the image stored in the server or database and it sends the image and is displayed through LCD display [9], thus completing the confirmation process of voter identity. If it is not matched, the result is displayed through the LCD display.

The main contributions of this paper are:

1. Application of emerging technologies to design a Cloud computing-based Voting System
2. Facial recognition of voters using One Shot Learning, a type of classification task which requires one or a few instances per image class
3. Application of transfer learning to use pre-trained model for efficient model training

## METHODOLOGY FOR FACE RECOGNITION

One of the most crucial and challenging intelligence applications is Face Recognition. In these types of face recognition systems, the aim is to detect a person's identity by supplying one picture of that person to the system. If it is a match with the picture stored in the database, then the person is identified successfully. If it fails to recognize the picture, it shows that the picture is not stored in the system's database.

### Dataset used

The dataset uses the Extracted Faces from face-recognition-dataset, which is derived from the Labelled Faces in the Wild dataset [12]. The Haar-Cascade Face-Detection (CV2) is used for extracting the faces using the base images in the Extracted Faces dataset. For our work, we have used images of 500 different individuals from the Extracted Faces dataset.

### One-shot Learning using ResNet Model

The proposed approach encompasses a three-layer authentication for the voter. Hence, it is an extension of the proposed Cloud Voting System [5-7] covering facial recognition methodology. At first, the voter logs into the voting interface through a laptop or smartphone using MEC ID, which is then verified with the stored records. In the second step, the mobile number of the voter is verified by sending an OTP to the voter. Next, for the face recognition part, the voter's face is captured by the device's camera and the input image is passed through the facial recognition module using the One Shot Learning algorithm. A similarity score is generated between the input image and other matching images in the database. If the input image matches with the identical image stored in the database, then it is the case of an authorized voter; otherwise, it is the case of an unauthorized voter. This entire architecture of the methodology is depicted in the **Figure 1** below.

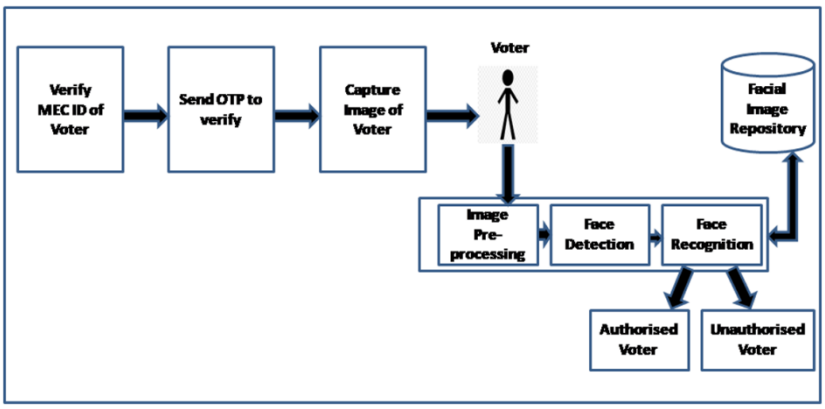


**Figure 1** Architecture of voter face recognition module

**One-shot Learning using Xception Model**

At first, the necessary packages of cv2, os, time, numpy, tensorflow, random, seaborn, matplotlib are imported into the Python program. The images of the dataset are read via cv2 and then split into training and test sets with a split size of 90%. The train and test lists of images are used to create triplets of (anchor, positive, negative) face data, where positive denotes the image of the same person as anchor and negative denotes the image of a different person than anchor. Next, a batch-generator is created to convert the triplet passed into batches of face-data and performs the preprocessing before returning the data into separate lists.

The Siamese network does not classify the images into particular classes or labels; it rather computes the distance between any two given images. If the images belong to the same person, then the network should be capable of learning the parameters in such a way that it should produce a smaller distance between the two images, and if they belong to different persons, then the distance should be greater.

**RESULTS**

**Facial Recognition using ResNet Model**

One Shot Learning can be utilized to perform Face Recognition in Python as it image class. The Face Recognition includes two steps:

1. Detecting a face in the image
2. Performing Face Recognition for the detected image

At first, we have to import the required Python packages. The facial landmark detection will be done by using dlib. The several image operations will be done by using cv2. The different orientations of the faces have to be aligned by using an Imutils face aligner. The training folder will be iterated upon containing one image for each individual. The image is loaded using cv2 and then converted to grayscale. The image is then passed to the cv2.dnn model to locate the face in the image.

All the detections provided by the cv2.dnn model will be iterated upon. The confidence threshold is set as 0.7 for the experiment. If the confidence value is above 0.7 for any detection, it will be accepted as the face image and will be taken forward to the face aligner for alignment of the face. The landmarks will be extracted from the aligned face and passed to the face encoder, which is the pre-trained ResNet model. This model is used to provide the (128,1) dimension encoding for all the images. Next, for the testing of the model, the model is first loaded from the disk. The image is then loaded which is to be tested and converted to a grayscale. Similar to the training process, the test image is passed to the cv2.dnn model, and the detections are extracted for the face. The image is then forwarded to Face Aligner for aligning the face and the resulting facial landmarks are passed to the face encoder to generate (128,1) dimension encoding for the image. This 128-dimension vector is used to compute its Euclidean distance with all the 128-d vectors that were calculated before the training process. The least ten values are extracted which signifies that these ten images are the closest match to the input image.

Here, the image “Aaron_Tippin_0001.jpg” is passed as input and from the output section, we can see the least distance image is of “Aaron_Tippin_0001.jpg” and the distance is 0.106799 as from **Table 1**. Thus it can be concluded that the input image matches with the correct image in the dataset. Hence, the person can be declared to be an authorized user of the cloud voting system.

**Facial Recognition using Xception Model**

In the next step, authors have constructed the Encoder which converts the passed images into their feature vector representation. Here, the authors have applied a pre-trained model, Xception model which is based on the Inception_v3 model. The reason we are using transfer learning is to significantly reduce time and size of the dataset. The model is connected to the Fully Connected (Dense) layer and the data is normalised in the last layer using L2 normalisation. The Siamese network is then created which accepts 3 parameters (anchor, positive, negative) and

utilises the encoder above for encoding the images into their feature vectors. These features are passed to a distance layer which calculates the distance between the pairs of (anchor, positive) and (anchor, negative). After this, we compute the Triplet loss using the Triplet loss function.

**Table 1** Euclidean distance details

| Image File Name in Output | Euclidean Distance from Input Image (upto 6 decimal places) |
|---|---|
| Aaron_Tippin_0001.jpg | 0.106799 |
| Aaron_Peirsol_0004.jpg | 0.566578 |
| Abid_Hamid_Mahmud_Al-Tikriti_0001.jpg | 0.591679 |
| Adrien_Brody_0004.jpg | 0.592128 |
| Abdullah_Gul_0008.jpg | 0.598707 |
| Adam_Kennedy_0001.jpg | 0.614224 |
| Adrien_Brody_0009.jpg | 0.620661 |
| Abdullatif_Sener_0002.jpg | 0.623291 |
| Abdullah_Gul_0011.jpg | 0.626685 |
| Abdullah_Gul_0009.jpg | 0.635249 |

Siamese network can be trained by taking an anchor image and performing a comparison between the anchor image and a positive sample and the anchor image and a negative sample. There should be a low dissimilarity between the anchor image and the positive image and a high dissimilarity between the anchor image and the negative image [10, 11].We run 20 epochs with batch size of 128 and obtain a test accuracy of 87.916% at the end of epoch 20 as given in **Figure 2**.

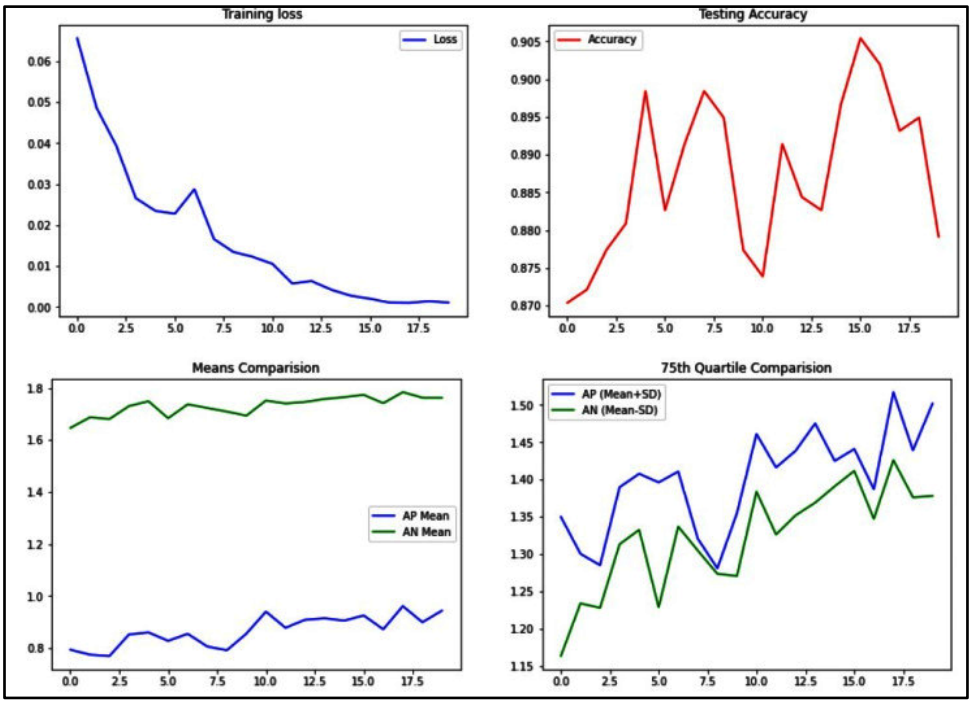


**Figure 2** Result graphs of Siamese network model using Xception pre-trained model

## CONCLUSION

The Cloud Voting System (CVS) proposed here in this paper, involves the participation of several stakeholders for its

successful execution. Facial Recognition has been implemented in this research work using One-Shot Learning, a deep learning-based object classification algorithm, with a few samples per class covering an image dataset. Facial recognition has its security challenges such as spoofing attacks which are used to fool the system. In the future, the authors can attempt to develop a more robust facial recognition system with anti-spoofing approaches. In addition to this, the authors identified the need for integrating Facial Recognition technology with user interface design principles and how it can change the user experience design by simplifying the voter authentication procedure.

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196_IEC44417

# A Comprehensive Approach for Enhancing Mental Well-Being through the Application of Restorative Frequencies

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***Abstract:*** *The research aims to elucidate the distinct patterns of neural activation across different brain lobes. Through meticulous statistical analysis of EEG signals, the underlying mechanisms governing brain activity before and after listening healing sounds using EMOTIVE. The study employs advanced signal processing techniques and AI analysis to discern temporal and spatial dynamics in neural responses. The research uses EEG data from 20 subjects, both male and female, to analyze brain function by applying these conditions, highlighting the challenge of mapping and integrating the data into a device. It optimizes therapeutic auditory experiences to each person's unique brainwave patterns using EEG data and accurate frequency analysis, encouraging mental endurance and emotional well-being. This approach optimizes the therapeutic power of sound and enhances mental health outcomes by designing personalized sound environments.*

***Keywords:*** *Electroencephalography (EEG); Brain Activity; Emotion Recognition; Linear Regression Classification; Mental Health Monitoring*

## INTRODUCTION

It's critical to understand the complex connections between human emotions [1] and mental functions in order to explore the depths of human psychology and advance general wellness. Our attitude, decisions, and behaviours are mostly shaped by our emotions, but our cognitive processes provide the basis for our ability to perceive, interpret, and interact with our environment [2]. Our innovation includes providing solutions based on detecting individual human brain signals and mental condition through EEG [3] data. Our innovation fills a crucial gap in the Indian market by introducing a device dedicated to mental well-being through EEG data. Unlike existing sound therapy instruments, our device targets depression and mental stress directly. The most challenging aspect lies in mapping EEG data and integrating it into the device, ensuring precise and effective personalized interventions. This unique approach sets our innovation apart as a pioneering solution for mental health [4] enhancement. The development of non-invasive [5,6] techniques for the real-time monitoring [14] and assessment of these internal states has therefore been given priority by developments in affective computing [15,17] and cognitive neuroscience. Brain science [7, 16] has become an essential field of study to unravel the mysteries of life due to developments in biomedical technology and our growing understanding of the brain. Our innovative solution harnesses the power of EEG data to create a sophisticated sound therapy [7, 8] device tailored for mental well-being. We conducted comprehensive EEG data collection from a diverse group of 30 subjects, including faculty members and students of varying genders. This dataset serves as the foundation for our device, where meticulous mapping and decoding of EEG data enable precise implementation into our technology. We will use our 3-D printing machine in our lab to design and developed the structure of our device. By leveraging advanced algorithms and real-time processing capabilities, our device translates EEG signals into therapeutic sound patterns, providing personalized interventions for emotional regulation and stress alleviation. This fusion of neuroscience and technology represents a ground-breaking approach to mental health care, offering individuals a unique and effective tool for enhancing their well-being.

Our idea, is intricately linked to themes such as Sonic Therapy [9, 10], and Sound Healing therapy. Our device adapts therapeutic auditory experiences to individuals' brainwave patterns by utilizing EEG data and precise frequency analysis [11], promoting emotional well-being and mental resilience [12, 13]. This approach harnesses the power of sound as a healing modality, creating personalized sonic environments that align with established principles of sonic and neuroacoustic therapies, ultimately enhancing mental health outcomes. Our idea addresses the significant impact of mental health challenges, including depression and stress, on individuals and society. By providing a solution that

device can effectively alleviate these issues. Using this non-invasive method, we contribute to a healthier and more resilient society. Additionally, as our approach relies on EEG data and does not involve harmful chemicals or invasive procedures, it has a minimal impact on the environment, aligning with sustainable practices in healthcare innovation [18]. In our busy life we all want to lead a healthy life. So we focused on the topic and introduced our device for individual subject's choice. The five primary channels in the dataset are AF3, AF4, T7, and T8. These channels each represent micro voltages (μV), which measure brain activity's strength. The dataset includes a timestamp parameter for accurate EEG recording times, providing valuable insights for researchers, practitioners, and experts in neurophysiological studies, cognitive research, and EEG signal-processing projects.

## METHODS AND PROCEDURE

**Figure 1** represents the data process and analysis system. This study involved sixteen participants aged 20-35, using an EMOTIV 5-channel device to gather electroencephalography (EEG) data. The data was collected during two independent data collection periods: before listening the healing sound and after listening the healing sound. We gave a mathematical addition task to the subjects. We collected data in two sequence before listening the healing sound we collected brain signals and after listening healing sound we again collected brain activity responses. We observed both the results in graphical format. We noticed the variation of the brain signal responses and effect of healing sound. The electrodes were strategically placed in the AF3, AF4, T7, and T8 brain regions to capture neural activity from a variety of cortical locations. A thorough data processing pipeline was used to guarantee data quality and dependability for further analysis. This covered methods for pre-processing. The desired signal was obtained by carefully cleaning the raw EEG data using pre-processing techniques, which also involved eliminating noise, artifacts, and baseline drift correction with band-pass filters. To make it easier to examine brain responses in detail, the data was divided into epochs that corresponded to different experimental situations. From the segmented data, relevant characteristics were identified with a focus on time-domain qualities in order to capture brain dynamics connected to tasks. In order to extract valuable insights from the data gathered, a number of analytical techniques were used, such as group-wise comparisons utilizing Origin software, descriptive statistics, and correlation analysis to find noteworthy patterns in brain activity. Additionally, patterns of brain activity throughout cognitive task phases and rest were examined using ANOVA analysis with linear best-fit curve modelling. By offering solid insights into neural activity responses under resting and task-oriented settings, these rigorous analytical techniques hope to further our knowledge of cognitive functions and brain dynamics.

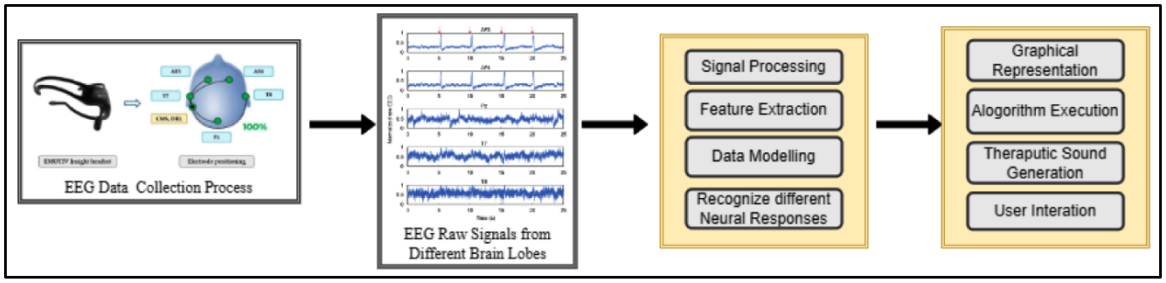


**Figure 1** Block diagram of data process and analysis

## PROCESS FLOWCHART

We mainly planned to make this device for Autism patient. In our project collected real-time data from normal subjects and we observed the variation of brain signal response before and after listening the healing sounds (**Figure 2)**. Shows the process flowchart of software and hardware interface. We notice how improved brain activity after listening the healing sound. We acquire brainwave data from the user's scalp using high-fidelity EEG sensors in the first step of our system, called EEG Data Acquisition. These sensors pick up on electrical impulses that the brain produces, which change depending on the activity and mental state. The obtained EEG data is subjected to thorough processing and mapping during the Data Processing and Mapping step in order to interpret certain brainwave patterns and frequencies related to mental health issues like stress and sadness. By analyzing the mapped EEG data and interpreting brainwave patterns, the Algorithm Execution Engine uses sophisticated machine learning algorithms to

determine the user's mental state, focusing on diagnosing feeling down states. The Therapeutic Sound Generation module then applies the algorithmic analysis to generate personalized therapeutic music or sounds suited to the user's mental state and can be used as uplifting, soothing, or mood-regulating auditory stimuli. The User Interface facilitates interaction with the device, offering a display for visual feedback and controls for input, thereby enabling users to access information about their therapy sessions and adjust settings or provide feedback. The Connectivity and Feedback module oversees data transmission and user feedback, incorporating connectivity options such as Wi-Fi or Bluetooth for seamless data exchange and interaction with external devices or applications. Finally, the Power Management module ensures efficient power supply regulation, optimizing power consumption during operation and standby modes to prolong battery life and enhance overall device efficiency.

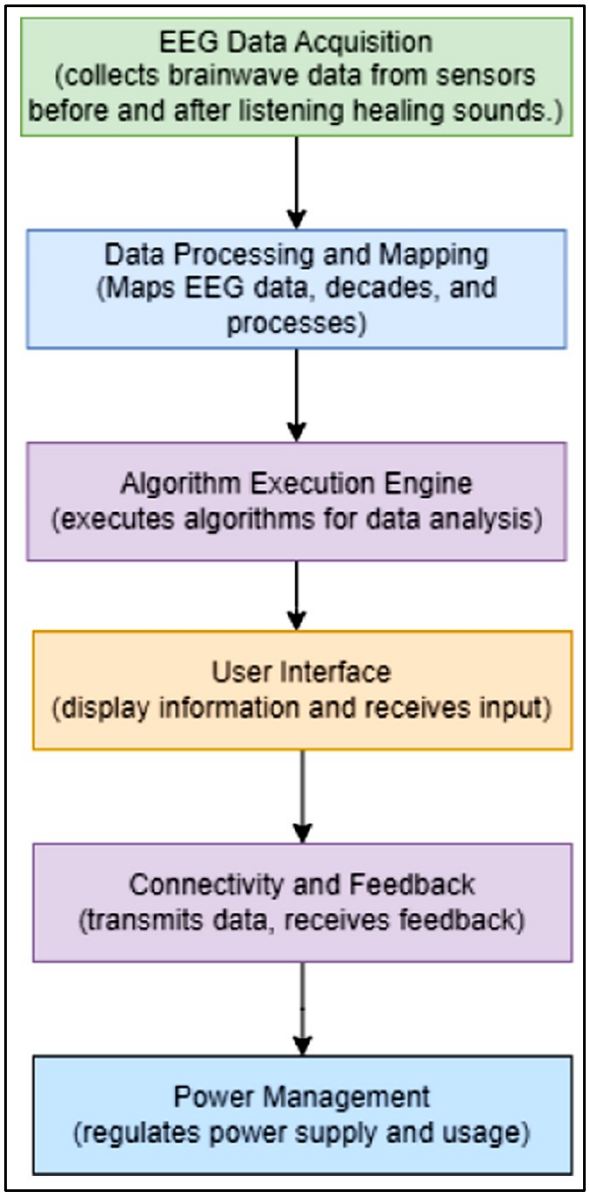


**Figure 2** Process flowchart of hardware and software interface

**MATHEMATICAL STATEMENT**

ANOVA Analysis: This is the basic formula of ANOVA analysis. In equation (1), F is F-Statistic and we calculate F-value from EEG dataset. MS (between) means the mean square value between the different features which we extracted from our dataset. MS (within) means mean square value with each and every features and gives the

variability of the data. Now we present all the formula which we calculated for statistical analysis in our real-time EEG dataset.

$$\blacksquare F = \left(\frac{\mathrm{MS(between)}}{MS\ (within)}\right) \quad (1)$$

$$\mathrm{SS(total)} = \sum_{i=1}^{N} (Xi - X)^2 \quad (2)$$

$$\mathrm{SS(between)} = \sum_{j=1}^{k} \mathrm{nj}\ (Xj - X)^2 \quad (3)$$

$$\mathrm{SS(within)} = \sum_{j=1}^{k} \sum_{i=1}^{nj} (Xij - Xj)^2 \quad (4)$$

From **Equation (2)** $X_i$ is an individual observation, X is grand mean value i.e. total average value of our EEG dataset and N represents total number of observations. In our data analysis we vary the N to get better observation according to our requirement. We need proper and more accurate statistical values to build up our device. This statistical value used as an input value. In **Equation (3)** $X_j$ shows as the mean value of group j (brain lobes: AF3, AF4, T7, T8) and $n_j$ is total number of observation and k is the number of groups. Respectively in **Equation (4)** $X_{ij}$ is the observation of group i in group j. We also calculate Degree of Freedom (df) because to get the F-statistic and compute the mean squares. The number of independent values that could vary throughout the computation is reflected. In our calculation, df (between) = (k-1) and df (within) = (N-k).

Statistical values, such as the mean value difference between two emotional parameters, are observed in an ANOVA to forecast the mental state. **TABLE I** and **TABLE II** are discussed about statistical tests that were carried out to evaluate the significance and dependability of the linear models, such as p values and R-squared values. ANOVA analysis was utilized in the context of our NeuroSonic device to examine the EEG data obtained while the patients were performing additional problems both before and after hearing the healing sound. The statistical significance of the variations in cerebral activity (Frontal and Temporal lobes) was identified by a comparison of the means of brainwave properties under each of these circumstances. We calculated Sum of Square (SS), Mean Square (MS). Certain properties are shown in the above tables, such as prob>F, Mean Square (MS), Mean Square Error (MSE), F-Value, and Sum of Squares (SS), are obtained with the Origin program. We noticed that after listening the healing sound subjects doing the mathematical problem in a short time. Variation is shown in curve (graphical representation) and also get a huge significant difference in statistical values. It means healing sound impact in our brain activity response.

**Table I** Statistical analysis of brain lobes in before listening the healing sound

| Lobes | SS (Error) | MS (Error) | Adj. R-Square | F Value | Prob>F |
|---|---|---|---|---|---|
| AF3 | 3.7 | 6.7 | 6.6 | 3.6 | 1 |
| AF4 | 2.2 | 6.2 | 10.9 | 3.3 | 1 |
| T7 | 5.1 | 7.6 | 7.2 | 3.4 | 1 |
| T8 | 6.3 | 7.2 | 3.6 | 3.8 | 1 |

**Table II** Statistical analysis of different brain lobes in after listening healing sound

| Lobes | SS (Error) | MS (Error) | Adj. R-Square | F Value | Prob>F |
|---|---|---|---|---|---|
| AF3 | 3.37 | 1.05 | 0.00479 | 1.5 | <0.0001 |
| AF4 | 1.9 | 7.2 | 0.00128 | 3.6 | <0.0001 |
| T7 | 2.7 | 1.2 | 0.0068 | 1.56 | <0.0001 |
| T8 | 4.3 | 1.6 | 0.00229 | 1.2 | <0.0001 |

## RESULT AND ANALYSIS

Understanding EEG data and its dynamic changes in brain activity over time, especially when analyzing cognitive process patterns, requires the use of FFT analysis. We collected data from each subject more than 15 minutes and get more than 20 thousand datasets. Look for oscillations in the EEG signal's amplitude and frequency bands, especially in the areas associated with executive functions (prefrontal cortex, AF3, AF4). This FFT techniques contribute in the creation of pattern recognition algorithms, the study of brain dynamic connections, and the detection of aberrant EEG patterns associated with neurological illnesses. The graphical depiction of the EEG signal. In the **Figure 3**, X-axies frequency are in Hz and Y-axies shows electrical pulse response of brain lobes in amplitude.

**Figure 4** shows the visual plotting of the EEG signal amplitude of the subjects where we collected data after listening the healing sounds. The EEG graphs, plotted with frequency on the x-axis and amplitude on the y-axis, illustrate the brain's neural activity before (**Figure 3**) and after (**Figure 4**) listening to music. The x-axis represents different brainwave frequencies, including delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-100 Hz), each associated with distinct cognitive and emotional states. Amplitude on the y-axis measures the intensity of these brainwave signals. Before listening to music, the graphs (**Figure 3**) show higher beta activity (13-30 Hz), indicating mental engagement, stress, or cognitive effort, alongside reduced alpha wave activity (8-13 Hz), suggesting a lack of relaxation. After listening to music, the graphs (**Figure 4**) typically reflects increased alpha and theta wave amplitudes, associated with a more relaxed or meditative state. This shift in the frequency amplitude distribution suggests a calming effect, with lower beta activity reflecting reduced mental strain. These findings support the hypothesis that music can positively influence neural processes and emotional well-being, aligning with the therapeutic application of music in mental wellness interventions.

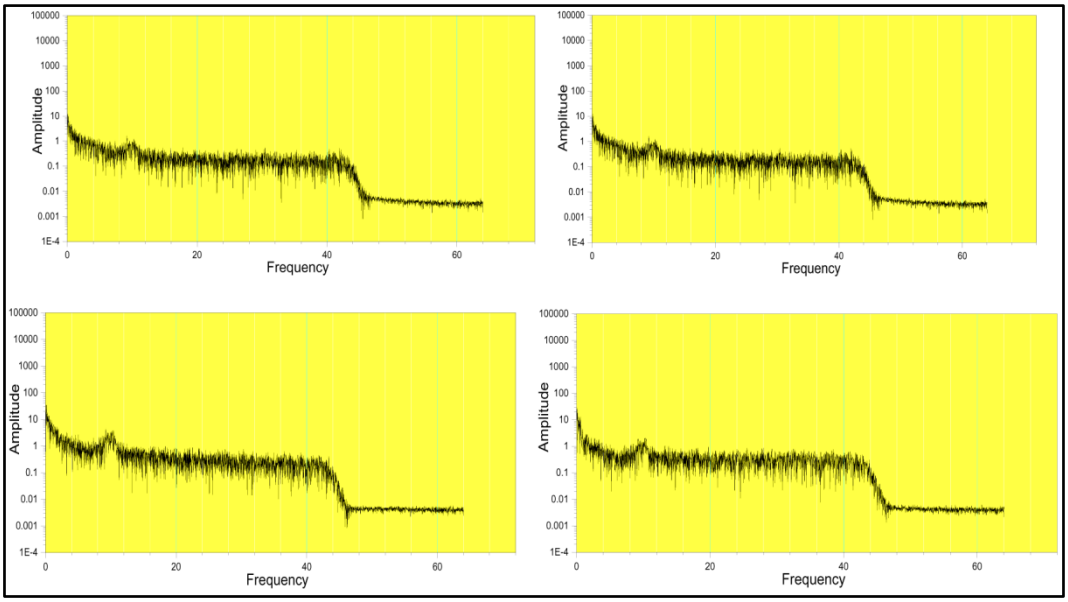


**Figure 3** Amplitude and Frequency of different brain lobes: AF3, AF4, T7, and T8 before subjects are listening the healing sounds

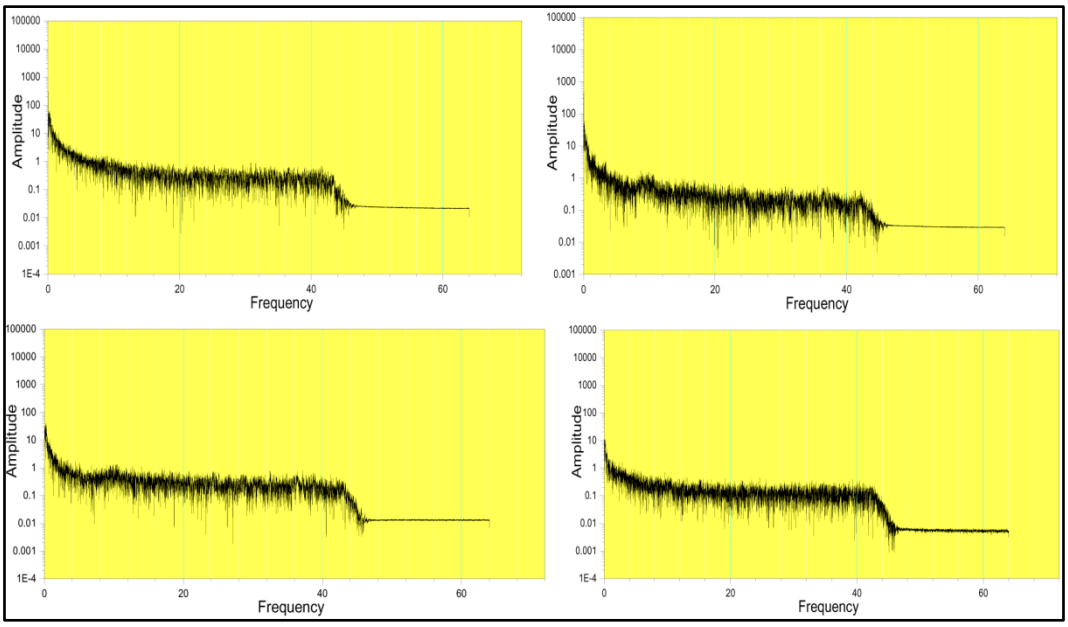


**Figure 4** Amplitude and Frequency of different brain lobes: AF3, AF4, T7, and T8 after subjects are listening healing sound

## CONCLUSIONS

The research demonstrates the intricate connection between mental processes and physiological responses by examining individual heterogeneity in brain activity responses during cognitive activities. The results emphasize how crucial it is for cognitive neuroscience research to take individual variability and task-specific neural signatures into account. Customized tactics, multimodal integration, real-time brain-computer interfaces, and clinical translations are a few future projects that may enhance treatment results and provide specialized treatments. By integrating artificial intelligence, EEG data processing and interpretation are improved, leading to the creation of personalized therapeutic soundscapes that promote mental health. The EEG analysis before and after music listening demonstrates a significant shift in brainwave patterns, particularly in the amplitude of alpha and theta waves, which are linked to states of relaxation and emotional balance. The reduction in beta wave activity post-music intervention suggests a decline in mental stress or cognitive effort, while the increase in slower frequency bands like theta and alpha highlights the calming and therapeutic effects of music on the brain. These findings align with the broader understanding that music can act as an effective tool for enhancing mental wellbeing and emotional regulation, supporting its potential use in therapeutic applications for stress reduction and mental health maintenance.

### Ethical Considerations

All participants gave their consent with knowledge, confidentiality, data privacy, and the freedom to withdraw from the study without facing consequences were all carefully followed in this research. We also get permission from the ethical community of our Institute.

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214_IEC77249

# Effects of Frequency and Mass Variations on QCM Response by Eco-Friendly Green Synthesis of Silver Nanoparticles Derived from Murraya Koenigii Leaf Extract

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***Abstract:*** *The evaluation of Indian cumin quality can be performed using a sensor developed from a 10 MHz Quartz Crystal Microbalance (QCM). To prepare the sensor, silver nanoparticles (SNPs), synthesized from MurrayaKoenigii (MK) leaf extract and AgNO3 solution, were deposited onto the QCM surface via drop-coating. The initial frequency of 9993702 Hz decreased by 3470 Hz after 10 coating cycles, achieving the maximum mass deposition. Frequency changes caused by the deposition were analyzed using a chronogram, confirming the sensor's fabrication. The chronogram analysis, as described in the results, demonstrates that the process significantly impacts the effect of mass and frequency variations during sensor fabrication over the crystal.*

***Keywords:*** *Quartz Crystal Microbalance (QCM); Mass Deposition; Frequency Deviation; Chronogram*

## INTRODUCTION

A gas sensor is developed using a 10 MHz Quartz Crystal Microbalance (QCM) to detect the significant aroma of Indian cumin for quality detection. The sensor was made by drop-coating over the quartz crystal after finding silver nanoparticles (SNP) produced through the reduction of silver ions (Ag+) in the presence of leaf extract from MurrayaKoenigii (MK) with the help of the solvated electron method. As silver nanoparticles with murrayakoenigii leaf extract have been deposited over the surface of QCM as suspended particulate matter, a wide experimentation was carried out to assess the effect of mass deposition over the QCM surface unless and until the pre-set loading frequency has been achieved for the aroma detection. The initial frequency of the QCM was observed as 9993702 Hz. It has been observed that a minimum of 10 shots through the drop-coating method are required to achieve the expected loading frequency of 3470 Hz and after that, no significant frequency deviation was observed. The effect of frequency deviation due to mass deposition over the surface of QCM was observed through a Chronogram, where significant deposition of particle matter was observed [1]. In this work, a straightforward and low-cost sensor development method was used and easily available materials were used to sense the aroma of cumin.

## METHODOLOGY

At first 10 MHz AT-cut Quartz Crystal Microbalance (QCM) piezoelectric quartz with an 8 mm diameter was taken for doing the necessary coating over the surface to detect identified volatiles. Two gold electrodes with 5 mm are present on both sides of the crystal. After proper cleaning, the crystal was attached to the e-Nose to locate the initial frequency. The e-Nose consists of IC 8284A to generate real-time frequency into the system, a frequency counter with 32-bit MK20DX256VLH7 chip, a sensor chamber to attach the crystal, a data acquisition system using Raspberry Pi 2B to process the necessary data and a touchscreen-based graphical user interface (GUI) to display the frequency-deviations of the crystal under consideration [2]. After noting down the initial frequency (9993702 Hz) of the crystal, one side of the gold plate has been coated with silver nano-particles extracted from the mixture of aqueous AgNo3 solution and commonly available pulverized MurrayaKoenigii (MK) leaves extracts using drop coating (2 uL) method [3,4]. After this, the coated crystal is kept inside a 10-litter vacuum desiccator to dry out the silver nano-particles naturally over the surface of the crystal [5,6]. After 45 minutes, the crystal is taken out from the desiccator and attached inside the sensor chamber carefully at (24 ± 1)°C temperature and relative humidity of 61% so that the

effect of temperature and humidity can be kept constant throughout the experiment. The frequency deviation (2049 Hz) was noted in the display unit after the first shot of coating. As some mass is deposited over the surface of the crystal, for this an oscillation over the surface of piezoelectric quartz is occurring. Using Sauerbrey's equation (**Equation (1)**), the deposited mass has been calculated to find the correlation between frequency deviation and amount of mass deposition [1,7].

$$\Delta f = \frac{2f_0^2}{\sqrt{\mu_q \rho_q}} \frac{\Delta m}{A} = -C_f \frac{\Delta m}{A} \qquad (1)$$

Here, $\Delta f$ is the change of frequency in Hz, $f_0$ represents the fundamental frequency of the QCM's resonance in Hz, $\mu_q$ is the AT-cut quartz crystal shear mode ($= 2.947 \times 10^{11}$ g•cm$^{-1}$•s$^{-2}$), $\rho_q$ gives the quartz density ($= 2.66$ g•cm$^{-3}$), $\Delta m$ is the small change in mass in gram, A represents the effective area of the quartz crystal and $C_f$ is constant.

A similar process has been continued for several shots to achieve the pre-set loading frequency. The details of the results are shown in the following section.

**RESULTS**

As mass is deposited over the surface, from the next shot of coating the amount of frequency deviation and amount of mass deposition will decrease. The amount of frequency shifts w.r.t. each shot of coating has been checked. It is observed that after 10 shots, no further mass deposition is possible.

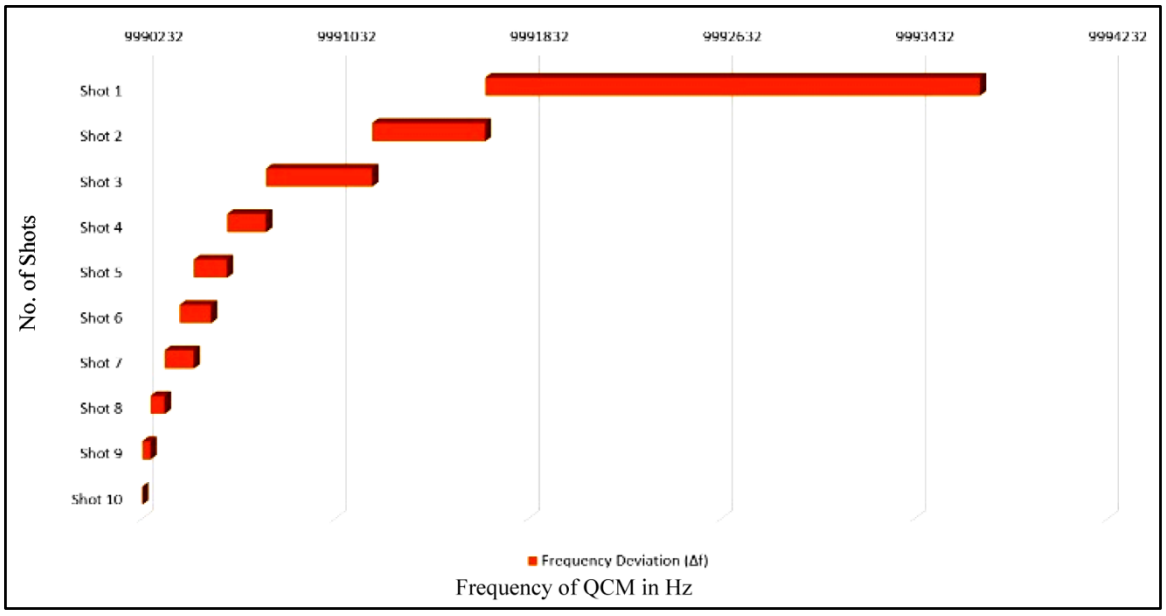


**Figure 1** Chronogram of Frequency change due to mass deposition over 10 MHz QCM

**Figure 1** represents a chronogram where the identified starting and ending frequencies of the crystal has been noted. It is needless to say once again, at the 10th shot of coating the frequency change is not significant at all.

Similarly, in the chronogram given in **Figure 2** exhibits the mass deposition that occurred over the electrode surface of the crystal and once again it is indicated at the 10th shot of coating, there is no significant mass change observed.

During the experiment 2uL coating material was drop coated over the crystal and the drying process continued for 45 minutes. In **Figure 3**, in the first shot maximum amount of mass has been deposited. But as long as we continue with the other shots, the amount of mass deposition w.r.t. time was also diminishing. The change of frequency approaches zero value at the last shot and no further significant mass deposition was possible as the quartz crystal reaches the

expected loading frequency.

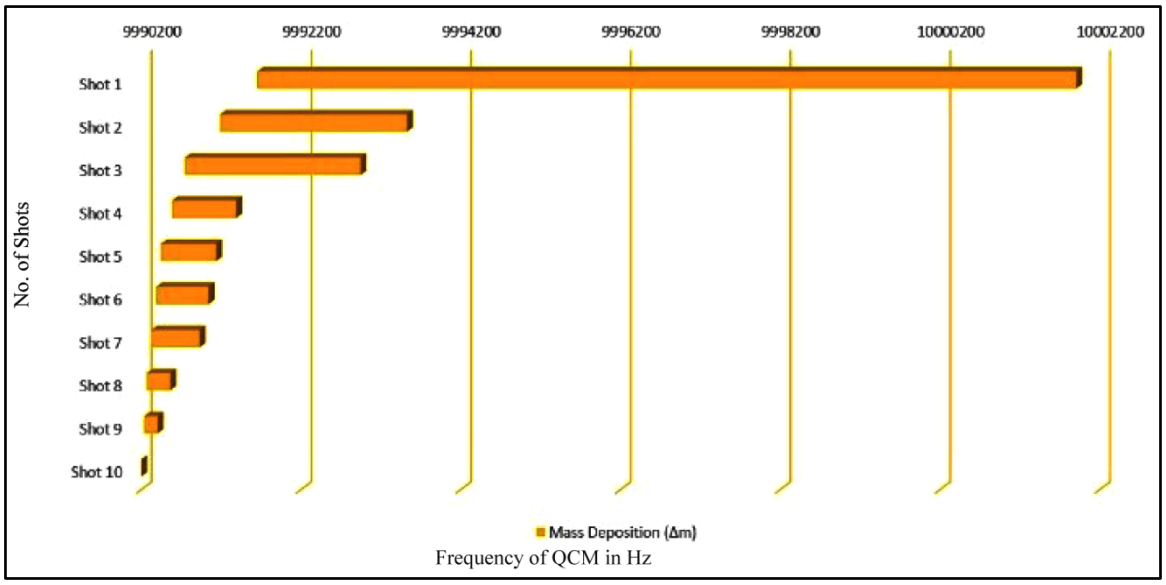


**Figure 2** Chronogram of mass change due to mass deposition over 10 MHz QCM from each initial frequency before loading

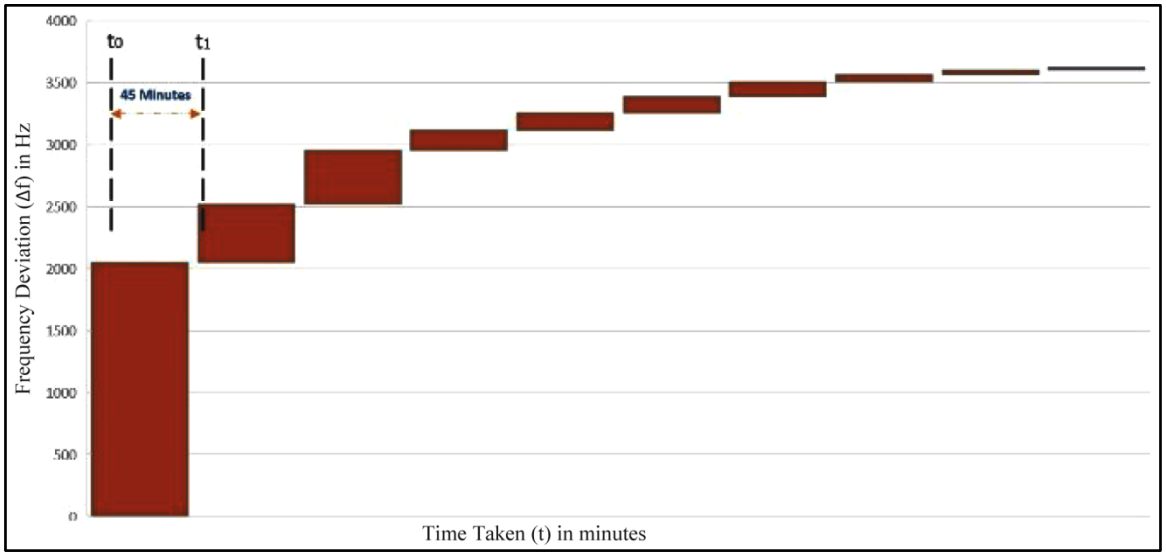


**Figure 3** Chronogram of ten depositions of the same volume (2 µL) on a 10 MHz QCM at an equal time interval

## CONCLUSION

In this study, a quartz crystal sensor has been developed with silver nanoparticles evolved from the mixture of aqueous AgNo3 solution and commonly available pulverized MurrayaKoenigii (MK) leaf extracts. In the future, the experiment to detect significant volatiles from cumin or any agro material will be done as India is one of the largest producers of agro material where quality detection is very important. Here, the straightforward approach, economical design, and strong performance analysis w.r.t. frequency measurement give practical usefulness to the quartz crystal-based sensor. In this paper, the effect of oscillating frequency due to mass deposition on the QCM response has been studied. The effect of the oscillation has been observed unless and until the sensor reaches the expected loading frequency. The chronogram approach as described in the result section proves that the used process is actively putting effect over the performance of the crystal. In the future, the dimension of the nano-particle material deposited over

the surface may be found. This kind of approach may be used to design an array of mass and frequency-detecting systems to monitor the effect of mass deposition over the crystal surfaces.

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215_IEC44546

# Estimation of Chilli Growth Parameters: Monitoring Length and Width in Field Conditions with Low-Cost, Portable IoT-based Device

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***Abstract:*** *Chilies (Capsicum annuum) are vital for their flavor and color. India, particularly West Bengal, is a leading producer of this spice. Monitoring chili quality, including growth, color and pungency is crucial but challenging due to large-scale production. An IoT-based automated system using the ESP-32 camera module addresses this issue by capturing high-resolution images of chilies in real-time. Machine learning algorithms, including Logistic Regression, Random Forest and PLSR, analyze the data to estimate growth parameters accurately. PLSR showed strong correlations for length ($R^2$ = 0.95–0.97) and width ($R^2$ = 0.74–0.84). This low-cost solution improves chili quality assessment, reducing human error in agriculture.*

***Keywords:*** *Image Processing; OpenCV; RGB; ESP32 Cam; Machine Learning*

## INTRODUCTION

Chilli peppers (Capsicum annuum) are widely used globally for their color and flavor in various cuisines and beverages. India, particularly West Bengal, is a significant producer and exporter of chilies, with over 400 varieties cultivated worldwide and 12 popular types in India alone [1,2]. In 2020-21, India produced 2,049,213 tons of chilies across 702,047 hectares of land [3]. Assessing chili quality, especially regarding color and pungency, is crucial but challenging due to the large-scale production. Modern technologies like image processing offer a more accurate and efficient method for measuring parameters such as length and width, replacing traditional manual interventions.

In this study, we conducted an investigation into the growth patterns of locally available chilli peppers. Given the substantial scale of chilli production, there's a critical need for an automated system that can accurately estimate the quality of harvested chillies. To address this, we employed a straightforward setup involving an IoT-based camera capture device for continuous image acquisition. These images were then automatically stored in the cloud for further analysis, as depicted in **Figure 1**. Subsequently, we implemented an image processing-based algorithm, illustrated in the flowchart in **Figure 2**, to extract dimensional parameters such as the length and width of the chillies. These dimensions are significant indicators of chilli growth. For capturing the image, ESP camera module has been used. The ESP camera module refers to a camera module that is compatible with ESP32 or ESP8266 microcontrollers. These camera modules are designed to work seamlessly with ESP development boards, allowing developers to integrate camera functionality into their IoT (Internet of Things) projects. ESP camera modules typically include features such as image capture, video streaming, and sometimes onboard image processing capabilities. They are often used in applications such as surveillance systems, smart home devices, and other IoT projects that require visual data processing [4].

To assess the accuracy of our growth parameter measurements, we applied machine learning techniques including Logistic Regression, Random Forest Classifier, and Partial Least Square Regression (PLSR) using a training-testing methodology. Among these, the PLSR model proved particularly effective in generating highly accurate predictive linear relationships between the measured and estimated values of the length and width of chillies. This comprehensive approach not only enables automated and precise quality estimation but also demonstrates the potential of machine learning in enhancing agricultural practices and productivity.

## METHODOLOGY

### Material Used

Chilli samples, locally known as 'Lanka' in West Bengal, were harvested from chilli plants when they were nearly fully grown. Two main varieties (Jhanti Lanka from Tajpur, Howrah and Bullet Lanka from Bandel, Hooghly) of chilli plants were selected for harvesting the chillies used in this experiment.

A total of 40 chilli samples with different colors, size and shape were collected for the experiment, with 20 samples from each of the two selected varieties. These samples were chosen to represent a diverse range of shapes and sizes, ensuring a comprehensive dataset for analysis and evaluation.

### Experimental Setup Used

The ESP camera module plays a crucial role in the image processing approach used to capture images of different varieties of chillies in this study. The setup model of this proposed system is depicted in **Figure 1**, which shows how the camera is positioned relative to the samples. The ESP camera module, renowned for its technical prowess, boasts features like high-resolution imaging, low-light sensitivity, and real-time streaming capabilities. Its compact design, coupled with Wi-Fi connectivity and onboard processing, enables seamless integration into IoT systems for surveillance, home automation, and industrial monitoring [5]. Advanced functionalities such as motion detection, facial recognition, and cloud storage support make it a versatile solution for diverse applications. With its ability to capture clear and detailed images even in challenging environments, the ESP camera module stands out as a reliable and efficient tool for visual data acquisition and analysis. One key aspect of this setup is the maintenance of a consistent distance between the camera device and the center position of the object, which in this case is the chilli samples placed on a white background paper. This fixed distance is set at 10 centimeters for all samples to ensure uniformity and accuracy in capturing the images. By standardizing the distance, variations in image quality due to distance differences are minimized, allowing for reliable and consistent image data acquisition across different chilli varieties.

The ESP32-CAM module features a clock speed of up to 160 MHz, providing a summary computing power of up to 600 DMIPS. Furthermore, it supports image output in JPEG (OV2640 support only), BMP, and GRAYSCALE formats, with a spectrum range of 2412 to 2484 MHz. The resolution of the captured image is 800 × 600.

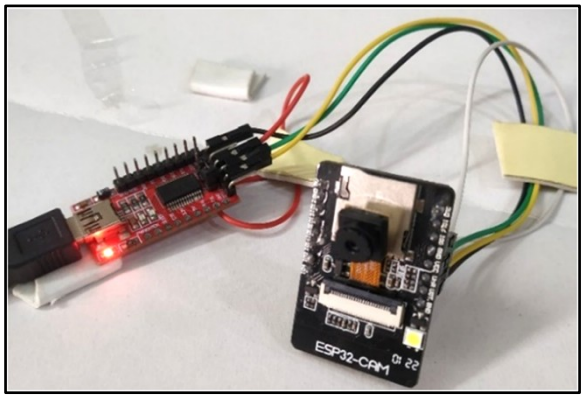


**Figure 1** IoT based image acquisition set-up

### Image Analysis

The measurement of chilli length and width involves the utilization of a real-time IoT-based camera system. Image analysis is conducted using the OpenCV library to process the captured images. These images are wirelessly transferred to Google Drive and accessed through Google Colab for subsequent processing. Several techniques are implemented to enhance image sharpness, facilitating the automated measurement of length and width of chilli. A

detailed flowchart outlining the steps of image processing for determining the growth parameters of chillies is depicted in **Figure 2**. How image is analysed, that is explained step by step below.

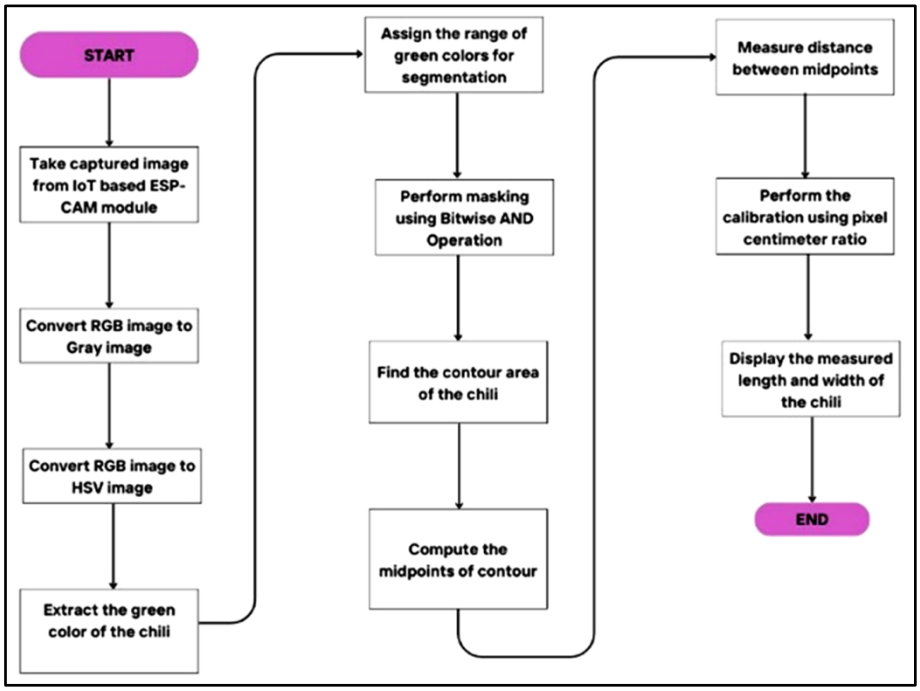


**Figure 2** Flowchart Flow of real-time size determination system

## RESULTS

Statistical-based parameters derived from manually measured chilli parameters are compared with those obtained from the image processing algorithm and presented in **Table 1** for detailed analysis.

**Table 1** Different statistical parameters of chilli for length and width measurement for different varieties of chillies

| Type | Parameter of Measurement | Mean (cm.) | Standard Deviation (cm.) | Standard Error Mean (cm.) | Correlation ($R^2$) |
|---|---|---|---|---|---|
| Variety 1 | Chilli length using manual method | 9.78 | 1.75 | 0.39 | 0.95 |
| | Chilli length using image processing algorithm | 10.00 | 1.85 | 0.41 | |
| | Chilli width using manual method | 0.97 | 0.30 | 0.07 | 0.74 |
| | Chilli width using image processing algorithm | 1.57 | 0.32 | 0.07 | |
| Variety 2 | Chilli length using manual method | 6.40 | 1.45 | 0.32 | 0.97 |
| | Chilli length using image processing algorithm | 6.91 | 1.29 | 0.29 | |
| | Chilli width using manual method | 1.85 | 0.27 | 0.06 | 0.84 |
| | Chilli width using image processing algorithm | 2.12 | 0.25 | 0.05 | |

Three machine learning techniques(Logistic Regression, Random Forest Classifier and Partial Least Square Regression) [6,7,8] are applied to compare measured data from actual length or width with data obtained through image processing. Using 80% of the data for training and the rest for testing, logistic regression initially shows good accuracy (>75%) during training but decreases during testing. Similarly, the Random Forest Classifier exhibits high training accuracy (100%) but drops significantly during testing for length and width prediction. Conversely, the Partial Least Square Regression method achieves over 80% accuracy in both training and testing, making it suitable for accurately predicting unknown length or width measurements of chillies across varieties.

The accuracy of chilli's original length or width compared to the measured values is assessed using the correlation regression coefficient ($R^2$). The image processing techniques yield highly satisfactory correlation coefficients for

length and width prediction. Specifically, for variety 1 of chilli, the correlation coefficient between actual and predicted measurements using image processing is 0.95 for length and 0.74 for width. The relationship between measured and original length of chilli is depicted in **Figure 3a**, while **Figure 3b** illustrates the same for width.

Using image processing techniques, the calculated correlation coefficients ($R^2$) are very satisfactory for length and width prediction. For variety 1 of chilli, the correlation coefficient value between actual and predicted measurement using image processing method is 0.95. At the same time, the correlation coefficient for width prediction is 0.74. The relation of measured and original length of chilli for both length and width is shown in **Figures 3a** and **3b**, respectively.

Similarly, the process is repeated for variety 2 of chilli, yielding a correlation coefficient of 0.97 for length and 0.84 for width prediction using image processing methods. The relationship between measured and original length of chilli for both length and width is illustrated in **Figures 3c** and **3d**, respectively.

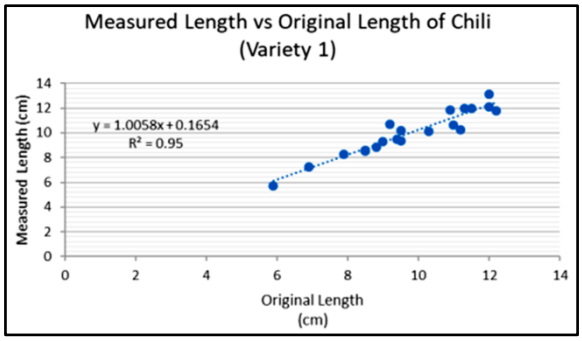


**Figure 3a** Relation of the length of chilli for variety 1 between original measurement and predicted measurement using image processing method

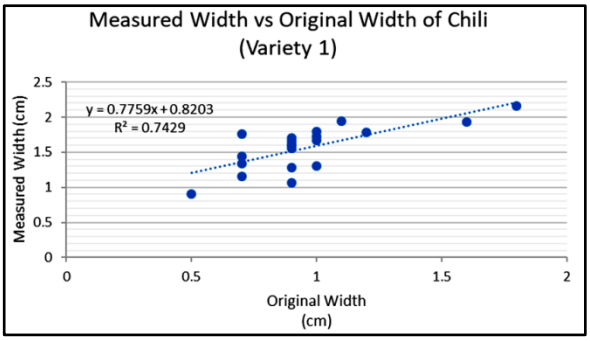


**Figure 3b** Relation of the width of chilli for variety 1 between original measurement and predicted measurement using image processing method

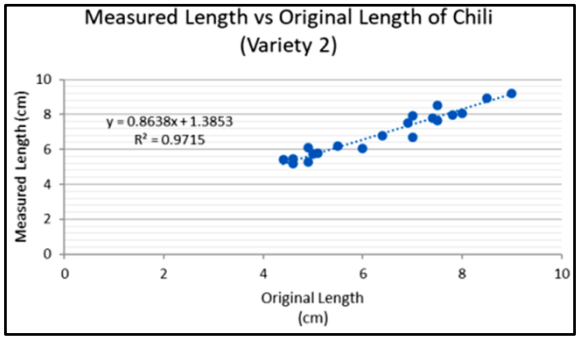


**Figure 3c** Relation of the length of chilli for variety 2 between original measurement and predicted measurement using image processing method

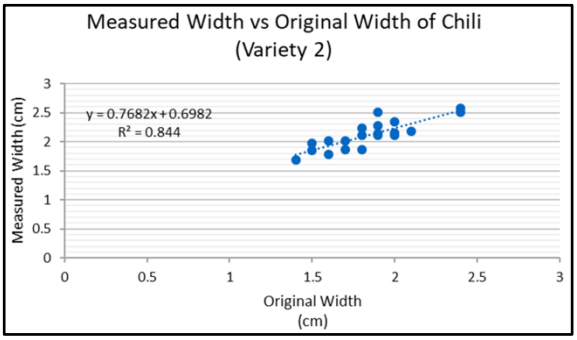


**Figure 3d** Relation of the width of chilli for variety 2 between original measurement and predicted measurement using image processing method

## CONCLUSION

The proposed image processing method using a low cost portable IoT based device proves beneficial for estimating unknown parameters of spices (chilli) with large production volumes, reducing human error. Storing images continuously in Google Drive using ESP32 Cam necessitates adequate memory and internet connectivity. Machine learning algorithms like Logistic Regression, Random Forest Classifier, and PLSR are compared for accuracy in estimating chilli growth levels. PLSR demonstrates strong correlations ($R^2$ = 0.95-0.97 for length, 0.74-0.84 for width) across different chilli varieties. OpenCV-Python facilitates image processing and machine learning, requiring a computer or laptop post image capture. Moreover, monitoring chilli growth and infection status is possible by analyzing RGB component changes through histogram analysis.

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219_IEC66194

# Enhancing Human Behavior Analysis in Digital Systems through Domain Adaptation in Facial Emotion Recognition

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***Abstract:*** *This work presents a method for human behaviour analysis using a facial emotion recognition system. Implementing this system requires the digital transformation of facial images captured in an unconstrained imaging environment. The overall systems' implementation has three segments: image preprocessing, feature representation followed by classification, and transformation of techniques in the cross-sectional domain for real-time applications. The image processing step extracts the facial region from an input image that undergoes feature extraction using deep learning techniques. Then, the computed features undergo a classifier to build the recognition system. Domain adaptation techniques have been employed to enhance the recognition system's performance for real-time applications. The performance of the proposed system has been tested with two standard benchmark databases, KDEF and FER2013, and the performance with state-of-the-art methods shows the superiority of the proposed system.*

***Keywords:*** *Human Behaviour Analysis; Facial Expressions; Domain Adaptation; Deep Learning; Digital Transformation*

## INTRODUCTION

The scientific study of human behavior analysis [8] is concerned with understanding why people behave in certain ways and how to modify behavior. Behavior analysts can enhance the lives of individuals and families by applying the concepts of learning theory. Analyzing human behavior involves looking at the behaviors, attitudes, and mental processes that influence people's activities. It is applicable to a number of disciplines, including marketing, sociology, psychology, and artificial intelligence. Numerous psychological, social, and environmental elements influence how people behave in their daily lives. Worrying about the human behavior analysis with their activities are vital in the current quality of living. Aiming to better match technology with human behavior, human behavior analysis is currently being conducted in artificial intelligence (AI) fields such as human-computer interaction (HCI).

In recent years, computer usage has had a profound impact on society since its introduction. Activities such as web browsing, video streaming, gaming, online education and exams, e-commerce, and data storage and retrieval are just a few examples of how computers are integrated into daily life. Many of these applications require extensive user interaction, which has led to the rise of Human-Computer Interaction (HCI) [9] as a dynamic field of research, playing a key role in the digital transformation of various industries and applications. HCI-based applications enhance the quality of life by simplifying everyday challenges. An intelligent user interface in HCI design not only analyzes facial movements but also detects the user's emotional state. By recognizing emotions, machines can interact and communicate with humans more naturally, making this technology valuable in areas such as children's entertainment, interactive computing, smart sensors, and social robotics.

Facial expressions are patterns of movement in the facial muscles or a type of abnormality that can transmit minute details about a person's emotional or physical status. A person's intention may feel. It is an essential nonverbal means of human communication. Different researchers have found that 70% of human communication is conveyed by nonverbal elements and just 30% is vocal. Research on human facial expression recognition (FER) for emotion classification has received a great deal of interest in the recent few decades from a wide range of disciplines, including computer animation, affective computing, perceptual, and cognitive sciences. The two most difficult computer vision tasks are facial expression detection and emotion classification. Facial expressions, such as those indicating anger, happiness, contempt, fear, sadness, neutrality, and surprise, are universal ways for individuals to convey their emotions and mental state. These expressions are distinguished by subtle changes, such as wrinkles or bulges, and more prominent alterations in key facial regions, including the lips, eyes, nose, forehead, cheeks, and

brow. Observers often interpret facial expressions to gauge mood, attitude, personality, and emotion. Ekman and Friesen [13] introduced a method to analyze facial behavior using eight distinct emotions, as well as valence and arousal levels, in an orthogonal dimensional space. However, predicting valence and arousal levels in this continuous space presents challenges, especially when annotating discrete emotions, as human annotations can vary widely. An example of facial expression class for FERS are shown in **Figure 1**.


**Figure 1** Example for seven facial expressions for a facial expression recognition system (FERS).

The digital transformation of facial expression recognition systems has greatly improved applicability across different industries by advancing the ability to identify and understand human emotions. FER's real-time analysis capabilities serve a range of applications, including virtual assistants, interactive gaming, customer service, and healthcare monitoring. This is made possible by the combination of edge computing and optimized algorithms. Every now and then FERS can be combined with other modalities, such as voice, gestures, and physiological data, thanks to digital transformation, giving researchers a more comprehensive picture of a user's emotional state. In the fields of social robotics and human-computer interface (HCI), this is extremely helpful. Therefore, in the digital transformation of the face expression recognition system, the image acquisition environment is critical to the system's dependability and performance. Certain aspects, including movement and motion blur, glasses, masks, hair occlusions, complex backgrounds, posing variations, camera quality and resolution, and lighting conditions affect the digital transformation of FERS for various applications [10], which are demonstrated in **Figure 2**.

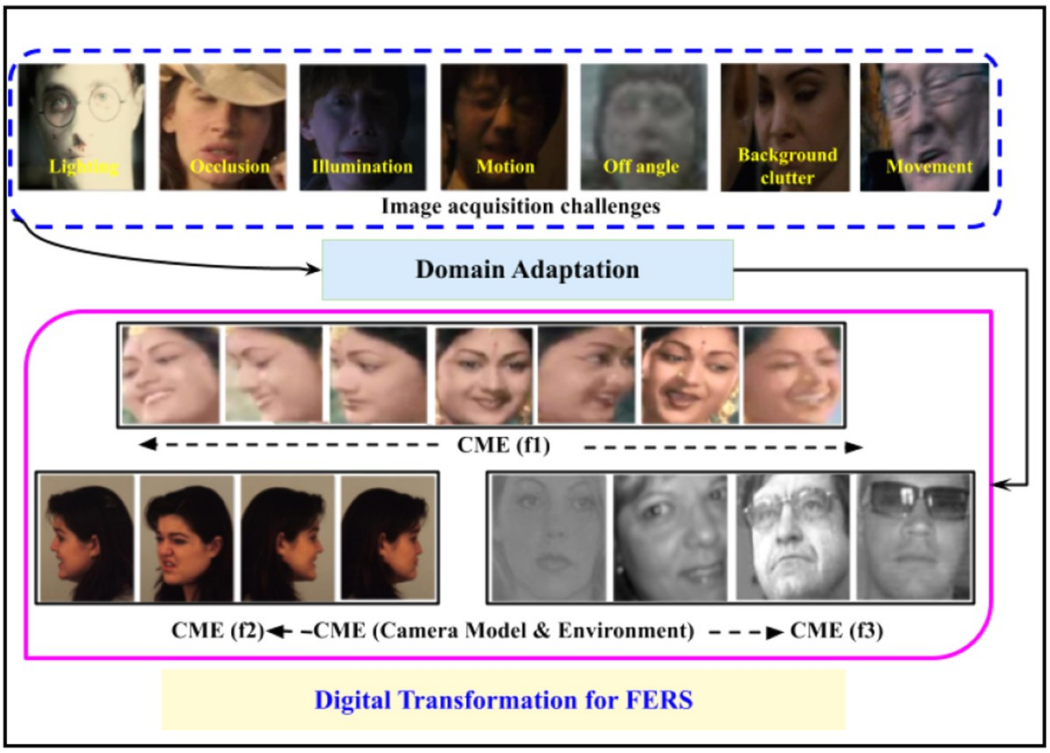



**Figure 2** Example for image acquisition challenging issues with different domain adaptation situations considered for the proposed FERS

Yan et al. has proposed an unsupervised facial expression recognition using domain adaptation based dictionary learning approach in [1], where the unsupervised cross-domain FER problem where all the samples in target domain are completely unannotated. Correcting Sample Selection Bias by Unlabeled Data for domain adaptation in machine learning tasks has been discussed in [2]. The improved data augmentation techniques have been applied to the facial image to enrich the learning parameters of the convolutional neural network developed in [3]. A comparative analysis for deep learning based facial expression recognition systems has been done in [4]. Hence, based on these existing works, this work builds a facial expression recognition system (FERS), with accepting several challenging issues of image acquisition as mentioned in Figure2, with implementing the system with deploying domain adaptation techniques to make the system generic for various realtime industries applications. This work is organized as follows: Section 2 discusses the step-wise proposed methodology for implementing the proposed system. Section 3 discusses the experimental results. Section 4 concludes the work.

## PROPOSED METHODOLOGY

This section outlines the methodologies used to implement the proposed facial expression recognition system (FERS), which aims to analyze human behavior through facial emotions. The implementation process involves three key steps: (i) image pre-processing, (ii) feature representation, and (iii) classification. In the first step, an input image is captured and subjected to pre-processing, which includes detecting the facial region of the subject. Next, the extracted facial image is utilized to derive discriminative features, resulting in a feature vector that is then classified. The classification task identifies the various expressions present on the subject's face. The recognition of facial expressions is further explored to understand human behavior in specific contexts. Since identifying human behavior is an open-class problem, it does not pertain to subject authentication; rather, it is influenced by the external environment in which an individual behaves. This open-class nature presents several challenges, including issues related to image acquisition and the differences between constrained and unconstrained imaging environments. Addressing these challenges necessitates domain adaptation techniques that can improve the proposed system's performance across various real-time applications. To evaluate the effectiveness of the proposed system, performance is assessed in three scenarios: (i) individual FERS performance (Scenario-1), (ii) cross-domain FERS performance (Scenario-2), and (iii) domain adaptation FERS performance (Scenario-3). The block diagram of the proposed methodology is demonstrated in **Figure 3**, which defines all the symbols required to represent the proposed system.

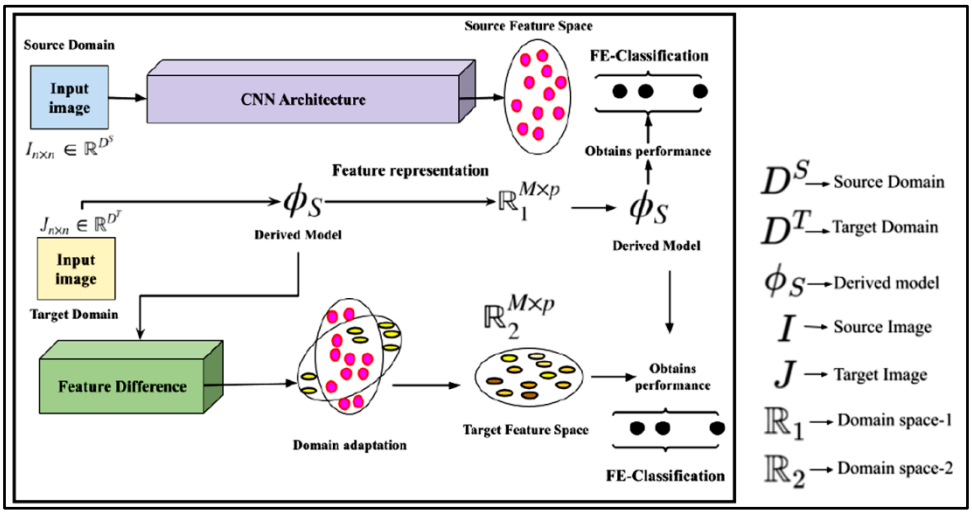



**Figure 3** Block diagram with working flow of the proposed facial expression recognition system (FERS).

### Image Preprocessing

The captured images present several challenges, including variations in expressions, poses, lighting conditions, and occlusions caused by accessories, all of which can lead to low-resolution artifacts that degrade image quality. Specifically, issues related to frontal and profile poses, facial expressions, and accessories (such as makeup, hats, and

glasses) have been taken into account. To address these challenges, a Multi-task Cascaded Convolutional Neural Network (MTCNN) [11] is employed as a facial landmark detection algorithm, consisting of three convolutional networks: P-Net, R-Net, and O-Net. The purpose of this approach is to create multiple scaled copies of the same image to improve face detection across different sizes. A 12 ×12 kernel scans each scaled image, starting from the top-left corner (0,0) and moving through sections of the image (from (0,0) to (12,12)). Each scanned section is then passed to the P-Net, which returns the bounding box coordinates if a face is detected. This process continues by shifting the kernel 2 pixels to the right or down, systematically covering the entire image. The stride refers to the number of pixels the kernel shifts during each operation. Using a stride of 2 helps minimize computational errors while ensuring that all faces are detected.

**Feature Representation followed by Classification**

After preprocessing, the detected facial region undergoes feature extraction to capture distinctive traits, transforming the input image into a set of discriminative features. In this study, images captured in controlled environments often contained noisy artifacts, leading to lower image quality. To overcome this, we employed a variety of effective feature representation techniques capable of grouping and distinguishing images of the same subject. In modern computer vision research, deep learning methods, particularly Convolutional Neural Networks (CNNs), have shown great success in extracting unique features from images and videos. CNN architectures are widely used due to their outstanding performance, especially in complex image analysis tasks. Within the CNN framework, filters perform convolution operations on input images, and pooling techniques with weight sharing generate diverse training parameters. Recent advancements in CNN-based feature extraction for facial expression detection have demonstrated their competitive edge over traditional computer vision methods, such as structural and statistical approaches. CNN features are especially robust in handling obstructed and segmented facial images captured in challenging environments, significantly improving overall system performance. In this research, the proposed feature representation method is implemented using a Convolutional Neural Network (CNN) architecture (**Figure 4**). At the core of the CNN architecture is the convolution operation, which is essential for extracting features from images through its convolutional layers. The architecture concludes with an output layer featuring a dense layer. The 'Adam' optimizer is employed during compilation to enhance optimization.

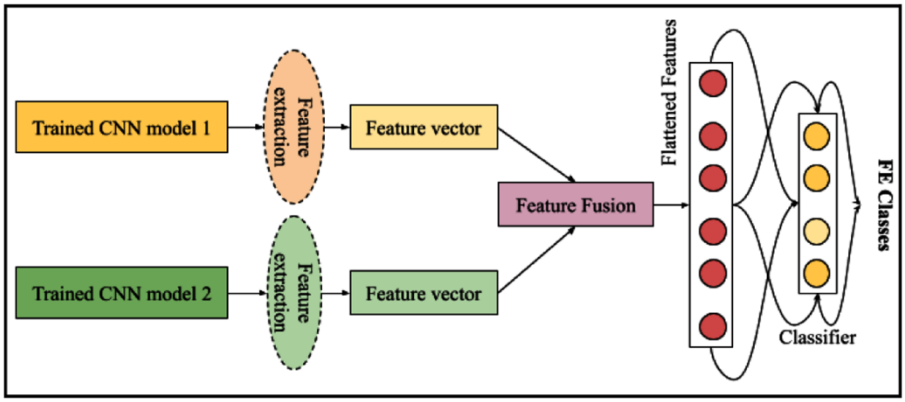



**Figure 4** The feature representation scheme employed for the proposed FERS.

**Individual Model (Scenario 1)**

In this scenario, a model is trained with a set of image samples captured in $R_1$ domain, and its performance has been evaluated with the same domain test samples (**Eq.(1)**), similarity-trained image samples in $R_2$ domain, the obtained model is tested with domain $R_2$ test samples (**Eq.(2)**).

$$P_I \leftarrow \phi_S(I) \quad \text{Eq.(1)}$$

$$P_J \leftarrow \psi_T(J) \quad \text{Eq.(2)}$$

**Cross-domain Model (Scenario 2)**

In this scenario, a model is trained with a set of image samples captured in $R_1$ domain, and its performance has been evaluated with the $R_2$ domain test samples (**Eq.(3)**), similarity-trained image samples in $R_2$ domain, the obtained model is tested with $R_2$ domain test samples (**Eq.(4)**).

$$Q_I \leftarrow \psi_T(I) \quad \text{Eq.(3)}$$

$$Q_J \leftarrow \phi_S(J) \quad \text{Eq.(4)}$$

**Domain Adaptation Model (Scenario 3)**

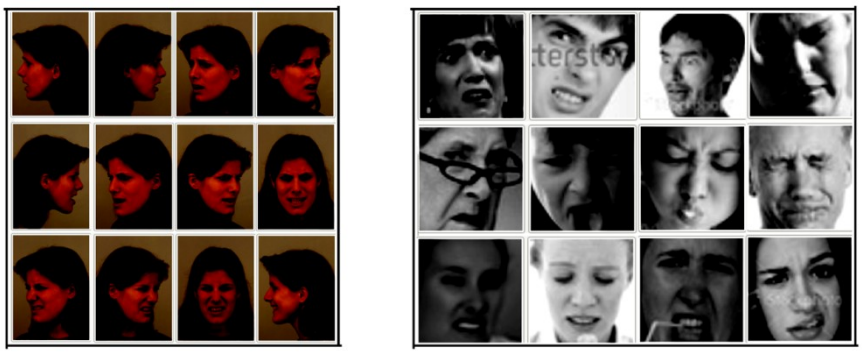
In this scenario, the method of domain adaptation technique has been applied to the model obtained from Scenario 2 such that the model obtained from **Eq.(5)** will obtain performance for $R_2$ domain test samples, and **Eq.(6)** will obtain performance for $R_1$ domain test samples. Here for domain adaptation purposes, the Two-Stage Transfer AdaBoost (TSTA) [5] for Regression algorithm is employed, which is a supervised, instance-based domain adaptation approach. In the first stage, the weights of the source instances are kept fixed, while the target instances are updated following the TSTA algorithm. In the second stage, the weights of the target instances are frozen, and the source instances are updated using the TSTA algorithm. During each first-stage iteration, cross-validation scores are calculated using the labeled target data. These cross-validation scores are then used to select the best estimator from all boosting iterations.

$$R_I \leftarrow \phi_S(I) \xrightarrow{DA} R_J \quad \text{Eq.(5)}$$

$$U_J \leftarrow \psi_T(J) \xrightarrow{DA} U_I \quad \text{Eq.(6)}$$

**EXPERIMENTATION**

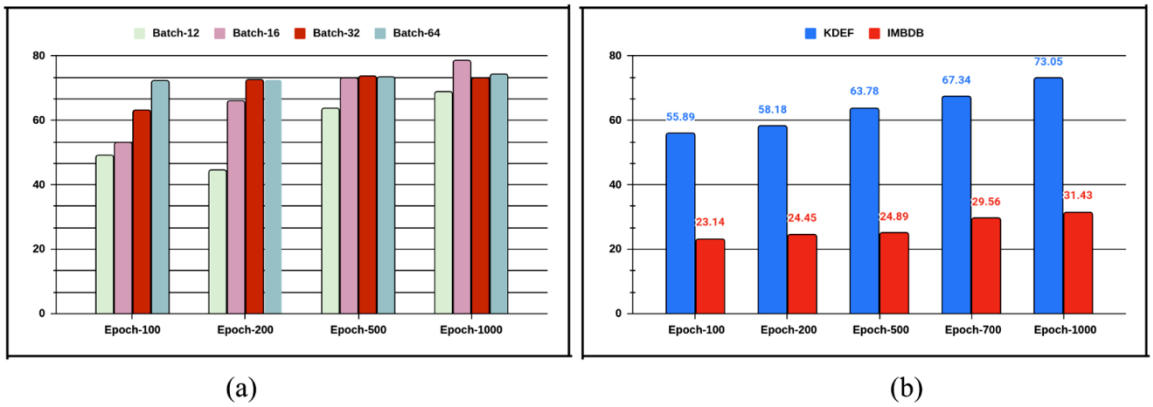
The proposed system was implemented on a Windows 10 platform, equipped with 16GB of RAM and an Intel Core i5 processor running at 3.20GHz. Several Python libraries, including NumPy, OpenCV, Keras, and TensorFlow, were used during the implementation phase, with Keras and TensorFlow specifically supporting the development of the deep learning-based CNN model. The first dataset used was the Karolinska Directed Emotional Faces (KDEF), containing 70 subjects (35 male, 35 female) with five pose variations and labeled across seven basic expression categories. For this study, 1,210 samples were used for training and 1,213 for testing, as these were the only available samples from the licensed download. The second dataset was the FER2013 (Facial Expression Recognition 2013), which consists of 48 × 48 pixel grayscale images categorized into seven emotions: Angry, Disgust, Fear, Happy, Sad, Surprise, and Neutral. Sample images from both datasets are shown in **Figure 5**.



(a) (b)

**Figure 5** Some image samples from (a) KDEF, and (b) FER2013 databases employed by the proposed system for experimental purposes

Here, the experiment starts with extracting a 200 × 200 facial image sample extracted from each input image I. Then, each extracted facial image undergoes the deep learning based trained convolutional neural network architecture such as MobileNet.v2[6], and Inception-v3[7] models. The trained model MobileNet.v2 computes 1024-dimensional feature vectors, while Inception-v3 computes 2048-dimensional feature vectors respectively, from each facial region. Then these feature vectors are fused together to undergo the proposed 1D convolutional neural architecture (CNN) to build the model for the proposed facial expression recognition system (FERS). The training of this CNN architecture requires parameter learning such as Batch and epoch, which have been experimented in **Figure 6**, which shows that for 32-batch size and 1000 epochs the performance would be better for the proposed system.




(a) (b)

**Figure 6** (a) Batch vs. epoch experiment, (b) with fixed batch epoch variations corresponding to employed databases for the proposed system

Hence, these parameters are further used to build the individual FERS for the employed databases, and its performance has been demonstrated in **Table 1**, which supports the Scenario-1 experiment. From this Table, it has been observed that the proposed FERS achieve F1-score of 72.34% for KDEF, whereas 32.96% for FER2013 respectively. The performance of this experiment has also been compared with some state-of-the-art methods [12], in **Table 2**, that show the individual model obtains better performance.

**Table 1** Performance of the proposed system using Individual Model (Scenario-1 Eq.(1) & Eq.(2))

| Database | Precision | Recall | F1-score | Accuracy |
|---|---|---|---|---|
| KDEF | 74.56 | 72.56 | 72.34 | 74.67 |
| IMFDB | 34.56 | 32.18 | 32.96 | 33.76 |

**Table 2** Performance comparison of the proposed system using the Individual Model (Scenario-1)

| | KDEF | | IMFDB | |
|---|---|---|---|---|
| | Accuracy | F1-Score | Accuracy | F1-Score |
| IP+PCA | 48.93 | 0.4813 | 19.56 | 0.1754 |
| GLCM+Haralick | 43.67 | 0.4281 | 18.13 | 0.1656 |
| LBP | 56.87 | 0.5521 | 18.31 | 0.1805 |
| HoG | 55.85 | 0.5543 | 16.78 | 0.1615 |
| DSIFT | 57.98 | 0.5075 | 23.21 | 0.2303 |

Now, the experiment for cross-domain (Scenario-2), has been experimented in **Table 3**, that shows the performance degradation due to cross-domain testing of samples by the implemented FERS. So, to enhance these performances, the domain adaptation technique has been employed using the TSTA algorithm. The experiment of the proposed system using domain adaptation (Scenario-3) has been demonstrated in **Table 4**. As compared to the performance reported in **Table 1**, and **Table 4**, it has been observed that the performance reported in both these tables are more or less similar to the corresponding databases. Hence, it can be concluded that utilization of domain adaptation methods

is beneficial for the human behaviour analysis for various real time applications.

**Table 3** Performance of the proposed system using cross-domain Model (Scenario-2, Eq.(3) & Eq.(4))

| Database | Precision | Recall | F1-score | Accuracy |
|---|---|---|---|---|
| KDEF | 43.06 | 41.67 | 39.67 | 42.12 |
| IMFDB | 20.21 | 19.34 | 18.86 | 19.45 |

**Table 4** Performance of the proposed system using domain adaptation Model Scenario-3, Eq.(5) & Eq.(6))

| Database | Precision | Recall | F1-score | Accuracy |
|---|---|---|---|---|
| KDEF | 73.06 | 72.81 | 71.15 | 72.78 |
| IMFDB | 33.52 | 31.89 | 32.21 | 33.61 |

## CONCLUSION

This work introduces a method for analyzing human behavior through facial expressions, leading to the development of a facial expression recognition system (FERS). While FERS addresses several challenges in real-time applications, its performance can be impacted by varying imaging conditions. To overcome these challenges, the proposed system utilizes domain adaptation techniques and deep learning-based feature representation methods, improving the accuracy and robustness of real-time human behavior analysis.

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223_IEC98532

# A Compact and Non-Invasive Photoacoustic Sensor with AI for Volume Solids Measurement of Paints

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***Abstract**: A non-invasive and compact photoacoustic (PA) sensing method with AI model is proposed in this study to measure the Volume Solids of paint. Conventionally, Volume Solids is measured by the laboratory based time consuming methods. A time domain photoacoustic signal obtained from the paint can predict the Volume Solids values in near real time (within 3-5 seconds). The temporal shift of a time domain PA signal is used as a feature to predict the Volume Solids. A linear regression model is trained with the 75% of the total data sets and remaining 25% are used for testing purpose. A total of 16 samples with distinct Volume Solids are used in this study. The accuracy of the model to predict Volume Solids is found to be approximately 88%. Although the limited number of samples are involved in this study, the residual plot confirms that there is no overfitting in the model.*

***Keywords:** Volume Solids; Paint Rheology; Photoacoustic Sensing*

## INTRODUCTION

Paint is a complex fluid comprising solvents, binders, additives, pigments, resin, etc[1]. Out of the different rheological properties of the paint, 'volume solids' is the very important and critical property particularly for the coil coating industries and others including automobile paint shops, submarines, aerospace, etc. The Volume Solids (VS) is measured to predict the dry film thickness of the paint coating from the wet paint. Physically, VS is the measure of total volume of the solid materials in a given volume of wet paint, expressed in percentage. VS is given as [2] —

$$VS = \frac{volume\ of\ binder + volume\ of\ pigment}{Total\ volume} \times 100 \qquad 1$$

The change in VS affects the overall rheology of the paint including the aesthetic quality of the paint coatings. Apart from the paint ingredients, the VS is impacted by the physical conditions like temperature, pressure and moisture. Hence, monitoring the VS in a specific time interval is of a particular importance to the industries. Conventionally, VS is measured by measuring the wet film thickness once the paint is applied and then allowing the paint to oven dry and further measuring the dry film thickness of the paint. Wet film thickness gauge is used to measure the wet film thickness whereas cross-sectional microscopy is used to measure the dry film thickness of the paint layer. These methods are usually cumbersome, time-consuming and laborious. Alternatively, some researchers have proposed a method to measure VS by measuring weight of the wet paint, its specific gravity and dry film thickness of a particular area. With this method VS is given as [3] —

$$VS = \frac{A.t.\rho}{W} \qquad 2$$

Where, A is the area of the dry film thickness, t is the dry film thickness, ρ is the density of wet paint and W is the weight of the wet paint. Since, these methods measure the dry film thickness, it becomes time consuming as the oven drying of the paint needs a specific time. In current practices, a small portion of a sample is painted to measure the VS and if the desired value of VS is achieved then the overall sample is painted [4]. Additionally, certain modifications to the wet paint or painting process are made if the desired VS is not achieved. To our best, there is no sensor available to measure the VS of a paint from the wet paint.

This study proposes a novel, compact, non-invasive and cost-effective, photoacoustic sensor combined with AI for measuring the VS from a wet paint. Briefly, photoacoustic (PA) is a hybrid sensing modality comprising of optical excitation and the acoustic acquisition [5]. In PA, the optical pulses of a particular wavelength and time-width are

used to irradiate the sample. The sample absorbs the laser pulses and undergoes thermoelastic expansion followed by contraction to generate the acoustic or PA waves. These time domain PA waves are processed and analyzed to determine properties of the different materials in solid, liquid or gases states. For this study, paint samples are irradiated with the laser pulses to obtain the PA waves. From the paint samples, the PA waves can depict its optical as well as mechanical properties as it involves acoustic waves [6,7]. Equations (1) and (2), suggests that the VS of a wet paint is directly proportional to the density of the paint. Hence, estimating the density of the PA wave can help to predict the VS of the wet paint. For quantitatively measuring the VS through a PA sensor, this study adapts the regression-based AI model to predict the VS of the paint samples. Due to the limitation of paint samples with actual ground truth of VS, a total of 16 samples with 12 samples for training the model and remaining 4 samples for testing are used. A residual analysis is performed to ensure that there is no overfitting to the model.

## METHODOLOGY

### A. **Theory**

In PA, the irradiation of a nano-second (ns) laser pulse results in the localized temperature excursion within the sample leading to the transient pressure rise and thermoelastic expansion. Thus, the PA source act as a strain source. Since, paint is a highly heterogeneous visco-elastic fluid, the spatial variation in pressure wave induces the PA waves of wide frequency range at the irradiation point. The wide range of frequencies in the PA waves can be attributed to the narrow time width PA signal. These waves propagate through the medium by momentum transfer and is represented by the following equation [8]:

$$\left(\nabla^2 - \frac{\rho}{k}\frac{\partial^2}{\partial t^2}\right) P(r,t) = \frac{-\beta}{C_p}\frac{\delta Q(r,t)}{\delta t} \qquad 3$$

Where P(r,t) stands for the time domain PA pressure wave, Q(r,t) denotes the laser enabled heating function, ρ is the density of the medium, β is the thermal expansion coefficient, k is the wave number and Cp is the specific heat at constant pressure for the given medium. **Equation (3)** reveals that the change in density can be observed from the time domain PA signal. Thus, (1), (2) and (3) theoretically signifies that the VS can be depicted from the time domain PA wave.

### B. **Experimental Setup**

**Figure 1** shows the photoacoustic experimental setup to measure the Volume Solids of the paint sample. The pulsed laser diode module (L-cube, 9-40/200 from Laser Components) is used for irradiating the paint samples. The laser pulse of pulse width 400ns at a peak power of 1W and beam width of 1mm is used for irradiation. The paint samples are placed in a transparent container for the laser excitation. The generated PA waves within the paint sample is propagated through the sample and acquired by the ultrasound sensor (V-303, SU from Olympus Inc.). The ultrasound sensor is placed in contact with the sample container through the coupling gel. The pulse repetition frequency of 1 kHz with a real time averaging of 200 times is applied to enhance the Signal to Noise Ratio (SNR) of the acquired PA signal. Due to the low SNR of the averaged PA signal, it is amplified through a custom built pre-amplifier at a gain of 60dB. Further, the Analog Discovery-2 (AD2) is used as a data acquisition (DAQ) system to digitize and transfer the PA signal to the computer for signal processing and analysis. Also, the AD2 is used to trigger the laser pulses and synchronize the data acquisition. For the entire set of experiments, the physical conditions, the laser power and the position of the laser and ultrasound sensor is kept fixed.

The volume solids measurement of a paint through a photoacoustic sensor is shown here. **Figure 2(a)** shows the time domain PA signal for five paint samples exhibiting different VS values. Since the amplitude of PA signal is dependent on the color of the pigment, the PA signal is normalized with respect to its peak amplitude. The identical set of containers are used for experiments and thus the temporal shift of the PA signal is due to the change in the sample's property. The paint samples used in the experiments are measured for their VS using the conventional methods. Therefore, the shift in the peak time (time corresponding to the peak amplitude) corresponding to the VS can be observed in **Figure 2(a)**.

In **Figure 2(a)**, the shift in peak time is due to the change in velocity of the PA wave propagating through the paint medium. The change in density (VS) results in the change in velocity of the PA waves. Thus, this study adapts the peak time as a feature of VS of a paint. For the clear observation, just 5 PA signals are shown in **Figure 2(a)**and not all. As discussed, a total of 16 paint samples with different VS are used in the study. 75% (12 samples) of the total samples are used to train the model and remaining 25% (4 samples) are used to test the model. **Figure 2(b)** shows the regression model with linear fitting. The accuracy (goodness of fit) of the model is obtained to be 87.8%. The following model given by (4) is used to measure the VS of the paint from the peak time of the PA signal.

$$VS = |(a * m) - b| \qquad (4)$$

Where, a and b are the slope of the regression curve and intercept respectively, and m is the peak time of the PA signal. For this study, the values of a and b are 0.285 and 288.6 respectively. Since VS is the dimensionless quantity, a & b in (4) does not possess any dimensions. The accuracy of the model can further be enhanced by increasing the sample size. Due to the limited paint samples with VS ground truth, the model is validated for its overfitting and efficiency. A four-fold cross validation is performed with 16 samples data (total dataset) and mean error is found to be approximately 10%. Further, the residual plot is shown in **Figures 2(c)** & 2**(d)**. The symmetrical distribution of the probability density function over the predicted VS shows that the model is efficient. The random distribution in **Figure 2(c)** validated no overfitting in the proposed model. **Table 1** shows the predicted VS for the four samples used for testing and the error in their measurements with respect to the ground truth.

The error is calculated using the following equation-

$$Error\ (\%) = \left|\frac{(Measured\ value - True\ value)}{True\ value}\right| \times 100 \qquad (5)$$

The error can further be mitigated through rigorous experimentation involving different types of paints with distinct values of VS. Identifying certain more features can help to enhance the accuracy of the measurements. Since, this is the first time VS is measured through some non-invasive sensing method, further investigations and studies in this direction would be very helpful for the paint shops in different industries and to the paint manufacturers.

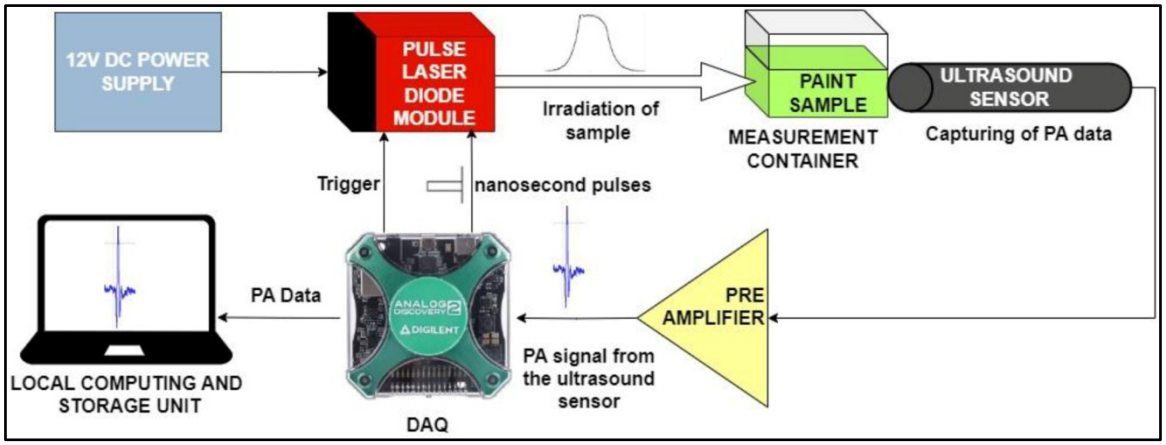


**Figure 1** Experimental setup

**Table 1** Comparison of volume solids for S1- S4 using PA sensing and conventional measurement

| Sample No. | Volume Solids (%) | | Error (%) |
|---|---|---|---|
| | *PA Sensing* | *Conventional method* | |
| S1 | 36.13 | 40.42 | 10.61 |
| S2 | 51.22 | 46.72 | 11.77 |
| S3 | 53.13 | 49.31 | 7.74 |
| S4 | 42.88 | 52.46 | 18.2 |

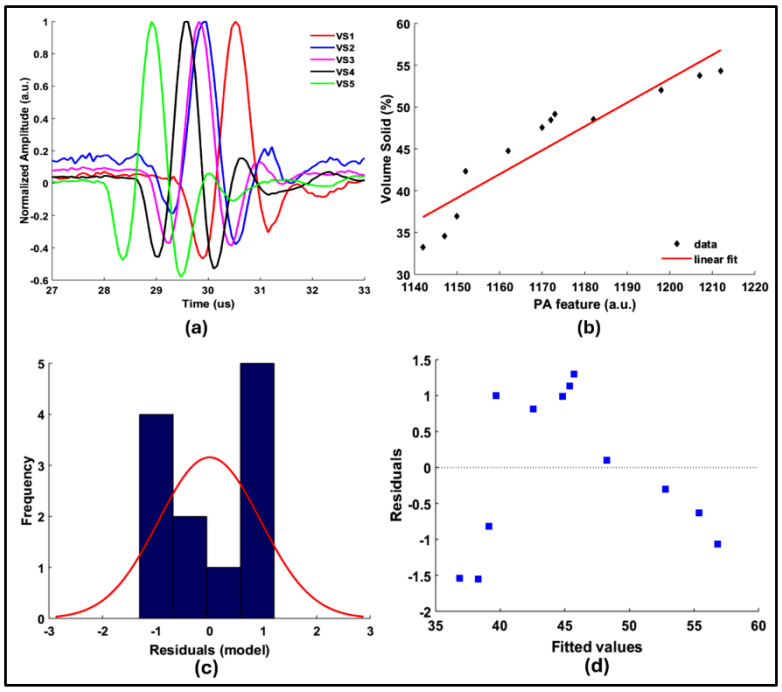


**Figure 2** (a) Time Domain PA signals for different VS paints, (b) Variation of peak time of PA signal with VS, (c) Residuals histogram, (d) Residuals scattered plot

## CONCLUSION

This study proposes a novel, non-invasive, compact and cost-effective photoacoustic sensor with AI to predict the Volume Solids of a paint. The shift in peak time of a PA signal is used as a feature to predict the VS of a paint. The regression model shows the accuracy of approximately 87.8%. Further, by enhancing the dataset and retraining the model with more relevant features the accuracy can be increased. With enhanced accuracy this sensor would be very much useful for the different industries including paint manufacturers, coil coating industries, automobile paint shops, etc. Since, VS measurement is required in different segments, this study can be further applied and tested with different liquids like cosmetic, food, etc.

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224_IEC62614

# Computerized Verification Analysis for Digitally Printed Receipts

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***Abstract:*** *Digital print-document forgery is a growing problem for both the public and private organizations. So, document image tampering is a relevant problem in terms of negative economic impact for every country or society. Document forensic science has a crucial and imperative role for this forgery detection. Though, such forensics research is quite a sensitive topic, and also work is not progressing or seen so much, as very limited and restricted datasets are available. In this scenario, it is important to resort to forensic techniques to seek and analyze inconsistencies in the document image analysis. In this study, we present a classification-based approach for forgery detection by using a conventional neural network (CNN) with a unique branch mark real dataset. Results using CNN for character based classification show that computational systems are able to detect forgeries in digitally printed documents like pay slips, pay receipts, bills, etc. Our proposed computational model got more than an 88% average accuracy rate for character level fraud detection.*

***Keywords:*** *Document Forensic Science; Conventional Neural Network (CNN); Optical Character Reorganization (OCR); Image Processing*

## INTRODUCTION

At present, the document image analyses are mostly focused on document forensic, i.e., identifying the use of different printers or scanners for a single document to detect inconsistencies [2], the analysis of the contents of images, Printed text is analyzed to find all abnormalities: characters with identical shapes [3] or irregular fonts [4], or lines that are skewed, misaligned, bigger or smaller than others [2] etc. Here, digital print documents, particularly pay slips, vouchers, etc., which are more useful in bushiness deals, are not only considered images but also experimentally considered in textual information that can be processed, analyzed, and verified. The present demand is to build a smart and sound framework to verify, analyze, or process such imagetext corpus images. Here, our aim of our work is to build a model to provide an important solution.

In literature, we have seen few works on printed document images for forensic application. Particularly on the area for automatic processing of print-document like automatic extraction of items, signature verification, recognition of date from the cheque, amount filled by the user etc. The challenging tasks concern the analysis of digital document images like print text abnormalities like identification of print fonts or shape [8] handwritten bank cheque images [10] and others OCR based application [6] .

Several researchers contributed their work in this field such as, Shanker and Rajagopalan proposed for better verification of hand printed signatures[10], Jayadevan et al. worked on hand written bank note processing[10], Ayan et al. proposed Text Recognition[7] and another work by Jayadevan et al., has worked on Recognition of Words from legal amounts of Indian bank cheques[9]. But very few studies have seen for digital pay receipts or bill verification. In Cruz.et al. and Cozzolino et al. worked this area but not exposed by updated machine learning tools like CNN[3],[4].

A genuine, real document is needed to build a sound framework for this kind of research-work. At the present time, one of the most challenging and important corpus of real images provided by L3i Laboratory, available around 2,500 documents, from December 2016 to June 2017 [1]. These are a huge number of real digital money-receipts that were from different stores or restaurants, with different fonts, sizes, pictures, barcodes, QR-codes, tables, etc. Yet, there are lots of noises due to paper type, bad print ink, folds, dirt, rips, and many other hazards for the print process. Even, the receipts are present with fake and genuine combinations. Here, **Figure 1** presents genuine and related fake images on left and right, respectively.

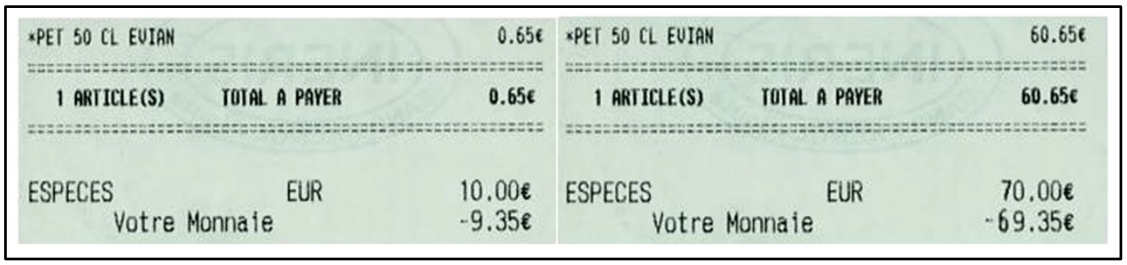


**Figure 1** Example of forgeries on prices: left image is the genuine receipt and right image is false

Here, our main focus is on the problem of detecting tampered regions from digitally printed receipt documents and aims to provide a better understanding of this forgery field. The rest of the paper is organized as follows: In Sect. 4, we describe the methodology, where every sequential process is illustrated. Then, in Sect. 5, we specify the result and their respective analysis. Finally, in Sect. 6, we draw the main conclusions of this work.

## METHODOLOGY

For our experiment, two types of scanned digital documents of pay-receipts are provided. One set of documents is a fraud document, where the fraud location is specified by /xml script, and another is a genuine document. Each receipt obtains one receipt per document. The resolution of these images is 300 dpi. Each character of the experiment document is considered for resign of interest (ROI). Next, we follow the following steps of working Procedures/Proposed approach that are depicted in **Figure 2**.

### Pre-processing

In this sub-section, model is concentrated two specified task one is noise removal and another one is to generated region of interest (ROI). Each specified character which Two different subset i.e., fraud and genuine dataset, has generated region that's considered as ROI. In these generations, we were taking help of individual information documents information provided by \xml script [1]. Total experimental character–segmented dataset prepared and compiled through OCR segmentation tools [5]. Sample of image segment and character stock image are shown in **Figure 3**.

### Data Splitting

Here, 1st step normalized all image data set be fixed image size, after than mixed up and split into three different dataset i.e. train, validation and test dataset. We have followed normal four-fold division ratio i.e. train: test: validation 2:1:1.

### Detection Phase

Architectures of our detection approaches make the explicit assumption that the inputs are character-images, which allows us to encode certain properties into the CNN-architecture [11]. These then make the forward function follow some sequential layers and structure is as the sequence:

conv2D+Maxpooling+conv2D+maxpolling+conv2d+Maxpooling+conv2D+flatterning+Dense+Dense+Dense

This is depicted on **Figure 4**.

### Decision Phase

This is the final steps of our present experiment. Here, we are tested of our test dataset by using train model that formed as compiled in sub-section II. The final prediction or percentage of accuracy is shown in this stage. If any character segment is identify fake then we assume that whole document (i.e. pay bill receipt) consider as fraud.

The task of our method aims to discovering which ones are forged. The spotting of the character based falsification in

the document (many falsifications can occur in one document). This work is also overcome many inconsistencies like disruption in fonts, localization of visual anomalies, default of texture, etc. Finally our method conclude character level accuracy rate of digital document images.

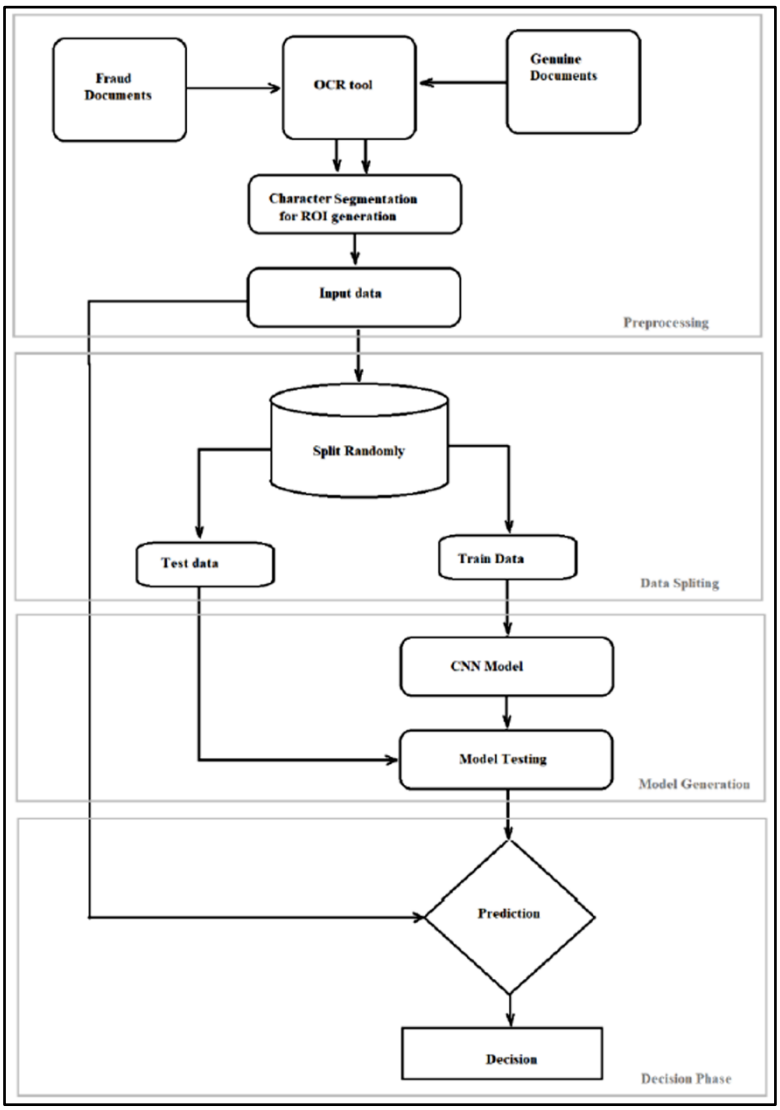


**Figure 2** Working procedures/proposed approach

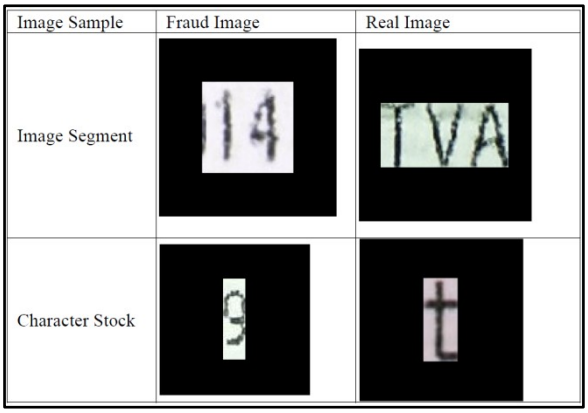


**Figure 3** Image sample of ROI segment and character stock form fraud and real sample

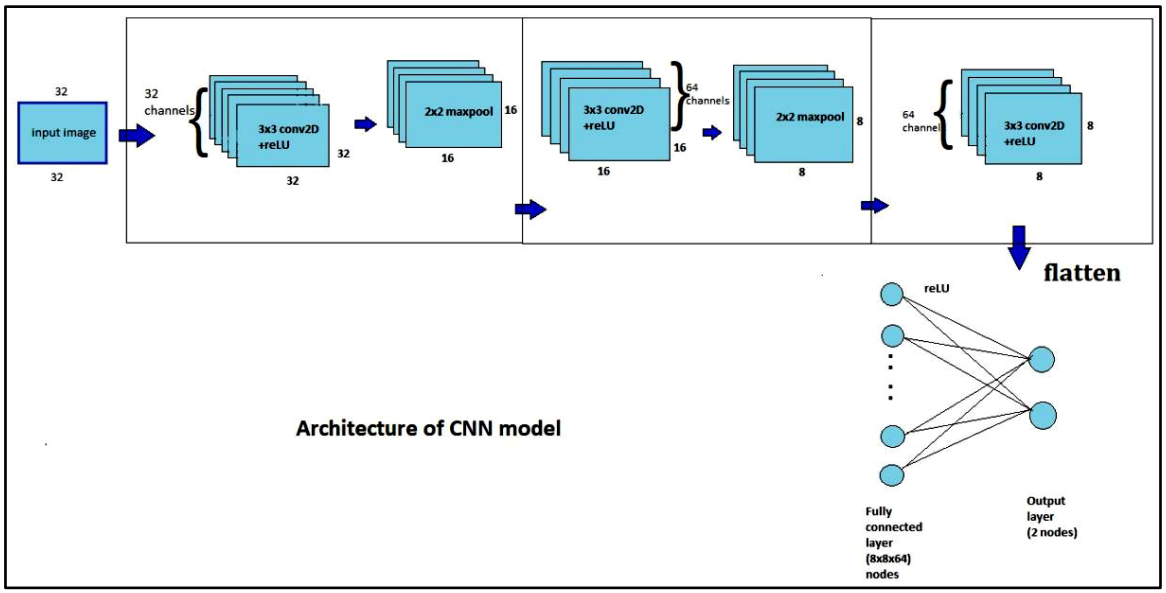


**Figure 4** Architecture of CNN model

## RESULTS

In this experiment, we considered 500 digitally captured documents with 300 dpi resolution from Li3 dataset, where 200 documents are fraud document types and 300 documents are genuine document types [1]. These Li3 datasets contain very different receipts, from different stores or restaurants, with different fonts, sizes, pictures, barcodes, QR-codes, tables, etc. So, with the help of OCR based tools and/or applying different image processing techniques, we generated 250 fraud characters and 350 genuine characters as follows pre-processing stage on previous section 4 (II). As per Section 4(III), we have split data randomly according 2:1:1 (i.e. train vs. validation vs. test) ratio. So 200 character-segment datasets were treated for train and 100 character-segment datasets were treated as validation as well as testing. As the proposed model has run four different times, so 4-time split these datasets randomly. In the training phase, min-pooling is applied for CN3 where three different CN2 layers are present.

Final stage, 64 neurons used for the input layer of ANN, where RLU is used for the activation function. In the decision phase, 100 test characters are fitted in this trained model, which gives a binary decision with the original decision as our test characters. Final output shown on **Table 1**, where four separate compilations/executions of our proposed model are specified, and it's shown 87% average accuracy. And also in **Figure 5**, the accuracy rate with respect to epochs for Run4 is plotted, indicating every epoch accuracy rate increases to reach the highest score.

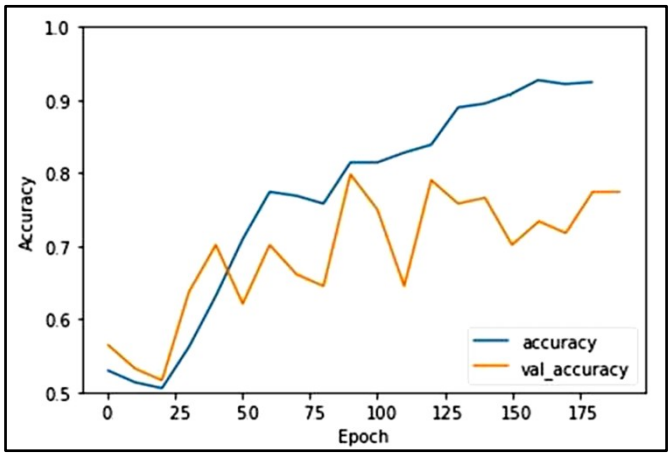


**Figure 5** Accuracy rate with respect of epochs

**Table 1** Four separate run of our proposed model to calculate average accuracy

| | Train | Test | Accuracy |
|---|---|---|---|
| Run1 | 200 | 100 | .89 |
| Run2 | 200 | 100 | .84 |
| Run3 | 200 | 100 | .86 |
| Run4 | 200 | 100 | .90 |
| Average | 200 | 100 | .8725 |

## CONCLUSION

This paper has presented a categorization of digital print documents forgeries usually present on pay slips, vouchers, bills (electric or phone) etc. This study has paid attention to different tampering processes, and that's result produces the most frequent visual clues, regarding character base texture features of that document image content. Here, we are addressing and developing automatic methods for the detection of these forgeries. This detection result helps such a document-forensic community establish certain guidelines in what refers to the categorization and targeting of this type of problem. It's also noted that document forensic work is a never ending process, every-time a forgery maker tries to introduce a new clue to make things more complex. So we believe more work is needed for multimedia forensic analyses on digital print-document images.

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243_IEC27886

# Development of Smart Helmet for Safety of Underground Mine Workers

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***Abstract:*** *Miners' safety is currently a key concern. Workers health and lifestyles are affected by a number of serious difficulties, including not just the working environment, but also its consequences. Mining processes emit hazardous and toxic fumes, putting the lives of the workers involved in the process in danger. The mining sector is under a lot of strain as a result of this. An innovative technique is essential to boost mining output and lower costs while also keeping worker safety into account. The health of miners is affected by the hazardous gases that are frequently discharged in underground mines. Human eyes are unable to recognize these gases easily. The presence of harmful gases in vital places, as well as their consequences on miners, will be investigated. A smart helmet for environmental monitoring and early warning system for mines and industrial worker safety is designed using wireless network with many sensors. This device keeps track of humidity, temperature as well as several hazardous toxins in the surrounding environment. This device additionally offers an early voice alarm warning, that will assist all employees within the underground mine in saving their lives before any fatalities happen. All Sensing devices (HTU2X, MICS CO, $NO_2$, NH3, NDIR Methne ($CH_4$), Audio Alarm and Battery) were integrated into a single Smart Helmet.*

***Keywords:*** *Mining and Safety; Arduino; Hazardous Gases; Voice Alarm; Battery*

## INTRODUCTION

In terms of worker safety and health, underground mining operations are a challenging job. Such safety risks are major concerning in the mining industry. As a consequence, worker safety should also be a top priority in any type of mines, whether it's for coal and other such minerals. Ventilation systems are essential in underground mines for supplying appropriate oxygen, maintaining non-hazardous circumstances, and maintaining a productive working underground mines. To a significant extent, mine safety and production. Using realtime position awareness, wireless sensor system has evolved to become one of the more efficient ways of developing communication channels between these industrial assets to improve overall control, visibility, and collective utilisation[1]. The mines produce dangerous CO and $CO_2$ gases, which are detected by an intelligent helmet. The miner can easily be alerted to the dangerous gas by wearing this helmet. When a miner's helmet is removed while working in the mining industry, this method can inform the worker. We use GPRS to transmit the information from the mining industry to the servers in this system. The Internet of Things (IoT) is a commonly utilised process of information communication [2]. In South Africa's coal mining industry, automation was developed with productivity, health, and safety in mind. They looked into the coal interface detection (CID) and employed two well-known ways to accomplish as such vibration analysis and natural gamma radiation. They evaluated infrared, power line carrier radio, and optical fibre communication channels for data transfer in coal mines [3]. The fundamental idea behind this intelligent helmet for coal mines is to measure the methane concentration, humidity level, and temperature of the mining environment using Zig zag wireless connection. Such information will be wirelessly transferred to the ground station through Zigbee. The miner is notified of the event by the person monitoring in the ground station via voice communication [4]. A miner's safety helmet that uses ZigBee wireless technology to monitor gas concentration, humidity, and temperature. The data collected is wirelessly transferred to the control centre through Zigbee. When the sensed data deviates from typical values, an alert is delivered via Zigbee, which involves the lighting of several LEDs and the sounding of an alarm. Coal mine workers will be required to wear safety helmets. A methane (ch4) and carbon monoxide (co) gas sensor is included in this helmet. This sensor detects gas, and the data is wirelessly communicated to the control centre via a Zigbee wireless module connected to the helmet [5].

## METHODOLOGY

### A. Hardware Development

The development of the smart wearable system (**Figure 1**) starts with the development of the sensor node. Sensor nodes consist of Microcontroller (Atmega328P) interfaced with various types of sensors for detecting environmental parameters of the industrial workers in a hazardous environment. Battery (Alkaline/Li-ion) with a voltage regulator circuit is used to power the sensor nodes. Activators like buzzers and LEDs are activated for any of the sensing parameters crossing the threshold value. In Stage I, we focus on the sensor node's development. Sensor nodes are tested and calibrated as a prototype first on a breadboard. Next, after the successful testing of the working of the sensor node and power module, we move to Stage II. In Stage II, we develop the PCB of the designed and tested circuit. After the PCB is developed, we get started with Stage III where the product is packaged. The packaging is IP68 rated [1], which means it is protected from total dust ingress and protected from long-term immersion up to a specified pressure.

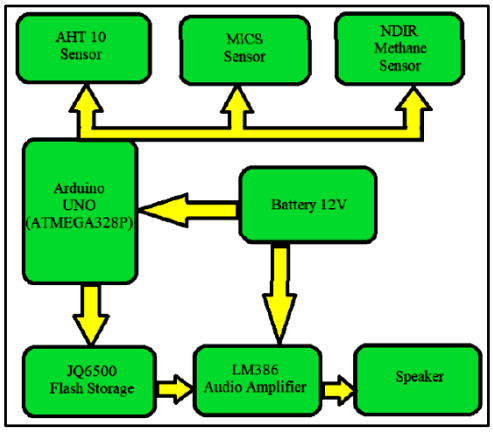


**Figure 1** Component connection flowchart

### B. Sensors used

The sensors used in the design must be industrial grade and must be able to detect conditions above the safety limit. They should have a low response time and must be able to operate in a harsh environment. They must also have a good operation cycle.

#### 1) AHT10 Temperature and Humidity Sensor

AHT10 sensor is a fast response fully calibrated temperature and humidity sensor. It has a strong anti-interference ability and provides long-term stability. The sensor information is provided in **Tables I** and **II**. The Sensor operates at a range of 1.8 to 3.6 V and AHT10 sensor, as shown in **Figure 2**.

**Table I** Humidity sensor specifications

| PARAMETERS | TECHNICAL SPECIFICATIONS |
|---|---|
| Typical accuracy (RH) | ±2 % |
| Operational range ( RH) | (0-100)% |
| Response time | 8 sec |

**Table II** Temperature sensor specifications

| PARAMETERS | TECHNICAL SPECIFICATIONS |
|---|---|
| Typical accuracy | (±0.3) °C |
| Operating range | (-40 to 100) °C |
| Response time | 5 to 30 sec |

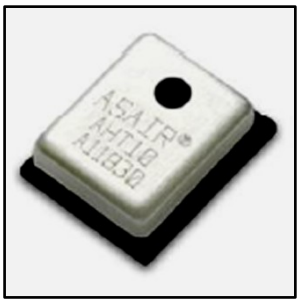


**Figure 2** AHT10 Sensor

**2) NDIR Methane (CH4) Sensor:**

A nondispersive infrared sensor (or NDIR sensor) is a simple spectroscopic sensor often used as a gas detector. It is nondispersive in the fact that no dispersive element (e.g a prism or diffraction grating as is often present in other spectrometers) is used to separate (like a monochromator) the broadband light into a narrow spectrum suitable for gas sensing. The majority of NDIR sensors use a broadband lamp source and an optical filter to select a narrow band spectral region that overlaps with the absorption region of the gas of interest. In this context narrow may be (50-300) nm bandwidth. Modern NDIR sensors may use Microelectromechanical Systems (MEMS) or mid-IR LED sources, with or without an optical filter. **Table III** gives the specification of the NDIR sensor, SJH-5. This sensor operates at 3.3 Volts and has an operating temperature of -40 to 70°C. It also has a lifespan of over 10 years and the NDIR Methane (CH4) sensor, as shown in **Figure 3**.

**Table III** Methane sensor specifications

| PARAMETERS | TECHNICAL SPECIFICATIONS |
|---|---|
| Range (volume) | (0 to 5) % |
| Accuracy (volume) | (±0.06) % |
| Resolution (volume) | (0.01) % |
| Response time | 25 sec |


**Figure 3** NDIR Methane sensor

**3) MICS Sensor**

MICS sensor is a MEMS sensor used to detect carbon monoxide, nitrogen dioxide, and ammonia. It is a heater-based sensor with 3 different sensors, one for oxidizing gas, one for reducing gas, and the third one for ammonia integrated on a single chip. The sensor information is shown in **Tables IV**, **V** and **VI** and MICS sensor, as shown in **Figure 4**.

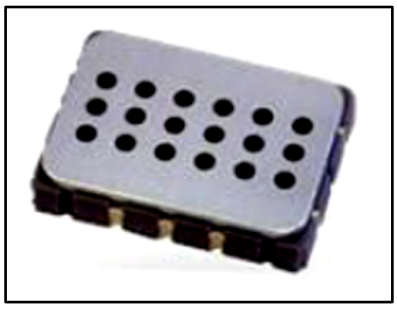

**Figure 4** AHT10 sensor

**Table IV** Nitrogen dioxide ($NO_2$) sensor specifications

| PARAMETERS | TECHNICAL SPECIFICATIONS |
|---|---|
| Sensing Resistance | (0.8 to 20) kΩ |
| Range | (0.05 to 10) ppm |
| Sensitivity | (2) % |

1) Sensing resistance in air $R_0$ is measured under controlled ambient conditions, i.e. synthetic air at (23±5)°C and (50±10)% RH for the RED sensor and synthetic air at (23±5)°C and (≤ 5)% RH for the OX sensor.
2) Sensitivity factor is defined as Rs in air divided by Rs at 60 ppm CO. Test conditions are (23±5)°C and (50±10)% RH.

**Table V** Carbon monoxide (CO) Sensor Specifications

| PARAMETERS | TECHNICAL SPECIFICATIONS |
|---|---|
| Sensing Resistance | (100 to 1500) kΩ |
| Range | (1 to 1000) ppm |
| Sensitivity | (1.2 to 50) % |

1) Sensing resistance in air $R_0$ is measured under controlled ambient conditions, i.e. synthetic air at (23±5)°C and (50±10)% RH for RED sensor and synthetic air at (23±5)°C and (≤ 5)% RH for OX sensor.
2) Sensitivity factor is defined as Rs at 0.25 ppm $NO_2$, divided by Rs in air. Test conditions are (23±5)°C and (≤ 5)% RH.

**Table VI** Ammonia sensor specifications

| PARAMETERS | TECHNICAL SPECIFICATIONS |
|---|---|
| Sensing Resistance | (10 to 1500) kΩ |
| Range | (1 to 300) ppm |
| Sensitivity | (1.5 to 15) % |

1) Sensing resistance in air $R_0$ is measured under controlled ambient conditions, i.e. synthetic air at (23±5)°C and (50±10)% RHc for RED sensor and synthetic air at (23±5)°C and (≤ 5) % RH for OX sensor.
2) Sensitivity factor is defined as Rs in air divided by Rs at 1 ppm of $NH_3$. Test conditions are (23±5)°C and (50±10)% RH.

## ALGORITHM IMPLEMENTED

In order to implement the system's operational logic, sensor readings are continuously monitored in real-time. These sensor values are then compared against predefined threshold limits, which represent the safe operating parameters within the underground mining environment. The system is designed to detect critical conditions such as the presence of toxic gases, temperature variations, or abnormal humidity levels that could pose a risk to miners' safety.

When any sensor detects a value that exceeds the established threshold as shown in **Table VII**, an immediate alert is triggered. This alert is twofold: first, an audible alarm is activated through a speaker system to ensure all personnel in the vicinity are notified. Second, a visual warning is provided via LED indicators, which serve as a backup alert mechanism, particularly useful in noisy environments or for individuals who may have hearing impairments.

The combined use of sound and light-based alerts ensures a robust warning system, increasing the likelihood that workers can quickly and efficiently evacuate the underground site before any dangerous conditions escalate. This safety protocol is crucial in preventing accidents in hazardous mining environments where early detection of threats can be the difference between life and death.

The logical flow of the implemented algorithm is illustrated in **Figure 5**. The algorithm governs the process of data acquisition from sensors, threshold comparison, and subsequent alarm activation. Additionally, the algorithm is designed with failsafe mechanisms to ensure redundancy, such that if one alert system (e.g., the speaker) fails, the other (e.g., the LED) will still function. This redundancy further enhances the reliability of the system under various

conditions.

**Table VII** Threshold levels

| PARAMETERS | THRESHOLD LEVELS |
|---|---|
| Temperature | (52) °C |
| Humidity ( RH) | (75)% |
| Methane(CH4) | (2)% volume |
| Carbon Monoxide (CO) | (100) ppm |
| Nitrogen Dioxide (NO2) | (0.5) ppm |
| Ammonia (NH3) | (25) ppm |

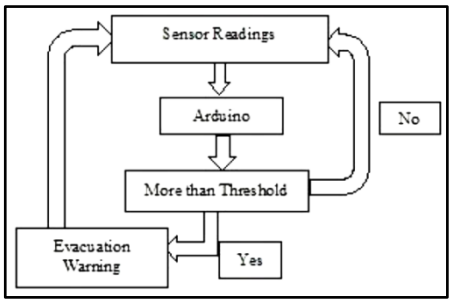


**Figure 5** Algorithm flowchart

## RESULTS

The measurements taken with the MICS and NDIR methane sensors at different reference temperatures show that these sensors work well for accurately monitoring temperature. This makes them suitable for use in industries and environmental studies. Future research should look at how these sensors perform in different environmental conditions to ensure their reliability. The laboratory prototype setup is illustrated in **Figure 6**, the front view of the prototype schematic is shown in **Figure 7**, and the final smart prototype helmet is depicted in **Figure 8**.

**Figure 6** LAB prototype

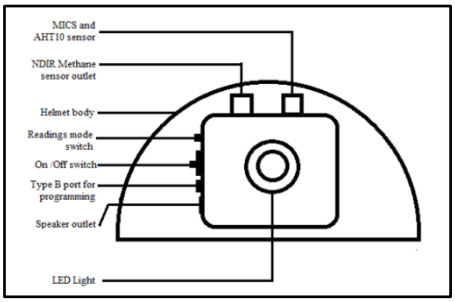


**Figure 8** Smart helmet prototype

**Figure 7** Prototype front view schematic

### A. Temperature and Humidity Sensor (AHT10) Calibration

1) Temperature is calibrated from (20-32)ºC and Humidity is calibrated from (28-95) % RH. Reference Meter used during calibration was Mastech-MS8229 as shown in **Table VIII** and **Table IX**.

**Table VIII**

| S.NO. | Reference Temperature (ºC) | Sensor Reading (°C) | Accuracy (in %) |
|---|---|---|---|
| 1 | 20.6 | 21 | 1.94 |
| 2 | 25.3 | 25 | -1.18 |
| 3 | 27.8 | 28 | 0.72 |
| 4 | 29.1 | 29 | 0.34 |
| 5 | 31.6 | 32 | 1.26 |

**Table IX**

| S.NO. | Reference Temperature (ºC) | Sensor Reading (°C) | Accuracy (in %) |
|---|---|---|---|
| 1 | 28.3 | 28 | -1.06 |
| 2 | 35.2 | 35 | -0.57 |
| 3 | 55.2 | 55 | -0.36 |
| 4 | 75.7 | 76 | 0.4 |
| 5 | 92 | 93 | 1.09 |

### B. NDIR Methane Sensor (SJH-5) Calibration

1) The calibration is performed with pure methane source in the Dept. of Mining Engineering, IIT(ISM), Dhanbad. Calibration data is shown in **Table X** below.

**Table X**

| S.NO. | Methane source (% vol | Methane sensor (peak stable data) | Accuracy (in %) |
|---|---|---|---|
| 1 | 0.53 | 0.57 | 7.54 |
| 2 | 1.03 | 1.04 | 0.97 |
| 3 | 2.45 | 2.49 | 1.63 |

## CONCLUSION

This system continuously monitor and reports hazardous gases, providing a low-cost and affordable smart helmet solution. A notable feature of this smart helmet is the integrated voice alarm system, along with LED indicators for enhanced safety. In the future, this technology can be extended to other hazardous industries, such as steel and petrochemical sectors. Additionally, the collected data can be sent to a server for monitoring and predictive analysis.

## ACKNOWLEDGMENT

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248_IEC27842

# Meijering Filter based Approach for the Identification of Papaya Seed Adulterants in Black Pepper

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***Abstract:*** *The food industry has seen a rise in fraudulent practices, necessitating the development of detection methods to reduce substantial health risks. Black pepper, widely recognized for its culinary and medicinal properties, is often subject to adulteration due to its high economic value. Unscrupulous merchants frequently add substances such as dried papaya seeds to increase their margins. This study aims to employ image processing techniques to differentiate between black pepper and papaya seeds, offering a swift, cost effective, and portable solution for the detection of adulteration in whole black pepper.*

***Keywords:*** *Black Pepper Adulteration; Image Ridge Detection; Hessian Transform; Meijering Filter*

## INTRODUCTION

The purity of a spice is compromised by the presence of elements other than the spice itself. While on many occasions these elements are often the husks or dust of the same spice, many a times they are also stones, sawdust, or dirt particles coated with toxic paints. The inclusion of husks and poor-quality seeds results in quality degradation. Lack of awareness in this regard leads to unsuspecting consumers getting tricked into believing that they are receiving the best quality for the price they are paying, while the reality is that they are being duped and often at the risk of putting their health and safety in jeopardy[8,11,12]. Black pepper (piper nigrum) is one of the most highly traded spices all over the world. They are consumed in both their whole and powdered form, and both forms have been known to be equally prone to adulteration for centuries. The dried seeds of the ripe papaya fruit are the most common adulterants here owing to their exceedingly high morphological similarities. Given a handful sample of whole black pepper mixed with papaya seeds, held at an arm's length, briefly it would be almost impossible to identify the papaya seeds, even more so when the person in question is oblivious to the presence of such impurities in the sample. The seeds of ripe black pepper vary from dark brown to black in colour, the shape resembling that of a sphere with a mostly shiny coat and polygonal undulations. In comparison, on very close observation, a dried, ripe papaya seed is elliptical in shape, has a dull brown colour and has a detailed ridge-like structure. Although these differences are microscopic and would be visible to the naked eye only on very close observation, a handheld high resolution camera would be able to capture good-quality images that would lend themselves to effective image analysis using existing image processing techniques.

This paper documents the study carried out on smart phone camera images of papaya seeds and black pepper seeds to be able to programmatically identify the presence of papaya seeds as adulterants in a sample of whole black pepper granules. There exists a plethora of published research on effective techniques for analyzing the purity of black pepper samples [3,10,13].

All the analytical methods have been proven to successfully detect the purity of the samples under test. However, a pertinent concern that applies to each of the afore mentioned techniques is their resource utilization with respect to time, money, and space. These methods involve the use of specific apparatus and instruments, which are quite expensive, require dedicated space, and cannot be moved around at will. The execution of these methods also requires trained professionals who possess the skills to handle the instruments. The processes are time-consuming and thus fail to lend themselves to real-time analysis. To add to it, the samples under test are often rendered useless owing to them being treated with different chemicals as part of sample pre-processing techniques. These observations, when merged with the fact that black pepper is such an extensively used spice in the culinary arena worldwide, thus open the door to research possibilities for the development of less resource-intensive mechanisms of spice fraud detection. This research was conducted to test the feasibility of using a smartphone camera to capture images of black pepper and

papaya seeds for analysis and subsequent classification. Various filters were applied to the images and the results compared. It was observed that the best representation of the ridges of a papaya seed was extracted by a combination of the Hessian transform, Butterworth filter, and Meijering filter. The filtered images of both black pepper and papaya seed reveal that owing to the ridge-like structure of the dried papaya seed, the average grayscale intensity of the same would be higher compared to that of black pepper. This difference in intensity then aids in determining the presence of papaya seeds in a sample of black pepper.

## METHODOLOGY

The line of research pursued to identify a tainted sample of whole black pepper is the identification of the presence of papaya seeds by highlighting their subtle morphological dissimilarities. The following optically zoomed images of a black pepper seed and a dried papaya seed have been captured by a smartphone camera, held at a height of 12 cm from the sample surface, which was illuminated by a white LED light source.

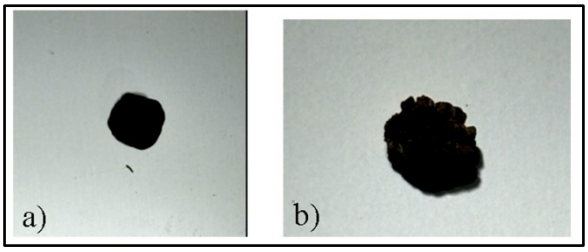


**Figure 1** Zoomed in images of a) whole black pepper b) dried seed of ripe papaya

The images indicate that a papaya seed can be predominantly demarcated from a black pepper by its ridgelike outer shell. However, it is also evident that even such closely captured images are also nearly indistinguishable to the naked eye of the observer. It is evident that an accurate pinpointing of the ridges of each papaya seed under consideration is the key to achieving the best classification of the images of pure samples of black pepper and those of adulterated ones.

A grayscale image is a two-dimensional matrix where the value of each cell denotes the intensity of the image at any pixel location. This mathematical representation of an image lends itself to a widespread array of image manipulation techniques and forms the backbone of the ever-expanding domain of image processing.

A Hessian matrix is a mathematical operation on a matrix that returns a symmetric matrix of second derivatives of each point. In image processing, this can be closely linked to the identification of edges in an image. A Hessian matrix-based approach has been successfully employed in the analysis of human retina images [4]. Drawing parallel from that, here prominence of the ridges on a papaya seed has been achieved applying the same theory. The Meijering filter [6, 7] was applied to the images in question, and the ridges of the papaya seeds were highlighted using the same. Following are the images displaying the efficacy of this filter in accentuating the finer structural characteristics of the papaya seed.

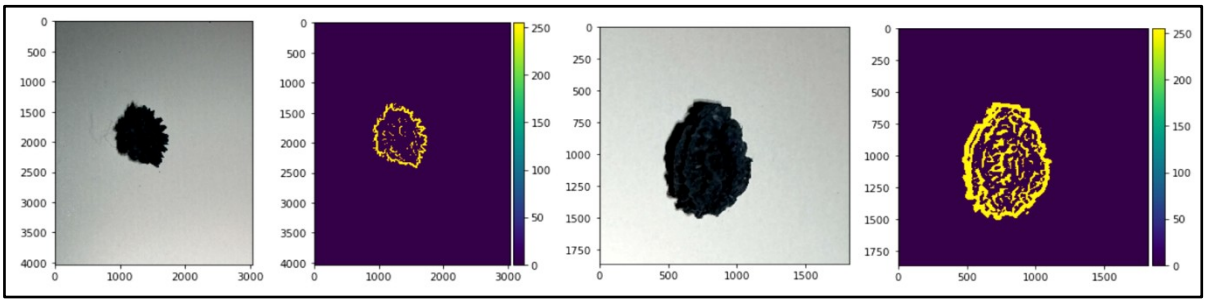

**Figure 2** Filtered images of dried papaya seeds along with the original image

The same theory was then tested on an image of a bunch of black pepper mixed with papaya seeds and the proposed method was capable in singling out the location of each papaya seed in the image.

## RESULTS

The following image depicts the result of applying the proposed algorithm to images of different adulterated samples of whole black pepper.

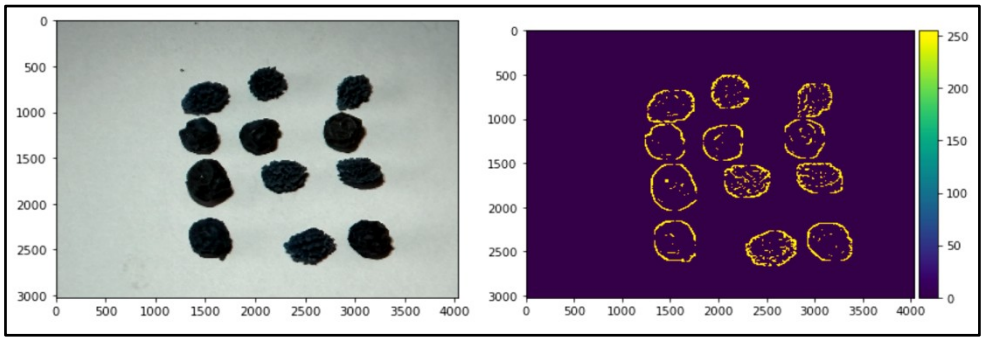

**Figure 3** Original image of black pepper sample along with the corresponding processed image

As seen in the above images , the processed image has more speckles of bright spots (marked in yellow) wherever there are papaya seeds. This implies that wherever there are papaya seeds, those localized spots would have an average brightness level greater compared to the spots where there is black pepper. These locations of increased brightness can be identified programmatically, thereby revealing the presence of the papaya seeds. A test set of 50 samples were considered in this research and in all of them, the papaya seeds could be identified wherever present.

## CONCLUSION

Food fraud is a menace that has plagued the society for ages. Widespread awareness among the masses regarding the fraudulent practices of economically motivated adulteration of spices would help consumers keep up their guard during procurement of the spices. Along with this, if the common consumer is equipped with a tool that can readily determine the quality of the spice at the time of buying it, the society can go a long way in combating the menace of food fraud that has been plaguing the society for ages. The method of detection of adulterant in a given sample of black pepper proposed here, can be gainfully employed in the development of a portable system for detecting the purity of black pepper samples. This method has the potential to be further upgraded to extract the feature vectors of papaya seed and black pepper, and subsequently use those to form a AI classification model of detecting adulteration in Black Pepper.

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252_IEC80967

# Current Trends and Technological Features of E-Textile, Smart Garments and Intelligent Apparels: An Overview

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***Abstract:*** *The rapid growth, evolution and expansion of the electronics, data science, artificial intelligence (AI), machine learning (ML) and augmented reality (AR) etc., It is obvious that such technological excellence and applications are integral part of our daily life. From morning to night, till we fall asleep, a number of electronic gadgets are inseparable components of our daily activities. And even, when we are in sleeping state, we are dependent on some electronic devices for monitoring of our different physical parameters, as and when required. Also, in the outset of the AI, Deep Learning etc, we are entering in the age, where we can trust some non-living devices to take some decisions or pattern identification on our behalf. On the other hand, the textile and clothing are one of the three basic needs of civilised human society. Apparels are integral parts of our life since the inception of the ancient human civilization, thousands and thousands of years ago. And here comes the possibility and need of the optimum unification and amalgamation of textiles and electronics and AI. It is the most desired situation where textile goods and apparels can be equipped with electronics and AI, so that consumers don't need any separate electronic device or wearables to carry with, other than his or her very own and very handy fashionable garments. In other words, the apparel which serves the purpose of covering and protecting the body, can also act as an electronic device, for performing different needs relevant to different domains like health-monitoring, measuring crucial physical parameters during sports , defence and military purpose , remote and wireless communication for security , decision makings regarding climate , temperature , toxicity etc , fashion and lifestyle requirements, and what not. Therefore, continuous improvement, cost reduction, diversification and consumerisation of E-garments, E-Textile, Smart Fabrics, AI enabled Apparels are one of the most popular and promising thrust areas of research for the past one decade or more. The objective of this review paper is to present an exhaustive overview and critical review of the current research and development along with salient technological details in this field.*

***Keywords:*** *E-Textile; Smart Garments; Artificial Intelligence; Conductive Textile; Intelligent Apparel; Smart Fabrics*

## INTRODUCTION

Electronic textiles (E-Textile), popularly known as smart textile, is one of the fastest growing fields of research and development. However, in true sense the E-Textile is a bit different from the Smart-Textile. It can be said that E-Textile is a subset of the Smart-Textile or Smart-Garments. Smart clothing generally refers to a functional garment with the ability to enable/disable a specific task such as monitoring a person's physical condition [1], whereas an E-Textile includes an additional layer of intelligence such as connection to a peripheral or embedded electronic device into the garment or fabric, delivering added value and service to the wearer. It is reported by the researchers that, the demand for usable and wearable technology is constantly growing and the projected market share of e-textiles is from 2981 Million Dollars (2022) to 8508.1 Million Dollars (2028) [2,3].

In addition to that, in this era of rapid growth in the application of AI, ML, VR, IOT etc., the intelligent apparel or intelligent fabric, i.e. the fabric equipped with certain capability of decision making, pattern recognition, self-actuation, self-regulation etc. are also the recent domains of research interest. Also, numerous approaches have been reported, in the context of producing electrically conductive fabrics, including metallized textiles, conductive polymer-based textiles, and composite nanoparticle coatings, for e-textiles. Among such fabrics is nanocarbon-based conductive textiles. The integration of graphene, carbon nanotubes (CNTs), and carbon nano/micro fibers (CNFs) with textiles are gaining popularity [4-9].

The prime objective of this review paper is to explore and present the recent trends and developments, with a critical

analysis of the future scope and potential in this domain.

## REVIEW OF LITERATURE

### Clothing as Wearable Computers

Textile fabrics are flexible in nature and wear-friendly. Therefore, it has certain advantages to be used as the basic structure for developing wearable computational circuit. As the clothing materials have mechanical, aesthetic, and material advantages, and it is one of the three basic needs of the civilised human being, therefore integration of electrotonic circuits with or within the clothing materials have tremendous advantage, compared to other non-textile wearables [10,11].

### Application in Defence and Military Application

Electronic textile research includes the development of integrated sensor arrays and various embedded sensing technologies for deployment in clothing, backpacks, tents, or vehicles. Biofeedback system inbuild in the smart uniforms of the soldiers, which can track and monitor a soldier's vital signs to enhance endurance and overall health [10,12]. Also, sensing of the surrounding environmental can detect enemies or potential biochemical threats. For example, in this context, a woven conductive fabric equipped with button-size microphones which can detect the sound of remote objects such as approaching vehicles [13]. By comparing and analysing the received sounds from each microphone, a microcontroller can algorithmically identify the location, distance and speed of the approaching sound [10]. Also, the research paper by Sumedh Joshi and Malhar Jojare provides a fair understanding about application of wireless data transfer technology such as artificial intelligence and Internet of Things in the Air-Force and the Naval force sectors (**Figure 1**) [14].

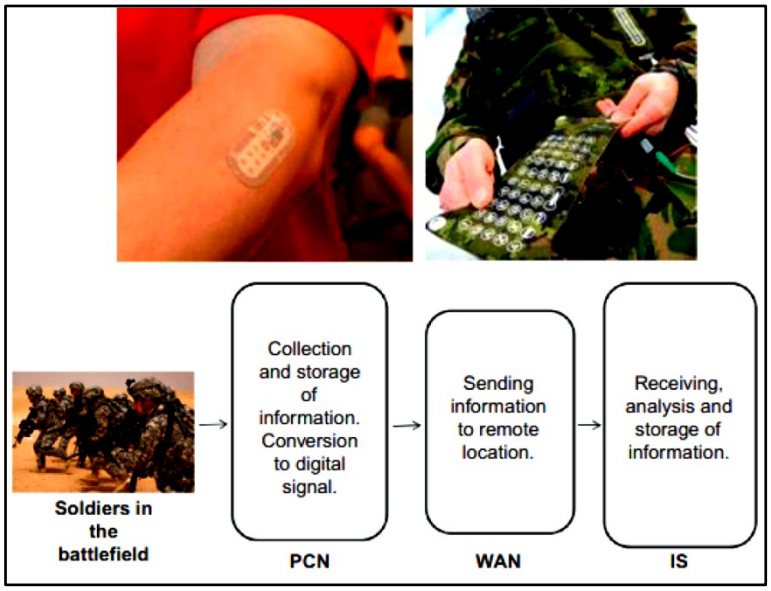


**Figure 1** Military uniform with wearable computer and keyboard, along-with three areas of communication devices for military applications[14]

### Application in Health-Monitoring and Medical-Textile

As the research suggests, the IOT-enabled electronic textile can be effectively used to monitor, analyse and transmit crucial cardiovascular data along with other health related parameters, to ensure preventive actions for potential health problems. So far as the commercial application is concerned, companies such as Body-Media already offer wearable products to collect, store, process, and present physiological and lifestyle information such as calories burned, personal activity levels, and sleep states [15]. Also, another commercially available brand FitSense focuses specially on performance monitoring systems for runners and walkers that provide instant statistical data on speed,

distance, and heart rate [10,16]. Furthermore, VivoMetrics produces the Life-Shirt vest equipped with embedded electrodes for heart monitoring. It has three conductive bands that measure the movement of the heart and lungs, based upon sensing the changes in their magnetic fields [17]. The Smart-Shirt System developed by Sensatex has developed proprietary interconnection technology to enable sensing, monitoring, and information processing devices to be networked together within a fabric. Described as "the shirt that thinks," the SmartShirt measures and/or monitors individual biometric data—such as heart rate, respiration rate, body temperature and caloric burn—and provides readouts via a wristwatch, personal digital assistant (PDA), or voice synthesis. Also, the biometric information is wirelessly transmitted to a personal device (**Figure 2**) [18].

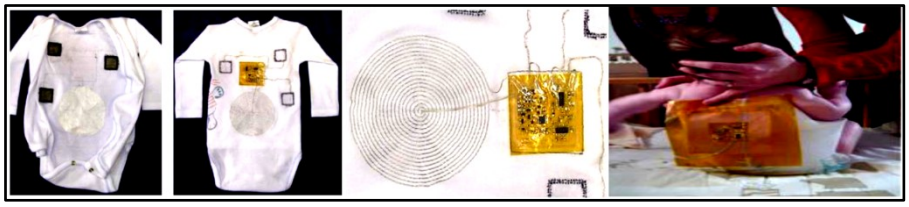

**Figure 2** Baby suit prototype. Left: inside showing the Textrodes; right: backside, Detail of the backside of the baby suit, showing the embroidered coil and the flexprint, Demo set-up with belt prototype, worn by a 12 weeks old baby [18]

**IOT-based Connectivity and Surveillance**

In the domain of location tracking and surveillance, the electronic textile can play a very significant role. In this regard, Philips Smart Connections has developed a range of prototype garments where modern communication technologies such as mobile phone network and GPS (global positioning system) devices are embedded into clothing materials. Such technology can be very effective to protect children, as the parents can track their locations and even communicate with them [10,19]. Textiles integrated with electronic sensory devices driven by global positioning system can detect one's exact location anytime and in any weather. Fabric area networks (FANs) equipped with the electronic devices, are capable to exchange required information, power and control signals within the user's personal space and remote locations [20][21].

**AI enabled E-Textiles**

The integration of industry 4.0 elements like AI, AR, IOT etc. with the electronic textile refers to an entirely new domain of modern smart clothing with a huge leap in technology level. It's reported by the researchers that neuromorphic computing (crossbar analysis, memristors, stacked and layered design-based approaches) and key architectural properties of SNN (artificial neurons and synapses) can be applied across to drive emerging innovations in the e-textiles domain (**Figure 3**) [22].

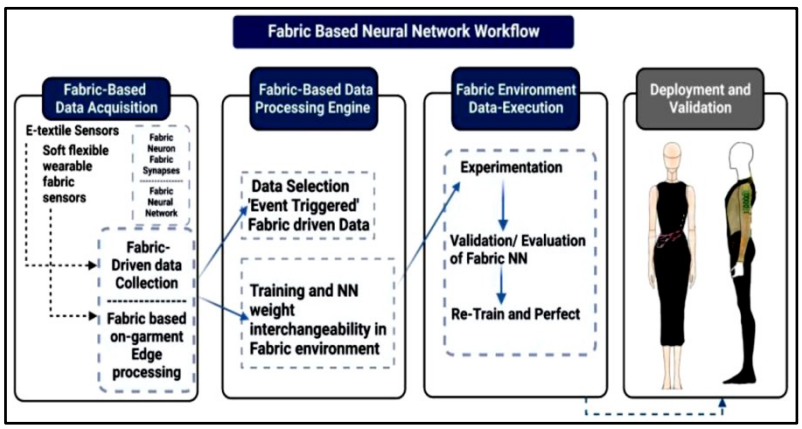


**Figure 3** Schematic diagram of the workflow in Fabric based Neural Network [22]

**Application of E-Textile in Sports Activities**

Aim of this sub-segment is to highlight features and application of E-textile in sportswear: - The intelligent Textiles with the objective to improve performance of sports person and personal comfort, plays a crucial role. For example, am intelligent sock with a foot pressure sensor and measurement technology for walking-distance measurement, which can be used to measure the physiological performance of the sports person. The collected and measured data can be transmitted wirelessly to a remote receiver device like Smartphone. Likewise, a sports person can wear intelligent bands, jackets, caps to continuously monitor crucial physical parameters like pulse rate, blood pressure, body temperature, fatigue level etc. The necessary data can be sent to remote location through IOT architecture, where it can be analysed and may be used to enhance the performance of the sports person. Similar types of devices can be used by sky divers, swimmers or other sports persons to monitor, analyze and improve their performance [21,23].

**Application of E-Textile in Fashion and Lifestyle**

There are intelligent dresses and sleep suit which emits scents depending on the mood and requirement of the wearer. Intelligent fibers are being developed that can change colour and its shape as per the commands of the wearers. The conductive fibers could change colour on command from an electric signal that alters the reflective quality of this special fiber. Thereby increasing function as well as fashion. Intelligent Textile with thermoregulation properties are also being developed. There are also interactive fibers which incorporates electronics that are activated by a power source [21,24].

**Energy Harvesting and Storage**

The most crucial hurdle in this direction is to ensure suitable and inbuild power sources for e-textiles. Also, in today's world several electronic gadgets are integral part of our daily lives. Therefore, to ensure sustainable and continuous supply of electrical energy even in the remote locations, it is required to explore some non-conventional, renewable and continuous source of electrical energy, apart from the conventional sources. For example, smart-garments, e-textile, automatic health monitoring devices, smart watches, cell phones, tabs etc. require continuous supply of electrical energy. In this context, another ancillary research-domain of e-textile is in the domain of generating the electrical energy utilizing the metabolic heat and the natural movements of the human body [25]. As, reported by Stephen Ornes, the scientists in South Korea have developed a flexible, foldable and wearable fabric-system that generates electricity during its movements like bending and flexing (**Figure 4**) .

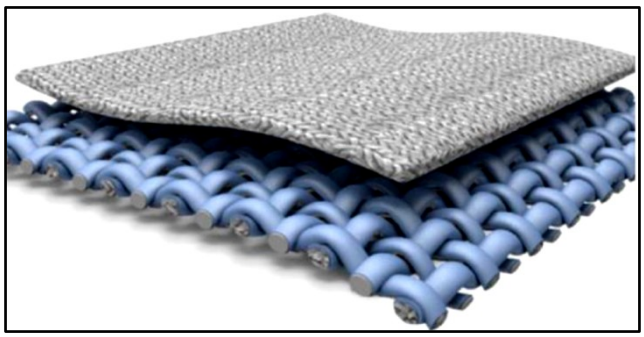

**Figure 4** New fabric material developed by physicists in South Korea generates electricity during its movement [25,26]

**SUMMARY AND CONCLUSIONS**

The unification of electronics and textiles has indeed initiated a paradigm shift, so far as the application of modern technology in daily life is concerned. The data communication and digital technology coupled with the unique properties and flexibility of textile materials has started creating the wonders. Such E-textiles can be effectively applied for sensing, computing, actuating, and communicating. Electronic sensors and other hardware can be

incorporated with apparel, and a wearable system can lead to more adaptable, user-friendly and multidimensional application. Starting from automatic health monitoring or application in defence related domains, up to the intelligent garments with autoregulation and auto-adaptation to external atmospheric conditions, the potential is enormous. Also, it is gaining immense popularity in the sportswear domain, so far as the physiological monitoring of the sportsperson is concerned. Furthermore, the role of E-garments in the energy harvesting, and generation of sustainable and non-conventional energy is very promising and encouraging. In addition to that, the garments enabled with AI elements and algorithms is also a popular subject of modern research and developments. Though the recent advances in e-textiles have been phenomenal, it still faces some serious shortcomings. It has still more steps to go to standardize and prepare consumer-friendly, affordable and easily available equipment and sensors for e-textile application. In addition, the e-textile systems are not washable or waterproof nor weather-resistant. Also, the concerns regarding the toxicity of the nanomaterials used in certain smart fabrics are prevalent.

So, it can be said that, still it is required to overcome several hurdles in the field of intelligent textile. High production costs, the absence of standardized operating processes, and limitations in the efficiency of energy harvesting and communication technologies, unavailability of suitable gateways, sensor and actuators, data analytics etc continue to hinder its widespread application. The development of more durable, flexible, and cost-effective materials and device structures is still needed. Additionally, the miniaturization i.e. size reduction of components and improvements in power utilization systems must be achieved to fully realize the potential of e-textiles in future. Therefore, The use of standardized manufacturing techniques to produce textile-based sensors, or sensors which are compatible to flexible textile goods, energy harvesting devices, and other smart electronics as well as techniques that allow for easy integration and compatible amalgamation and synchronization with wearable garments to unleash mass-market potential, are the main thrust area of research in this domain.

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# A Novel Lightweight Cryptographic Protocol for Smart Home IoT Security using CoAP

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***Abstract***: *A smart environment seeks to improve human existence by boosting efficiency and simplicity. These days, most computer networks have IoT tools, and the IoT paradigm has developed into a critical technology for building smart. However, IoT devices are vulnerable to cyber-attacks during this transition. Consequently, security and privacy are major concerns in real-world smart home applications. This manuscript aims to propose the Broken-Stick Regressive Lightweight Speck Ephemeral Cryptography-based Constrained Application Protocol (BRLSC-CoAP) to enhance data security in smart home environments while minimizing computational costs. IoT devices collect real-time data and transmit it to authorized users. To secure this process, BRLSC-CoAP incorporates registration, encryption, authentication, and decryption steps. A lightweight Speck ephemeral cryptography algorithm is used for encryption, and Forbes indexive Broken-stick regression ensures user authentication. The experimental results show that BRLSC-CoAP outperforms conventional methods by improving authentication accuracy, precision, and confidentiality, while reducing computational cost, delay, and overhead.*

***Keywords:*** *Smart Home; Constrained Application Protocol (CoAP); Data Security; Lightweight Speck Ephemeral Cryptography; Authentication; Forbes Indexive Broken-Stick Regression*

## INTRODUCTION

The Internet of Things (IoT) is recognized as a disruptive force with a significant impact on daily life, particularly in smart homes and similar environments. IoT devices are connected to the Internet to collect and exchange information. With advances in communication technologies, smart homes have emerged as a promising IoT paradigm, where devices like smart screens can be controlled remotely from anywhere, at any time. In these smart home environments, users benefit from advanced functionalities and high levels of service aimed at improving their quality of life. Traditional techniques, such as lightweight encryption, cryptography methods, and mutual authentication, have been used for data transmission in IoT devices, but they introduce numerous security risks and efficiency issues. Attackers can intercept communications between devices and users, making the data gathered by these smart devices vulnerable to compromise. Malicious actors may gain access to sensitive user data, including daily behavior patterns, for illicit purposes.

A secure authentication system based on smart cards was introduced in [9] to protect home IoT networks. However, it struggled with minimizing overhead within the secure authentication system. Additionally, a gateway-based two-factor authentication scheme developed in [10] aimed to enhance the safety of IoT device management. Nevertheless, it fell short in finding a more secure and effective framework for IoT organization. To address the shortcomings of existing methods, a novel protocol, BRLSC-CoAP, has been introduced with the following key contributions:

- Enhanced Data Communication Safety
- Enhanced Attack Detection Accuracy
- Increased Data Confidentiality
- Performance Comparison
- Experimental Assessment

## RELATED WORK

To successfully defend against insider threats, a provably secure authentication technique was established for smart

home environments in [11]. This method, which made use of the Real or Random model, also decreased storage expenses. It was discovered, therefore, to be ineffective when managing a high volume of users. In [12], a security system was designed that included a gateway board, nodes, and application modules. Meanwhile, [13] developed a multi-tiered artificial neural network (ANN) model for accurately detecting security attacks. This model optimized hyperparameters to reduce overhead but incurred high computational costs. In order to reduce computation and communication costs, a threshold- and password-based mutual authentication system was devised for smart homes in [14]. To withstand offline attacks, this protocol used a bilinear map and a secret sharing method, and an on-the-fly model checker was used for verification. It failed to accomplish mutual authentication, though. **Table 1** provides the summary of related work.

**Table 1** Comparison of related

| Method | Contribution | Merits | Demerits |
|---|---|---|---|
| Lightweight Mutual Authentication Scheme | Introduced a lightweight mutual authentication scheme tailored for smart home surveillance systems. | Efficient and secure authentication for smart homes | Potential scalability issues |
| Two-Factor Authentication using ECC | Developed a robust two-factor authentication scheme using ECC for smart home IoT environments. | Enhanced security with two-factor authentication | Complexity in implementation |
| Anomalous behavior detection | Proposed an approach for authenticating users based on detecting anomalous behavior in smart home systems. | Detects unusual behavior for enhanced security | False positives may occur |
| Three-Factor Authentication | Designed a three-factor authentication scheme that preserves privacy for IoT-enabled smart homes. | High privacy and security | Increased computational overhead |
| ECC-based CoAP | Integrated ECC with CoAP to enhance security in IoT communications. | Strong security with ECC | Resource-intensive |
| PUF-based Authentication | Introduced a secure and anonymous user authentication scheme using PUF for IoT-enabled smart homes. | High security and anonymity | Hardware dependency |
| ECC and deep LSTM for malware detection | Enhanced IoT device security by combining ECC with deep LSTM for malware detection. | Improved security and malware detection | High computational cost |
| Lightweight Authentication Scheme | Proposed a lightweight authentication scheme specifically for smart home IoT devices. | Efficient and lightweight | Limited to specific IoT devices |
| Secure Authentication Scheme | Developed a secure authentication scheme for IoT applications in smart homes. | Robust security for smart homes | Implementation complexity |
| Secure User Authentication | Created a secure user authentication scheme for rapid management of smart home IoT devices. | Fast and secure authentication | Potential vulnerabilities in rapid deployment |

## PROPOSED METHODOLOGY

This section details the BRLSC-CoAP design for smart home applications. BRLSC-CoAP, which employs Broken-Stick Regressive Lightweight Speck Ephemeral Cryptography, restricts access to the smart home network to authorized devices. It also facilitates key generation, encryption, authentication, and decryption to enhance security. The BRLSC-CoAP's structural design for secure data exchange in smart home contexts is depicted in **Figure 1**.

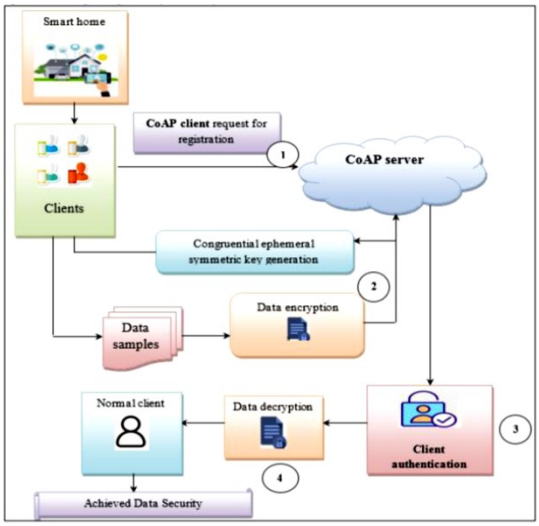


**Figure 1** Architecture of proposed system

The algorithmic sequences are as follows

**Algorithm :BRLSC-CoAP**

**Input:** Number of CoAP Client $CL_1, CL_2, CL_3, \ldots . CL_n$, CoAP server '$CS$', Data $PD_i = PD_1, PD_2, \ldots PD_m$
**Output:** Enhance the security

**Begin**
\\ **Registration phase**
**For each client** $CL_i$
$CS$ ask to enter the details
$CL_i$ enters their details and submit to '$CS$'
$CS$ send successfully registered message to $CL_i$
$CS$ generates Symmetric key '$SK$'
**End for**
\\ **Encryption**
**For each** registered client $CL_i$
**Perform data encryption**
Partition data into $PD_l$ and $PD_r$
Encrypt the data using symmetric key using (8) (9)
Send Ciphertext '$C_l$' and '$C_r$' to $CS$
**End for**
\\ **Authentication**
**For each** registered client $CL_i$
$CS$ Verifies the authenticity using (9)
**If** $(FI = 1)$ **then**
Normal client '$NC$'
**else**
Anomalous or attack
**End if**
**End for**
\\ **Decryption**
**For each** normal client $NC$'
$CS$ allows to decrypt the data
$NC$' Obtain the original data using (13)
**End for**
**End**

The procedures to improve information transmission security in a smart home setting are outlined in Algorithm . The first step in the procedure is user registration, where each registered user has their congruential ephemeral symmetric key generated. These keys are then used by the encryption process to transform the original data into ciphertext. The server receives this ciphertext after that. The Forbes Index is used by the server to confirm a client's identity before granting access to the smart home data upon request. The regression function categorizes the client as normal if the keys match. If not, a DoS attack or anomaly flag is raised against the client. Lastly, the server ensures improved anonymity in data connection by allowing data decryption only for clients categorized as normal.

## COMPARATIVE PERFORMANCE ANALYSIS

Execution result examination of BRLSC-CoAP and LMAS-SHS [1] and Solid two-factor confirmation plot [2] are analyzed through remarkable estimations.An exploratory assessment of BRLSC-CoAP, LMAS-SHS [1], and the Good Two-Part Check Plan [2] was driven. The tests were performed using Python on a structure with Windows 10 working framework, 8GB RAM, a 1TB Hard Disk and a web protocol,

For the analysis, the DS2OS traffic follows dataset was utilized, accessible at https://www.kaggle.com/datasets/francoisxa/ds2ostraffictraces. This dataset incorporates follows gathered from IoT locales furnished with light regulators, thermometers, and different gadgets, each having various associations and administration counts. It was explicitly made for assessing abnormality identification calculations. The dataset is 5 MB in size and highlights 13 credits with 357,952 information tests acquired from essential reproduction access follows. Key ascribes incorporate source ID, source address, objective location, and objective sort. For the examination, information tests of shifting sizes — 10,000, 20,000, 30,000, up to 100,000 — were separated.

Performance Metrics: Using both suggested and current methodologies, the experiment measures a number of

metrics, such as accuracy, computation cost, and data secrecy. Ten rounds are used to test each parameter for both the suggested and the current approaches. Following figures depict the comparison of Performance metrics.

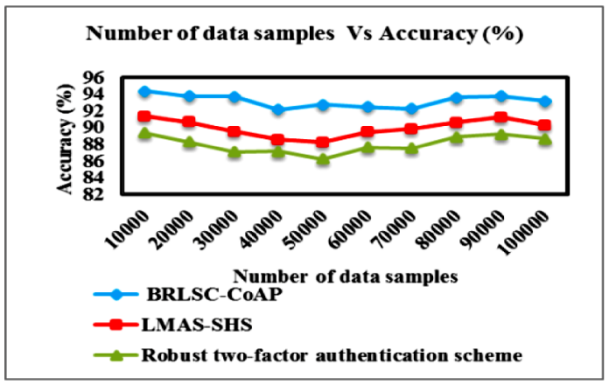


**Figure 2** Performance analysis of accuracy

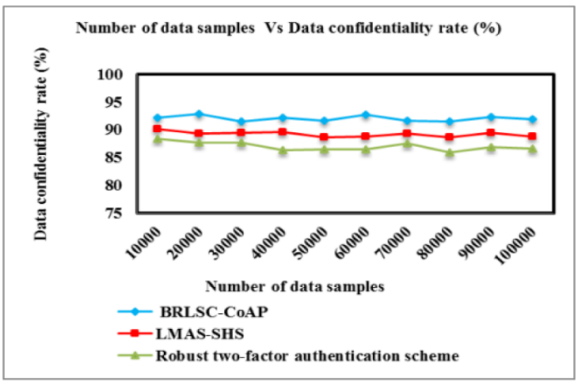


**Figure 3** Performance analysis of data confidentiality rate

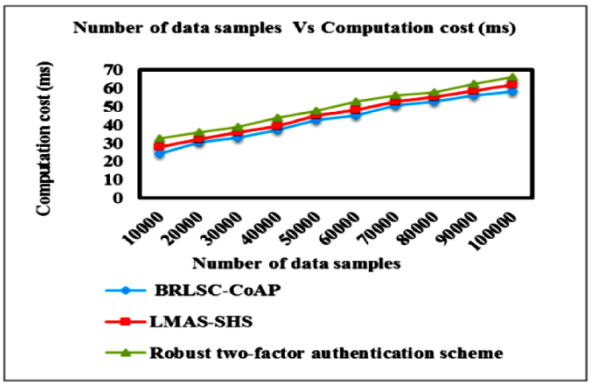


**Figure 4** Performance analysis of computational cost

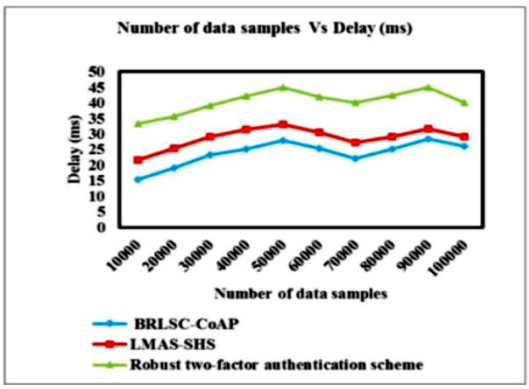


**Figure 5** Performance analysis of delay

## CONCLUSION

Smart home technologies, while convenient, pose significant security and privacy risks due to IoT's openness. This study introduces BRLSC-CoAP as a solution, combining CoAP with Lightweight Speck ephemeral cryptography for secure data delivery. Forbes Indexive Broken-Stick Regression enhances data secrecy, while linear congruential ephemeral encryption securely stores sensitive data. BRLSC-CoAP handles key generation, encryption, authentication, and decryption efficiently. Experiments show BRLSC-CoAP reduces calculation costs by 10%, time by 30%, and overhead by 29%, with 5% improvements in accuracy, precision, and confidentiality. Future work will explore new cryptographic methods and metrics like recall and F-measure.

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262_IEC61857

# Enhancing Security in User Authentication: A Hybrid Approach using Biometric and Behavioral Analysis

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***Abstract:*** *A cyber threats continue to evolve. The traditional password-based and two-factor authentication (2FA) are becoming more apparent. This paper presents a hybrid authentication framework that integrates the Convolutional Neural Networks(CNN) for biometric verification with Long Short-Term Memory(LSTM) networks for behavioral analysis. The system is designed to function effectively with or without 2FA, providing flexible and adaptive security for a variety of applications such as social media, online banking etc. The CNN handles biometric inputs such as facial recognition and fingerprint scans etc, while the LSTM analyses user behavior-such as typing speed and mouse movements etc- to detect anomalies. If an anomaly is identified, the system can block the potential attacker or request further verification. The framework ensures that legitimate users can access their accounts through an additional biometric check, even if traditional security methods fail. This paper outlines the architecture, potential applications and future research directions for implementing this hybrid model in real-world scenarios.*

***Keywords:*** *Hybrid Authentication; Biometric Security; Behavioral Analysis; Convolutional Neural Networks (CNN); Long Short Term Memory (LSTM); Anomaly Detection*

## INTRODUCTION

In an era marked by the rising frequency and complexity of cyber threats, the need for strong authentication methods has become more critical than ever. Traditional password based system are increasingly susceptible to breaches, and while two factor authentication (2FA) offers improved security. It is not immune to attack. Hackers have devised methods susch as SIM swapping and phishing to circumvent 2FA, putting user accounts at risk of unauthorized access.

To address these security challenges, this paper proposes a hybrid authentication system that integrates biometric data with behavioral analysis to offer enhanced security. The system employs Convolutional Neural Networks (CNN) for processing biometric inputs, such as facial recognition and fingerprints etc, while Long Short Term Memory (LSTM) networks analyse user behavior, including typing dynamics and mouse movements. This dual layer approach allows the system to detect anomalies that may indicate an unauthorized access attempt, even if the attacker has bypassed conventional authentication methods.Moreover, the system is designed to function independently of 2FA providing flexibility across different applications.

## LITERATURE REVIEW

The field of authentication has undergone significant advancements in the recent years, driven by the need for more secure systems. Traditional password based authentication has been criticized for its vulnerability to various forms of attacks. leading to exploration of more secure alternatives.

### Biometric Authentication

Biometric authentication utilizes the distinct physical or behavioral traits of individuals for identity verification. Convolutional Neural Networks (CNNs) have become widely used in this field for their ability to accurately recognize and classify patterns within biometric data. LeCun et al. (1998) demonstrated the potential of CNNs in image processing for facial recognition and fingerprint verification, laying the groundwork for contemporary biometric systems.

**Behavioral Authentication**

Behavioral biometrics, on other hand, focus on analysing the user behavior to establish identity. Techniques such as keystroke dynamics and mouse movements etc, have been employed for this purpose. Research by Sultana and Anwar (2021) suggests that behavioral patterns can effectively differentiate between legitimate users and impostors, even in the absence of biometric data.

**Integration of Biometric and Behavioral Authentication**

Although both biometric and behavioral authentication have seen substantial advancements, research has predominantly focused on each as separate systems. The potential for integrating these two approaches remains largely untapped. This paper seeks to address this by proposing a novel hybrid model that combines strengths of Convolutional Neural Networks (CNNs) for processing biometric data with Long Short--Term Memory (LSTM) networks for analysing behavioral patterns. By merging these techniques, the proposed system offers a more robust and comprehensive authentication solutions that leverages both physical and behavioral traits for enhanced security.

## METHODOLOGY

**System Overview**

The proposed hybrid authentication system consists of two main components:

- Biometric Authentication using CNN: This module captures biometric data, processes it using a CNN and authenticates users based on stored profiles.
- Behavioral Authentication using LSTM: This module monitors user behavior during login attempts and identifies any deviations from established patterns.

**Biometric Authentication (CNN)**

The biometric component processes data from cameras or fingerprint scanners. The CNN architecture includes the several convolutional layers for the feature extraction, followed by fully connected layers for classification. If the biometric input matches stored profile. The user is authenticated otherwise, they are flagged for further verification.

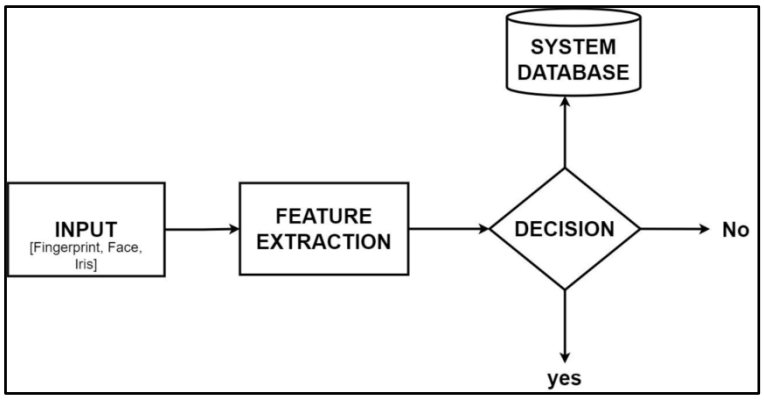


**Figure 1** Biometric authentication flow with CNN

**Behavioral Authentication (LSTM)**

The behavioral component analyses the dynamic of patterns during user login attempts. The LSTM network processes the sequences of user actions, such as typing rhythm and mouse movement patterns etc. The model is trained on historical data, enabling it to recognize typical user behavior and detect anomalies that may indicate unauthorized access.

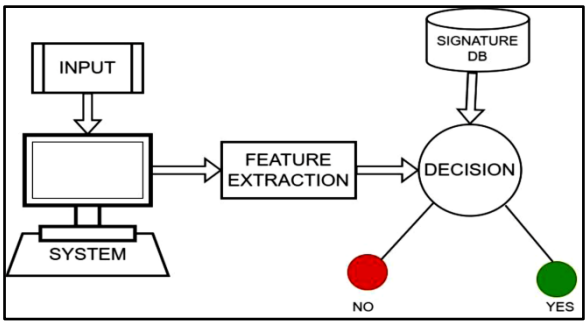


**Figure 2** Behavioral authentication flow with LSTM

**Anomaly Detection and Response**

Upon login, both CNN and LSTM modules operate in tandem. If either module detects an inconsistency. The system will

- Block access and notify the account owner.
- Request further biometric verification.
- Grant limited access based on predefined security protocols until the anomaly is resolved.

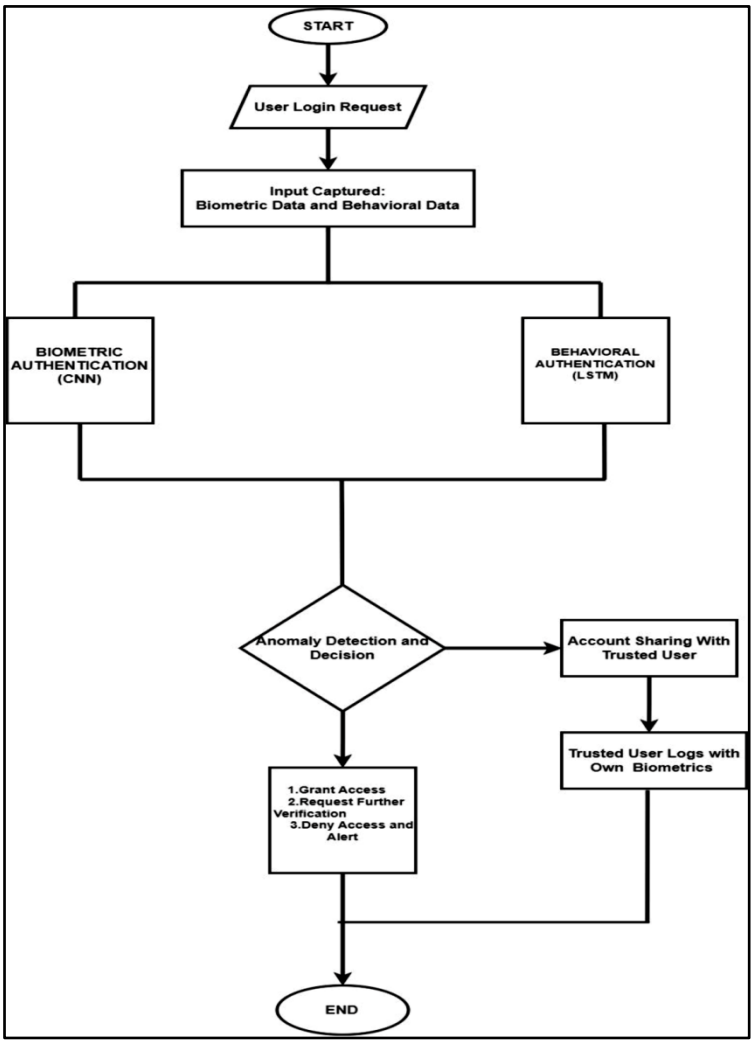


**Figure 3** Hybrid approach for user authentication

To facilitate the secure sharing of accounts, The system allows the account owner to grant access to trusted users through biometric verification. This approach ensures that even if passwords or tokens are compromised, access is limited to those who can provide the correct biometric data.

User Login Request (Start)

- Action: The user initiates a login request on the platform.
- Input Captured: The system captures both biometric data (e.g., fingerprint, face, iris) and behavioral data (e.g., typing speed, mouse movement).

Biometric Authentication (CNN)

- Input: Biometric data such as fingerprint, face, or iris.
- Action: A Convolutional Neural Network (CNN) processes the biometric input. The CNN extracts features from the data and compares it with the stored information in the database.
- Decision:
  - Match: The biometric data matches the stored records.
  - No Match: The biometric data does not match.

Behavioral Authentication (LSTM)

- Input: Behavioral data such as typing speed, mouse movement, etc.
- Action: An LSTM--based model processes the sequential behavioral data. The LSTM analyzes the pattern against the stored behavioral profile of the user.
- Decision:
  - No Anomaly: The behavioral data is consistent with the user's previous behavior.
  - Anomaly Detected: The behavior is unusual and could indicate potential fraud or an unauthorized user.

Anomaly Detection and Decision

- Input: Results from both the biometric (CNN) and behavioral (LSTM) authentication processes.
- Decision:
  - Grant Access: If both biometric and behavioral data match (no anomaly detected), the system grants access to the user.
  - Further Verification Needed: If one of the checks (either biometric or behavioral) fails, the system prompts the user for additional verification (e.g., 2FA, secret code).
  - Deny Access: If both biometric and behavioral checks fail, the system denies access and alerts the account owner of a potential breach.

Account Sharing with Trusted User

- Action: If the account owner wants to grant access to a trusted user, they share their biometric data with the system. The trusted user logs in using their own biometric data.
- Decision:
  - If the trusted user's biometric data matches the shared data, the system grants access.
  - If there is no match, access is denied.

End

- Action: The system either grants or denies access to the user, based on the authentication and verification results.

**Figure 1** showcases a hybrid approach to user authentication, combining biometric (CNN--based) and behavioral (LSTM--based) methods. The biometric authentication extracts features from fingerprint, face, or iris data. while the behavioral model analyses time--series data like typing speed or mouse movement etc. If both authentications are

successful, the system grants access. If one fails, further verification (like 2FA) is required. If both fails access is denied and the account owner is alerted.

## CONCLUSION

This paper presents a hybrid authentication system that effectively combines biometric authentication using Convolutional Neural Networks (CNN) and behavioral authentication using Long Short--Term Memory (LSTM) networks. The proposed system offers enhanced security across various applications by functioning independently of traditional methods such as two--factor authentication (2FA). By integrating biometric and behavioral data, the system can detect anomalies that may indicate unauthorized access, thereby providing a robust layer of protection. Future research will focus on the practical implementation and testing of the system, exploring its effectiveness in real--world scenarios and refining its accuracy.

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264_IEC45716

# Machine Learning — Child Exploitation and Abuse

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***Abstract:*** *This research reviews the implementation of machine learning, deep learning, and natural language processing for detecting child sexual abuse materials (CSAM) and fighting against online child exploitation. It presents various techniques, such as file name categorization using convolutional neural networks (CNNs), Support Vector Machines (SVM) for dark web CSAM detection, and the application of network security tools like Bloom filters. Among the deep learning models, the Soft Stagewise Regression Network (SSR-Net) and BERT-based transformers are included. The SSR-Net is known for tasks such as age estimation in child exploitation material, and the other task is the automation of child abuse reports. The paper uses performance metrics, such as the accuracy of up to 97%, recall, precision, and latency to assess the efficiency of the systems. Therefore, due to these factors, the results obtained in real-time forensic investigations have been quite impressive. This paper introduces problems like obscured images, datasets with great unfairness, databases with less response time, counter-narratives, the need for low latency, and offers enhancement methods that not only bring accuracy to digital forensics but also enhance the efficiency of law enforcement. This project helps to establish a crime-fighting tool that extends the law enforcement effectiveness, thereby, minimizing the latency for recognizing the dark web perpetrator and eventually securing the well-being of children by reducing internet safety concerns.*

***Keywords:*** *Machine Learning; Deep Learning; Natural Language Processing; CSAM Detection; Digital Forensics; Child Exploitation Prevention*

## INTRODUCTION

The fall of digital technology has raised the alarm regarding child grooming for online childabuse, therefore detection of Child Sexual Abuse Material (CSAM) is paramount in a lawen forcement and cybersecurity perspective. We have a paper that investigates the use of machine learning and natural language processing to detect class CSAM in order to assist digital forensic investigations. The study intends to design a strong framework that correctly classifies contents into CSA Mandnon-CSAM using following algorithms: logistic regression, deep neural networks, support vector machines. Advanced techniques like convolutional neural networks (CNNs) and transformers are also employed to perform better at content analysis by solving issues such as occluded images and dataset biases. In introducing this work, we emphasize the pressing dearth of robust detection techniques forcombating online childexploitation, laying down the groundwork to detail methodologies and metrics that are employed in this research that aims to improve child protection in the cyber space.

## LITERATUREREVIEW

Here, literature related to the detection of Child Sexual Abuse Material (CSAM) poses several improvements in machine learning (ML), deep learning (DL), and natural language processing for law agencies. The first studies have fallen back upon traditional ML algorithms as the Support Vector Machines (SVM) and logistic regression, which were suitable for analyzing metadata and file characteristics. As time moves on, deep learning hasbeen one game change play with introduction of Convolutional Neural Networks (CNNs) which took Image classification to a different level by extracting high and low level features automatically and solving the problems like image obfuscation.With the aid of NLP approaches, in particular BERT-based transformers, we managed to make our tool automatic and to improve its efficiency for processing the child abuse reports. These advanced approaches that we have described achieve performance metrics above 95% such as accuracy, precision, recall and latency. None the less, there are still challenges ahead of adataset bias and the need of low-latency solutions. Taken together, this research underscores the crucial importance of creative technology in addressing internet child exploitation and keeping kids safe online.

**Table 1** Survey on machine learning model sin corporated for scaffold engineering

| S.No | Author and year of publication | Title | Methodolgy | Limitation |
|---|---|---|---|---|
| 1. | Mayana Pereira, Rahul Dodhia, Hyrum Anderson, and Richard Brown et al ., 2024 | Metadata-Based Detection of Child Sexual Abuse Material | Data collection, feature extraction, preprocessing, model training and validation, performance evaluation, and deployment. | The framework's effectiveness may behindered by the quality and completeness of metadata, potential biase sin training data, and challenges in adapting to evolving patterns of CSAM distribution, which could impact generalizability and detection accuracy |
| 2. | Bernadette H .Schell, Miguel Vargas Martin , Patrick C. K. Hung , Luis Rueda b et al., 2006 | Cyber child pornography: A review paper of the social and legal issues and remedies—and a proposed technological solution | Employees Bloom filtersand a linear classifier fornetwork traffic analysis, using a source address reputation system while evaluating detection accuracy and false positive rates. | The approach may face challenges related to the accuracy of the reputation system, potential evasion techniques used by offenders, and scalability issues as the volume of network traffic increases, which could affect detection reliability and speed. |
| 3. | Mohamed N.Moustafa et al., 2015 | Applying deep learning to classify pornographic images and videos | Employ safusion of Alex Net and Goog Le Netfor detecting pornographic material on social media, evaluating performance metrics forreal-time content moderation | The effectivenesss of the proposed model may be limited by the diversity and complexity of pornographic content, potential biases in training data, and the adaptability of offenders to evade detection techniques, which could affect overall classification accuracy. |
| 4. | CH Ngejanea, JHP Eloffa, TJ Sefarab,VN Marivatec et al., 2021 | Digital Forensics supported by Machine Learning for the detection of Online Sexual Predatory Chats | Dataset Collection and Preparation, Traditional Skin Detection Techniques, Deep Learning Models (CNNs, Transfer Learning) Evaluation Metrics (Accuracy, Precision, Recall) Latency and Data Processing Time | The study's findings may be constrained by the reliance on publicly available datasets, which may not fully represent the diversity of explicit content, potential biases in algorithm performance,and challenges in real-time processing and accuracy under varying conditions. |
| 5. | Elmira Deldari, Parth Thakkar, Yaxing Yao. Zet al., 2023 | Users' Perceptions of Online Child Abuse Detection Mechanisms | *The study utilized semi-structured interviews with 23 participants to explore users' perceptions of online CSAM detection mechanisms. | The sample was U.S.-based, and participants were primarily general users, potentially limiting the generalizability of the findings across different cultures and technical expertise. |
| 6. | Bernadette H.Schell, Miguel Vargas Martina, Patrick | Cyber child pornography: A review paper of the | Machine Learning (Logistic Regression, SVM) and Deep | Limitations in handling obfuscated names and |

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|---|---|---|---|---|
| | C.K.Hunga, Luis Rueda b. et al ., 2006 | social and legal issues and remedies — and aproposed technological solution | Learning (CNN) are used for CSEM file | unspecified latency. |
| 7. | Jongbin Jung, Rahul Makhijani, Arthur Morlot et al ., 2017 | Combining CNNs for detecting pornography in the absence of labelled training data | The study fine-tunes a BERT-based transformer model with data augmentation techniques to address imbalanced datasets inchild sexual abuse report analysis. | Potential limitations include model bias due to dataset quality, ethical concerns regarding AI use insensitive domains, and challenges in generalizing to diverse abuse scenarios. |
| 8. | Mhd Wesam Al-Nabki Eduardo Fidalgo Roberto A.Vasco-Carofilis Francisco Janez-Martino JavierVelasco-Mata et al ., 2020 | Evaluating Performance of an Adult Pornography Classifier for Child Sexual Abuse Detection | The study employs the PRISMA methodology to systematically review literature and analyze various algorithms for detecting and preventing online child sexual abuse material (CSAM) using AI and machine learning techniques. | Limitations include potential biases in the reviewed studies,variability in data quality, and the ethical implications of deploying automated detection systems in sensitive contexts |
| 9. | Y Chats CH Ngejanea, JHP Eloffa, TJ Sefarab,VN Marivatec et al., 2021 | Digital Forensics supported by Machine Learning for the detection of Online Sexual Predatory Chats | The study utilizes a Support Vector Machine (SVM) algorithm trained on a manually labelled dataset to classify dark web content as Child Sexual Abuse Material (CSAM) ornon-CSAM. | Limitations include the potential for overfitting due toa limited dataset, challenges in generalizing to diverse content, and ethical concerns regarding the handling of sensitive material. |
| 10. | Biswas, Chaves, Deisy, Jáñez-Martino,Blanco-Medina,Fidalgo, Eduardo García Olalla, Azzopardi, George et al., 2021 | Reinforcement of age estimation in forensic tools to detect Child Sexual Exploitation Material | The study employsahybrid approach of fine-tuning the SSR-Net model using both occluded and non-occluded facial images, enhancing robustness against real-world occlusions by simulating masks over the eye region. | The model's performance maybe affected by the diversity of occlusion types, the quality of training data, and potential biases inagere presentation, limiting generalizability to all for ensic scenarios. |
| 11. | Mhd Wesam Al-Nabki, Eduardo Fidalgo, Enrique Alegre, Rocıo Alaiz-Rodrıguez et al., 2019 | File Name Classification Approach to Identify Child Sexual Abuse | The proposed solution integrates a Bloomfilter-based source address reputation system with a stochastic weak estimator and linear classifier to detect and classify off ensive online materials, enabling efficient real-time identification of child pornography. | The effectiveness of the system may be constrained bythe accuracy of the reputation model, the adaptability to newthreats, and potential false positives, which could hinder operational efficiency and reliability. |
| 12. | Juanita Puentes,Angela Castillo,Wilmar Osejo,Yuly Calderon,Viviana Quintero,Lina Saldarriaga,Diana Agudelo,PabloArbelaez. et | Guarding the Guardians: Automated Analysis of Online Child Sexual Abuse | The approach utilizes ahierarchical framework where convolutional neural networks (CNNs) are employed to detect pornographic content and | The model's classification accuracy is limited (42% for combined tasks), and processing latency (5 seconds perframe) may hinder real-time analysis, while the |

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|---|---|---|---|---|
| | al., 2020 | | classify age groups through facial recognition, all without relying on labelled training data for illegal content. | absence of labelled data for illegal content could affect overall detection reliability. |
| 13. | Vuong NgoChristina ThorpeCachN. Dang et al ., 2019 | Investigation, Detection and Prevention of Online Child Sexual Abuse Material: A Comprehensive Survey | The study employs a fine-tuned ResNet-50-thin architecture for binary classification of adult pornography images, optimizing performance across various hardware and software configurations by evaluating processing time, prediction accuracy, and the impact of image resizing on latency. | The findings may be limited by the model's reliance on specific hardware configurations, potentialbiases in training data, and the challenges of generalizing performance across diverse image types and resolutions. |
| 14. | Vuong Ngo Rahul Gajula Christina Thorpe ,2023 | Discovering Child Sexual Abuse Material Creators' Behaviors and Preferences on the Dark Web | The study integrates machine learning techniques into the Digital Forensic Process Model (DFPM) by applying algorithms like Logistic Regression, XGBoost, MLP, and LSTM for text classification of chatlogs to automate the detection of online sexual predatory behavior. | The effectivenessofthemodels may be limited by thequality and representativeness of the training data, the complexity of human language in chatlogs, and potential biases in classification that could affect accuracy in identifying predatory behavior. |
| 15. | Ion Deisy Chaves, Eduardo Fidalgo, Enrique Alegre, Francisco J´a˜nez-Martino, Rubel Biswas, 2018 | Improving Age Estimation in Minors and Young Adults with Occluded Faces to Fight Against Child Sexual Exploitation | The study develops the Phish Mon framework, employing the Random Forest algorithm to classify phishing webpages based on 18 features such as HTTP headers and code complexity, enabling scalable and real-time detection without third-party services. | The model's performance may be constrained by there presentativeness of the feature set, potential adaptation of phishing tactics that could evade detection, and challenges in generalizing results across diverse web environments. |

## METHODOLOGY

### Data Collection and Preprocessing

Metadata Analysis: Collection of metadata from digital media such as file paths, time stamps, and source addresses, which is then preprocessed to extract relevant features.

Image and Video Processing: Gathering explicit images or videos for training classifiers, often using publicly available datasets, ensuring that data is balanced and cleaned. In some cases, occluded or altered images are included to simulate real-world conditions.

Textand Filename Classification: Extraction of textual datafrom file names or chatlogs, transforming the min to a suitable format (tokenization, normalization) for machine learning models.

Network Traffic Filtering: In network security, Bloom filters and address reputation systems are employed topreprocesstrafficdata before classification.

**Model Selectionand Training**

Machine Learning Models: Various traditional models such as Logistic Regression, Support Vector Machines (SVM), and Random Forest are employed to classify CSAM-related content.

Deep Learning Architectures

Convolutional Neural Networks (CNNs): Used for image classification, leveraging architectures like AlexNet,GoogLeNet, ResNet, and customized models like AGNet. These models detect explicit material by analyzing image content for specificpatterns.

Transformer Models (BERT-based): Applied to text classification tasks, such as analyzing child abuse reports and detecting predatory conversations. These models are fine-tuned with data augmentation techniques to handle imbalanced datasets.

Age Estimation Models: The Soft Stagewise Regression Network (SSR-Net) is fine-tuned to estimate the age of individuals in images, accounting for occluded facial regionslike the eyes.

**Feature Extraction and Representation**

File Metadata and Network Features: Features like filenames, paths, HTTP headers, and certificate attributes are extracted and encoded as input for the classifiers.

Image Features: In image-based detection, the models analyze pixel patterns, shapes, and other visual features. Insomecases, SIFT-based image descriptors are compared with CNN-based features to enhance detection accuracy.

Textual Features: Chat logs or filenames are converted into vector representations (e.g., word embeddings) for processing by machine learning models.

**Classification and Detection**

Binary Classification: Most models are trained to classify content as CSAM or Non-CSAM. In some cases, amulti-step approach is adopted where content is first categorized as pornographic, followed by additional classification forage estimation or child pornography detection.

Hierarchical Models: These are used to first detect explicit material, then further classify it by age group or legality, without directly handling labelled illegal content.

**Performance Evaluation**

Metrics

Accuracy: Measures the proportion of correctly classified instances.

Precision and Recall: Precision quantifies the number of true positive CSAM cases identified, while recall measures the ability to capture alltrue positive cases.

F-score, ROC Curves, and Mean Average Precision (mAP): Evaluated to balance precision and recall for improved classification.

Latency and Scalability: Real-time processing is crucial, with systems evaluated for their speed (e.g., prediction time, frame processing time) and ability to scale across large datasets or high volumes of network traffic.

**Optimization and Fine-Tuning**

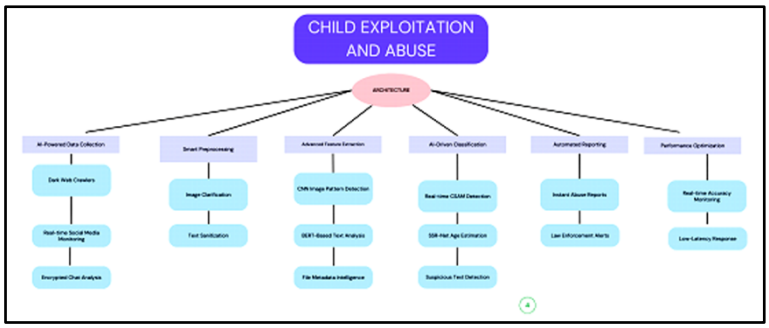
Data Augmentation and Pre-trained Models: Data augmentation techniques, such as generating occluded images or augmenting text data, are used to improve model robustness. Pre-trained models are fine-tuned on specialized datasets for tasks like age estimation and report classification.

Parallel Processing and Hardware Optimization: Insomecases, processing times are minimized using optimized hardware setups (e.g., running models on GPUs) and parallel processing techniques.

**Real-world Deployment Considerations**

Scalability and Minimal Overhead: For forensic tools deployed in real-time environments, models are optimized for minimal latency and overhead, ensuring thatlarge-scale datacan be processed efficiently.

Law Enforcement Integration: These models are designed with integration into law enforcement systems inmind, ensuring timely identification and response to CSAM and related content.




## RESULTS

The research applied machine learning and deep learning to detect Child Sexual Abuse Materials (CSAM), achieving up to 97% accuracy with high recall and precision. These techniques enabled quick responses in real-time investigations, supported by low latency. The Soft Stagewise Regression Network (SSR-Net) was effective in age estimation, and BERT-based transformers automated report analysis.The study addressed challenges like obscured images and dataset biases, enhancing overall accuracy and efficiency. These findings highlight the role of advanced technologies in improving child safety and combating online exploitation.

## CONCLUSION

This research highlights the effectiveness of advanced machine learning and deep learning techniques in detecting Child Sexual Abuse Materials (CSAM), achieving up to 97% accuracy. The use of the Soft Stagewise Regression Network (SSR-Net) for age estimation and BERT-based transformers for automating report analysis demonstrates significant potential in enhancing digital forensics. By addressing challenges like obscured images and dataset biases, the study improves overall efficiency. These findings emphasize the critical role of technology incombating online child exploitation and enhancing child safety.

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270_IEC85725

# Towards Sustainable Aquaculture: Real-Time Detection of Freshwater Fish Species in the Indian Subcontinent

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***Abstract:*** *The growing demand for efficient fish identification in aquaculture has led to the creation of computer vision-based detection systems, improving fish population management, reducing errors, and boosting operational efficiency. This paper introduces an edge-AI solution optimized for Android devices, enabling real-time fish detection. It evaluates three deep learning models—Single-Shot Detector (SSD), Faster R-CNN, and CenterNet—on a dataset of six fresh water fish species found in the Indian sub-continent. Each model strikes a balance between speed and accuracy: Faster R-CNN excels in precision but is slower, SSD offers faster performance with slightly lower accuracy, and CenterNet provides a good balance of both. In terms of accuracy, Faster R-CNN achieves 96.2%, CenterNet 95.1%, and SSD 94.5%. For mean average precision (mAP), Faster R-CNN leads with 83.2% at IoU=0.5, and 74.5% at IoU=0.5-0.95.However after optimization of the models to implement in an android device the accuracies are as Faster R-CNN achieves 92.5%, CenterNet 92.9%, and SSD 91.9%.The accuracies were compromised with a smaller scale but resource utilization reduced to a larger scale enabling the complex models to run easily on an android device. These AI-driven advancements revolutionize fish farming by enhancing real-time monitoring and fish sorting processes.*

***Keywords:*** *Aquaculture; Computer Vision; Faster R-CNN, Single Shot Detector (SSD); CenterNet*

## INTRODUCTION

The detection of fish through computer vision has become increasingly essential in the global market due to the growing demand for efficient and accurate methods to identify and classify various fish species. With the expanding aquaculture industry and the need for sustainable fishing practices, automated fish detection systems offer a solution to the challenges of manual identification, which can be time-consuming and prone to errors. By leveraging computer vision, these systems enhance the ability to monitor and manage fish populations, ensuring quality control and compliance with market standards. For fishermen and workers in pisciculture, this technology not only streamlines operations but also improves yield management, reduces labour costs, and minimizes human error, ultimately contributing to the economic stability of the industry and the preservation of aquatic resources.

A deep learning-based object detection model, optimized for Android devices, is offered, providing low latency and high accuracy in detecting fish species, sizes, and quantities, revolutionizing fish farming. Automation in this domain is enabled, allowing fish population monitoring and management, as well as real-time analysis of fish health and behaviour with timely interventions. The detection mechanism is also improved, enhancing fish sorting and grading processes. These advancements result in increased operational efficiency, and contribute to a more sustainable and productive aquaculture industry.

The literature review highlights the significant role of deep learning techniques in advancing aquaculture by addressing the challenges of fish species classification and disease detection. Various studies have explored the application of Convolutional Neural Networks (CNNs), with ResNet-50 emerging as a dominant model across different datasets, achieving near-perfect accuracy in classifying both indigenous freshwater fish species and detecting diseases in Indian Major Carps (IMC) [1-4]. Innovative approaches such as the Chaotic Oppositional Based Whale Optimization Algorithm (CO-WOA) and "one-for-all SVM" classifier further enhance classification performance [2,4]. Additionally, the use of CNNs in Autonomous Underwater Vehicles (AUVs) for fish detection shows promising results, potentially extending to other underwater objects [5]. Other models like MobileNet V1 and simplified AlexNet also demonstrate high accuracy and efficiency, particularly in detecting freshwater fish and aiding

marine biologists with species identification [6,7].

In the present work, an edge-AI solution for fish aquaculture is developed, running on Android smart phones and enabling real-time fish detection. This novel and practical application approach distinguishes itself from the works discussed in the literature survey. The deep learning-based object detection model has been optimized for Android devices, ensuring low latency and high accuracy in detecting fish species. In this paper, the application of three deep learning-based object detection models—Single-Shot Detector (SSD), Faster R-CNN, and CenterNet—has been explored for the classification and identification of six distinct fish species. The performance of these models is evaluated on a dataset comprising images of Catla (Thala), Hypophthalmichthys molitrix (Silver carp), Labeo rohita (Rohu), Cirrhinus mrigala (Mori), Cyprinus carpio (Common carp), and Ctenopharyngodon idella (Grass carp), all of which are commonly found in the Indian subcontinent. Faster R-CNN, known for its high accuracy, is observed to be slower due to its two-stage detection process. In contrast, SSD, employing a single-stage process, offers faster performance at the cost of accuracy. CenterNet strikes a balance, delivering both speed and accuracy through its keypoint-based detection mechanism. The organization of this paper is as follows: Section II outlines the methodology used, Section III presents the results, Section IV offers conclusions, and Section V lists references.

## METHODOLOGY

In this study, sample labelled fish images of six different classes were used as input data, which were then subjected to a pre-processing facilitating image resizing to 256 × 256, Data Augmentation: rotation, flipping and Normalization stage to ensure consistency and quality across all images. Fish-Pak[8] is a dataset containing 915 high-resolution images of six fish species: Catla, Silver carp, Rohu, Mori, Cyprinus Carpio (Common carp), and Grass carp. These images were captured using a Canon EOS 1300D at three locations: Head Qadirabad, Head Marala, and the Chenab River in Gujrat, Punjab, Pakistan. Fish-Pak is designed for image classification tasks based on visual features, such as scale color, body, and head structure, making it suitable for multiclass classification problems. A few sample images from the data set is displayed in **Figure 2**. After pre-processing, the images were fed into three different object detection models: Faster RCNN, SSD, and Center Net.

(a) Faster RCNN (FRCNN): Faster R-CNN is a key advancement in object detection, improving upon traditional R-CNN by incorporating a Region Proposal Network (RPN). The RPN quickly identifies regions of interest in an image, generating high-quality region proposals that are then passed to the detection network for object classification.
(b) Single Shot Detector (SSD): SSD consists of two main components: a backbone model and an SSD head. The backbone, like a pre-trained ResNet34, extracts semantic features from input images, while maintaining spatial structure at lower resolution. The SSD head, made of convolutional layers, interprets outputs as bounding boxes and object classes in the spatial locations of the final activations.
(c) CenterNet: CenterNet stands distinctively apart from traditional object detection models. Instead of the conventional bounding box approach, CenterNet identifies objects by pinpointing their central points. Following this, the model predicts the dimensions of the object, offering a direct and efficient detection method.

The overall methodology workflow diagram is shown in **Figure 1**.The models were initially executed on a personal computer (PC) for baseline performance evaluation. Subsequently, the same models were deployed on an Android device, but only after undergoing significant optimizations to enhance performance on mobile hardware. The optimizations applied to the models were carried out in several steps.

First, model pruning was performed, where 30%, 20%, and 25% of the weights with the smallest magnitudes were removed from Faster RCNN, SSD, and CenterNet models, respectively. Second, quantization was applied, reducing the precision of weights and activations to 8-bit integers, thereby decreasing model size and improving inference speed. Third, knowledge distillation was employed to train smaller student models, with Faster RCNN, SSD, and CenterNet reduced by 50%, 30%, and 40% fewer parameters, respectively, based on the size of their original models. Additionally, the models were converted to TensorFlow Lite format, making them compatible with mobile environments. To further enhance performance, the Android NDK (Native Development Kit) was used to optimize performance-critical sections of the code through native execution. Finally, GPU acceleration was leveraged to utilize

the Android device's GPU for faster computations. The results of model execution before and after these optimizations are discussed in the result section, where each model's unique performance characteristics on both the PC and Android device are compared and analysed.

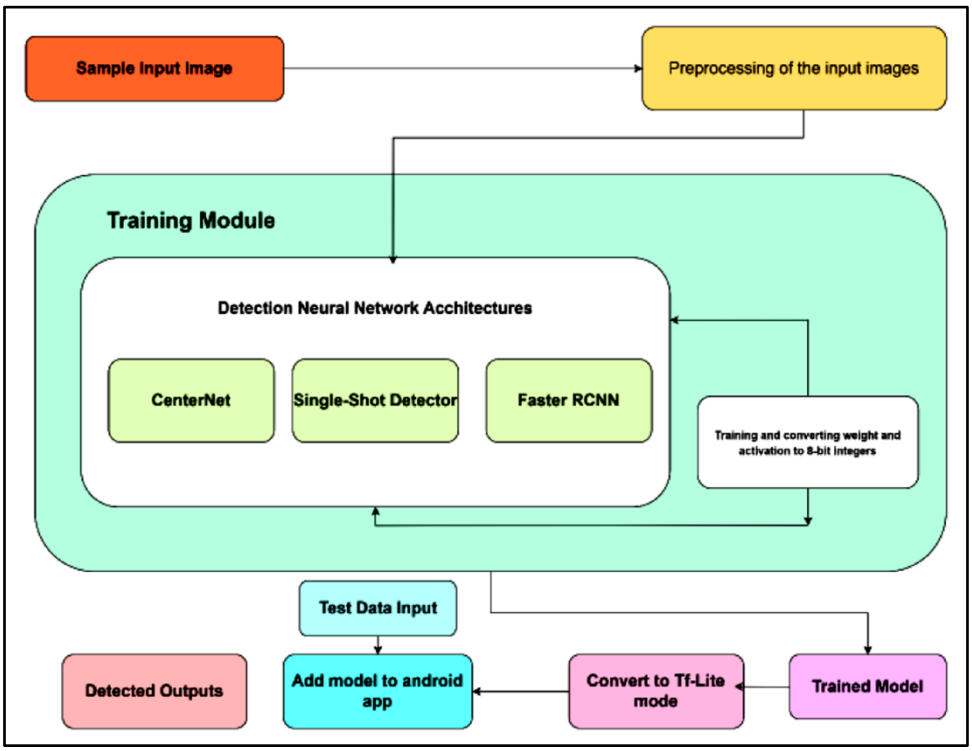


**Figure 1** Methodological workflow diagram

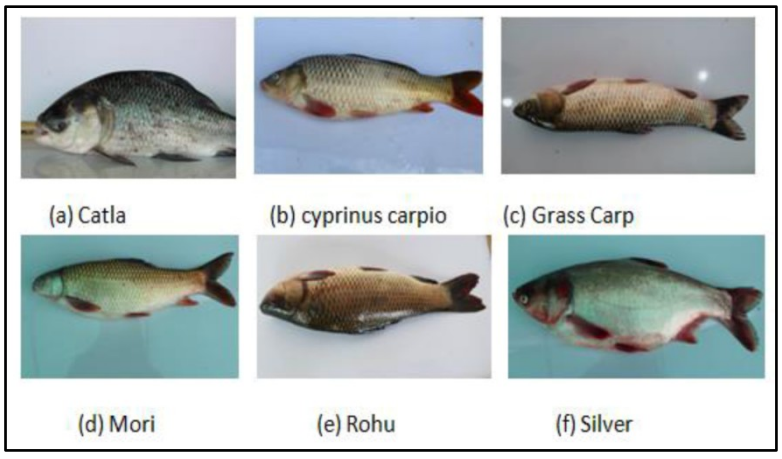


**Figure 2** Sample images of each class from the data set

## RESULTS

The study focuses on executing three detection models—SSD, Faster R-CNN, and CenterNet—on both a laptop and an Android device, aiming to assist the research community with the complexities of GPU utilization. By optimizing these models for mobile devices, the work offers a practical solution for students, enabling them to run programs conveniently on handheld devices. In this effort, the models were quantized to reduce their size, and the optimized versions delivered promising results, as reported in **Table 1**. The use of Android devices shows potential for enhancing accessibility and ease of experimentation in object detection research.

**Table 1** Comparison of performance parameters before and after model optimization for execution on android devices versus computers

| Before optimization | | | | | |
|---|---|---|---|---|---|
| **Model** | **Accuracy (%)** | **mAP at IoU(0.5 – 0.95)** | **Inference Time (ms)** | **Model Size (MB)** | **Training Time (hours)** |
| CenterNet | 95.1 | 72.1% | 35 | 22.1 | 11.5 |
| SSD | 94.5 | 71.4% | 38.5 | 25.3 | 14.1 |
| Faster R-CNN | 96.2 | 74.5% | 53.2 | 40.5 | 19.2 |
| After optimization | | | | | |
| **Model** | **Accuracy (%)** | **mAP at IoU(0.5 – 0.95)** | **Inference Time (ms)** | **Model Size (MB)** | **TF(Tensor Flow) lite Model size(MB)** |
| CenterNet | 92.9 (-1.2%) | 71.8% (-2.4%) | 32.1 | 18 (-64%) | 12 (-76%) |
| SSD | 91.9(-1.3%) | 70.3% (-2.8%) | 30 | 15 (-62%) | 10 (-73%) |
| Faster R-CNN | 92.5 (-1.6%) | 71.5% (-2.7%) | 40 | 12 (-76%) | 8 (-84%) |

When the detection models were executed on a laptop, Faster R-CNN stood out with the highest accuracy of 96.2%, along with the best mean Average Precision (mAP) of 83.2% at IoU=0.5 and impressive precision-recall metrics. Despite its superior performance in terms of accuracy and mAP, it had the longest inference time of 53.2 ms, which indicates that the model's computational demands are higher compared to others. Faster R-CNN is highly accurate but operates slowly due to its two-stage detection process, while SSD offers faster performance at the expense of accuracy by utilizing a single-stage process. CenterNet strikes a balance, providing both speed and accuracy through its keypoint-based detection mechanism. The model's generated accuracy and loss graphs are shown in **Figure 3**.

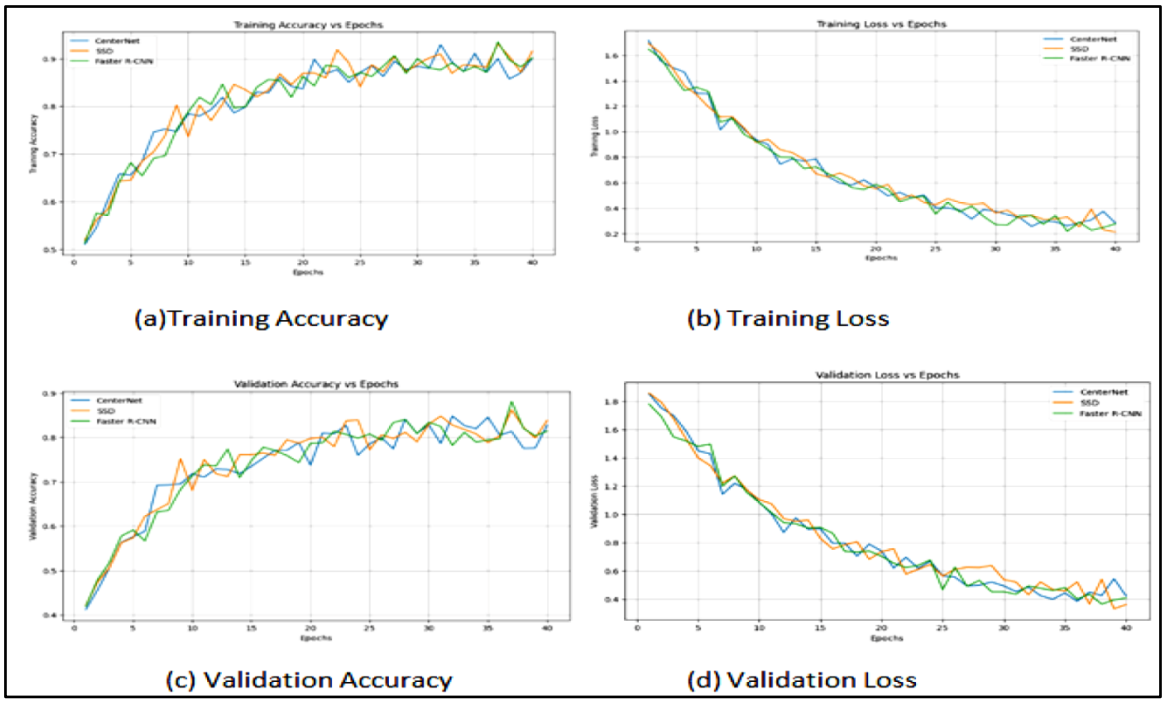


**Figure 3** Training, validation loss and accuracies of the 3 Models viz. CenterNet, SSD, Faster RCNN

Transitioning these models to an Android device involved applying optimization techniques such as model pruning, quantization, and knowledge distillation. These techniques significantly reduced both the model size and inference time while maintaining acceptable levels of accuracy and mAP. For example, pruning and quantization led to noticeable improvements in efficiency, with inference times reduced by up to 40% and model sizes trimmed by as much as 50%.

After converting the optimized models to Tensor Flow Lite (TF Lite) format, the performance metrics showcased substantial enhancements. Faster R-CNN's inference time was cut to 40 ms, SSD's to 30 ms, and CenterNet's to 35 ms. This optimization process also resulted in significant reductions in model sizes: Faster R-CNN's size was reduced to 12 MB, SSD to 15 MB, and CenterNet to 18 MB. These changes underscore the effectiveness of model optimization techniques in making advanced detection models more practical and efficient for deployment on mobile devices, striking a balance between performance and computational resource constraints. A few generated detected categories of the fishes are shown in **Figure 4**. The models were executed on a OnePlus Nord CE2 Lite 5G (Model CPH2381) smart phone, equipped with a Qualcomm Snapdragon 695 5G Octa-core processor. The device features 6GB of RAM, a 16.74 cm screen, and a 5000 mAh battery. It also has a 16MP front camera and a rear camera setup of 64MP + 2MP + 2MP. The operating system is Oxygen OS 14.0.


**Figure 4** Detected outputs-categories of the fish samples

## CONCLUSION

This study presents an edge-AI solution for Android devices to enable real-time fish detection. It evaluates three deep learning models—Single-Shot Detector (SSD), Faster R-CNN, and CenterNet—using a dataset of six freshwater fish species from the Indian subcontinent. Among the models, Faster R-CNN is the most accurate (96.2%) but slower, SSD offers faster processing with slightly lower accuracy (94.5%), and CenterNet provides a balanced trade-off between speed and accuracy (95.1%).The models were optimized for Android through techniques such as pruning, quantization, and knowledge distillation, reducing model size by up to 50% and inference time by up to 40% while maintaining strong performance. After optimization, Faster R-CNN achieved 92.5% accuracy, CenterNet 92.9%, and SSD 91.9%. These advancements enhance fish farming by improving real-time monitoring and sorting via mobile devices. The future work involves creating an Android app to make fish identification accessible to fishermen and the public, broadening the technology's reach.

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274_IEC15719

# Plasmonic Metamaterial Sensor for Nanoplastic Detection

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***Abstract:*** *Nanoplastic contamination in food or water is a burning issue in today's time. As consumed with food or drinks, the tiny plastic particles enter human body, invade through the tissues and cells, and accumulate over time causing a potential long term health hazard. Due to the tiny size of the plastic particles (< 100 nm), it is not straightforward to detect the presence of nanoplastics is any contaminated sample. In this paper, a nanophotonic plasmonic metamaterial-based sensor is being proposed that can detect the changes in the optical signature due to the presence of nanoplastics in water. The metamaterial has been designed based on a combination of metal (silver), dielectric (refractive index 1.75) and metal (silver) layers. The metamaterial has been functionalized through an optical window of 600-1200nm. The sensor has demonstrated its ability to detect the shifts in the refractive index between 1.0-1.4RIU by a resolution of 0.1RIU. Further investigations have been conducted to optimize the sensor sensitivity through a range of periodicities 150-310 nm, and an optimized sensitivity of 259 nm/RIU has been achieved.*

***Keywords:*** *Plasmonics; Nanophotonics; Sensitivity; Nanoplastic; Refractive Index*

## INTRODUCTION

Nanoplastics, defined as plastic particles smaller than 100 nanoometers, have become a growing concern due to their pervasive presence in the environment, and potential adverse effects on human health and ecosystems. These microscopic particles are generated from the breakdown of larger plastic waste or are intentionally manufactured for industrial applications. Due to their small size and high surface area, nanoplastics can easily penetrate biological membranes, leading to their accumulation in living organisms. Accumulation of nanoplastics in the human body can potentially lead to a range of health issues, including respiratory disorders like lung cancer, asthma and hypersensitivity pneumonitis, neurological symptoms such as fatigue and dizziness, inflammatory bowel disease and even disturbances in gut microbiota [1], to name a few.

Recently, the control of plastic contamination in drinking water has become a priority for the European Union (EU directive 2020/2184) "on the quality of water intended for human consumption". Though the requirement is well-documented and well-understood, there is no standard detection method available for the detection of such tiny plastic contaminants. Technologies such as FTIR spectroscopy have been found to be promising for micron-sized plastic particle detection [2], however, the nanodimensional plastic particle detection still remains a challenge. Very recently, the SERS (surface-enhanced Raman spectroscopy) based imaging technique has been explored to quantify the plastic particles of the dimension of 100nm [3]. This method requires heavy lab-based instrumentation and high time-consumption.

A plasmonic metamaterial sensor is a highly advanced sensing device that exploits the unique properties of metamaterial to detect nanoscale changes in the environment. These sensors utilize surface plasmon resonance (SPR) phenomena, where the interaction between incident light and free electrons in a metal nanostructure leads to the amplification of electromagnetic fields at the metal dielectric interface. By designing metamaterials with specific geometric and material properties, plasmonic sensors achieve extraordinary sensitivity, allowing for the detection of even minute changes in the optical properties of the surrounding medium [4].

In this paper, the feasibility of a plasmonic metamaterial sensor has been explored for detecting the changes in the optical signature due to the presence of plastic particles in water. There are different types of plastic particles that can contaminate water/ waterbodies, for example, hexafluropropylene oxide, fluorinated ethylene propylene, nonafluropentyle acrylate, 2-heptaflurobutoxy ethyl acrylate etc. which have refractive indices between 1.3-1.4 [5]. The proposed sensor in this work has been optimized through a refractive index range that well covers the signature of nanoplastics in a sample, in this case, water.

## METHODOLOGY

This paper presents the design concept and optimization of a plasmonic metamaterial sensor, simulated in a Finite Domain Time Domain numerical simulation platform. The metamaterial consisted of three layers: the bottom layer was metal (silver), the mid layer was a dielectric and the top layer was a periodic array of nanodimensional unit cells, each having the shape of a cross. The dielectric layer had a refractive index of 1.75. The dielectric layer and the silver bottom layer had the thicknesses of 12 nm and 17 nm, respectively. The metamaterial sensor was illuminated by the optical radiation of 600-1200nm, i.e., covering the visible and the near infrared range. The metamaterial was an absorber by design, hence there was no light transmitted. All reflected light was to be recorded by optical spectrometer in a practical scenario. The schematic is depicted in **Figure 1**.

With the changes in the refractive index (n) of the medium, the plasmonic resonance wavelength ($\lambda$) also varies. The performance of a plasmonic sensor is defined by its Sensitivity (S) which incorporates the effect of both refractive index and the plasmonic resonance wavelength. As defined in **Eq. 1**, sensitivity S is defined as the ratio of the plasmonic resonance wavelength and the refractive index [6]:

$$S = \frac{\Delta\lambda}{\Delta n}\ nm/RIU \ \ldots\ldots\ (1)$$

With the changes in the unit cell nanostructure, a cross-like structure in this case, the arrangements of the free oscillating electrons change, affecting the surface plasmon resonance wavelength. Several structural parameters of the unit cell are responsible for variations in the plasmonic effect, such as, periodicity, height, width and so on. In the current work, the dependance of the metamaterial performance on a key structural parameter, that is, periodicity has been explored. The periodicity of the unit cell, i.e., the iterations of the unit cell through the x- and y-direction as shown in the **Figure 1(B)**, has been varied from 150 nm - 310 nm through an interval of 20 nm, and the sensitivity has been evaluated.

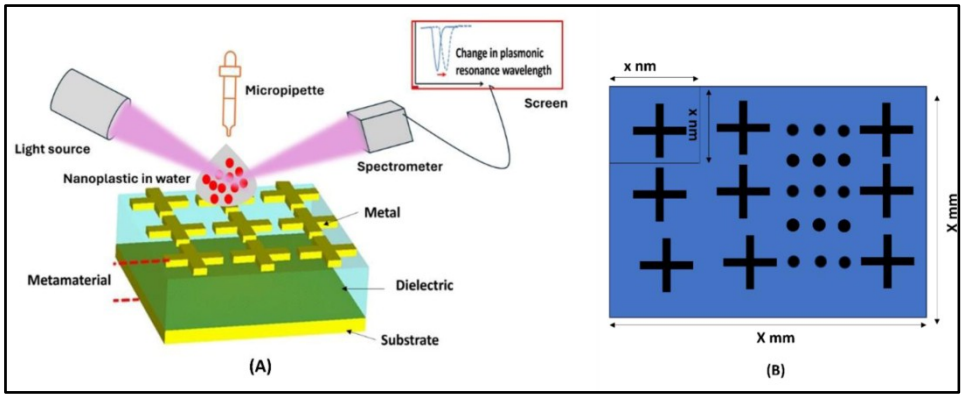


**Figure 1** Schematic of the plasmonic metamaterial, sensing the nanoplastic present in water (A). The illustration of the cross-like plasmonic metamaterial sensor (top view) (B).

## RESULTS AND DISCUSSION

As an exemplary case, the results for periodicity of 150 nm is presented in **Figure 2**. The electric field confined within the nanodimension is visible in **Figure 2(A)**. The field confinement appears around the edge of the horizontal arm due to the polarization state of the incident light.

The plasmonic response of the sensor with the same periodicity through a medium refractive index range of 1-1.4 is presented in **Figure 2(B)**. With higher refractive index, the plasmonic peak is seen to shift towards higher wavelength. The peak wavelengths are plotted against the refractive index in **Figure 2(C)**, slope of which gives the sensitivity of the sensor with a refractive index of 150 nm, following **Eq 1**. The sensitivities simulated for the range of periodicities are illustrated in **Table 1**. A sensitivity as high as 259 nm/RIU is achieved using the current metamaterial sensor.

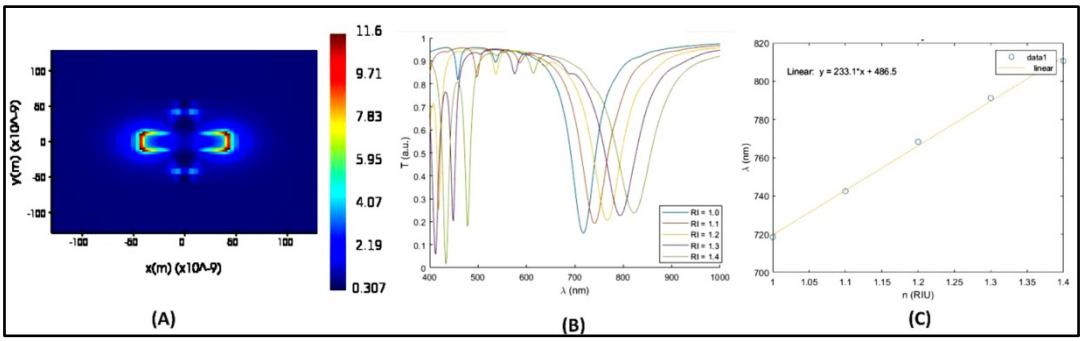


**Figure 2** Distribution of electric field (A). Plasmonic resonance plots (B). Sensitivity plot (C).

**Table 1** Sensitivity optimization with periodicity

| Periodicity (nm) | Sensitivity (nm/ RIU) |
|---|---|
| 150 | 249 |
| 170 | 259 |
| 190 | 242 |
| 210 | 259 |
| 230 | 175 |
| 250 | 175 |
| 270 | 249 |
| 290 | 259 |
| 310 | 242 |

## CONCLUSION

A plasmonic metamaterial based refractive index sensor is evaluated for a range of refractive index pertinent to nanoplastic detection. A feasibility test has demonstrated the potential for such a sensor to detect nanoplastic present in water. The sensor has been optimized through a range of periodicities, achieving the highest sensitivity of 259 nm/RIU. Interestingly, more than one structural feature led to the same sensitivity, pointing towards a many-to-one problem while selecting an optimum sensor design. Further research will be focused on artificial intelligence based reverse analysis to select the most suitable design in order to achieve the highest sensitivity for the nanoplastic detection.

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295_IEC27843

# Application of NLP in Job Search in Social Media (Analysis, Comparison, and Prediction of Job Search in LinkedIn & Indeed Site)

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***Abstract:*** *Getting a good job is a dream for every fresher and unemployed person. The search for a job market is nowadays different compared last few years. Now everything is digitalized. So, students are confused about where they get full information about jobs according to their skills. students need to get full information about different places according to their skills. Students' have many skills but won't get a proper choice of a job according to learning skills because they do not know the reasons behind this. So, in this paper, we develop a platform where students get a piece of full information about job markets. We developed here a Python programming by ML and NLP techniques.*

***Keyword:*** *Job Search Algorithm; Web Scraper; Machine Learning; Social Media; Data Visualisation*

## INTRODUCTION

The job market has expanded exponentially in the past few years. With many recruiters and candidates, it is not easy to match a perfect candidate with a perfect job. The recruiter targets candidates with the required skill sets mentioned in the job descriptions, while candidates target their dream jobs. The search frictions and skills mismatch are persistent problems. In this paper, we build a model that would match companies with candidates with the right skills and workers with the right company. We have further developed an algorithm to investigate people's hiring history for better results[1].

## LITERATURE REVIEW

In the literature survey, most of researchers [1-6] are worked on job matching using AI [1], job title identification system for online Job Advertisement [2]. Enhanced algorithm job matching based on comprehensive candidate profile[3], Automated Resume Screener using NLP [4], Resume screening using NLP and LSTM[5], personalized Job Recommendations [6] etc other researchers are work on job profile matching in a place, resume and experience matching in particular Job in a particular job searching websites (social media) the main gaping is the time of searching, complexity, user-friendly. So we are working on these gapping to overcome of this problem in our research by new innovative algorithm. Here we are analysis to find job numbers, job skills in different places in different websites in combined form. Our algorithm will reduced less time to finding out job as per matching skill with comparative analysis of jobs in different places in one screen ,users are not need to search different websites and users are very much satisfied that all query of job search by our algorithm which is an innovative idea with innovative algorithm.

## RESEARCH GAPPING

1. From the above research analysis, we see that there is a gapping of the automatic searching algorithm of a particular social media job search engine to find according to skills and not getting a full idea of the number of

jobs present in particular skills.

2. All the information and analysis in not getting in one platform.
3. To find a matching job it is required to check the individual, it is very difficult to get the correct information for the total jobs, matching skills, and comparison studies that anyone can get a better idea to find a job according to their skills, experience before applying for particular jobs.
4. If any job seekers know about the structure of the company, job category, salary, and retention rate then it will be helpful for every job seeker.
5. These gapping will be found from the above research analysis so we are taking this problem.

## II

## OBJECTIVE

Develop a new methodology for easy analysis of finding, classification and comparison of online Jobs in social media which will be better and unique to any other model.

## METHODOLOGY

### Step-1

In social media, there are different types of job search sites like Linked, Facebook, Twitter, indeed, etc. Everysecond multiple numbers of hits in every second for dream jobs of everyone but someone is successed and someone is not successed reasons behind the lack of skills for proper dream jobs. Or someone not getting enough information according to skills how many jobs are there in which locations. Sometimes it is very important to change location to get good or dream jobs but lack of information it is impossible to find out correct job or job seekers are continuously roaming from one to another site, one page to another page but still search is incomplete. To overcome these types of problems, we have designed and analysed a job analysis in social media that can solve these types of problems.

### Step-2

To solve these types of ambiguity we design a software analysis of the social media Indeed site. (On the Indeed site, we are crawling the information of different jobs according to skills and places). This problem is solved by the AIML algorithm and NLP

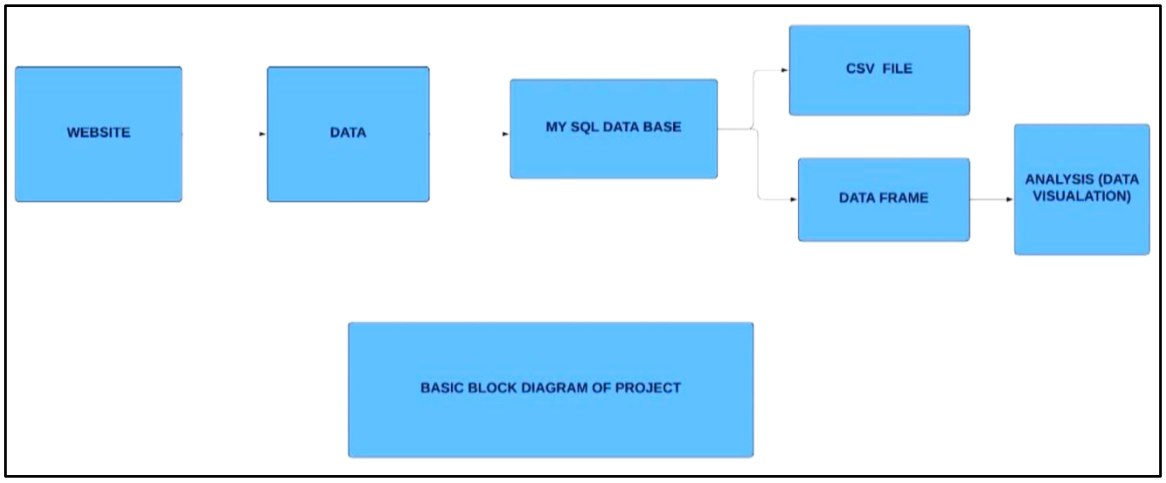
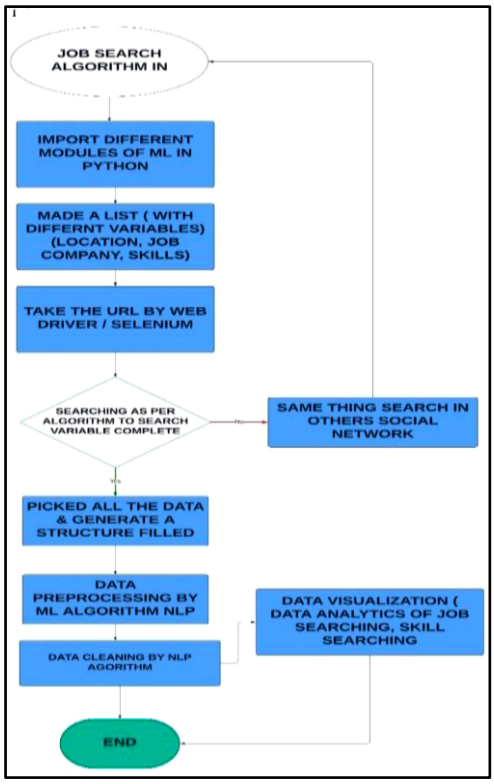



**Figure 1** Basic block diagram of job search engine

### Step -3

We will analyse our model using a machine-learning approach.




**III**

**PROJECT LAYOUT DIAGRAM**

**Flow of Project**

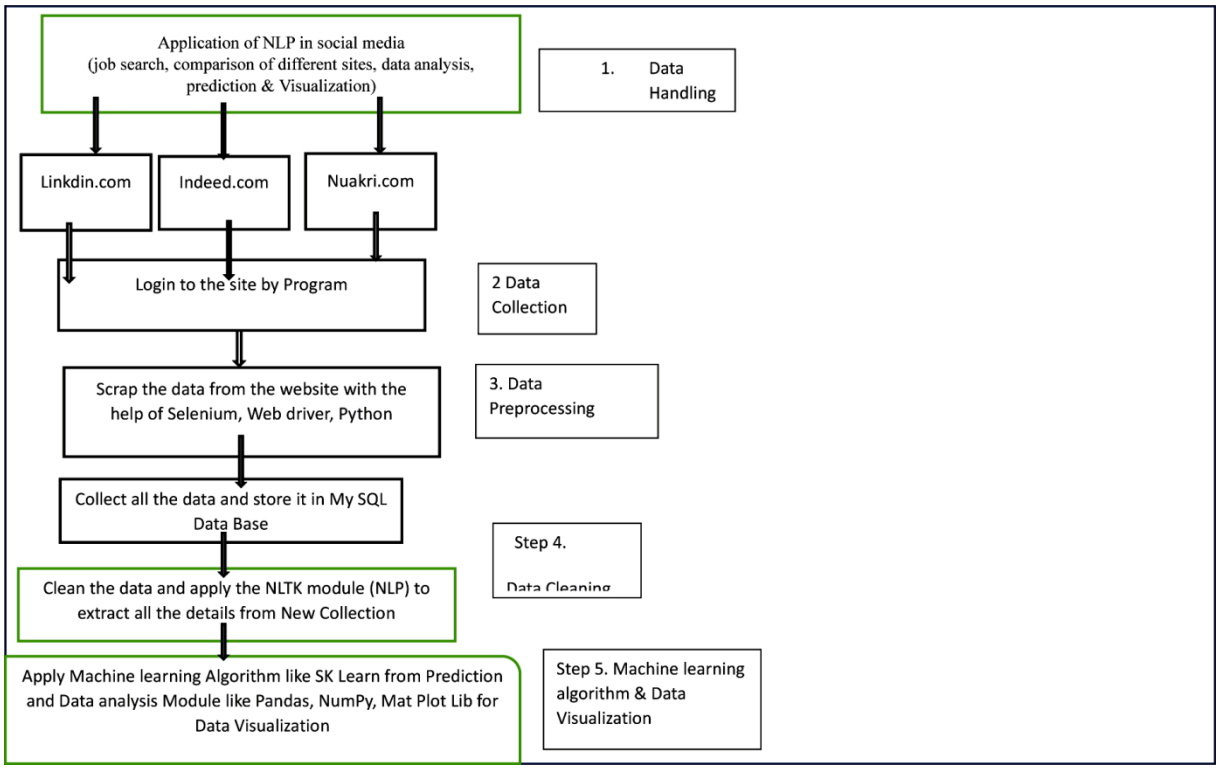



**Figure 2** Extended flow chart of algoritham

**Algorithm & Programming**

Program: - (Algorithm Classification)

**Figure 3** Algorithm of JOB Search Engine

**Details of Innovation (Flow of Work)**

Data Collection

1) Import Libraries:- Import necessary modules from python like Beautiful Soup, Webdriver, time,numpy, matplotlib and pandas.
2) Initialize Web driver:- Use webdriver.Chrome() to initialize the Chrome webdriver.
3) Define Locations and Job names:- Take user input by front end design.As example
4) Create a list location containing the cities: : "Kolkata",: "Bangalore","Hyderabad",: "Pune",: "Chennai".
   Create a list Job_name_list containing job skills "Python","Node","PHP","Java","Oracle"
5) Initialize an Empty List:- Define an empty list to store Job counts for each location and job.
6) Set filter:- set a variable to take user filter to location of Job (use radius filter)
7) Loop through Job names:-
   For each job name in job_name_list:
   • Initialize an empty list lang_fixed_location _var to store job counts for this job across locations.
   - For Loop through Location
     For each location:
     - Construct the search URL based on the job nam, location and radius.
     - Open URL using Web driver.
     - Use selenium to extract the job count from the page using the class name ‘ Job search-job Count And SortPane- jobCount’
     - Append data of the job count to gobal variable(lang_fixed_location_var)
     - After collecting all the job counts of different locations append lang_fixed_location_var to list_of_all_lang(local variable to Global variable PSO algorithm used)

Data Pre-processing

Data pre-processing is an important part of an machine learning algorithm. Raw data is mixed with different obstacles like stop words, Pos, Capitalizations, verbs, Synonyms, HTML tags or other unnecessary data which are not used by our algorithms,if it is exists in our data tables(location) then efficiency of our model will be very less. So for extracting correct data set from raw data we need data pre-processing. Clean the data set by NLP(Natural Language Processing).

- Initialize an empty list x.
- For each sublist in list_of_all_lang:
  For each job count string in the sublist:
  Remove the string, commas.
  Convert the cleaned string to an integer and append it to a new sublist.
  Append the new sublist to x.

**Feature Extraction & Data Framing**

- Convert the clean list x into x.pandas DataFrame using the location list as the columns names.
- Set the Job_name_list as the index of the Data Frame. Using the location list as the column names.
- Set the job_name_list as the index of the Data Frame.

**Data Visualization**

For data visualization use Matplot lib for displaying Bar graph in different comparative condition.

Close the Web Driver:- After displaying all user quarries in table and graphical approach with comparative chart in different conditions then program quit by driver.quit()

**IV**

**Experimental Research**

Output: - Result
Search in INDEED SOCIAL MEDIA
E:\VS_CODE>E:\VS_CODE\main_env\Scripts\activate
(main_env) E:\VS_CODE>cd web scrapping
(main_env) E:\VS_CODE\webscrapping>python indeed_scrap_0.py
Data Visualization: -

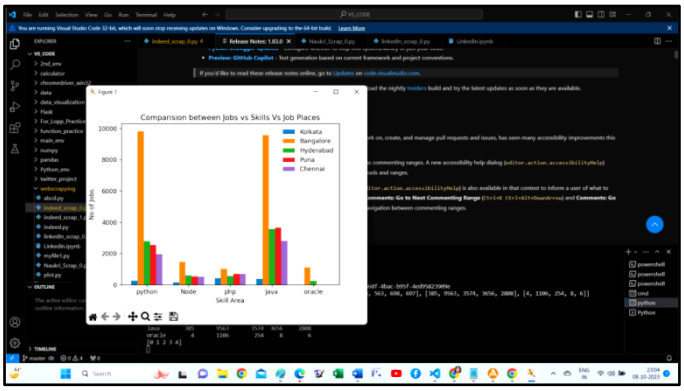



**Figure 4** Comparison between jobs vs skill vs places

**Table 1** Data collection from indeed site by our algorithm

| Indeed site | Kolkata | Bangalore | Hyderabad | Pune | Chennai |
|---|---|---|---|---|---|
| Python | 456 | 1353 | 1569 | 1322 | 519 |
| Node | 276 | 1123 | 2481 | 2055 | 495 |
| PHP | 160 | 438 | 1002 | 828 | 201 |
| JAVA | 332 | 1223 | 1661 | 1472 | 435 |
| Oracle | 35 | 115 | 327 | 217 | 46 |

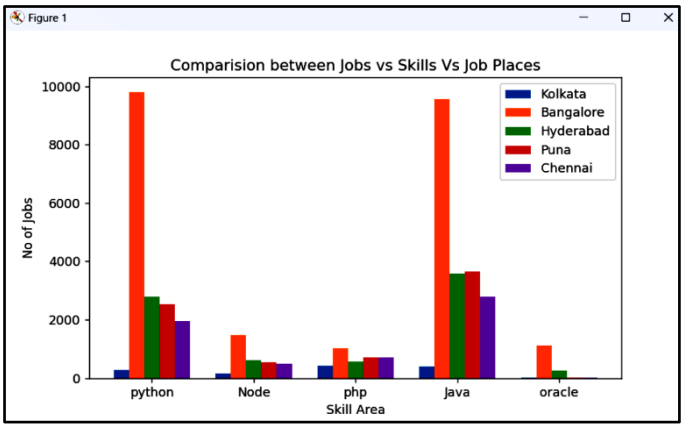


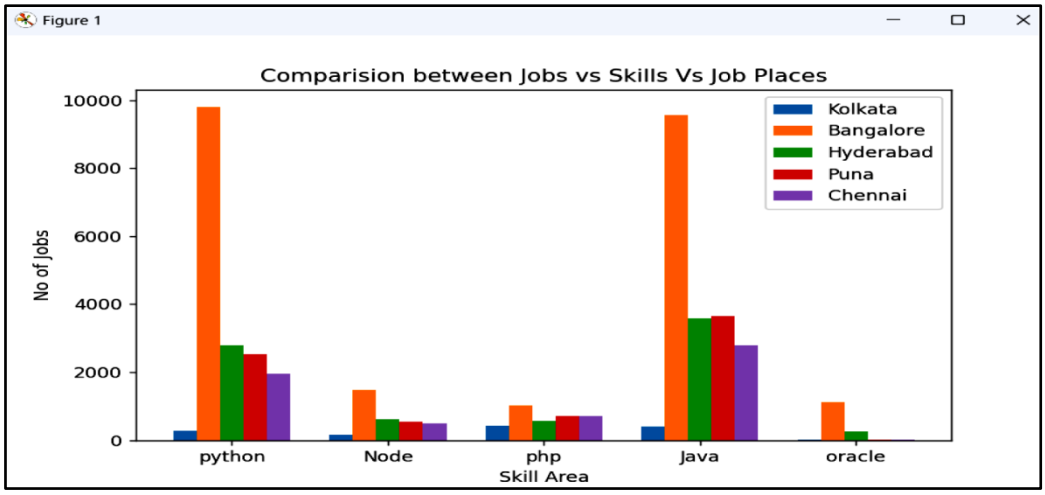

**Figure 5** Comparative study of different jobs in indeed site

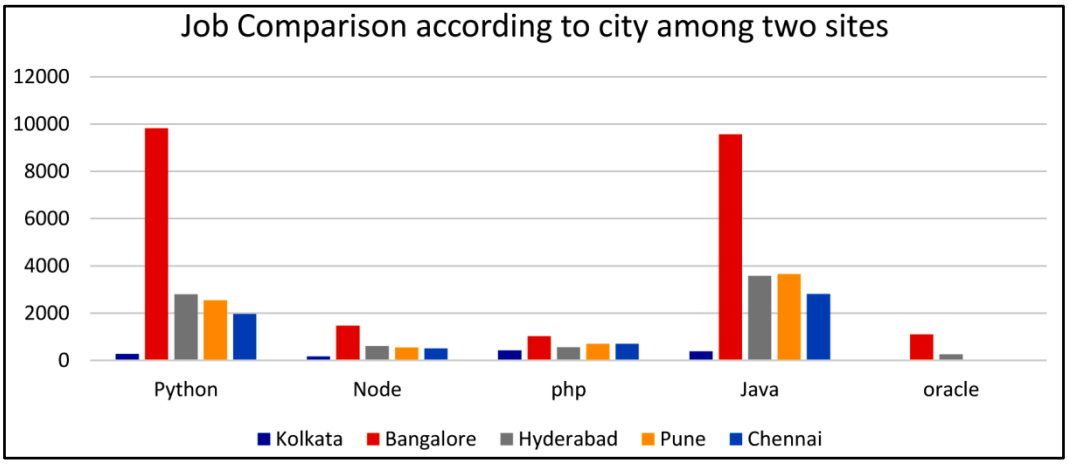
Output data from Link din
main_env) E:\VS_CODE\webscrapping>python Linkdin_scrap_0.py
[0 1 2 3 4]
Time taken 24 sec

**Table 2** Jobs numbers of different places.

| LinkedIn site | Kolkata | Bangalore | Hyderabad | Pune | Chennai |
|---|---|---|---|---|---|
| Python | 264 | 9815 | 2795 | 2536 | 1957 |
| Node | 163 | 1472 | 612 | 545 | 505 |
| php | 417 | 1026 | 563 | 698 | 697 |
| Java | 385 | 9563 | 3574 | 3656 | 2808 |
| oracle | 4 | 1106 | 254 | 8 | 6 |

Search in Link din SOCIAL MEDIA




## IV

## ADVANTAGES OF ANALYSIS & CONCLUSION

1) With this analysis anyone can get a clear idea in which state how many jobs are there and which site they will log which will reduce time and complexity for any Job seeker to make any decision.
2) Suppose anyone has the skill of Python then he/she can get a clear idea which site they will log on and where the number of job opportunities is higher.
3) Sometimes job seekers do not want to change location or they also get a clear idea of which other skills they

will upgrade themselves.

4) Students also get trends of the job market, skills, etc

## CONCLUSION

Natural Language Processing (NLP) has become pivotal in transforming job markets, mainly through social media platforms. Social media has emerged as a key resource for job seekers and recruiters. NLP enhances this process by efficiently analysing vast amounts of unstructured text data, such as profiles, posts, and interactions. It helps identify relevant skills, experience, and trends, bridging the gap between candidates and potential employers.

For job seekers, NLP-based tools like AI-powered resume builders, career recommendation systems, and interview preparation platforms help improve their visibility and match the right opportunities. On the employer side, NLP not only streamlines recruitment processes by analysing candidate profiles and identifying top talent but also instils confidence by predicting candidate success based on linguistic patterns. Additionally, social listening tools equipped with NLP help companies understand labour market trends, competitor activity, and candidate sentiment. Our algorithm is unique; no such algorithm has been developed to compare job analysis of user-choice able social media sites on one platform and reduce the search times of users. Time is a precious thing for all. If anyone gets all information in a single platform then the efficiency model is increases,

In summary, integrating NLP in the job market via social media platforms creates more efficient, data-driven, and intelligent hiring processes. As social media continues to grow as a key hiring avenue, NLP's role will likely expand, shaping the future of job recruitment and career development.

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# Novel Data Imputation Technique for Mental Health Prediction

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***Abstract:*** *Artificial intelligence and machine learning developments have greatly enhanced mental wellness. providing insights into various mental disorders. This study uses the Relational Data Imputation (RDI) technique to identify susceptible mental disorders early, aiming to reduce disease severity.Algorithms for deep learning and machine learning are critical for early detection of mental diseases, improving social and general well-being. Here, we use different algorithms with the likes of Support Vector Machine (SVM), regression learning, natural language processing (NLP), and random forest classification (RFC). All mental disorders differ from one another; thus, understanding different datasets for different mental diseases is important. The dataset we used has some missing values that have a greater impact on the model and its accuracy. We are proposing a Relational Data Imputation (RDI) technique to replace missing values in health-h-related data. Using the RDI Imputation method, we consider all mental health diseases in a single platform and identify them, which have not been previously performed. By applying the suggested RDI method, we want to increase the effectiveness of the machine learning and deep learning models that are presently being utilized for the early identification and categorization of mental diseases.*

***Keywords:*** *Alzheimer's Disease (AD); Dementia; Parkinson Disease's (PD); Bipolar Disease (BD); Schizophrenia Disease (SD); Mental Health*

The Paper is organized as follows Section I Introduce subject matter and literature review. Section II states the proposed methodology, in section III we performed experiment by discussing different models and evaluation matrices, In section IV result is discussed, Conclusion and future scope is defined in section V, Reference is given at section VI , at the end abbreviation and acronym is given in section VII.

## INTRODUCTION

Mental health is crucial for emotional, social, and psychological well-being, affecting our activity, thought processing, and overall well-being. Both our physical and mental health are impacted by common brain illnesses such schizophrenia, bipolar illness, Parkinson's disease, and Alzheimer's disease. Parkinson disease, a prevalent and deadly brain degenerative disorder, has doubled in number over the past 25 years, affecting all body parts and causing tremors. Schizophrenia affects individuals aged 16-30, while manic depression is a severe mental condition characterized by abrupt swings in behavior. Early identification and intervention are essential for addressing these non-treatable mental health issues.

## TYPES OF MENTAL DISORDER

Schizophrenia, a mental disorder characterized by delusions, illusions, neurosis, and decreased motivation, is a serious illness affecting young individuals under 30. MRI may be helpful in identifying the disorder, as there is no proven biomarker for it. Dementia, a progressive neurological disorder, primarily affects cognitive functions, leading to significant impairment in memory, thinking, behavior, and daily functioning. Early detection is crucial for timely treatment and improving patient outcomes. Bipolar brain disorder, also known as manic disorder, is characterized by major mood swings and changes in individual behavior. There is no known treatment for bipolar disorder, but proper management and care can minimize the post-effect of these episodes.

## LITERATURE REVIEW

This research paper discusses the use of Propose Imputation method in databases for eradicating missing values in health data. It highlights the superiority of DL-based data imputation methods over non-DL-based ones.Other imputation methods that employ hidden layers for input processing and data distribution capture are Multi-layer Perceptron (MLP), Recurrent Neural Network (RNN), and GAN.

**Table 1** Tabular representation of the literature survey on mental helath using different machine learniong model and different health dataset

| Reference | Data Type | ML Application (Approach) | Purpose | Motivation | Mental Disorder |
|---|---|---|---|---|---|
| Srinivasagopalan et al[10] | MRI Scanner Image | Implementation of the deep learning technique schizophrenia. | Detecting symptoms/condition of the occurrence of schizophrenia . | To assist in the early diagnosis of schizophrenia using machine learning model | Schizophrenia |
| Bae,Y at al [11] | Public post was collected from the reddit. | Uses Supervised learning Approach | Detecting symptoms/condition for the occurrence of schizophrenia | It Shows 96% accuracy. | Schizophrenia |
| Winterburn et al [12] | Three independent dataset from Centre for Addiction and Mental health (CAMH) | Models like LR, SVM and LDA | Detecting symptoms/condition of Schizophrenia | Classification of the schizophrenia using the given feature set. | Schizophrenia |
| Rabbi et al.[13] | Multiple(audio +activity) | The study focuses on developing a multi-modal mobile sensing device that passively senses common speech in naturalistic settings to assess mental and physical health simultaneously. | Detecting symptoms/condition | To keep an eye on someone's mental health using inexpensive, easy, secure, and privacy-protecting mobile sensing. | Mental health (generic) |
| Cao et al[14] | Mobile phone(acceleration) | The project aims to develop an architecture that mimics the typing dynamics of a mobile phone to infer emotional states in bipolar patients using a late fusion technique. | Detecting symptoms/condition | to support patients' everyday life in the subtle diagnosis of mental illnesses. | Bipolar |
| Arroyo-Gallego et al [15] | Mobile Touch screen typing | Utilizing machine learning methods to forecast motor decline in Parkinson's disease patients. | Identifying the motor impairment in PD. | Analyzing the touch screen feature of the person and monitoring the PD motor feature. | Motor Impairment in Parkinson disease (PD) |
| Basheer et al[16] | OASIS | M-Capsule Net | Identification Alzheimer's Dementia | Prediction of Dementia on the basis of the standard static data of the patient with Dementia or no dementia | Alzheimer's Dementia |
| Yi-WeiChien et al [17] | ADNI | CRNN | Identification Of Dementia | Identification of Dementia in a patient. | Dementia |

Features from the database are represented in the histogram format as seen in **Figure 1**. It shows the dynamics of the features available. The histogram gives the count of the Particular part in the dataset.SES, Visit, MR Delay, Age, EDUC, SES, MMSE, CDR, e TIV, m WBV, and ASF are the features of the dataset OASIS dataset

## PROPOSED METHODOLOGY

**Figure 2** displays the algorithm's work flow structured says that null values are removed and the database is displayed. Required features are considered. The feature correlation matrix is drawn. The dynamics of the feature are calculated using a histogram, heat map, and cat map. Standardization of the feature is performed. Logistic Regression classification model, KNN classification model, SVM model, Random forest classification model, k-fold classification model, and K-neighbor classification are applied to the sample data. The analysis is done by comparing the algorithms. Their accuracy is reached for the same data set. Dementia is predicted from the given set of observations from the above algorithm. Different accuracy value is calculated for the dementia prediction.

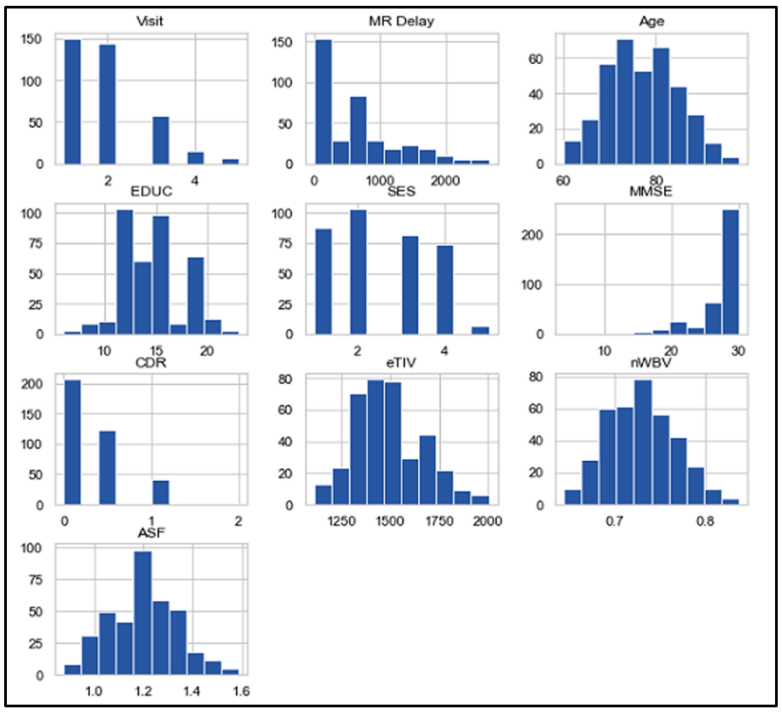


**Figure 1** Dataset visualization of OASIS dataset

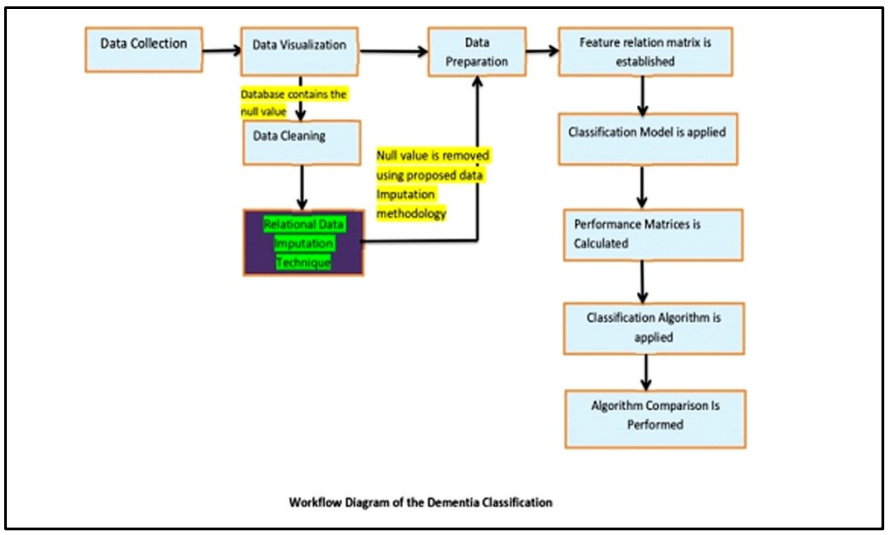


**Figure 2** Workflow diagram of the algorithm

### A. Dataset

As there are many mental health disease or difficulties. Such as Dementia, Schizophrenia, Parkinson, PSTD, Bipolar, Stress, Depression. Each of this needs to be identified as soon as possible to provide the early support to the patient. All these disease can be identified using different dataset for different mental health problem. Dataset are of different types like audio clinical data records, questionnaire dataset, protein dataset and many more. The different databases are ADNI, OASIS, and PPMI etc.

### B. Data PreProcessing

[18, 19, 20]The suggested machine learning model's precise method and algorithm are described in this section.. The proposed model is directed towards building a model which can be applied on the OASIS dataset to classify dementia with greater accuracy. Here in the model, Random forest classifier is used on the database. The database is cleaned of having null values. Here, data imputation technique is used to eliminate the missing value problem in the database as it is shown in **Figure 7**. The detailed algorithm is stated below, in this algorithm, the input is the database with missing values in the feature column. In the first instance the Missing value is calculate using the function isna ().sum. It gives the total number of missing values for each dataset column. A sorted correlation matrix is created, with the missing data placed in the appropriate column. Highly correlated data column coupled with the column. Let $\alpha$ denotes the column with missing values and $\beta$ denotes the column with highly correlated dataset column. The index of the null value of $\alpha$ is calculated. Let it be $\alpha_i$. Now I need to find the value in $\beta$ at i. Let it be $\beta_i$. If $\beta_i$ is also Null then it will revert back to couple with the next correlated data column. If it is not NULL, $\beta_i$ will search for its closest value in the column. Named it $\beta_j$. For this $\beta_j$ corresponding value in $\alpha$ is calculated and named it as $\alpha_j$. Finally, $\alpha_j$ gets placed in missing value place that means $\alpha_{i=}\ \alpha_j$. The database once gets updated with imputed value, can be used for a classification model for dementia.

## EXPERIMENT

The above study was experimented using a machine with the confirmation of 320GB SSD, 4GB RAM, Intel core i3 processor. An open library of Google collaborators has been used for the simulation to operate. The machine learning model is created using the keras library, while the machine learning classifier is created using the scikit-learning package.

### A. Machine Learning Model

Among the machine learning models are the KNN classification model, logistic regression classification (LR), CART classification model, linear discriminant analysis (LDA), and Random Forest classifier. LR uses binary classification, with the logistic function converting input features into binary outcomes. KNN is simple but expensive for large datasets. CART uses a binary decision tree, while LDA computes scatter matrices for bio-informatics, image processing, and pattern recognition.

### B. Evaluation Metrics

When assessing how well artificial intelligence models are employed, classification criteria are important. Accuracy, precision, recall, F1-score, ROC-AUC, and confusion matrix represent a few of these standards. Precision measures the proportion of true positive predictions among all positive forecasts, whereas accuracy measures the percentage of correctly classified instances. The percentage of genuine positive anticipates among all actual positives is shown by recall. The balanced harmonic mean of these metrics yields the F1-score, which is helpful in situations where class probabilities are not uniform or if the costs of false positives and false negatives differ. True positives, false positives, and false negatives are defined by the confusion matrix, but ROC-AUC gives a balance between cutoff values and the true positive rate. These measurements aid in the comprehension of how well classification algorithms function.

Accuracy = (Number of Correct Prediction) / (Total number of prediction)

Precision = (True Positives) / (True Positives + False positive)

Recall = Truepositives / (TruePositive + FalseNegative)

F1-score = 2*PrecisionXRecall / (Precision + Recall)

By taking into account both accurate and inaccurate predictions as well as the balance between different mistake kinds, these metrics aid in the understanding of the performance of classification algorithms. It's essential to choose an appropriate metric or metrics based on the needs of the assignment and the problem environment.

## RESULT AND DISCUSSION

On Searching for the best model for the identification of the dementia we have compare the results of different machine learning model. When the dataset were not pre processed and used without any data Imputation method and again with Proposed Imputation method. Accuracy of the result is compared in the table below.

**Table 2** Comparative dtudy of the acuracy obatined without applying any imputation technique with the novel RDI technique

| Classifier Model | Accuracy in percentage (OASIS database without imputation) | Accuracy in percentage (OASIS database with our novel imputation technique) |
|---|---|---|
| Linear Regression Model | 75 | 81 |
| Linear Discriminant Analysis | 70 | 79 |
| K Nearest Neighbor | 65 | 82 |
| Classification and Regression Tree | 72 | 88 |
| Support Vector Machine | 76 | 89 |
| Random Forest Classifier | 78 | 95 |

In **Table 2**, it is evident through the table of comparisons that imputation has an essential part in enhancing the accuracy of progress identification when comparing a model trained on an OASIS dataset without cleaning, or without imputation, to a model built on a dataset containing imputation. The random forest classifier performs superior to all other machine learning models in the classification of dementia, as shown by the table above.

**Table 3** Comparative study on accuracy obtained through standard imputation technique and rdi technique

| Classification Model | Accuracy (Standard Method like mean, mode etc) in Percentage (%) | Accuracy (RDI) in percentage (%) |
|---|---|---|
| Logistic Regression | 80.5 | 79 |
| Linear Discriminant Analysis | 79 | 80 |
| K Nearest Neighbor | 82 | 84 |
| Classification and Regression Tree | 88 | 88 |
| Naive Bayes | 79 | 76 |
| Support Vector Machine | 81.5 | 89 |
| Random Forest classifier | 86.8 | 94 |

Using the Relational Data Imputation Method, the mean cross-validated score of the best estimator is 0.958; however, in the case of generic data Imputation Methods like mean, median, and interpolation technique, this is 0.939. The parameter setting that produced the best results on the holdout data was {'min_samples_split': 4, 'n_estimators': 900}. Obviously, this data imputation technique provides the better result.

## CONCLUSION AND FUTURE SCOPE

The development of a system to accurately identify mental illnesses involves database understanding, description, feature selection, and data processing techniques. The model is selected based on performance matrix, demonstrating increased robustness and accuracy. The incorporation of cutting-edge technologies and creative ways has led to an increase in mental health diagnosis accuracy. To address the growing challenges, generic methods like Recurrent

Neural Networks, MLP, mean, median, and interpolation methods are used for imputation of missing values. Future research aims to develop imputation methods for any size of data base.

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## ABBREVIATION AND ACRONYM

RDI: Relational Data Imputation

323_IEC7296

# XceptionNet: A Truly Exceptional Deep Learning Network for Brain Tumor Characterization

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***Abstract:*** *In recent years, brain tumors have emerged as a crucial health concern worldwide. Improving patient outcomes depends on the early and accurate diagnosis of brain tumors and guiding treatment decisions. In this paper, seven leading deep learning networks i.e. ResNet-152, VGG-16, LeNet-5, XceptionNet, Residual Attention Network, GoogleNet and MobileNetV2 have been examined to characterize brain tumor from MRI images as "No Tumor", "Glioma", "Meningioma" or "Pituitary". Based on training and evaluation on a publicly available popular dataset, XceptionNet is found to perform exceptionally well in comparison with other networks (100% classification accuracy). In future, further exploration may be done to locate the tumorous region and map with corresponding tumor category to foster computer assisted diagnosis of brain tumors.*

***Keywords:*** *XceptionNet; Brain Tumor Classification; MRI Images; Computer Assisted Diagnosis; Deep Networks*

## INTRODUCTION

The artificial intelligence, human capabilities, and machines are steadily shrinking. Specifically, deep learning has many problem domains such as object detection, image segmentation, automated image labelling, natural language processing, video analysis, big data, and so on. The architecture of convolutional neural networks (CNNs) is widely used in deep learning, as is their ability to automatically identify relevant features without requiring any human supervision. The architecture of CNNs is inspired by neurones found in humans and animals. The effectiveness of CNNs has already been proven through their performance, efficiency, robustness, and low complexity. In this paper, seven leading CNN architectures such as LeNet-5, VGG16, GoogLeNet (Inception), ResNet-152, XceptionNet, MobileNet-v2, and the Residual Attention Model have been employed in Combination of MRI Brain Tumour (Figshare, SARTAJ dataset, Br35H).

The classification of the brain tumor is a serious task in the field of medical images, as early and accurate diagnoses are important for effective treatment planning. Deep training and medical visualisation expertise, automated systems for classification and detection brain tumours, as well as magnetic resonance visualisation (MRI), are widely used to analyse the brain tumour due to their resolution of high contrast and their non-invasive nature. In this study, the focus is on the classification of brain tumours using a combination of datasets (Figshare, SARTAJ, and Br35H), which are MRI brain tumour images. The MRI image dataset consists of different types of brain tumours, such as gliomas, meningiomas, and pituitary. The main purpose of these is to develop an effective, reliable, and low-complexity classification system that can accurately identify the type of tumour.

## RELATED WORKS AND MOTIVATION

To explore transfer learning techniques to overcome the challenge of limited annotated medical data. Sheeta et al. [4] used the pre-trained deep learning-based model VGG-16 for brain tumor classification. compared enhance accuracy for the dataset of MRI images and fine-tune the model.

In recent years, brain tumor classification has made significant strides. Convolutional neural networks (CNNs) and other deep learning architectures for brain tumor classification in MRI images. Saravanan, et al [5] Hybrid deep learning model that combines CNNs with techniques like Grey Wolf Optimizer (GWO). This technique achieves classification accuracy up to 98% in some cases. improve model accuracy and reduce redundancy of MRI dataset.

Helen, D. et al. [6] U-Net architectures are used for classification and segmentation tasks in brain tumors; this work is a is a combination of CNN and U-Net for brain tumor in an MRI dataset. Ensemble learning and transfer learning to

improve classification across different tumor types, such as gliomas, meningiomas, and pituitary tumor.

**Our Proposed Architecture Xception**

Xception stands as a short name for extreme inception. It was introduced by Francois Chollet in 2016 as a variation of inception architectures to improve both efficiency and performance of CNNs for image classification and other computer vision tasks. Xception architecture accepting an image input of the size 299 × 299 with the channel size 3, which is RBG colour. Xception architecture is a powerful pre-trained convolutional neural network that is used for feature extraction. 2048-dimension feature map xception model of the output. The model flattens the 2048-dimensional output into a one-dimensional vector, and on the other hand, it is preparing for further processing by a fully connected layer. To prevent overfitting, a dropout layer is applied after flattening and during the training, randomly dropping 50% of the units. The next layer is a dense, fully connected layer with 128 units; finally, the model has a dense output layer, which is 4 units. This model is designed for a classification task as well as an identification task with four possible classes.

**EXPERIMENTAL RESULTS**

**Overview of Dataset(s)**

In this study, a combination of three types of datasets these are figshare, SARTAJ dataset, Br35H, this brain tumor MRI dataset [3], is used. There are 7023 component images in all four classes, including 1621 glioma images, 1645 meningioma images, 1757 pituitary images, and no-tumor component images are 2000. This dataset spit into training, validation and testing. The training set contains 5712 validation set 655 and testing unknown sample set contain 656. A briefly describe outline of the dataset for the experiments conducted is included in **Table 1**.

**Table 1** Overview of the image data employed in this study

| Dataset(s) | #Category | #Training Samples | #Test Samples | Total |
|---|---|---|---|---|
| Combination of MRI Brain Tumor (figshare, SARTAJ dataset, Br35H) [3] | Glioma | 1,321 | 300 | 1,621 |
| | Meningioma | 1339 | 306 | 1,645 |
| | Pituitary | 1457 | 300 | 1757 |
| | No-Tumor | 1595 | 405 | 2000 |

**MRI Brain Tumor Classification Performance**

Performance of the employed CNN architectures has been obtained MRI Brain Tumor images Combination of (figshare, SARTAJ dataset, Br35H) **Table 2** reflect the experimental results of these experiments.

**Table 2** Performance of CNN architectures for Brain Tumor Classification

| Model | Precision | Recall | F1-Score | Accuracy |
|---|---|---|---|---|
| ResNet152 | 0.6946 | 0.7027 | 0.7778 | 70.27% |
| MobileNetV2 | 0.8625 | 0.8591 | 0.8596 | 85.91% |
| VGG16 | 0.9029 | 08994 | 08996 | 89.94% |
| GoogleNet | 0.9913 | 0.9911 | 0.9912 | 99.13% |
| XceptionNet | 1.0 | 1.0 | 1.0 | **100%** |
| Residual Attention | 0.8300 | 0.6863 | 0.6250 | 68.73% |
| LeNet-5 | 0.9417 | 0.9421 | 0.9418 | 94.22% |

It may be noted from **Table 2** that among the seven architectures XceptionNet produced the best performance on Combination of MRI Brain Tumor images (figshare, SARTAJ dataset, Br35H) classification with the highest accuracy of 100%.

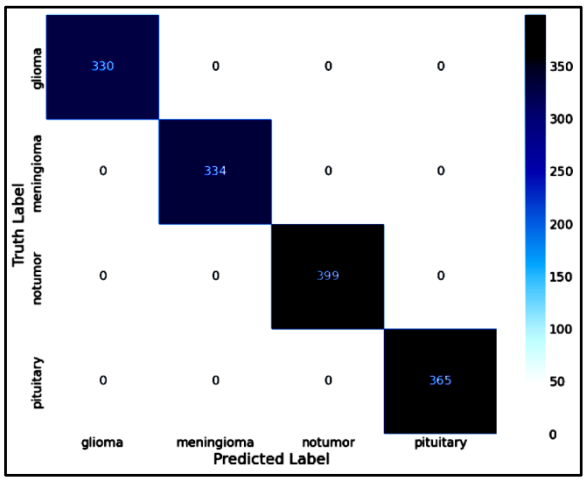


**Figure 1** Confusion matrix of proposed architecture

**Table 3** Comparison with the state-of-the-art performance

| Dataset | Method | Precision | Recall | F-Score | Accuracy |
|---|---|---|---|---|---|
| rs-fMRIdataset [1] | Ramzan et al. [1] | - | - | - | 97.92 |
| BraTS [2] | Sultan et al. [2] | - | - | - | 96.13 |
| Figshare, REMBRANDT, TCGA-LGG, TCIA [5] | Saravanan, et al. [5] | 0.9763 | - | - | 98.56 |
| MRI Dataset [6] | Helen, D et al. [6] | 0.9700 | 0.9700 | 0.9500 | 95.00 |
| MRI Brain Images [7] | Wasif, et al. [7] | - | - | - | 97.60 |
| Figshare, SARTAJ dataset, Br35H [3,8] | Md Monirul, et al. [8] | 0.9825 | 0.9800 | 0.9825 | 98.40 |
| Figshare, SARTAJ dataset, Br35H [3,9] | Marco Antonio, et al. [9] | 0.9797 | 0.9659 | - | 97.12 |
| Figshare, SARTAJ dataset, Br35H [3,10] | Nadia, et al. [10] | 0.9810 | 0.9820 | 0.9910 | 98.70 |
| Figshare, SARTAJ dataset, Br35H | Proposed | 1.0 | 1.0 | 1.0 | 100 |

## CONCLUSION

In this paper, computer assisted automatic brain tumor diagnosis from MRI images has been studied with seven leading transfer learning based pre-trained deep learning networks. It aims to identify the tumor-type if there is any tumor at all, else it reports as a normal sample. While MobileNetV2, VGG16 and ResNet strive to achieve 90% accuracy, LeNet, GoogleNet and XceptionNet produced over 90% correct prediction. Specifically,

GoogleNet and XceptionNet performed really well (99.13% and 100% respectively). This implies that XceptionNet is really powerful in brain tumor diagnosis. In future, the proposed model can be applied to various other MRI datasets as well as CT images.

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325_IEC17124

# Applications of Textural Features and PCA on Facial Recognition after Medical Alterations

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***Abstract:*** *Numerous algorithms have encountered difficulties in identifying the face, which remains unaffected by plastic surgery due to variations in skin texture. Even though plastic surgery presents a difficult problem for face recognition, the issue needs to be reconsidered from both theoretical and experimental angles. This paper presents a new approach to face recognition by using textural image features like local ternary patterns (LTP) and binary patterns (LBP). The support vector machine (SVM) is trained using numerous principal component analysis (PCA) method versions, which reduce the feature dimensionality. In order to train a support vector machine (SVM) model to recognize medical alteration faces, this paper takes advantage of textural features, which are highly associated with changes in face recognition. Images retrieved from the database of plastic surgery are used to train the SVM classifier model. Following the conversion of the dataset into LBP, features were extracted from the LTP image using PCA and 2D-PCA. Using 452 plastic surgery faces, procedures such as blepharoplasty, brow lift, liposhaving, malar augmentation, mentoplasty, otoplasty, rhinoplasty, rhytidectomy, and skin peeling were attempted. Tests conducted on a plastic surgery database demonstrate the suggested approach's competitiveness in comparison to certain subspaces-based techniques currently in use.*

***Keywords:*** *Plastic Surgery Face Recognition; Principle Component Analysis; LBP; LTP; SVM*

## INTRODUCTION

Human faces are multifaceted, intricate visual stimuli that reveal an infinite amount of insightful information about an individual's uniqueness. In the current era of image analysis and computer vision, face recognition has taken a new turn for security and authentication purposes. Examples of these applications include biometric authentication, surveillance, image retrieval, and human-computer interaction [1]. Typically, a face recognition system can perform recognition without the need for human interaction or the sense of touch. It is among the benefits of face recognition over alternative methods of recognition. Face recognition can indicate whether a phase is being verified or identified. The matching between two faces is resolved during the verification phase. Numerous techniques exist for achieving face recognition [2]. However, recognition accuracy isn't always high. This can be attributed to aging, varying lighting conditions, poses, low-resolution input images, or facial marks. To address the effects of pose, illumination, low resolution, aging, or a combination of any of them, several researchers have implemented various face recognition methodologies [3]. These doubts, though, are manageable to overcome, and in the case of plastic surgery faces, identification of the individual intensifies recognition even further [4]. Lack or variation in face components, skin texture, overall face appearance, and the geometric relationship between the various facial features all contribute to the inability to recognize faces that have undergone plastic surgery [5]. People from all over the world have been drawn to plastic surgery because it is both an affordable and sophisticated procedure. In order to address the issue of more precisely identifying plastic surgery faces, Sable et al. contribute the EV-SIFT methodology to the literature [6]. Some researchers are discuss a couple of plastic surgery based features, and local region analysis recognition [7, 8]. Additionally, a review has been conducted in [9] to demonstrate how multimodal features are used to identify plastic surgery based on contributions. The paper's contribution focuses on three sets of demonstrations. Maria De Marsico et al. [10] have applied region-based techniques to a multimodal supervised collaborative architecture known as Split Face Architecture (SFA) to achieve accurate facial recognition after plastic surgery. By comparing the Supervised SFA to FDA, conventional PCA, LBP in the Multiscale, Rotation Invariant version with Uniform Patterns, FARO (Face Recognition against Occlusions and Expression Variations), and FACE (Face Analysis for Commercial Entities), they have demonstrated the superiority of their methodology. The MPDL framework, developed by Naman Kohli et al. [11], does not attempt to compute norms for identifying typical faces, even if those faces have undergone

plastic surgery. Several projective dictionaries and compact binary face descriptors have been utilized to acquire the local and global representations of plastic surgery faces. This has made it easier to distinguish the plastic surgery faces from the original ones. Approximately 97.96% accuracy was achieved in the testing conducted on the plastic surgery database. Despite changes in illumination, expressions, and facial modifications resulting from plastic surgery, Chollette C. Chude-Olisah et al. [12] have overcome the degradation in face recognition performance and discovered that their approach outperforms the previously available plastic surgery face recognition approaches. This algorithm generates overlapping face granules at three different levels of granularity initially. Face recognition in plastic surgery has seen a number of advancements recently.

The rest of the parts of the paper are planned as follows. Section 2 describes material and methods.. The experimental results have been discussed in the Section 3. Lastly, Section 4 describes the conclusion.

## MATERIAL AND METHODS

The underlying theory is that a face can be identified by the human brain simply by focusing on the textural image. We suggest comparing LBP + PCA, LBP + 2DPCA, LTP + PCA, and LTP + 2DPCA in this section in order to take advantage of this. The proposed method's schematic diagram, which includes the necessary steps, is displayed in **Figure 1**. We transform the original face images into two formats: (i) LBP images and (ii) LTP images. To extract features and reduce dimension from these textural images, we have employed 2DPCA and PCA techniques.

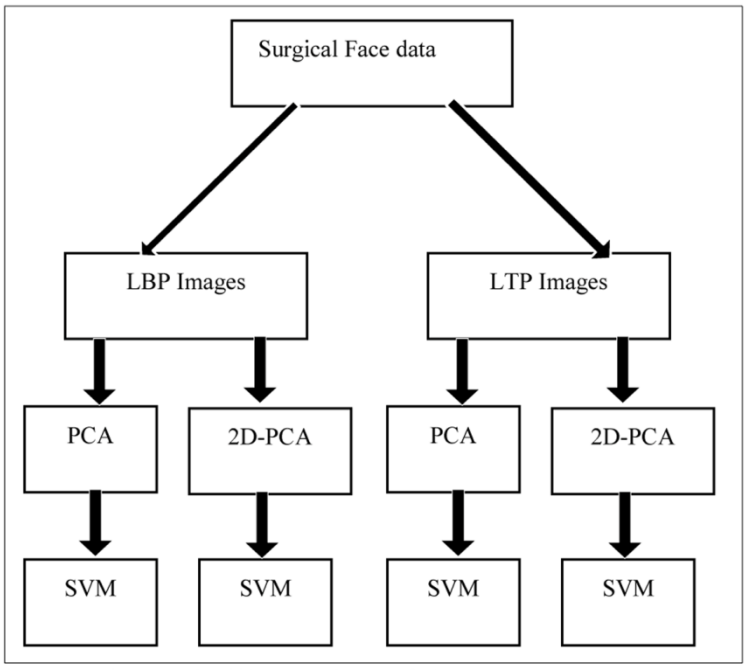


**Figure 1** Schematic illustration of the proposed approach

### Textural Face Creation using Local Binary Patterns (LBP)

Because of its highly discriminative texture localization features [2], the LBP operator is widely used in many computer vision applications. Because of their monotonic gray-level change invariance property, LBP operators can be helpful. LBP is referred to as a picture's textural feature descriptor. An essential low-level feature in images is the texture feature, which is used to characterize an image's contents or a specific area of it. Texture can be characterized as grained, coarse, smooth, fine, etc. Compared to regular greyscale images, textures provide more information about the image. Local Binary Pattern Recognition (LBP) involves sampling image pixels and comparing the value of the central pixel to the values of its eight neighboring pixels. In the event of a negative outcome, pixel values are encoded as 0, and in the other case, as 1. An anticlockwise or clockwise sum of the binary numbers for each set of eight neighboring pixels is then determined, starting with the top left pixel. Finally, the decimal value of the image's $3 \times 3$

pixel section is calculated. Until the entire image has been processed, the procedure is followed. The outcome is the conversion of the greyscale image into an LBP image, which is its final form.

$$LBP_{P,R}(x_c, y_c) = \sum_{p=0}^{p-1} s(g_s - g_c)2^i \quad (1)$$

where $g_c$ and $g_s$ represents the grey-level values of the central pixel and s surrounding pixel.

$$s(x) = \begin{cases} 1, & if\ x \geq 0 \\ 0, & if\ x < 0 \end{cases} \quad (2)$$

**Textural Face Creation using Local Ternary Patterns (LTP)**

A new textural operator [2] called LTP; which is more resilient than LBP when handling noise. The LTP operator is an extended form of the LBP operator, utilizing 3-valued code, like −1, 0, 1. LTP can be mathematically explained by using **Eq. 3**:

$$s'(u,i) = \begin{cases} -1, & (u-i) < -t \\ 1, & (u-i) > t \\ 0, & else \end{cases} \quad (3)$$

where u and i stand for the intensity of the central pixel and the $i^{th}$ pixel, respectively, and t is the threshold value. The upper and lower halves are generated and encoded following the threshold computation. The upper and lower half codes are then concatenated to create the final LTP image.

**PCA Method for Dimension Reduction**

A popular method for both feature extraction and data representation, principal component analysis (PCA) [13] is frequently used to reduce the dimension of feature vectors. Given that face images are points in a high-dimensional image space, classification and recognition require a significant amount of processing time.

Let N be the total number of training images. The training images contain C classes (subjects), and the $c^{th}$ class $C_C$ has $N_C$ samples satisfying $\sum_{c=1}^{C} N_c = N$. The covariance matrix E can be defined as follows:

$$\boldsymbol{E} = \frac{1}{N}\sum_{i=1}^{N} (\boldsymbol{F}_i - \overline{\boldsymbol{F}})(\boldsymbol{F}_i - \overline{\boldsymbol{F}})^T \quad (4)$$

Let D = ($D_1$, $D_2$, ..., $D_l$) be the set of l (l < (r × s)) eigenvectors of the covariance matrix E corresponding to the l largest nonzero eigenvalues. The reduced feature matrix $Y_i$, corresponding to $F_i$, is obtained by the following linear transformation:

$$\boldsymbol{Y}_i = \boldsymbol{D}^T \boldsymbol{F}_i;\ \ i = 1, 2, 3, \ldots, N \quad (5)$$

**2DPCA Method for Dimension Reduction**

The image matrix does not need to be converted into a vector before feature extraction because 2DPCA [13] is based on 2D image matrices rather than 1D vectors. Rather, the original image matrices are used to directly construct an image covariance matrix, from which the eigenvectors are extracted for the purpose of extracting image features. Let X represent a unitary column vector with n dimensions. Our plan is to use the following linear transformation to project image A, a m × n random matrix, onto X:

$$\boldsymbol{Y}_i = A\,\boldsymbol{X}_i;\ \ i = 1, 2, 3, \ldots, N \quad (6)$$

Consequently, the projected feature vector of image A, or Y, is obtained, and it is an m-dimensional vector. The covariance matrix trace of the projected feature vectors can be used to characterize the total scatter of the projected samples.

**Support Vector Machines**

By maximizing the margin between the classes, the support vector machines (SVM) determine the ideal separating hyper plane to divide them. Initially, it was intended to solve binary SVM, a two-class problem. The multi-class pattern recognition problems are then solved by ensembles of multiple binary SVMs. The implementation of SVM in detail is covered in [2].

Let the N labeled training samples be $\{(\boldsymbol{X}_i, y_i)\}_{i=1}^{N}, \boldsymbol{X}_i \in \Re^d, y_i \in \{+1, -1\}$. From this training samples, SVM finds a vector W and scalar b for the optimal hyper plane such that (W.X) + b = 0, W$\in \Re^d$. The classification decision function with respect to an input sample X is represented as follows:

$$f_X = sign(\boldsymbol{W}.\boldsymbol{X} + b) \quad (7)$$

**EXPERIMENTAL RESULTS**

The experiment of face recognition is shown using pre- surgery and post surgery faces. The data base for the pre-surgery and post surgery faces are downloaded from the URL: http://www.locateadoc.com/pictures/. In the corresponding data base, the pre-surgery and post surgery faces of 515 persons are present. The sample images of the database are shown in **Figure 2**.

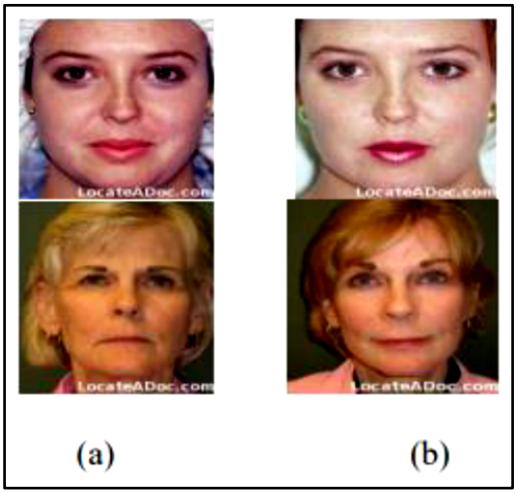


**Figure 2** Sample person of the data base (a) Pre-surgery faces (b) Post surgery faces

One aspect of all plastic surgery procedures is that they all involve some form of facial modification that deviates from the original. There are two main categories into which plastic surgery falls. The classification of surgery is carried out based on the percentage of surgical procedures. The degree and type of feature modification will determine this. The types of plastic surgery that fall under this category include the following:

1. Local surgery: This type of surgery is used to remove birthmarks, correct anomalies, counteract the effects of aging, and erase unintentional marks. Plastic surgery for disease correction is another name for local surgery. Rather than altering the entire region globally, it only modifies a portion of the face locally.
2. Global surgery: With this type of procedure, the entire texture of the face can be changed. Another name for this is a full facelift. This kind of surgery is typically advised in cases of fatal flame and bruise. It is predicated on the surgical process, wherein an individual can perform any type of surgery as needed (Eyelid surgery, Nose surgery, Otoplasty, Lip augmentation, Skin peeling) [4].

**Table 1** Performance evaluation of the cutting-edge technique using the surgical face database

| Te | Surgery | LFA (%) | GNN (%) | SURF (%) | PCA (%) | CLBP (%) | LBP + PCA (%) | SVM | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | LBP + PCA (%) | LBP + 2D PCA (%) | LTP + PCA (%) | LTP + 2D PCA (%) |
| Local | Dermabrasion | 25.5 | 43.8 | 42.6 | 20.2 | 42.1 | 53.7 | 54.2 | 54.4 | 54.8 | 55.1 |
| | Nose surgery | 35.5 | 54.3 | 51.5 | 23.1 | 44.8 | 62.4 | 62.7 | 62.9 | 63.2 | 63.5 |
| | Eyelid surgery | 40.2 | 61.4 | 53.9 | 28.3 | 52.1 | 72.3 | 72.5 | 72.8 | 73.1 | 73.4 |
| | Forehead surgery | 39.6 | 57.2 | 51.1 | 28.5 | 49.1 | 60.1 | 60.4 | 60.8 | 61.1 | 61.5 |
| | Ear surgery | 60.7 | 70.5 | 66.4 | 56.4 | 68.8 | 77.6 | 77.9 | 78.1 | 78.4 | 78.8 |
| | Other local surgery | 41.4 | 58.9 | 62.6 | 26.4 | 52.4 | 70.9 | 71.1 | 71.3 | 71.7 | 71.9 |
| Global | Facelift | 21.6 | 42.1 | 40.3 | 18.6 | 40.9 | 60.2 | 60.6 | 60.9 | 61.2 | 61.4 |
| | Skin Resurfacing | 40.3 | 53.9 | 51.1 | 25.2 | 53.7 | 69.6 | 69.8 | 69.9 | 70.2 | 70.6 |
| | Over all | 37.8 | 53.7 | 50.9 | 27.2 | 47.8 | 67.3 | 67.8 | 68.2 | 68.7 | 69.3 |

## CONCLUSION

This paper offers a thorough performance analysis comparing several PCA feature extraction and dimension reduction techniques for face recognition applied to a variety of textural images. The goal was to calculate textural information using all available textural image data (LBP, LTP) and determine which PCA technique produced the best discriminative features. The SVM was employed to classify data. Ultimately, it can be concluded that the efficiency of SVM performs better when the model is trained with LTP images and feature extraction with 2DPCA, after comparing various approaches of textural images and different versions PCA for surgical face recognition. Compared to regular greyscale images, transformed textural images contain lower-level information. As a result, the SVM model learned more effectively when it was trained on textural images as opposed to normal images, which have a higher level of information. So lower-level information is preferred as input to train SVM model to achieve the improved emotion detection accuracy. The LTP + 2DPCA method is more effective than other state-of-the-art methods for the task of face recognition using a support vector machine (SVM), according to the simulation results on the plastic surgery face database.

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327_IEC74465

# Hand Gesture Recognition for Deaf-Mute: Insights from RGB and RGB-D Driven Deep Networks

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***Abstract**: This paper presents a comprehensive comparative analysis of hand gesture recognition using two diverse datasets: the ASL Finger Spelling A dataset, which comprises both RGB and depth images, and the NUS Hand Posture dataset-II, containing only RGB images. The study evaluates the performance of state-of-the-art Convolutional Neural Network (CNN) architectures, namely, VGG19, Inception V3, and MobileNetV2, in recognizing hand gestures across these datasets. By training and testing these CNN architectures on both datasets, we assess their accuracy and generalizability across varying input modalities (RGB versus RGB-D). Our results provide a detailed comparison of these CNN architectures, highlighting their strengths and limitations in addressing the challenges of hand gesture recognition. We achieved a highest accuracy of 99.98% on the ASL Finger Spelling A dataset using RGB samples and the VGG19 network.*

***Keywords**: Hand Gesture Recognition; Convolutional Neural Networks; VGG19; Inception V3; MobileNetV2; RGB-D Images*

## INTRODUCTION

Hand gesture recognition has emerged as an essential area of research, particularly for developing communication aids for individuals with hearing or speech impairments. Automated systems that accurately interpret hand gestures or finger spelling can bridge the communication gap and enable more inclusive interactions in daily life. While gesture recognition has made considerable progress, accurately identifying static hand gestures, particularly from diverse data modalities like RGB and depth images, remains a challenge due to the subtle variations in hand positioning, lighting, and background noise.

Recent advancements in hand gesture recognition have been heavily driven by CNNs due to their capability to automatically learn spatial features from raw image data. Several CNN architectures, such as VGG, ResNet, and more recent models like Inception and MobileNet, have been widely explored for hand gesture recognition tasks. VGG-19, for example, has demonstrated strong performance due to its ability to extract deep hierarchical features, and it is effective for recognizing complex hand gestures [1]. Similarly, ResNet has been used successfully in gesture recognition by addressing the challenges of training deeper networks through its residual connections [2]. Furthermore, the combination of depth data with RGB images has shown potential for enhancing gesture recognition efficiency. Tekin et al. [3] highlighted that integrating RGB and depth data enables better differentiation of gestures that are visually similar in 2D but distinct in 3D space. This approach mitigates issues such as lighting variation and background clutter, which often pose challenges in visual recognition tasks.

Transfer learning has also become an essential technique in this field, where models pre-trained on large datasets like ImageNet are fine-tuned for specific gesture recognition tasks. Zou and Cheng [4] leveraged CNN-extracted features through transfer learning to achieve high recognition accuracy, even with limited labeled datasets. Although models like VGG-19 and ResNet-50 provide strong accuracy, their computational demands can make them unsuitable for real-time applications. Lightweight models like MobileNetV2 use depth wise separable convolutions to reduce computational complexity while maintaining competitive accuracy, making them suitable for mobile and embedded systems [5]. Recent research has introduced novel approaches to further improve hand gesture recognition systems. Miah et al. [6] proposed a multistage spatial attention-based neural network, which enhances the model's ability to focus on key areas of input data, improving recognition performance. Similarly, HyFiNet, introduced by Bhaumik et al. [7], uses hybrid feature attention mechanisms with multimodal data to achieve higher accuracy in recognizing gestures.

Despite these advances, limited studies provide a comparative evaluation of various CNN architectures, particularly in recognizing static hand gestures across multi-modal datasets (RGB and depth data). This research aims to fill this gap by comparing the performance of VGG-19, Inception V3, and MobileNetV2 on the ASL Finger Spelling Dataset A (with both RGB and depth data) and the NUS-II dataset (RGB only), offering insights into the trade-offs between accuracy and computational efficiency.

## METHODOLOGY

We have employed three CNN architectures, VGG19, Inception V3, and MobileNetV2, to evaluate hand gesture recognition performance. For datasets containing both RGB and depth images, each model processes the input data separately: first on RGB images, then on depth images, and finally on combined RGB and depth inputs. In contrast, for datasets that consist solely of RGB images, the models operate exclusively on those inputs. This approach allows for a comprehensive assessment of each model's performance across different data modalities. The accuracy of each model is recorded and analyzed.

### Datasets Description

In this work we have utilized two datasets: the ASL Finger Spelling A Dataset [8] and the NUS Hand Posture dataset-II [9]. The ASL Finger Spelling A dataset comprises RGB and depth images representing 24 static signs corresponding to each letter of the alphabet, excluding letters J and Z, which involve motion. The dataset was captured from five users across five sessions to ensure consistent lighting and background conditions, although the images vary in dimensions. All images in this dataset are in PNG format.

The NUS Hand Posture dataset- II consists of 2,000 hand posture images, categorized into 10 distinct classes. Each image is sized at 160 × 120 pixels and presented in RGB format as JPG files. Captured in various locations within and around the National University of Singapore (NUS), the dataset features hand postures set against complex natural backgrounds. The postures were performed by 40 individuals from diverse ethnic backgrounds, aged between 22 and 56. Each subject demonstrated the 10 different hand postures five times, relaxing their hand muscles between shots to introduce natural variations in shape and position. The 10 classes are labelled with the letters 'a' to 'j'. A snapshot of the RGB-D ASL Finger Spelling A dataset and the NUS II dataset is presented in **Figure 1**.

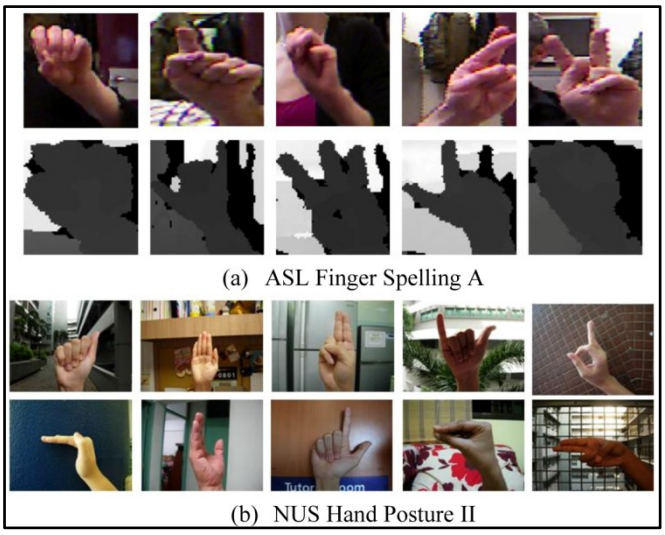


**Figure 1** Sample images from (a) the ASL Finger Spelling A dataset, which includes RGB-D images, and (b) the NUS II dataset, showcasing gestures in RGB format against cluttered backgrounds

### Architecture Overview

We have used three CNN architectures for hand gesture recognition in this work: VGG19, Inception V3, and

MobileNetV2. Each model processes images with the same input dimensions for both RGB and depth images, differing only in the number of channels. VGG19 uses 64×64, Inception V3 uses 75×75, and MobileNetV2 processes 128×128 inputs. RGB images have a 3-channel input, while depth images use a 4-channel input across all models.

VGG19 features 16 convolutional layers and is pre-trained on custom weights, utilizing two fully connected layers with 512 neurons, along with dropout and batch normalization to combat overfitting. Inception V3 employs multiple convolutional filter sizes to capture diverse features, followed by global average pooling and fully connected layers, also using dropout and batch normalization strategies. It is trained on the ImageNet dataset, enhancing its accuracy. MobileNetV2 is optimized for efficiency with depth wise separable convolutions and a compact architecture, balancing accuracy and computational load. Like Inception V3, it is also pre-trained on ImageNet.

Each model is trained with learning rate reduction techniques and optimized for gesture classification, handling 24 classes for the ASL Finger Spelling A dataset and 10 classes for the NUS II dataset. The models are evaluated using RGB, depth, and combined modalities to assess their recognition accuracy across the different datasets. These networks are trained using ReduceLROnPlateau with a patience value of 2, which reduces the learning rate when the validation loss plateaus over two consecutive epochs. A batch size of 128 has been used for ASL Finger Spelling, while a batch size of 32 has been used in the case of NUS Hand posture II. **Table 1** provides a comprehensive overview of the architecture details for each convolutional neural network employed in this work.

**Table 1** Detailed architecture specifications for the CNN models used

| Model | Input Size | Channels (RGB/Depth) | Learning Rate | Pretrained Weights | Top Layers | Optimizers | Epochs |
|---|---|---|---|---|---|---|---|
| VGG19 | 64 × 64 | 3 / 4 | 1e-5 | Custom | Dense (512), Dropout, BatchNorm | RMSProp | 25 |
| Inception V3 | 75 × 75 | 3 / 4 | 1e-4 | ImageNet | GlobalAvgPool, Dense (512), Dropout, BatchNorm | RMSProp | 20 |
| MobileNetV2 | 128 × 128 | 3 / 4 | 1e-4 | ImageNet | GlobalAvgPool, Dense (1024), Dropout | Adam | 20 |

**RESULTS**

We have trained various CNN models utilizing hand gesture images from two standard datasets, considering both uniform and complex backgrounds. The parameters are as follows for the ASL Finger Spelling dataset: Inception V3 (23,130,936), MobileNetV2 (3,192,920), and VGG19 (21,352,536). For the NUS II dataset, the parameters are: VGG19 (21,008,842), Inception V3 (22,066,346), and MobileNetV2 (2,423,242).

We have partitioned the ASL Finger Spelling dataset using a sequential splitting approach into three sets: a test set comprising 10% of the original data to ensure complete independence, a training set consisting of 76.5% of the remaining data (85% of the 90% left), and a validation set comprising the remaining 13.5% of the data (15% of the 90% left). This stratified approach allowed for effective training and validation while ensuring that the test set remained untouched during the training process. In contrast, for the NUS II dataset, we partitioned the data into 120 training images and 80 test images per class, resulting in a fivefold augmentation to produce a total of 7,200 training images and 4,800 test images. In **Table 2**, various performance metrics are presented to evaluate the effectiveness of the models, including accuracy, precision, recall, F1 score, and error rate.

The results presented in **Table 2** highlight the effectiveness of various architectures employed for gesture classification across the ASL Finger Spelling A and NUS Hand Posture dataset II dataset. VGG19 stands out as the leading model, achieving an impressive accuracy of 99.98% on RGB images from the ASL dataset and 96.54% on depth images. The combined RGB and depth input enhances performance further, with VGG19 attaining an accuracy

of 98.73%. Similarly, for the NUS Hand Posture II dataset, VGG19 demonstrates superior performance with an accuracy of 89.19%, outpacing MobileNetV2 and InceptionV3.

**Table 2** Performance metrics for various models applied to the ASL Finger Spelling A and NUS Hand Posture II datasets

| Dataset | Model | Precision | Recall | F-Measure | Error | Accuracy (%) |
|---|---|---|---|---|---|---|
| ASL Finger Spelling A Dataset (RGB) | **VGG19** | **0.9888** | **0.9998** | **0.9943** | **0.0102** | **99.98** |
| | InceptionV3 | 0.9890 | 0.9948 | 0.9919 | 0.0152 | 99.48 |
| | MobileNetV2 | 0.9870 | 0.9904 | 0.9887 | 0.0196 | 99.04 |
| ASL Finger Spelling A Dataset (Depth) | **VGG19** | **0.9667** | **0.9236** | **0.9448** | **0.1720** | **96.54** |
| | InceptionV3 | 0.9580 | 0.9033 | 0.9300 | 0.2160 | 95.98 |
| | MobileNetV2 | 0.9254 | 0.8824 | 0.9032 | 0.2040 | 93.96 |
| ASL Finger Spelling A Dataset (RGB+Depth) | **VGG19** | **0.9870** | **0.9904** | **0.9887** | **0.0196** | **98.73** |
| | InceptionV3 | 0.9423 | 0.9766 | 0.9591 | 0.0202 | 98.37 |
| | MobileNetV2 | 0.9100 | 0.9140 | 0.9120 | 0.0230 | 97.78 |
| NUS Hand Posture Dataset II | **VGG19** | **0.8980** | **0.8890** | **0.8930** | **0.2090** | **89.19** |
| | InceptionV3 | 0.8503 | 0.8040 | 0.8266 | 0.2952 | 80.48 |
| | MobileNetV2 | 0.8844 | 0.8267 | 0.8546 | 0.2747 | 82.67 |

However, while the addition of depth information is expected to improve model accuracy, it leads to a decrease in performance for some models. The highest accuracy is achieved using RGB images alone, suggesting that the incorporation of depth data does not always positively impact gesture recognition. Additionally, VGG19 is relatively large and computationally intensive, which poses challenges for deployment in real-time applications. The performance variations observed across different datasets indicate that the model's generalizability could be improved. This highlights the need for further exploration into optimizing data modalities and model architectures to fully leverage the strengths of depth information without compromising accuracy. The training versus validation accuracy and loss for the highest accuracy achieved in the ASL Finger Spelling A RGB (VGG19) dataset is illustrated in **Figure 2**.

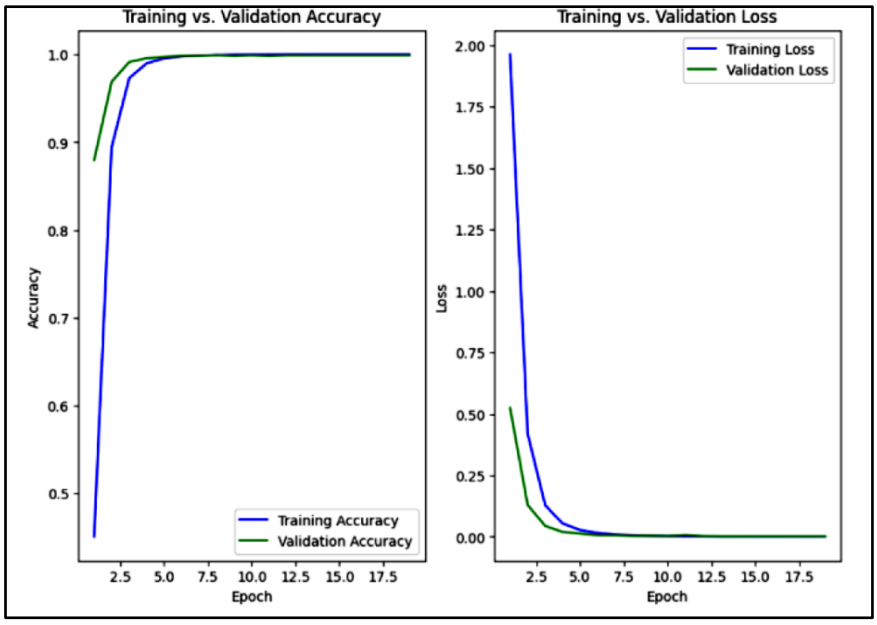


**Figure 2** Training and validation accuracy and loss curves for VGG19 model on ASL Finger Spelling A (RGB)

## CONCLUSION

This paper presents a comparative analysis of hand and sign language recognition using the ASL Finger Spelling A dataset and the NUS hand posture dataset II. We have evaluated the performance of three Convolutional Neural Network architectures, VGG19, Inception V3, and MobileNetV2, finding that VGG19 achieved the highest accuracy of 99.98% with RGB images from the ASL Finger Spelling A dataset. However, integrating depth data did not consistently improve performance, with some models showing decreased accuracy. While VGG19 demonstrated superior accuracy, its larger model size and computational intensity pose challenges for real-time deployment. This trade-off between accuracy and efficiency is critical when selecting models for practical applications. The experiments are conducted on a system configured with an AMD Ryzen 7 processor at 3.80 GHz, 16 GB of RAM, and an NVIDIA GEFORCE RTX 6 GB graphics card, ensuring robust processing capabilities for training the models. The insights from this study highlight the strengths and weaknesses of various CNN architectures in hand gesture recognition, paving the way for future advancements in this field.

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332_IEC78768

# Cave Mapping using Unmanned Remote Controlled Vehicle

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***Abstract:*** *Cave mapping is crucial for understanding underground environments. Generally, these methods take a long time and may be hazardous to humans. This dissertation proposes an innovative approach that introduces remote-controlled vehicles equipped with sensors and SLAM (Simultaneous Localization and Mapping) algorithms for autonomous mapping in caves. The unmanned remote controlled vehicle system uses LiDAR, cameras, GPS, IMU, and ultrasonic sensors. The research directly contributes to the development of efficient, accurate, and safe cave mapping solutions useful in speleology, geology, and safety operations during search and rescue.*

***Keywords:*** *Cave Mapping; Landscapes; 3D Maps; Remote Controlled Vehicle; Vegetation; Environment*

## INTRODUCTION

The cave maps with exploration often pose challenges but offer unique opportunities. Natural formations - to be typically represented by complex, unpredictable forms and structures - are vital to geology, archaeology, paleontology, environmental science, and ecology. While traditional approaches used for the exploration of caves have proven effective, they possess vast risks and limitations in many ways. It is where technology, especially remote-controlled vehicles equipped with superior sensors-can revolutionize the understanding of hidden landscapes.

Interfacing the vehicle with the LiDAR mapping tool makes it easier to conduct cave surveys without endangering the lives of researchers, with the added advantage of making it easy to map out internal features of the cave that cables may not reach. This gives rise to a system that is capable of taking accurate 3D images of the cave, but under extreme conditions where the safety of the scientists could be compromised. The 3D visualization of the cave space gives a clear picture of the cave system as well as information about the history of the site, and thus its archaeological value, in detail.

Purposes Cave mapping serves a variety of purposes-

- It supports scientific inquiry, including the analysis of geologists regarding rock formations, hydrology, and mineral deposits.
- Mapping caves is considered an understanding of archaeology, which can disclose antique artifacts and behaviours of earlier human generations.
- From an environmental perspective, caves are critical ecosystems, serving as habitats for unique species and critical components within groundwater systems.
- Cave mapping is crucial for explorers, miners, and researchers to avoid getting lost in complex cave systems and to identify narrow passages, street drops, and unstable formations.
- Map facilitates more effective rescue operations by pinpointing the exact locations.
- Proper mapping is integral to resource management so such efforts make conservation more knowledgeable and effective.

Challenges Traditionally, cave exploration techniques depend on a human spelunker who has learned to venture into the sites. Although one can get good data by using an experienced caver, this process somehow has some limitations related to physical endurance, visibility, and some risks such as falling rocks or sudden flooding in caves. Caves can have extreme temperatures, high humidity, and varying air quality. Signal loss can occur in caves due to geological structures, making communications difficult. It is also time-consuming and full of risks to reach remote areas inside the caves. Human errors and inconsistencies create problems during the analysis of any manually collected data.

**Our Visions**

To overcome those challenges, our visions would be -

- To create detailed 3D cave maps with high-resolution functioning to show geology, passageways, and chambers.
- To reduce the risk of exposure to human explorers as the vehicle is sent into difficult or dangerous environs.
- Environmental data, such as temperature, humidity, and mineral composition will be collected for use in scientific research.
- Our designed vehicle will be strong, waterproof, and compact enough to maneuver through close spaces. The vehicle will be equipped with LiDAR, cameras, and sonar for precise mapping and obstacle detection.
- It will also facilitate easy up- and downstream modifications based on required cave conditions or scientific investigation.
- Using the remote-controlled vehicle, images and sensor streams can easily be accessible back to operators for real-time analysis.
- To use advanced applications to process the gathered data into 3D models and highly interactive maps.

**Components and Their Working**

A laser sensor mapping device is usually a hardware-software integration that captures spatial data concerning the mapping of environments by measuring distance based on laser elements. The key components are-

Frame: Compact and low profile lightweight durable frame to navigate in narrow passages and withstand rugged cave conditions. Laser Sensor (LiDAR): It is a remote sensing technology that emits a rapid pulse of laser beams towards targeted areas to make distance measurements to build detailed, 3D maps of the environment. By repeating this process thousands of times per second across a range of angles, LiDAR generates a "point cloud" of data to represent a 3D space.

2D LiDAR: Captures distance in a 2D plane.

3D LiDAR: Captures depth information, resulting in a 3D point cloud

Ultrasonic Sensor: It is a device that emits high-frequency sound waves toward obstacles to measure distance and count objects.

Why LiDAR above Ultrasonic sensor -

LiDAR can achieve high accuracy in distance measurements.

It is capable of covering large areas quickly.

It can penetrate vegetation to capture ground features.

It produces rich, detailed 3D representations of the environment

Infrared Cameras: These cameras detect infrared radiation (heat) emitted by objects, allowing them to create thermal images even in complete darkness. It is very useful for exploring caves with minimum ambient lights.

360-degree HD cameras: To capture high-resolution panoramic images and videos.

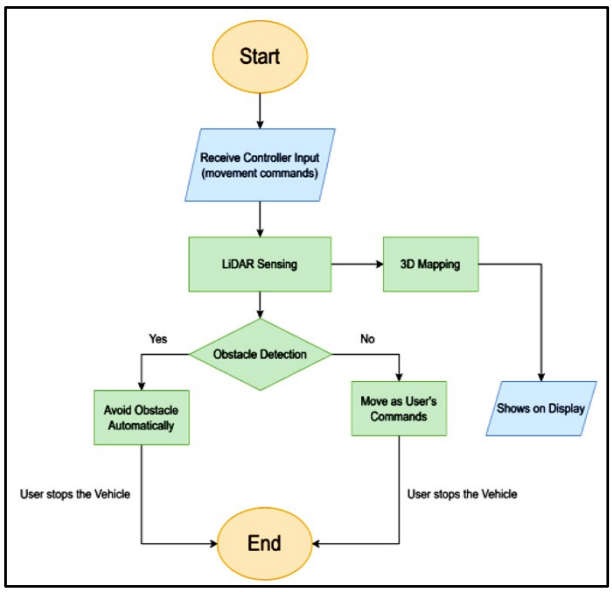
Temperature and Humidity Sensor: to gather environmental data.

Processor (e.g., Raspberry Pi, Arduino): For processing data from the sensor and sending it for display.

Motor: High torque motors to provide adequate power for climbing inclines.

Power Supply: Appropriate power setup for the sensor, controller, and any motors. Data Filters: It clean the noise of data in the sensor to enhance more accuracy. SLAM (Simultaneous Localization and Mapping): It is a widely applied methodology in which the device simultaneously maintains the map and tracks where it currently is in the environment. SLAM algorithms are important in the development of maps and the interpretation of spatial data in real-time. GPS: For outdoor navigation Software for Data Visualization: Software like MATLAB, and Python with libraries such as OpenCV and PCL used in mapping to visualize data into 2D or 3D.

Remote Control Unit: A user-friendly interface for maneuvering the vehicle. Data transmitters: Laser sensors usually have serial, USB, or Ethernet-based communication with the processing unit. Wireless communication via Wi-Fi or Bluetooth also can be used.




**Flowchart 1** The proposed unmanned remote controlled vehicle – operation through flowchart

## METHODOLOGY

Standard Remote-controlled cave mapping vehicles, without putting human lives in danger, can traverse even the most difficult terrains while collecting data in real-time.

Navigation: High-resolution cameras, LiDAR systems, and ultrasonic sensors will all play a major part in data acquisition. The high-resolution cameras allow for the gathering of maximum information about the surroundings. Mobilising: Rugged terrain requires the vehicle to be built with much potential for robust movements, mostly fitted with tracks or wheels that can stand on an uneven surface. It could also include systems to handle water, mud, or loose debris. Controlling: A strong control system will enable the deployment of such a machine in real-time from a safe distance which adjusts itself according to obstacles. Data Processing and Visualization: Thereafter onboard software is used to process the data captured and transform it into available maps using several algorithms [1], visualization tools, and integration [2] with a geographic information system (GIS). The proposed Unmanned remote controlled vehicle has been shown in the following **Figure 1**.

Advantages of Remote-Controlled Vehicles Safety: Inspection by a vehicle in potentially unsafe conditions may reduce risk for humans [3], including areas where rockfalls are common or areas with unstable footing [4].

Efficiency: Equipped with high technologies this vehicle can operate for extended periods for real-time data collection with accuracy [5].

Data Quality: The highly precise and reliable data is collected through advanced sensors which increases the accuracy of the map involved even under varied conditions.

Versatility: Researchers can fit various modules on the vehicle to include different sensors [6] according to their various research.

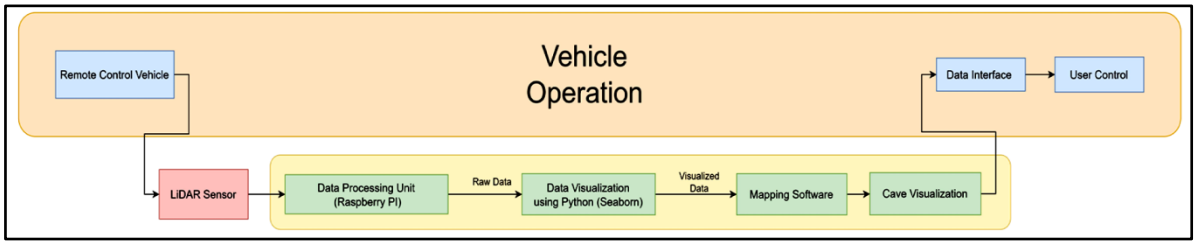



**Figure 1** Block diagram of the proposed unmanned remote controlled cave mapping vehicle

## FUTURE FEASIBILITY

A remote-controlled cave mapping vehicle, with continued advances in technology [7], would further exploit its capability to sense and map cavities. Soon, recent breakthroughs in artificial intelligence [8] may provide vehicles with more independent navigation and real-time environmental condition decision-making. Advanced imaging techniques will include thermal or multispectral imaging, which are very valuable tools in being able to penetrate cave features not visible to the naked eye. Ground vehicles may be integrated with drone technology to conduct aerial surveys of cave entrances and surrounding landscapes [9]; such integration would deepen the data collected. A collaborative mapping effort by multiple vehicles could be useful in achieving highly detailed cave system surveys over wide areas. For community engagement, the local citizens should be offered workshops in cave mapping techniques and encouraged to participate in data collection and mapping projects to bring them closer to nature. Collaborative work with geologists and cave scientists in order to fine-tune methods of data collection and enhance research outcomes.

## CONCLUSION

Unmanned Remote-controlled cave-mapping vehicles are an important step forward in our survey and analysis of subterranean environments. As a result of enhancing scientific research through safety, efficiency, and the possible collection of high-quality data, they also conserve vital ecosystems. Technology would progress even further down the road, while cave explorations would seem brighter into the future as they opened endless vistas of discovery and deepened our insights into that fantastic subterranean world beneath our feet. It would be by innovation that we could truly discover caves and, thereby preserve them for generations to come while enriching our understanding of planet Earth's geological and ecological diversity.

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367_IEC21843

# Generation of a Personal AI ChatBot using the Concepts of Natural Language Processing

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***Abstract**: The development of personal AI chatbots has gained significant traction, driven by advancements in Natural Language Processing (NLP). These chatbots enhance user interaction by providing personalized experiences and efficient communication. This paper outlines the fundamental concepts of NLP and the systematic approach to creating a personal AI chatbot. Key stages include defining the chatbot's purpose, selecting appropriate tools, designing conversation flows, and implementing NLP models. Additionally, the importance of continuous monitoring and updating post-deployment is emphasized to ensure optimal performance. By following these guidelines, developers can effectively create chatbots that meet user needs and enhance engagement.*

***Keywords**: AI Chat Bot; Natural Language Processing; Conversation Flow; Dialogue Management; Machine Learning; User Engagement*

## INTRODUCTION

The rise of artificial intelligence (AI) has transformed how we interact with technology. Personal AI chatbots, powered by Natural Language Processing (NLP), are increasingly popular for enhancing customer service and streamlining communication.

## METHODOLOGY

Natural Language Processing is a subfield of AI that focuses on the interaction between computers and humans through natural language. Key components of NLP include 0

**Tokenization**: Dividing text into individual words or phrases.

**Part-of-Speech Tagging**: Identifying the grammatical parts of speech in a sentence.

**Named Entity Recognition**: Recognizing and categorizing entities in text, such as names, dates, and locations.

**Sentiment Analysis**: Assessing the emotional tone behind a series of words. Text Generation: Creating coherent and contextually relevant text.

### Steps to Create a Personal AI Chatbot

Define the Purpose

Before development, define the chatbot's purpose, such as answering FAQs, scheduling appointments, or providing recommendations.

### Choose the Right Tools and Frameworks

Popular frameworks include:

**Rasa**: Open-source framework for building conversational AI.

**Dialogflow**: Cloud-based NLP tool.

**Microsoft Bot Framework**: Comprehensive framework for chatbot development.

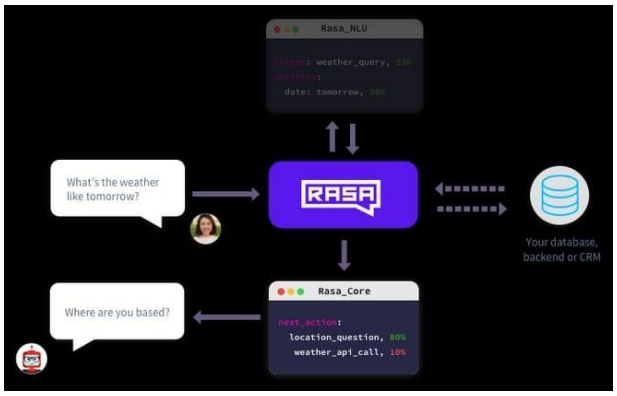


**Figure 1** Chatbots using Rasa

**Design the Conversation Flow**

Create a flowchart outlining user interactions, intents, and entities.

**Chatbot Conversation Flow**

The following flowchart represents a typical conversation flow for a personal AI chatbot:

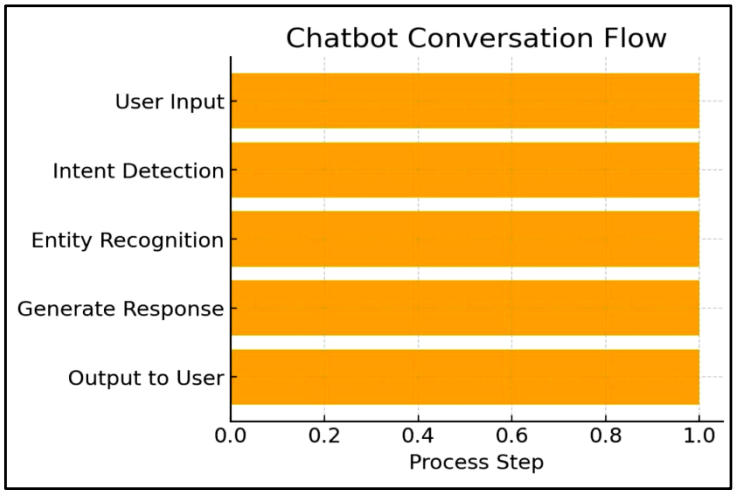


**Figure 2** Flowchart representing a chatbot's conversation flow

This flowchart illustrates how a user input is processed through various stages such as intent detection, entity recognition, and response generation before producing an output to the user.

**Develop the NLP Model**

Train the chatbot using NLP techniques to understand user inputs through data collection, preprocessing, and model training. The process can be represented by the following equation, which defines the relationship between input features and output predictions:

$y = f(X) + \epsilon y = f(X) + \epsilon y = f(X) + \epsilon$

Where, yyy = predicted output (response); f(X)f(X)f(X) = function mapping input features XXX to output; $\epsilon \epsilon$ = error term

**Implement Dialogue Management**

Dialogue management ensures the chatbot maintains context and manages conversation flow through context tracking and response generation.

**Test and Refine**

Conduct thorough testing, gather user feedback, and refine the model and flow.

**Deploy the Chatbot**

Deploy the chatbot on desired platforms, ensuring the technology stack is supported.

**Monitor and Update**

Continuously monitor interactions and update the NLP model to enhance performance.

## PERFORMANCE EVALUATION

**NLP Model Training Process**

The following graph represents the training process of the NLP model:

This graph shows the changes in accuracy and loss over several epochs during the training of the NLP model.

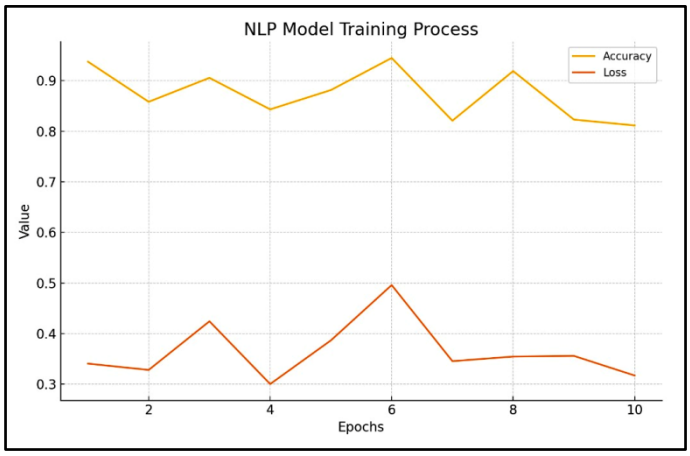


**Figure 3** NLP model training process

**Error Rate Analysis**

The following graph represents the relationship between the error term and the number of epochs during training:

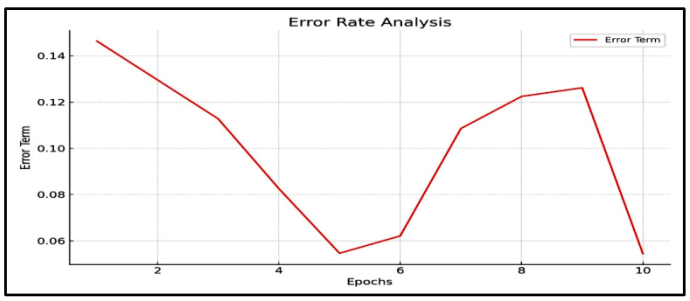


**Figure 4** Error rate analysis

This graph shows how the error term decreases as the model is trained over multiple epochs, indicating the model's learning progression.

**User Engagement Metrics**

The following graph represents the user engagement metrics before and after updates to the chatbot:

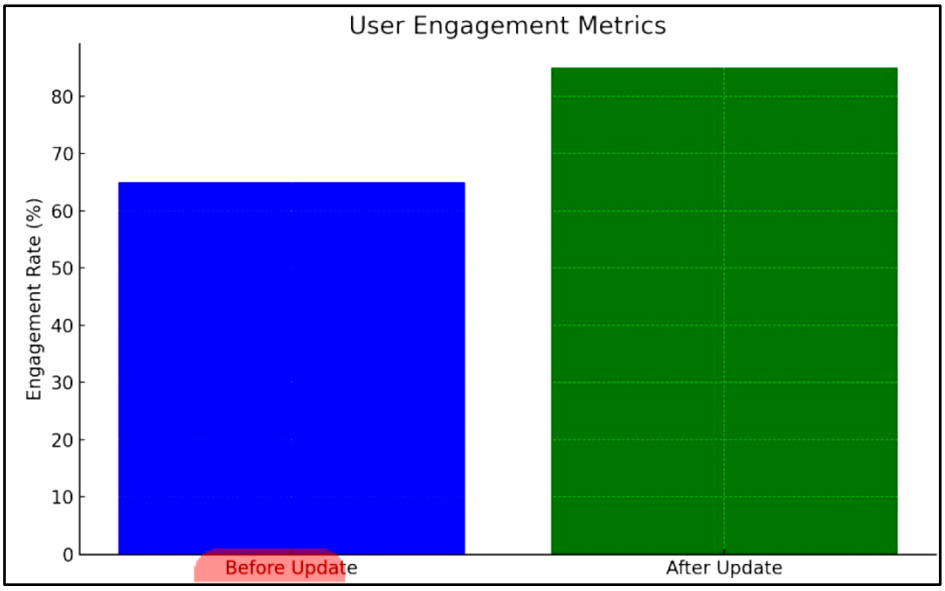


**Figure 5** User Engagement Metrics

This graph illustrates the improvement in user engagement metrics following updates to the chatbot, highlighting the importance of continuous monitoring and updates.

**CONCLUSION**

Creating a personal AI chatbot using NLP involves defining its purpose, leveraging tools, designing flows, and implementing techniques. Following these steps enables developers to build effective chatbots that enhance user engagement and meet specific needs.

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369_IEC31857

# A Robust Deep Learning Framework for Validation of Reduplicated Multiword Expressions in Digital Bengali Texts

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***Abstract:*** *Reduplicated multiword expressions (RMWEs) are crucial linguistic constructs in Bengali, acting as unified entities that convey meanings beyond the sum of their domains. However, effectively validating these expressions is difficult due to a need for annotated datasets and pre-trained Bengali models. This study proposes a deep learning strategy for validating redundant RMWEs in digital Bengali text datasets. The proposed approach transcends the related work due to its impressive recall and well-calibrated accuracy. The proposed model detects all valid RMWEs with an outstanding recall score of 100%. The proposed strategy distinguishes valid and invalid RMWEs with 89.37% validation accuracy. Despite its lower precision of 46.91%, this method's flawless recall makes it notably beneficial in situations requiring thoroughness and inclusivity.*

***Keywords:*** *Multiword Expressions; NLP; Text Processing; Reduplication; Deep Learning*

# Information & Communication Technology

## Microwave, Millimeter Wave and THz Communication

100_IEC59986

# A Novel Design of Metasurface Flat Antenna Modules for Low-Profile VSAT Mobile Terminal Applications

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***Abstract:*** *In most of the current VSAT applications, high gain parabolic dish antennas are used extensively, e.g., at Ku-band (12 to 18 GHz). A typical demand for such antennas is to mount them on top of vehicles. Parabolic antennas are large and complex to install and maintain. On the other hand, a flat panel antenna can greatly simplify the manufacturing process in addition to its being amenable to be mounted on vehicles. Flat panel antennas are ultra-thin, low-profile, weatherproof high gain antennas used to electronically acquire, steer, and lock a beam to any satellite. Multiple research investigations are ongoing to design such antennas primarily using the concept of metasurface. In this work, a novel design methodology of building flat antenna modules for VSAT mobile terminals has been demonstrated, using a standard half-wavelength dipole as excitor antenna backed by High Impedance Surfaces (HIS), at an operating frequency of 12.6 GHz, with a high gain of approximately 7dBi. The design has been optimized for large impedance bandwidth, circular polarization and easy tuneability using capacitors. The design scales for different frequencies without change in functionality. This design principle is amenable to low-cost printing processes for mass production, e.g., printing of antenna using inkjet technique.*

***Keywords:*** *5G; Metasurface; Flat Panel Antenna; VSAT Mobile Terminal; Ku Band*

## INTRODUCTION

In most of the current VSAT (Very Small Aperture Terminal) applications, high gain parabolic dish antennas [1] are used extensively, e.g., at Ku-band (12 to 18 GHz) [2], where the dish diameter is typically between 0.8 m to 1.3 m. The antenna needs to be manufactured with care and precision, thus leading to higher costs [3]. As the need arises on moving the operation range to higher frequencies (for larger bandwidth) [4, 5], more precise fabrication is required so that accuracy should lie within λ/100 limit. Moreover, a typical demand for such antennas is to mount them on top of vehicles. Parabolic antennas have complex mechanisms of installation, configuration, and maintenance. On the other hand, a flat panel antenna, in lieu of parabolic antennas, can greatly simplify the manufacturing process in addition to its being amenable to be mounted on vehicles [6]. Flat panel antennas are ultra-thin, low-profile, high gain antennas used to electronically acquire, steer, and lock a beam to any satellite [7]. Globally, multiple research investigations are ongoing to design such antennas using the concept of metasurface [8], which is anticipated to undergo exponential growth in the upcoming years.

Another key aspect of the state of arts is the need to have separate antenna design and manufacturing towards achieving different design needs, e.g., antenna gain. The advantage of a flat panel antenna over a parabolic dish antenna lies in the simple modular configuration and maintenance, as shown by J. Suryana et. al. in [9]. Recent advances in flat antenna technology combined with the high-throughput satellites (HTS) are facilitating new mobility applications for the end-users. In the last few years, an increasing interest has been shown in many satellite services at Ku-band [10], ranging from digital radio and TV broadcast to broadband internet services. The Ku, K and Ka frequency bands can support applications that require high transmission power. With the use of high throughput satellites (HSA), they are predicted to have higher rates of penetration through obstacles compared to the other segments.

In this work, a flat antenna design for VSAT mobile terminals has been proposed by using the concept of a standard half-wavelength dipole as excitor antenna, backed by High Impedance Surfaces (HIS) which is a variant of metamaterial-based design. The design is for a basic functional module with an aperture size of 1.15λ×1.15λ×0.22λ, at an operating frequency of 12.6 GHz. The functional module has been designed for circular polarization and high gain of approximately 7 dBi. The design scales for different frequencies, but functionality remains the same. The

fabrication tolerances may need fine tuning of performance after the module is printed. This fine tuning is done using a suitable choice of SMD capacitors. This design has been tightly optimized for large impedance bandwidth as well as circular polarization bandwidth (Axial Ratio <= 3 dB).

## DESIGN

### A. Flat Antenna Module

The flat antenna module consists of following components: a) L-bent printed dipole as the exciting antenna which has two feeding points on the two arms and is printed on a thin (0.5 mm) substrate (Rogers RT-Duroid 5880: εr = 2.2), b) a High Impedance Surface (HIS) consisting of 4×4 array of unit cells; where each unit cell consists of an S-shaped patch printed on a Rogers RT-Duroid 5880 substrate of thickness 3.2 mm and the bottom layer of the HIS substrate is backed by metallic ground plane, and c) the external RF which is fed to a Balun and transforms unbalanced 50 Ω to balanced lines. These lines pass through the substrate and get connected to the dipole antenna feed points. Flat Antenna module structure is displayed in **Figure 1**.

In this design, a standard half wavelength dipole antenna has been reshaped to an L-bent dipole, thereby easing the connectivity to a pair of transmission lines (balanced line) as shown in **Figure 1(b)**. The overall module dimension is 1.15λ×1.15λ×0.22λ (at center frequency of 12.6 GHz).

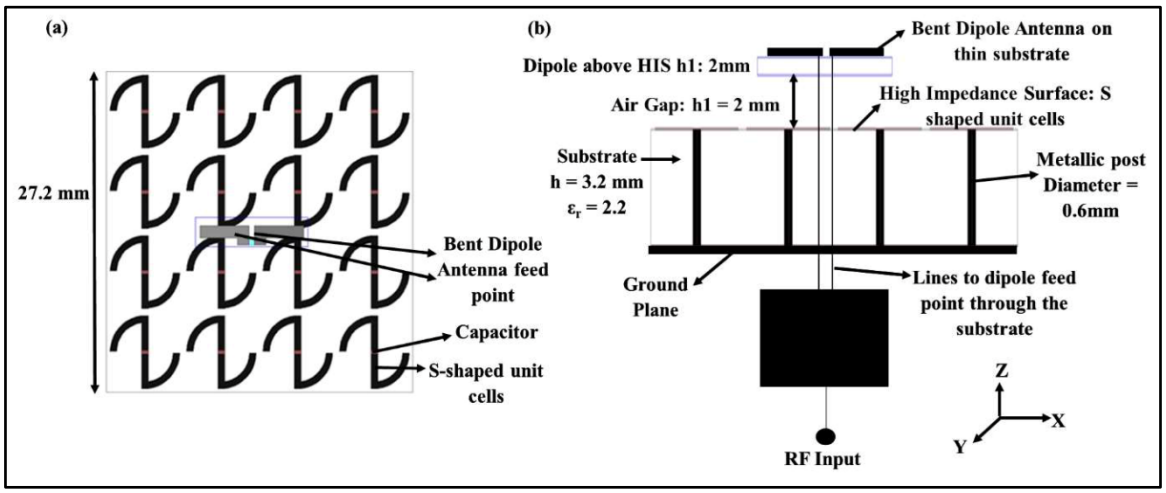


**Figure 1** Flat antenna module: (a) top view, (b) side view

### B. Unit Cell Design

It has been shown in an earlier work [11] that a S-shaped unit cell backed by ground plane displays strong linear cross-polarization over a wide frequency band as well as potential for circular polarization over a narrow frequency band. However, in the previously stated work, a combination of exciting antenna and the high impedance surface had been discussed only, without being evaluated. In the present design, it is shown that to obtain circular polarization (axial ratio <= 3 dB), the given S-shaped unit cell design needs two major changes:

1. The two halves of S-shaped patch are separated at the center by a suitable choice of capacitance value through a surface mount capacitor.

2. One half of the two parts (of S-shape) is shorted to the ground plane on the bottom of substrate with a cylindrical metallic post of a given dimension.

**Figures 2(a)** and **2(b)** display the structure of the unit cell.

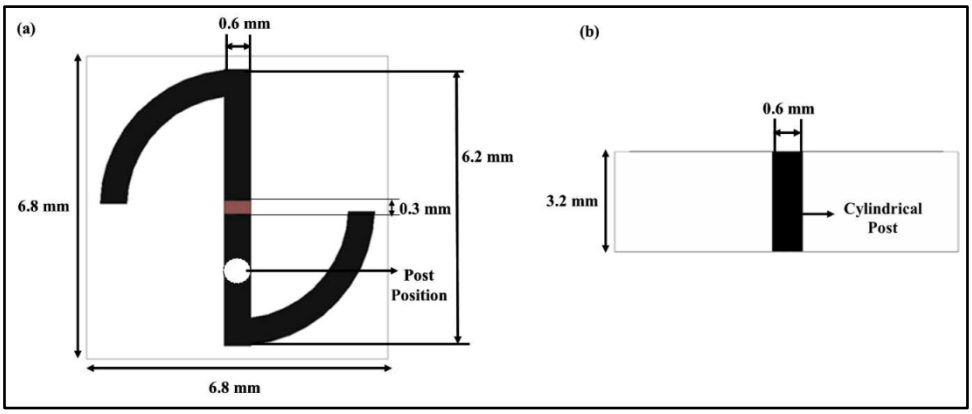


**Figure 2** Unit cell design: (a) top view, (b) side view

## PRINCIPLE OF OPERATION

When the dipole is excited, it radiates in both +/- Z axis direction (where Z axis is normal to the surface of the flat antenna module). The wave propagating in -Z direction impinges on the HIS and gets reflected. The S-shaped unit cells (which constitute HIS) display the functional property of linear-to-linear polarization conversion for the reflected wave from the surface. This means, if the electric field of incoming wave is directed along +/- X direction; after reflection from the surface, major part of the wave's electric field is along +/- Y direction. Now the reflected wave interferes with the direct radiated wave from the dipole (in +Z direction), resulting in net farfield pattern.

In order to obtain circular polarization (CP), two orthogonal beams equal in amplitude and separated by 90 deg in phase must be generated. It is already shown in [11] that the reflected wave displays strong cross-polarized component (i.e E-field along +/- Y direction). On the other hand, direct wave is co-polarized (i.e +/- X direction). Now the design need is to optimize the overall structure so that the conditions for circular polarization are met in far-field. This is done by optimizing the height of the dipole above the HIS, which is 2 mm in this case (**Figure 1(b)**). If the height is increased to 6 mm or more, CP is not obtained, instead dual linearly polarized wave is achieved, and when the height is further increased up to 11 mm, the beam shape distorts. Thus, the given design has optimum configuration for wide bandwidth CP antenna. The length and shape (L-bent) of dipole antenna is also optimized heuristically for attaining best performance.

## RESULTS AND DISCUSSION

The net effect of the modified unit cell structure leads to wide-band CP wave. Both parameters are useful for frequency tuneability. It is illustrated in **Figures 3(a)** and **3(b)** how different capacitance values shift the CP bandwidth while retaining the impedance bandwidth. As seen in **Figure 3(a)**, different capacitance values enable fine tuning the axial ratio bandwidth. Since the capacitors are assembled only after the surface module is printed, this method enables the engineer to test and tune as per the operational need; thereby taking into consideration the fabrication tolerances.

On the other hand, the return loss figures (**Figure 3(b)**) do not change significantly for capacitance range of 2 pF to 10 pF. Thus, the ability to retune the antenna with appropriate choice of capacitance values is a strong advantage of this design. The radiation pattern of the flat antenna module is shown in **Figure 3(c)**.

The main observation from **Figure 3(c)** is that the two orthogonal beams are well formed; still there exists an asymmetry in beam shape. This asymmetry can be intelligently utilized just like shaped-beam antennas. The most important point to note is the gain of approximately 7.3 dbi. A standard half-wavelength dipole has a gain of approximately 2 dBi only, whereas dipole gain of 5.2 dBi is obtained for dipole length L = 1.25λ, along with wideband circular polarization. Here, the module dimension of 1.15λ×1.15λ×0.22λ has provided a higher gain of 7.3 dBi along with wide-band circular polarization.

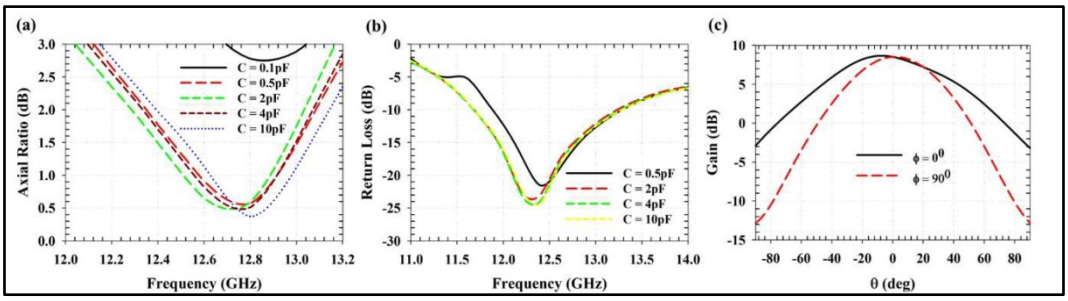


**Figure 3** (a) Axial ratio vs frequency and (b) return loss vs Frequency for different values of capacitors; (c) total realized gain for the flat antenna module in two orthogonal planes

## CONCLUSION

A novel design methodology of building functional flat antenna modules has been demonstrated, which are suitable for low-cost printing processes for mass production, e.g., printing of antenna using inkjet technique. The design has been configured and optimized for large impedance bandwidth, circular polarization and easy tuneability using capacitors. The design scales for different frequencies without change in functionality. The results are acquired from simulation in the Finite Element Method-based commercial software. The next step in the work is to fabricate the designed modules for experimental verification.

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106_IEC70946

# Minkowski Fractal Shaped Reconfigurable Intelligent Surface Design with Bi-Directional Beam-Tilt Performance

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***Abstract:*** *With the advent of next-gen communication systems and evolution of sensing-dependent IoT-based solutions, goals to achieve real-time beamforming and seamless beam-steering capabilities have become the focal point of research. This calls for effective design of ancillary devices which may redirect or shape the radiated beams from the primary radiators towards specific objects as per requirement. This article presents a novel and uniquely designed Reconfigurable Intelligent Surface (RIS), which offers the ability to steer the beam in dual orthogonal directions, is fully controllable through electronic means and describes polarization sensitive performance, enhancing the robustness of operation under practical use. The reflective unit cell design is conceived as the shape of a first iteration Minkowski fractal patch, operating at 3.5GHz. Rigorous simulation-based characterization is done to achieve the necessary phase variation for dual-direction beam-tilt operation. After fabrication and initial measurements, the realized RIS structure described bi-directional beam-tilt performance along the horizontal and vertical directions with ±15 degrees of obtainable tilt, which agrees with the simulations, validating its suitability for commercial use.*

***Keywords:*** *Reconfigurable Intelligent Surface (RIS); Real-Time Beam Tilt Operation; 5G Communication; IoT Devices; Minkowski Fractal Design*

## INTRODUCTION

To obtain real-time control over EM signals for communication, exquisite metasurface designs are used to ensure specific propagation/re-direction properties through various shapes and configurations of the components [1-4]. Reconfigurable Intelligent Surfaces (RIS) are now considered as indispensable components for futuristic communication suitable for 5G and 6G use-case scenarios. Smart wireless systems, which require effective power management and ensure secured communication through highly directed signal beams, often take help from the practical idea of RIS [5], for various applications of domestic and commercial use. For efficient non-LoS communication which aim to serve dense IoT environments and sensing applications, primary base stations or the source Access Point radiators (APs) act in coordination with the RIS structures, which assist to re-direct the reflected beam towards specific objects, ensuring economic use of radiated power [6].

Such reconfigurable reflecting structures are conceived as two-dimensional surfaces with large number of sub-wavelength reflecting/transmitting elements, generally augmented with active electronic components. These components, like varactors or other diode elements, are responsible for providing a calculated and pre-defined phase-shift to the reflected/transmitted signal allowing the beam to propagate and be anomalously reflected towards a specific direction [7]. In case of sub-wavelength Metasurface designs, the induced reflection/transmission phase may vary between a larger angular range of 180° or more with proper tuning characterization. If an active element like a varactor or PIN diode is used, then the same can be controlled in real-time just by changing the bias voltage of the element concerned. Different exquisite geometric shapes are now being utilized to design and develop novel unit cell structures those can be used as efficient constituent elements for conceiving larger RIS designs for robust, practical operation.

This article presents a novel Minkowski-shaped reflective unit cell design which is further utilized to conceive a larger RIS structure that has the ability to steer the beam in dual orthogonal directions. After fabrication and initial measurements, the realized RIS structure described bi-directional beam-tilt performance along the horizontal and vertical directions with ±15 degrees of obtainable tilt, which agrees with the simulations. The following section contains the initial design problem and discussions for selecting the shape of the unit cell, followed by the section containing the results, analyses and observations. Concluding comments and relevant references are appended

thereafter accordingly.

## UNIT CELL DESIGN

A Minkowski-shaped fractal patch inspired reflective unit cell design is proposed on top of a two-layer dielectric substrate. A narrow slit is etched out, which bisects the patch in the middle, enabling the varactor diode element to be placed there. The Minkowski shape is modified by appropriately choosing the indentation width and breadth to maximize the current path along the structure. This ensures effective miniaturization of the component and guarantees its suitable performance at the desired band of operation. The design dimensions exhaustively describe a suitably modified reflective unit cell component, which is inspired by the Minkowski fractal structure, and is designed to operate at the n78 band of frequencies.

The top view of the patch with all the design dimensions is described in **Figure 1**, (L=25mm, A=10mm, d=0.65mm, via_d=0.4mm), followed by an exploded view of the multi-layer structure. The perspective quantitatively describes the different layers of the unit cell and it shows the metallic sheet acting as the ground plane, sandwiched between the two substrate layers of the proposed configuration. Holes are driven through the ground plane and the corresponding substrate layers as necessary to establish the biasing circuit features for the diodes in the structure. The dimensions of the slit (d) and the semi-circular pads, having diameters via_d, were decided based on the dimensions of the diode model used (Model Number SMV2201-040LF, Skyworks Solutions). The biasing via rods were placed at the center of the patch as described to ensure voltage control of the varactor elements. The structure is designed and simulated on FR-4 glass epoxy substrate having dielectric constant 4.4 and thickness 3.2 mm respectively. Modified phase of the reflected waves from the reflective unit cell element is controlled through the capacitance of the varactor diode components. By applying suitable bias voltages, one may obtain different reflection phase values with different values of capacitance.

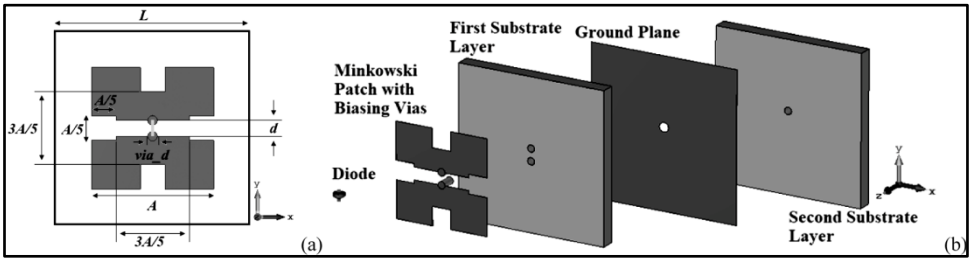



**Figure 1** Detailed dimensions of the prototype, (a) top-view and (b) exploded view of the structure

For this design, when the diode capacitance is varied from 0.3 pF to 3 pF in simulations, a phase variation from 115 degree to nearly -165 degree is obtained. This enables the conceived unit cell to be used to generate gradient phase reflecting surfaces by suitable voltage biasing techniques. By changing the phase of the reflected wave across the metasurface, it is possible to create constructive or destructive interference patterns in space that will cause the wave to be directed in a specific direction. This is achieved by designing the surface to have a spatially varying phase profile that induces the desired phase shift throughout the structure.

If a phase difference of $\Delta\phi$ is applied over the unit cells of the metasurface array then according to generalized Snell's law, the tilt angle of the beam $\theta$ is calculated as,

$$\theta = \sin^{-1}\left(\frac{\lambda}{\Delta P}\cdot\frac{\Delta\phi}{360}\right) degree \qquad (1)$$

Where, $\lambda$ = wavelength of the incident wave, $\Delta P$ = periodicity of the unit cell, $\Delta\phi$ = phase gradient between two adjacent unit cells (in degree)

## RESULTS AND ANALYSIS

Based on the unit cell design and Snell's Law formulation a 10×10 RIS tile is realized comprising of 100 unit cell

elements on the same. Correspondingly, the surface contained 100 varactor diodes whose biasing arrangements had to be done meticulously for precise operation. In **Figure 2** a standard depiction of the continually varying phase profile which is implemented on each row of the 2D surface is presented. Due to the limitation in obtainable phase range, five distinct phase points (corresponding to 5 distinct capacitance values obtained from 5 specific bias voltages) are chosen and the pattern is repeated in a sawtooth formation. Such patterns ensure a beam-tilt along the decreasing direction of the phase gradient as per Snell's formulation, and by choosing separate sets of such distinct phase values, the slope of the gradient can be varied to obtain variation in beam-tilt angles, offering a scanning performance. A description of the fully assembled fabricated structure is provided.

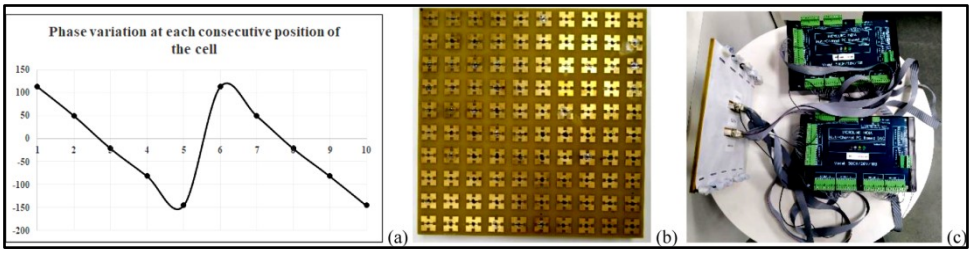
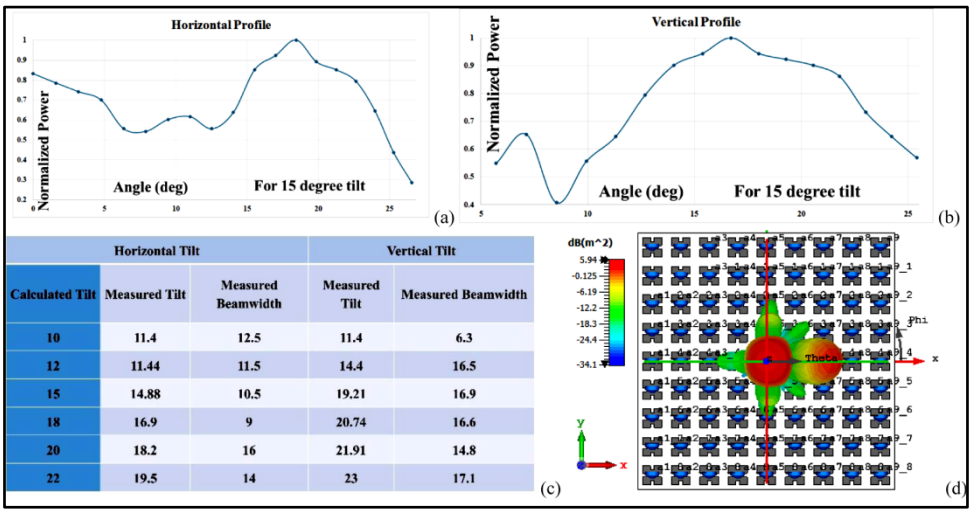



**Figure 2** (a) Representative phase profile, (b) the fabricated prototype and (c) its augmentation with the biasing arrangement

Orientation of the diode ensures a fixed current path, that in turn maintains polarization sensitive performance of the system. On the other hand, if one implements the phase profile on each columns, instead of rows as stated previously, the direction of beam-tilt changes from horizontal to vertical for the prototype, confirming dual-direction beam-tilt performance. Two separate control units having 50 voltage channels each, which are developed in-house, are used to arrange real-time biasing control for the 10×10 RIS configuration. The surface responds to vertically polarized incident signals and has the ability to tilt the beam in both the orthogonal directions through means of orthogonally applied phase profiles as discussed above.

**Figure 3** describes the measured beam-tilt performance in both horizontal and vertical directions, for vertically polarized EM signals, and a comparison table is added to describe the agreement of the measurements with the simulations. For each cases distinct phase profiles, following the sawtooth pattern, are developed by calculating the required phase-gradient or slope as per the Snell's Law formulation given in (1). The agreement between the calculated and measured tilt-angles in both the directions, ensure the suitability of the designed prototype for practical operation.




| Horizontal Tilt | | | Vertical Tilt | |
|---|---|---|---|---|
| Calculated Tilt | Measured Tilt | Measured Beamwidth | Measured Tilt | Measured Beamwidth |
| 10 | 11.4 | 12.5 | 11.4 | 6.3 |
| 12 | 11.44 | 11.5 | 14.4 | 16.5 |
| 15 | 14.88 | 10.5 | 19.21 | 16.9 |
| 18 | 16.9 | 9 | 20.74 | 16.6 |
| 20 | 18.2 | 16 | 21.91 | 14.8 |
| 22 | 19.5 | 14 | 23 | 17.1 |

**Figure 3** Measured radiation patterns for (a) horizontal and (b) vertical phase profile implementation, (c) table of comparison between simulation and measurements and (d) simulated 3D beam-tilt pattern for representation

## CONCLUSIONS

A Minkowski fractal shaped reflective unit cell, suitable for RIS design at n78 band of operation is designed and characterized in this article. The unit cell, after appropriate incorporation of a lumped varactor diode element, ensured real-time control over reflection-phase performance that justified its potential to be used as a constituent component for beam-tilting RIS configurations. Due to the precise incorporation of the diodes, the RIS described a polarization-sensitive beam-tilt performance that can be controlled in real-time through appropriate biasing arrangements. After fabrication and measurements, the realized RIS structure described bi-directional beam-tilt performance along the horizontal and vertical directions with ±15 degrees of obtainable tilt, which agrees with the simulations. The structure is designed to operate at 3.5GHz, which falls under the FR1 band of frequencies, suitable for 5G and 6G communication operation, which further validates its potential for futuristic commercial application.

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199_IEC53942

# Design and Characterization studies of Terahertz Antenna for Sustainable Health

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***Abstract:*** *In recent era, the developments in different technological fields are advancing to comply with the current aspects of the society. In the field of medical science also the researchers are finding way for the sustainable developments of the society. The requirements for better medical facilities are growing due to the sudden outbreak of nCovid-19 virus. According to WHO, 422 million people are affected with the diabetes across the globe. Also in addition to this, more than 972 million people are facing the issues caused by hypertension on earth. Death toll due to Covid-19 has crossed more than 6 million. The medical science needs the advancements in technological sector in terms of development of suitable imaging and detection system for early diagnosis. In this research work, the author tries to investigate on the design and characteristics studies of Terahertz antenna to be integrated with Terahertz source and system for application in Biomedical imaging unit that could be used for non-invasive imaging purposes. The study has been done through HFSS platform. The patch antennas show acceptable return loss, directivity, VSWR etc. Four designs are considered here and comparative studies of the four proposed patch antennas are plotted on the Matlab platform. To the best of author's knowledge, it is the first report on Terahertz antenna with considerably good directivity and return loss.*

***Keywords:*** *Patch Antenna; Gain; Return Loss; VSWR; Terahertz Antenna*

## INTRODUCTION

Antenna miniaturization and use of antenna for wireless applications has been increased from the last decade. In recent times the graphene has obtained a rich position in the recent advances. The author here tries to incorporate gallium nitride s as the substrate for the design of the patch antenna [1]. The objective of the work is to find a suitable terahertz antenna for application in imaging and detection system for early diagnosis. During the nCovid-19 pandemic times the people all around the world have faced many issues like costly medical diagnostics tests, unaffordable costs of some medical tests lead them to avoid the test and the result is of course not good. Many people died due to no medical support as no tests they can undergo. In government funded hospitals/ hospitals running under any charitable trusts/ Free health checkup camps are not in that much numbers available as well as thepeople are not getting the facilities of all kinds of medical diagnosis at a time from all of the mentioned places. Now have to think on it so that the entire mankind can be survived. The author here tries to find a suitable terahertz antenna for medical applications in the early detection and diagnosis. The terahertz frequency communication is a new dimension for the wireless communication. The antenna will attract special attention in the wireless technology [2,3].

### Rectangular Shaped Patch Antenna with One Slit – R1

The terahertz frequency is till now not that much explored by the researchers. Many researchers are working on the back stage for a solution in this frequency range. To the best of the author's knowledge the designed patch antennas are the novel antennas in this terahertz frequency. The medical diagnosis in this frequency is getting special attention as the terahertz ray can be incorporated in the medical diagnosis and detection. As a solution to this the author have designed four different patch antennas with gallium arsenide as the substrate material [4,5]. The first designed antenna named as R1 is shown in the **Figure 1**. The author has used the HFSS [6] simulation platform for the simulation study of the antenna [7].

The simulated antenna is having one slit and it has been shown in the **Figure 1**. The designed patch antenna shows considerable response at 2.18THz, 4.32THz and 5.69THz frequency respectively.

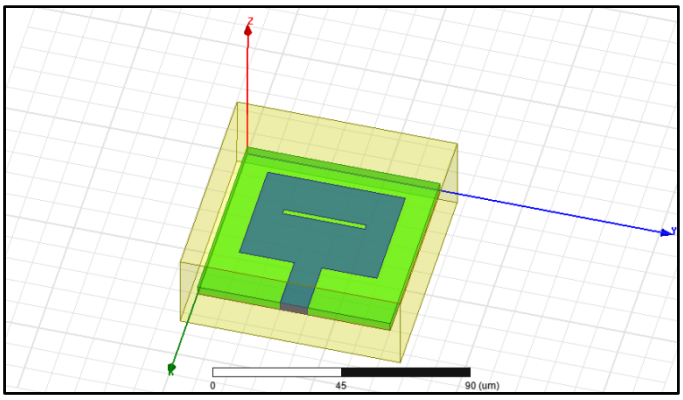



**Figure 1** Simulated patch antenna in HFSS software as per design proposal R1

**Rectangular Shaped Patch Antenna with Two Slits – R2**

The second design of the designed patch antenna is with two slits has been shown in the **Figure 2**. The simulated antenna with two slits showed the frequency response at 2.19THz, 5.66THz and 5.72 THz respectively.

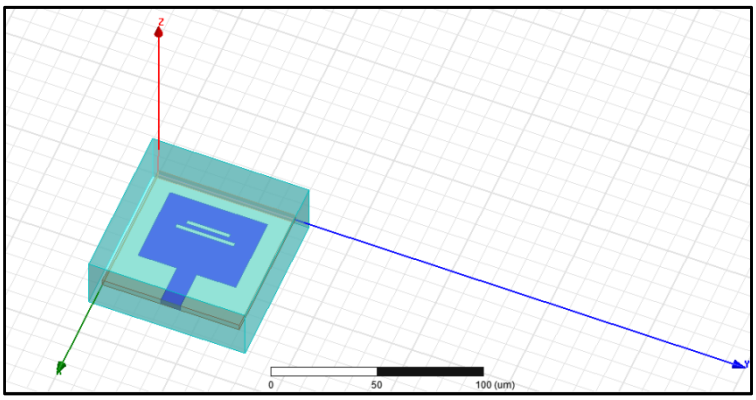



**Figure 2** Simulated patch antenna in HFSS software as per design proposal R2

**Rectangular Shaped Patch Antenna with Three Slits – R3**

Another rectangular patch antenna with three slits has been designed with the gallium arsenide as the substrate material. The simulated antenna in the HFSS platform has been shown in the **Figure 3**. The frequency response of the antenna has been found at 6.45THz, 6.67THz and 7.64THz.

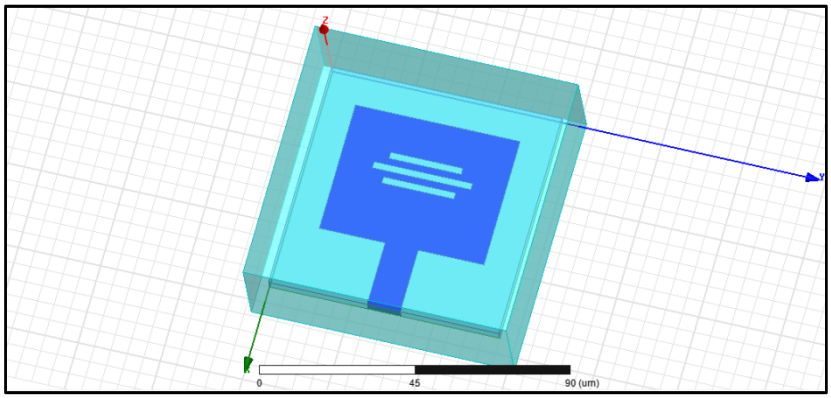



**Figure 3** Simulated patch antenna in HFSS software as per design proposal R3

**Rectangular Shaped Patch Antenna with Four Slits – R4**

The fourth design of the simulated patch antenna is with four slits has been shown in the **Figure 4**. The frequency response has been found at 2.4THz, 6.02THz, 6.81THz, 7.39THz and 8.66THz respectively.

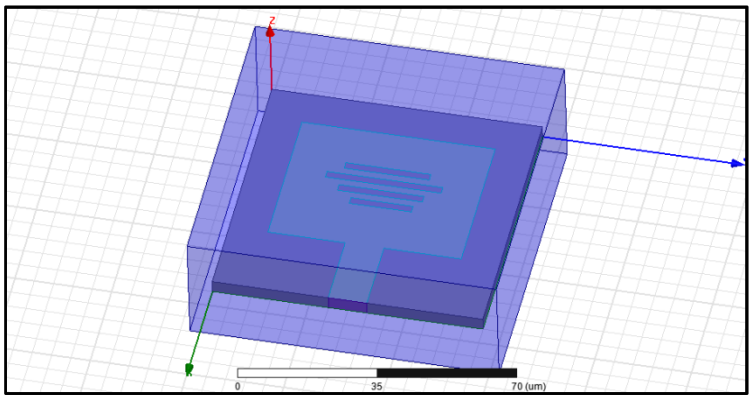



**Figure 4** Simulated patch antenna in HFSS software as per design proposal R4

## GALLIUM ARSENIDE AS THE SUBSTRATE

The conductivity of the gallium arsenide is considered with a complex surface conductivity $\sigma_{ga}(\omega, \mu, \Gamma, T)$ where $\sigma_{ga}$ is a function of which changes the surface conductivity of gallium arsenide for a tunable frequency. Here $\omega$ is the frequency of radiation, $\mu$ is the potential of the chemical doping, relaxation time = $(1/\Gamma)$ and T = temperature respectively.

The conductivity of the gallium arsenide is computed as intra-band and inter-band conductivity of the gallium arsenide and has been shown in the **Equation no. 1**.

$$\sigma_{ga}(\omega, \mu, \Gamma, T) = \sigma_{intra}(\omega, \mu, \Gamma, T) + \sigma_{inter}(\omega, \mu, \Gamma, T) \quad (1)$$

where, $\sigma_{intra}(\omega, \mu, \Gamma, T)$ is the intra-band conductivity of the gallium arsenide and $\sigma_{inter}(\omega, \mu, \Gamma, T)$ is the conductivity of the inter-band respectively.

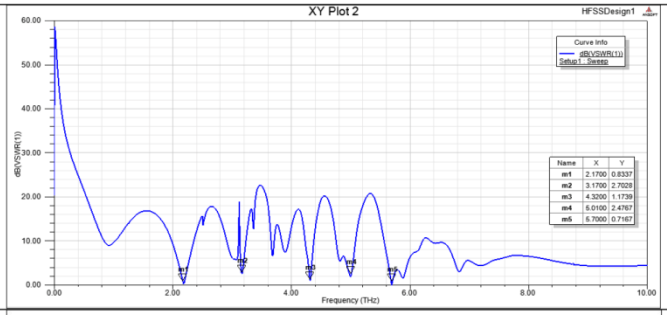
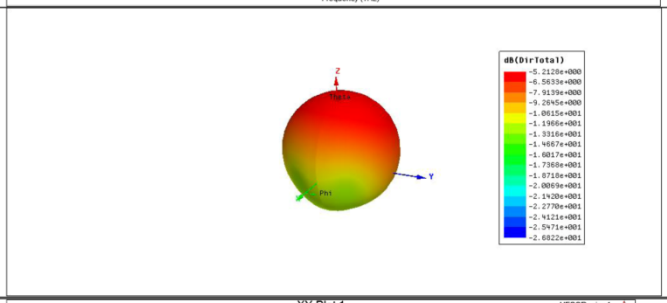
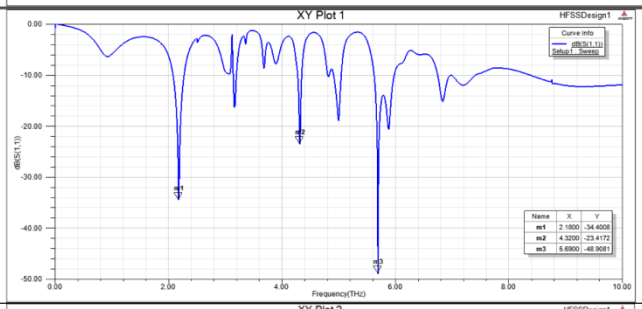
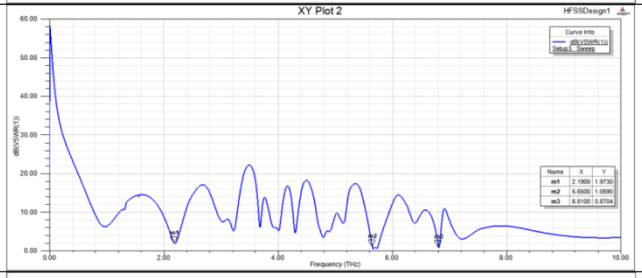
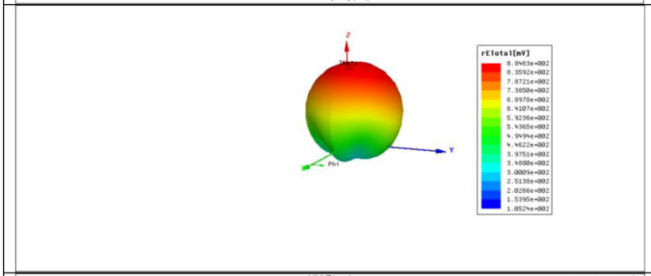
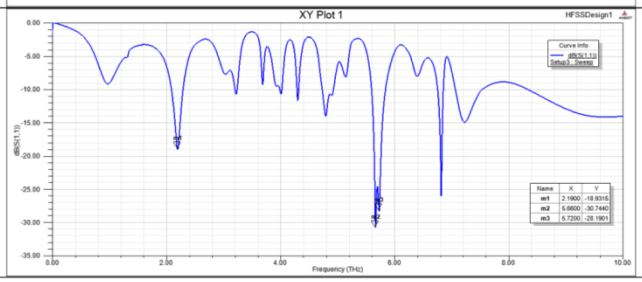
## METHODOLOGY

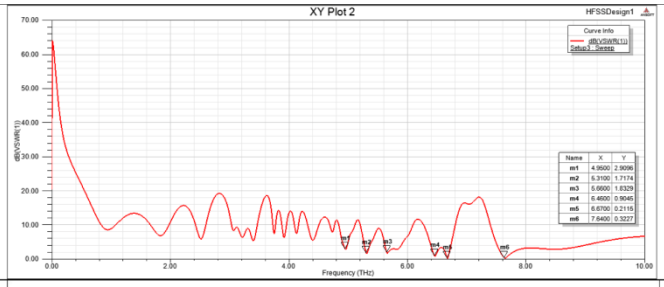
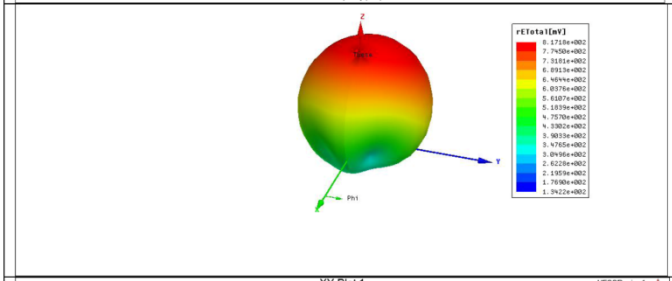
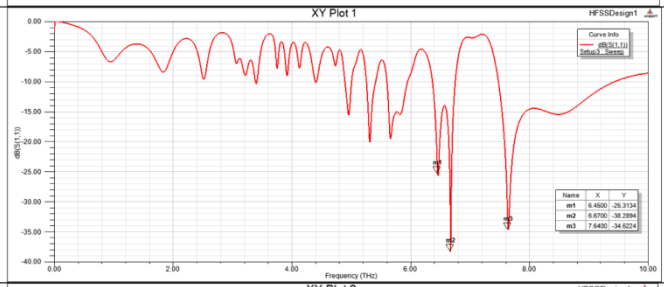
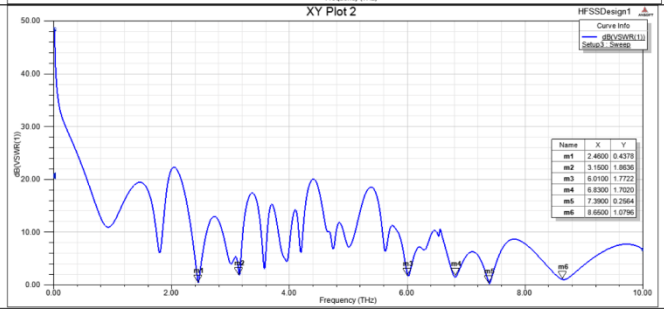
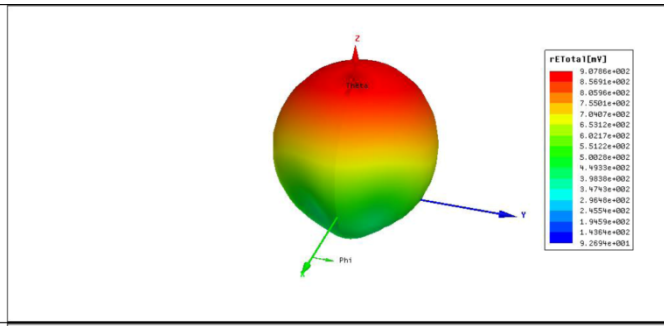
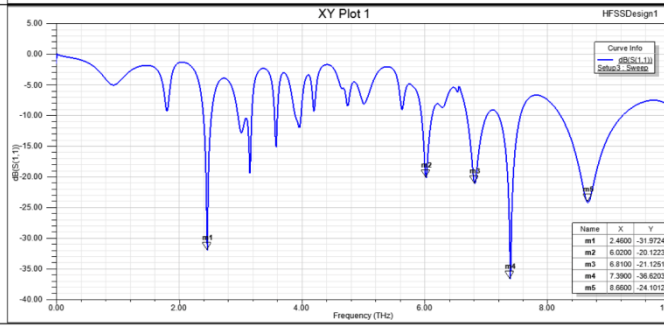
The proposed antenna has been simulated in the HFSS software. By the literature review it has been found that the authors are trying to found a solution in the terahertz frequency by evaluating the antenna for the specified frequency. The researchers are using graphene, Carbon nanotube etc. as one of the solution in the THz frequency. By exploring the features of gallium arsenide it has been found that if we can use the material in the formation of the antenna then a considerable results are obtained in the simulation process.

## RESULTS AND DISCUSSIONS

The simulated results of the VSWR vs frequency, Radiation Pattern, S11 vs Frequency for the four design has been shown in the following table for R1, R2, R3 and R4 designs respectively. The comparative study has been also made for all the four proposed patch antenna designs for S11 vs frequency and VSWR vs Frequency (comparative study has been computed in the MATLAB platform).

It has been found that at the frequency of 2.4THz, 6.02THz, 6.81THz, 7.39THz and 8.66THz for R4 a multiband frequency response has been computed. All the simulated results for R1, R2, R3 and R4 shows significant multiband response in the Terahertz frequency. Adequate amount of gain has been found for each of the designed patch antenna.

| Design Name | Simulated Results | Descriptions |
|---|---|---|
| R1 |  | Plot of VSWR vs Frequency for R1 |
| |  | Polar plot for rETotal for R1 |
| |  | Plot of S11 vs Frequency for R1 |
| R2 |  | Plot of VSWR vs Frequency for R2 |
| |  | Polar plot for rETotal for R2 |
| |  | Plot of S11 vs Frequency for R2 |

| | | |
|---|---|---|
| R3 |  | Plot of VSWR vs Frequency for R3 |
| |  | Polar plot for rETotal for R3 |
| |  | Plot of S11 vs Frequency for R3 |
| R4 |  | Plot of VSWR vs Frequency for R4 |
| |  | Polar plot for rETotal for R4 |
| |  | Plot of S11 vs Frequency for R4 |

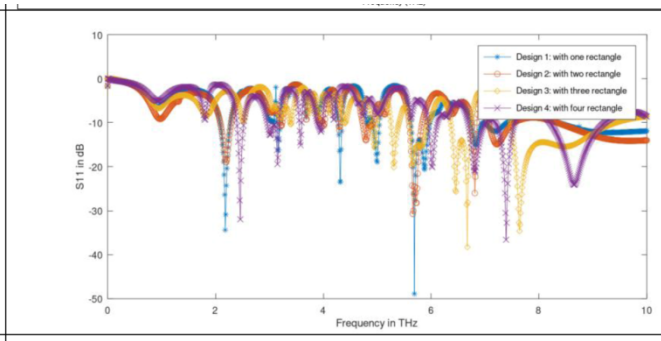
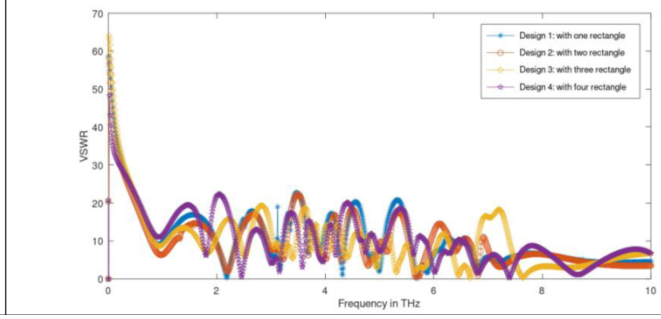
| | | |
|---|---|---|
| Comparison of R1, R2, R3 and R4 |  | Comparison of S11 vs Frequency for R1, R2, R3 and R4 |
| Comparison of R1, R2, R3 and R4 |  | Comparison of VSWR vs Frequency for R1, R2, R3 and R4 |

**Figure 5** Simulation results of the antenna designs for R1, R2, R3 and R4 respectively on HFSS and MATLAB platform

## CONCLUSIONS

The author has pointed out here with a significant amount of simulation study on the proposed patch antenna structures where the parameters like S11, VSWR, gain, radiation pattern of the entire four antenna are showing their ability to perform in the terahertz frequency. Furthermore, the characteristics of the four antenna are capable of the required amount of radiation for the application in the medical diagnosis and detection system. The study on THz antenna may open a new dimension in the medical sector. In many cases it has been found that the common people who are belonging to the below poverty level they could not afford the treatment or diagnosis cost for their family and the patient suffered as un-attended by the medical service due to costly diagnosis process are being involved. The proposed antenna can solve this issue of costly affair of medical diagnosis in near future.

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237_IEC32225

# Design of MIMO DRA with Isolation Strips and Metallic Rod for Enhanced Performance in Microwave Applications

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***Abstract:*** *In this work, a dual-port cylindrical dielectric resonator antenna (cDRA) with multiple-input multiple-output (MIMO) configuration is studied. Two cylindrical dielectric resonator antennas (cDRAs) are part of the antenna arrangement, and they are positioned above a FR4 substrate. Aperture coupling via a microstrip line excites each cDRA. The antenna elements have different polarizations as a result of the meticulous design of the feed systems. In order to increase the isolation between the antenna elements, copper striplines are attached to one side of the dielectric resonator walls. In order to further improve port isolation, a short metallic rod in the shape of a cylinder is placed between DR-1 and DR-2. This rod and stripline interact with some of the radiated power. As a result, the copper strips' and metallic rod's dimensions are carefully calibrated to reduce mutual coupling among the antenna's components, producing an astounding isolation of more than 25 dB between the ports. In addition, the antenna design covers the frequency range of 5.6 to 5.9 GHz with a bandwidth of 5.5%. The results demonstrate that the proposed novel MIMO antenna design is promising for various microwave applications.*

***Keywords:*** *MIMO; DRA; Isolation; Metallic Strip; ECC*

## INTRODUCTION

The need for increased data speeds and capacity in wireless communication has been growing quickly in the last several years. Multiple-Input Multiple-Output (MIMO) technology has evolved as a highly effective way to address these objectives. Through the use of parallel subchannels and a wider array of antenna elements, MIMO increases data speeds and channel capacity. Due to increased mutual coupling between antenna elements that share a ground plane, integrating several antenna elements into a single system is a challenging task. The coupling has an adverse effect on the overall efficiency of the system, hence one of the main challenges in MIMO antenna design is to simultaneously optimize element count and isolation [1-2].

With so many benefits, the Dielectric Resonator Antenna (DRA) has gained popularity among design engineers. Because there are no metallic losses with DRA, compared to standard microstrip patch antennas, radiation efficiency is increased and a variety of radiation patterns are supported [3]. The full potential of DRAs in MIMO systems is still being fully utilized, despite these advantages. Utilizing diversity to improve MIMO performance is the subject of few research in the literature [4–8].

To increase isolation, a number of strategies have been used, including the use of metallic reflectors [4], back-to-back dielectric resonator (DR) orientation [5], degenerate mode excitation [6–8], and defective ground structures [9]. A lot of these methods call for extra structures, which can deteriorate the properties of radiation. While excitation in degenerate modes avoids extra structures, it is not an easy task to produce such modes within a single DRA.

This article presents an innovative MIMO radiator employing a dual-port Dielectric Resonator (DR) configuration. The arrangement has two cylindrical DRAs situated in close proximity to the substrate, resulting in substantial mutual interaction between them. A metallic isolation strip is deliberately positioned along one side wall of each DRA to mitigate mutual coupling. The meticulous integration of these metallic strips markedly improves both isolation and the interrelation among the ports. A metallic rod is positioned between DR-1 and DR-2 to enhance isolation and diminish the envelope correlation coefficient (ECC). The proposed design attains remarkable isolation, surpassing 25 dB, by the integration of metallic strips and a metallic rod. A thorough performance assessment is conducted utilizing diversity metrics, including the ECC.

## ANTENNA ARRANGEMENT AND ITS ANALYSIS

The proposed structure is formulated using a sequential methodology. A fundamental MIMO DRA is first developed without the integration of any isolation methods. In the second phase, to improve isolation, two metallic isolation strips are affixed to the sidewalls of the DRAs. In the concluding phase, a metallic rod is introduced between the antenna elements to enhance isolation further.

In the first stage, A MIMO DRA composed of two cylindrical dielectric resonators has been constructed, as seen in **Figure 1**. The DRAs are fabricated from alumina ceramic (εDRA=9.8) and are situated on a ground plane, which is positioned above a FR4 epoxy substrate. In this setup, each DRA is excited by a microstrip feed line that is vertically attached from beneath the substrate. The ground plane features two slots, meticulously engineered for aperture coupling of the dielectric resonator antennas, ensuring proper alignment with both the dielectric resonators and the microstrip feedline. The dimensions of the proposed MIMO antenna shown in **Figure 1** are provided in **Table 1**.

The rectangular slots in the suggested design are arranged to facilitate HE11δ mode excitation in DR-1. **Figure 1** depicts the antenna configuration, featuring an inter-element spacing of 4 mm between DR-1 and DR-2. The distance between the antenna elements is deliberately reduced to provide significant mutual coupling. **Figure 2** illustrates the S-parameters of the dual-port antenna devoid of isolation strips, indicating a about 12 dB isolation between the ports and comparable impedance bandwidth for each port.

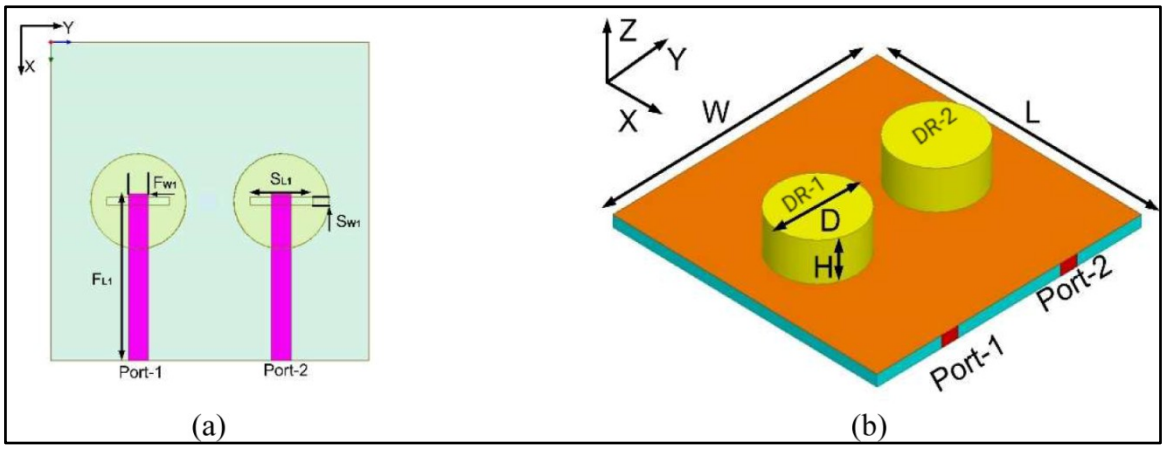


**Figure 1** Vertical feed MIMO CDRA (a) top view; (b) 3D view

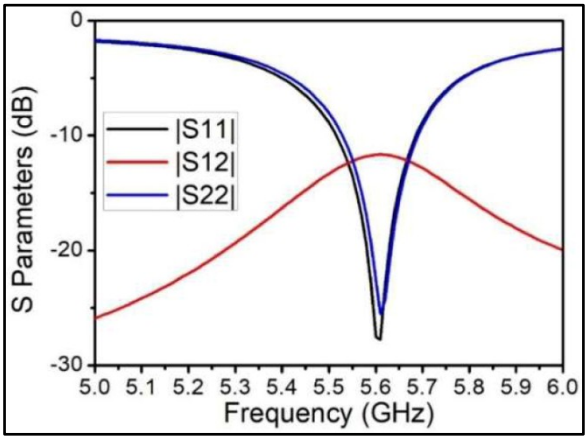


**Figure 2** S-parameters of the antenna without isolation strips

**Table 1** Antenna dimensions

| Parameter | Dimension (mm) | Parameter | Dimension (mm) |
|---|---|---|---|
| W | 40 | $F_{L1}$ | 22 |
| L | 40 | $F_{w1}$ | 1.75 |
| H | 7 | $S_{L1}$ | 8 |
| D | 14 | $S_{W1}$ | 1 |

To improve the isolation between the ports, two metallic isolation strips are attached to the side walls of the rectangular DRAs, as depicted in **Figure 3**. In this setup, identical strips are affixed to both DR-1 and DR-2, as illustrated in **Figure 3(b)**. In this design, only the metallic strips are incorporated, while the other components of the framework remain unaltered. **Figure 4** illustrates the S-parameter plots for the proposed antenna. The implementation of metallic strips results in port isolation exceeding 25 dB over the operational frequency range, as demonstrated in **Figure 4**. Moreover, the reflection coefficients for both ports remain largely unaltered.

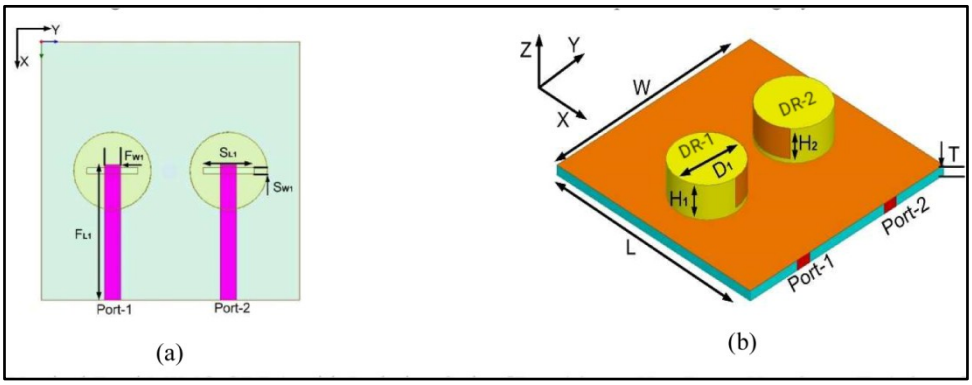


**Figure 3** Vertical Feed MIMO CDRA with Isolation Strips [D1= 14mm, H1= 7mm, H2= 6mm, T=1.6 mm]

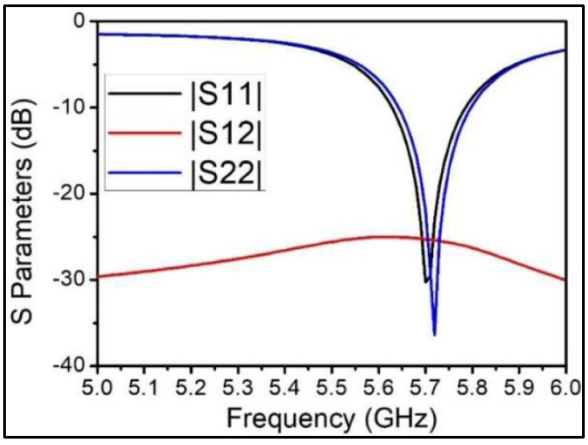


**Figure 4** S-parameters of the antenna with isolation strips

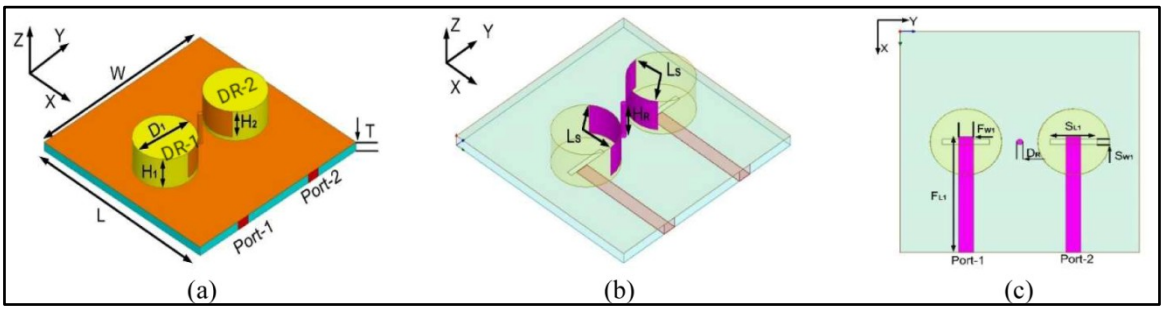

**Figure 5** Configuration of the proposed antenna (a) top view; (b) 3D view; (c) bottom view [HR= 5 mm, DR= 0.5 mm, remaining dimension stays unchanged]

In the final step, a metallic rod is positioned between the antenna elements in the configuration described earlier. **Figure 5** shows the antenna arrangement for the suggested design. The S-parameters of the horizontal feed MIMO DRA using a copper rod are shown in **Figure 6**. To determine whether isolation has improved, these outcomes are contrasted with those from the isolation strips. At the resonant frequency, the S12 value is measured at 32.1414 dB. The notable decrease in the S12 value suggests that the isolation of the antenna has improved.

**Figure 7** displays plots that exclusively depict the enhancement in isolation—without isolation techniques, with metallic strips, and with both metallic strips and rods. **Figure 8** demonstrates that the incorporation of metallic strips on the lateral surfaces of the cylindrical DRA significantly enhances isolation. The research indicates that the isolation level is roughly 12 dB without isolation strips, however the inclusion of isolation strips elevates this level to exceeding 26 dB. Moreover, the incorporation of metallic rods significantly improves isolation among the ports. The integration of these strategies yields an enhancement above 30 dB in isolation. The efficacy of the suggested metallic strips and rods is unequivocally shown.

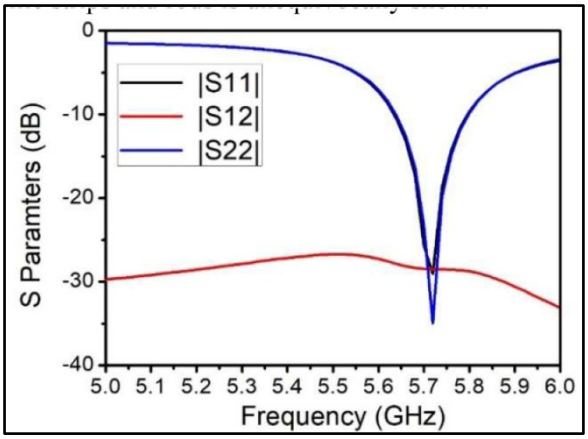


**Figure 6** S Parameter of the vertical feed MIMO CDRA with isolation strips and metallic rod

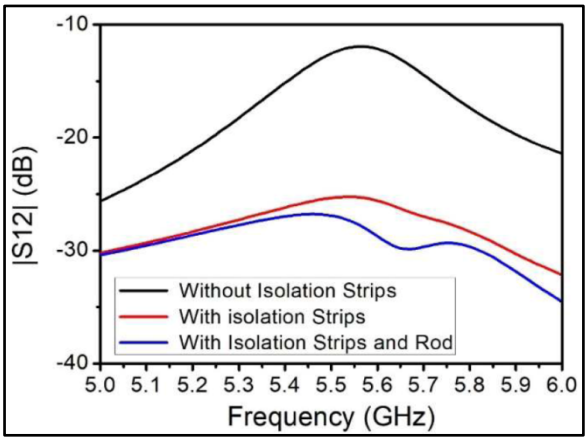


**Figure 7** Isolation variation without, with metallic strip and with metallic strips with rod

**Figure 8** demonstrates the improvement in isolation by showing the distribution of E-field intensity in DR-1 and DR-2. **Figure 8**(a) illustrates the distribution of the electric field (E-field) in DR-1 and DR-2 in the absence of metallic strips. In this situation, electromagnetic (EM) radiation engages with DR-2 upon the activation of port-1 to stimulate DR-1, resulting in substantial mutual coupling between port-1 and port-2. The proposed design includes a metallic strip and a metallic rod. **Figure 8(b)** illustrates the electric field distribution for this setup. The metallic strip on the

side wall of the DRA and the metallic rod efficiently inhibits the coupling of electromagnetic energy to DR-2 when port-1 is active, leading to a substantial enhancement in isolation. The proposed configuration attains an isolation level beyond 30 dB. The utilization of metallic strips and rods is advantageous for DRA-based MIMO antennas.

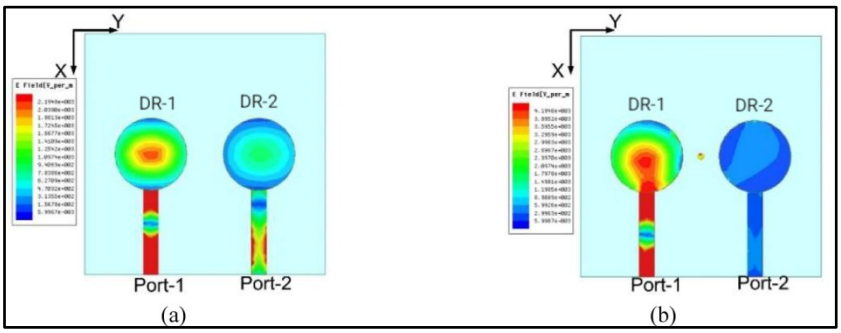


**Figure 8** E-field distribution in the DRA: (a) absent metallic strips; (b) with metallic strips and a metallic rod [In all scenarios, port-1 is activated]

The suggested antenna's three-dimensional polar plot is shown in **Figure 9**. The broadside direction of primary radiation is a characteristic of the HE11δ mode. As shown in **Figure 9**, both DRAs (DR-1 and DR-2) radiate in the broadside direction when ports 1 and 2 are enabled. As a result, the insertion of metallic strips improves port isolation while preserving the antenna's radiating capabilities.

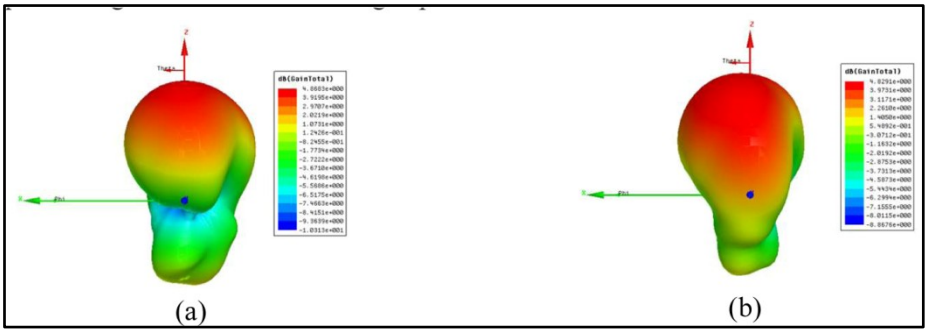


**Figure 9** Vertical Feed CDRA 3D Polar Plot (a) port 1 is stimulated, (b) port 2 is stimulated

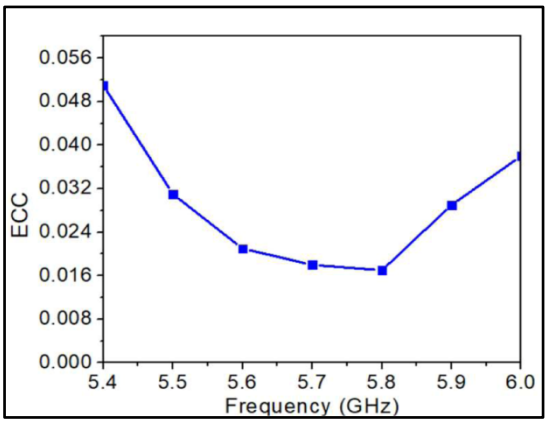


**Figure 10** ECC of the proposed antenna

**Figure 10** shows the antenna configuration's envelope correlation coefficient (ECC). The ECC estimation for the suggested radiator is obtained via a far-field-based relationship, as described in reference [4]. In contrast to port 1, ECC values were computed for port 2 at particular frequencies. It is evident from **Figure 10** that the ECC values continuously stay below the recommended cutoff point of 0.50, as mentioned in reference [4].

## CONCLUSION

The design and properties of a dual-port cylindrical Dielectric Resonator Antenna (DRA) optimized for MIMO applications are examined in this paper. The design incorporates metallic strips and a metallic rod to improve the isolation between the ports. An astounding isolation of more than 30 dB is obtained between the antenna ports using this method.

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# Information & Communication Technology

# Optical Fiber Communication

149_IEC98331

# Fiber Bragg Grating Sensor for Precise Monitoring of Healthcare Parameters

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***Abstract:*** *Optical Fibers are most promising for development of sensors required for modern healthcare systems. The Fiber Bragg Grating sensors plays vital role in such healthcare systems to transform healthcare globally for improved clinical diagnosis. The Fiber Bragg Grating sensors offers unique advantages over electronic sensors due to its small size, immunity to electromagnetic interference and precise measurement of healthcare parameters. Fiber Bragg Gratings function as distributed Bragg reflectors, reflecting desired wavelength while transmitting others. The reflected wavelength from the Fiber Bragg Grating depends on physical factors like temperature and strain which are useful for healthcare parameter monitoring. The performance of Fiber Bragg Grating sensor depends on certain parameters which includes sensor dimensions, grating period, grating length, modulation index and refractive index profile. These parameters affect reflectivity and bandwidth of sensor. The high reflectivity, narrow bandwidth and minimal side lobe levels are essential for sensing applications. The Fiber Bragg Grating sensor is simulated by OPTIGRATING simulation tool to show the effect of grating length and apodization profiles. The sensor parameters are optimized to obtain high reflectivity and minimum side lobe levels. The proposed design is useful for precise monitoring of healthcare parameters in modern healthcare systems.*

***Keywords:*** *Fiber Bragg Grating Sensors; Grating Parameters; Reflectivity; Bandwidth; Side Lobe Levels*

Uniform Bragg Grating sensor structure is simulated and its reflection spectrum and side lobe level spectrum is obtained. The wavelength of 1550 nm is used to test the properties of sensor.

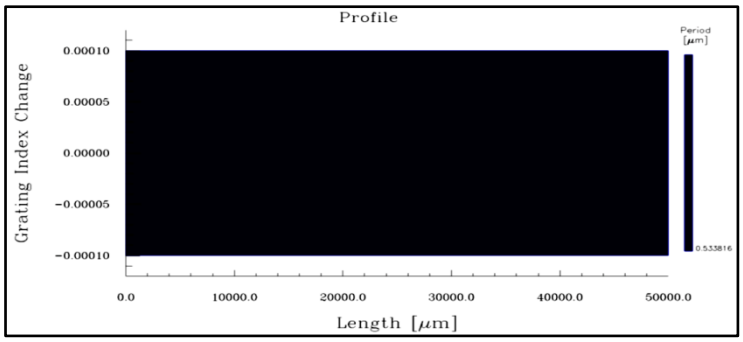


**Figure 1** Uniform Grating Profile

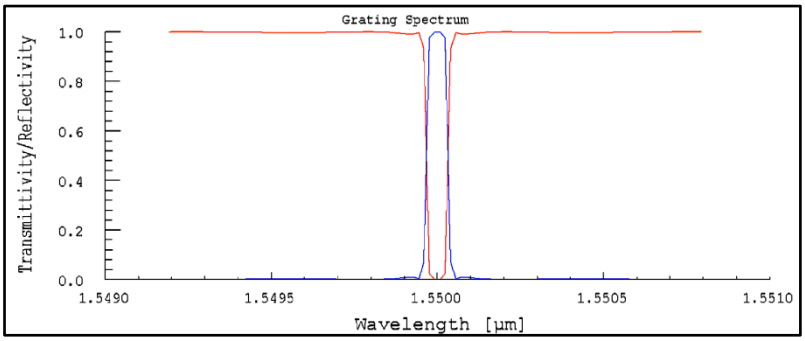


**Figure 2** Spectrum of Uniform Grating

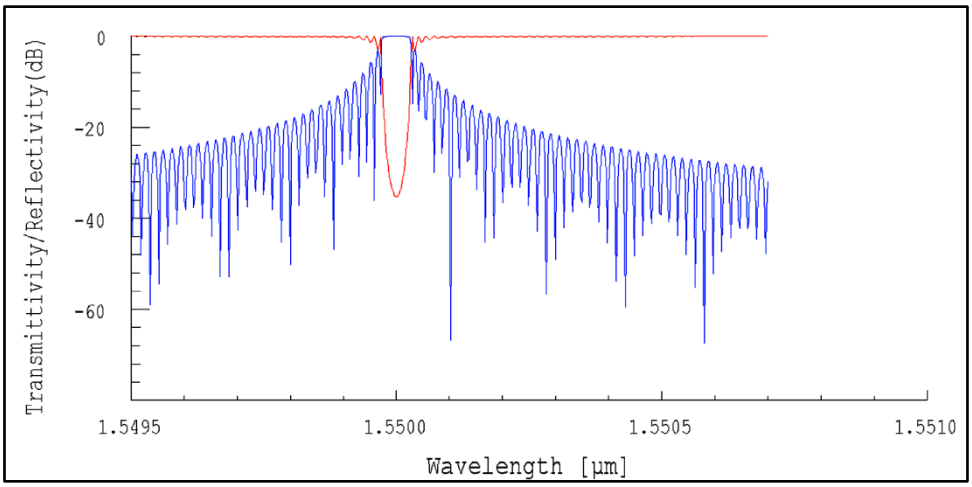


**Figure 3** Side lobe level spectrum of Uniform Grating

The wavelength shift and reflectivity depend on grating length, period and index profile. The Uniform Fiber Bragg Grating sensor can provide the high reflectivity at the desired wavelength as shown in **Table 1**.

**Table 1** Transmittivity/ reflectivity of uniform grating

| Sr. No. | Wavelength [µm] | Transmittivity | Reflectivity |
|---|---|---|---|
| 1 | 1.550072 | 0.990102 | 0.009898 |
| 2 | 1.550056 | 0.997346 | 0.002654 |
| 3 | 1.55004 | 0.930825 | 0.069175 |
| 4 | 1.550024 | 0.024458 | 0.975542 |
| 5 | 1.550008 | 0.000437 | 0.999563 |
| 6 | 1.549992 | 0.000437 | 0.999563 |
| 7 | 1.549976 | 0.024446 | 0.975554 |
| 8 | 1.54996 | 0.930744 | 0.069256 |
| 9 | 1.549944 | 0.997355 | 0.002645 |
| 10 | 1.550072 | 0.990102 | 0.009898 |

## CONCLUSION

The Fiber Bragg Grating sensors provides accurate measurement of healthcare parameters. This sensor should provide maximum reflectivity and minimum side lobe level which is essential for sensing application. From simulation results it is observed that, Uniform Bragg grating can give reflectivity of 99%. It is also observed that, Uniform Bragg Grating gives higher side lobe levels which affects accuracy. The parameter optimization with suitable Grating profile can give the desired performance required for sensing applications.

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# Information & Communication Technology

## Quantum Computing- Quantum Sensing, Quantum Security, Quantum Communication

65_IEC48667

# The Convergence of Quantum Computing and AI in Defense: Shaping the Future of Global Security

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***Abstract:*** *The rapid advancement of Artificial Intelligence (AI) and Quantum Computing has begun to reshape modern military strategies, introducing unprecedented capabilities and transforming global security dynamics. As these technologies converge, they offer the potential to revolutionize decision-making processes, enhance the speed and precision of military operations, and shift the balance of power on the global stage. However, the integration of these technologies into defense systems also presents significant risks, including ethical concerns, challenges in governance, and the potential for an arms race in AI and Quantum-based weaponry. This extended abstract explores the current state of AI and Quantum Computing integration in military applications, examines their influence on international security, and discusses the ethical and legal implications associated with their militarization. The paper also provides scenario-based foresight into the future of warfare, focusing on how these emerging technologies could shape global security in the coming decades. Key research questions addressed include the strategic integration of AI and Quantum Computing, their impact on power dynamics, the risks and challenges of militarization, and the broader societal implications of deploying these technologies in warfare [1,2].*

***Keywords:*** *Quantum Computing; Artificial Intelligence; Modern Warfare; Ethical Implications; Military Strategy*

## INTRODUCTION

The intersection of Artificial Intelligence (AI) and Quantum Computing is poised to redefine the landscape of modern warfare, offering both unprecedented opportunities and profound challenges. As nations invest heavily in these technologies, their integration into military strategies and operations becomes increasingly crucial for main-taining competitive advantage on the global stage [3]. This research explores several key questions: How are AI and Quantum Computing being integrated into modern military strategies and operations? How do advancements in these technologies influence the balance of power and international security dynamics? What are the potential risks and challenges associated with their militarization, and how can they be mitigated? Finally, what are the ethical, legal, and societal implications of deploying these technologies in warfare?

Quantum Computing, with its ability to process complex calculations at speeds unattainable by classical comput-ers, offers transformative potential in areas such as cryptography, logistics optimization, and artificial intelligence [4], [5]. Similarly, AI has already demonstrated its value in autonomous systems, decision support, and cyber warfare, among other domains [6], [7]. The convergence of these technologies could result in a new generation of defense capabilities that not only enhance the effectiveness of military operations but also alter the global balance of power [8].

The militarization of AI and Quantum Computing raises significant ethical and legal concerns. The potential for autonomous weapon systems to make life-and-death decisions without human intervention, the risk of escalation in an AI-driven arms race, and the challenge of establishing international norms and regulations are all critical issues that must be addressed [9], [10]. This paper seeks to provide a comprehensive analysis of these challenges while offering foresight into the future of global security shaped by AI and Quantum Computing.

## METHODOLOGY

The methodology employed in this research is based on scenario planning, a foresight technique that allows for the exploration of possible future developments by considering a range of plausible scenarios. This approach is particularly well-suited for analyzing the uncertain and rapidly evolving field of AI and Quantum Computing in defense. By constructing multiple scenarios, we can better understand the potential impacts of these technologies on military strategy, operations, and global security, as well as identify key risks and opportunities.

## RESULTS

The results of this scenario-based analysis indicate that the convergence of AI and Quantum Computing could lead to several significant developments in military strategy and global security. These include the enhancement of cyber capabilities [11], the development of more sophisticated autonomous systems [12], and the potential for new forms of warfare that leverage the unique capabilities of quantum technologies [13]. However, the analysis also highlights the risks associated with these advancements, including the potential for increased geopolitical tensions, the proliferation of autonomous weapons, and the challenge of ensuring ethical use of these technologies [14], [15].

## CONCLUSION

The integration of quantum computing and AI into military operations presents both opportunities and challenges. While these technologies have the potential to enhance the efficiency, accuracy, and security of military strategies, they also introduce new ethical dilemmas and risks. The study concludes that there is an urgent need for interna-tional governance frameworks to regulate the use of quantum computing and AI in warfare [6]. Such frameworks should address the ethical concerns related to autonomous weapons, ensure the responsible use of quantum tech-nologies, and promote transparency in military AI applications [16].

Furthermore, the study emphasizes the importance of developing quantum-safe cryptographic systems to protect sensitive military data in the quantum era [13]. It also calls for continued research into the ethical implications of AI in warfare, particularly in areas such as accountability, decision-making, and the potential for AI-driven con-flicts [17].

The integration of Quantum Computing and AI into military strategies and operations represents a critical frontier in the evolution of global security. While these technologies offer significant advantages, they also introduce new risks and challenges that must be carefully managed. The potential for an AI-driven arms race, the ethical impli-cations of autonomous weapon systems, and the need for robust international governance frameworks are all areas that require urgent attention [18]. As we move forward, policymakers, military leaders, and technologists must work together to ensure that the benefits of these technologies are realized while minimizing the risks associated with their militarization [19], [20].

In conclusion, quantum computing and AI are set to play a pivotal role in the future of warfare. As these technol-ogies evolve, policymakers, military leaders, and technologists must work together to ensure that their develop-ment and deployment contribute to global security and peace, rather than fuelling conflict and instability [11].

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294_IEC8235

# Quantum Algorithms and Computational Advantages for Fintech Safety

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***Abstract:*** *Financial technology (Fintech) has grown rapidly in recent years, incorporating advanced computational methods to enhance security, optimize transactions, and ensure regulatory compliance. However, with increasing complexity and cyber threats, traditional computational techniques are increasingly strained. Quantum computing, with its unique computational paradigms, offers potential for unprecedented advancements in cryptography, optimization, and risk management in the Fintech sector. This paper explores how quantum algorithms can be leveraged for Fintech safety and provides an analysis of the computational advantages they bring over classical methods.*

***Keywords****: Quantum Computing; Fintech, Cryptography; Quantum Algorithms; Cybersecurity; Computational Advantage; Financial Security*

## INTRODUCTION

Quantum computing poses both a significant threat and a potential solution for the field of cryptography. Modern cryptographic systems, which secure digital communication, financial transactions, and sensitive data, rely on mathematical problems that are difficult for classical computers to solve. However, the development of large-scale quantum computers could break many of these cryptographic systems, exposing them to quantum attacks. On the other hand, quantum computing also offers opportunities for developing new cryptographic techniques that are resistant to quantum attacks, known as post-quantum cryptography and quantum cryptography.

Fintech has become an essential driver of modern economies, reshaping how financial services operate through the integration of technology. However, the increasing digitization of financial operations has led to new vulnerabilities, making cybersecurity a primary concern. Traditional cryptographic systems, while robust, face increasing threats from both the growing power of classical computers and the advent of quantum computing. Quantum computing, with its promise of solving complex computational problems exponentially faster than classical systems, presents both a threat and an opportunity for Fintech. This paper aims to explore quantum algorithms and their computational advantages in enhancing the safety of Fintech systems.

## OVERVIEW OF QUANTUM COMPUTING

Quantum computing harnesses the principles of quantum mechanics—such as superposition, entanglement, and quantum interference—to perform computations. Unlike classical computers, which use bits (0 or 1) to process information, quantum computers utilize qubits, which can exist in multiple states simultaneously due to superposition. This feature allows quantum computers to perform many calculations in parallel, offering significant advantages in solving specific types of problems.

Quantum computers excel at problems involving optimization, factorization, and large-scale data analysis. These are precisely the types of problems Fintech companies face when addressing challenges like fraud detection, secure communication, and risk management.

## QUANTUM ALGORITHMS RELEVANT TO FINTECH SAFETY

Quantum algorithms hold the key to quantum computing's potential. Below, we review several key quantum algorithms that have significant applications in Fintech safety.

**Shor's Algorithm**

One of the most significant quantum algorithms is Shor's algorithm, which solves the integer factorization problem exponentially faster than classical algorithms. This has direct implications for Fintech security, as most encryption protocols, such as RSA, rely on the difficulty of factoring large numbers. A sufficiently advanced quantum computer running Shor's algorithm could break RSA encryption, rendering current cryptographic systems obsolete.

In response, Fintech companies are exploring post-quantum cryptography, which involves cryptographic algorithms that are resistant to quantum attacks. However, Shor's algorithm exemplifies the need for more advanced security models in a quantum computing era.

**Grover's Algorithm**

Grover's algorithm provides a quadratic speedup for unstructured search problems. This can be applied to enhance various aspects of Fintech operations, including database searches, fraud detection, and optimization of financial portfolios. Though Grover's algorithm does not provide an exponential speedup like Shor's, it offers significant improvements in the efficiency of tasks that involve searching large datasets.

For instance, in fraud detection systems, Grover's algorithm could significantly reduce the time needed to search through large transaction datasets for anomalies, thus improving the speed and accuracy of identifying fraudulent activities.

**Quantum Key Distribution (QKD)**

Quantum Key Distribution (QKD) offers a new frontier for secure communication in Fintech. Unlike classical encryption methods, which rely on the computational difficulty of certain mathematical problems, QKD is based on the principles of quantum mechanics, specifically the no-cloning theorem and entanglement. This guarantees that any attempt to eavesdrop on a quantum communication channel will be detected.

QKD provides an unconditionally secure method for distributing cryptographic keys, which is crucial for secure financial transactions. Several experimental QKD systems have already been deployed, offering secure channels between financial institutions.

**COMPUTATIONAL ADVANTAGES IN FINTECH SAFETY**

Quantum computing's primary advantage lies in its ability to solve problems exponentially faster than classical systems for specific use cases. Below, we explore several key areas where quantum algorithms can enhance Fintech safety.

**Enhanced Cryptography**

Classical cryptographic systems are built on the assumption that certain problems, like factoring large numbers or solving discrete logarithms, are computationally infeasible for classical computers. However, quantum algorithms such as Shor's challenge this assumption. The advent of quantum computing necessitates the development of quantum-resistant cryptographic methods, such as lattice-based or multivariate polynomial cryptography, which remain secure even against quantum attacks.

**Improved Fraud Detection**

Financial institutions rely on detecting anomalies in large datasets to prevent fraud. Quantum algorithms, such as Grover's search, offer a more efficient way to search through and analyze large datasets. Combined with machine learning techniques, quantum computing could enable real-time fraud detection, significantly reducing the time between detecting fraudulent activity and taking action.

**Risk Management and Optimization**

Quantum algorithms also excel in optimization problems, which are central to financial portfolio management and risk assessment. Classical methods often rely on heuristic techniques to find approximate solutions to complex optimization problems. Quantum optimization algorithms, such as the Quantum Approximate Optimization Algorithm (QAOA), have the potential to find optimal solutions much more efficiently, allowing for better portfolio diversification and risk mitigation in real time.

**Secure Communication**

Quantum Key Distribution ensures secure communication channels, a vital need for financial institutions handling sensitive client data. Quantum-based communication systems can detect eavesdropping attempts, providing a level of security unattainable by classical methods. The integration of QKD with current Fintech infrastructure could significantly enhance the security of financial transactions and sensitive information exchanges.

Case Studies

- Fraud Detection: Fraud detection in Fintech requires identifying suspicious transactions among millions of legitimate ones. A major fintech company implemented an AI-based fraud detection system, reducing fraud-related losses by 30%. Quantum algorithms can significantly speed up the process of detecting patterns of fraud by enabling faster data search, clustering, and optimization techniques.

- Credit Scoring: Credit scoring involves evaluating various financial indicators such as payment history, credit utilization, length of credit history, and other factors to assess the creditworthiness of an individual or entity. Modern credit scoring models rely on advanced analytics to process financial data and make predictions about future credit risk. An AI-driven credit scoring model provided more accurate risk assessments, allowing the company to approve loans for underserved demographics.

**Methodology and Work Flow**

Firstly, we will discuss flow diagram of the existing Fintech System

The diagram includes four main services:

- Money Transfer
- Balance Check
- Loan Application
- Investment

Fig. 1 Flow of Existing Fintech System.

Fig. 2 Flow of Fintech Security Challenge Using Quantum Computing

I've created above given flow diagram that outlines the methodology for applying quantum algorithms to enhance fintech safety. Here's a brief explanation of the key steps:

- The process begins with identifying specific fintech security challenges.
- We then assess the limitations of classical computing in addressing these challenges.
- A decision point determines if quantum computing can help solve the problem.
- If quantum computing is applicable, we select appropriate quantum algorithms from categories like quantum encryption, quantum random number generation, and quantum machine learning.
- These algorithms are then implemented in specific applications like quantum key distribution, enhanced cryptographic seed generation, and improved fraud detection models.
- The quantum solutions are integrated with existing fintech systems and tested through hybrid simulations.

- The computational advantages and security improvements are analyzed and quantified.
- The implementation is refined through iteration.
- Finally, the solution is deployed in a production environment with continuous monitoring and updates.

## CHALLENGES AND FUTURE OUTLOOK

While the potential of quantum computing in Fintech is immense, several challenges remain before it can be fully realized:

### Hardware Limitations

Current quantum computers are still in the early stages of development, with limited qubits and error rates that make practical applications challenging. However, advancements in quantum error correction and the development of more stable quantum hardware will gradually overcome these obstacles.

### Post-Quantum Cryptography

As quantum computing becomes more advanced, there is a pressing need to develop and implement post-quantum cryptographic systems that are resistant to quantum attacks. This requires collaboration between cryptographers, financial institutions, and government bodies to ensure that Fintech systems remain secure in the face of quantum threats.

### Regulatory and Ethical Considerations

The integration of quantum technologies into Fintech will require new regulatory frameworks to ensure the ethical use of quantum computing, particularly in areas like privacy, data protection, and algorithmic transparency.

## CONCLUSION

Quantum computing represents a double-edged sword for Fintech safety. While quantum algorithms like Shor's threaten current cryptographic systems, they also offer solutions to improve security, optimization, and risk management. As the field of quantum computing continues to evolve, the Fintech industry must proactively explore quantum-resistant cryptography and harness the computational advantages of quantum algorithms to ensure the safety and integrity of financial systems.

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# Information & Communication Technology

# VLSI

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# Comparative Analysis of Intercalation Doped MLGNR-based On-chip Inductor

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***Abstract:*** *This work presents the comparative study on analytically extracted effective inductance of an on-chip pristine and intercalation doped MLGNR-based inductor. The large relaxation time leading to higher mean free path (MFP), enhanced time and level of doping of carrier concentration are taken into consideration during the extraction of the on-chip inductance. Additionally, it has been demonstrated that intercalation-doped MLGNR increases the effective Fermi energy, subsequently, the conductivity, thereby enhancing high kinetic inductance. At the same time, a unique analytical approach has been adhered to determine the inductance by varying the width and thickness of the MLGNR. It has been observed that the kinetic inductance improves with intercalation doping with considerable carrier concentration and it becomes progressively dominant with alleviated width and thickness. The $Br_2$-doped MLGNR has been observed to exhibit superior performance as an on-chip inductor compared to Cu, Pristine MLGNR as well as $AsF_5$-, $FeCl_3$-doped MLGNR at lower widths and thicknesses in the micrometre regime.*

***Keywords:*** *On-Chip Inductor; Graphene Nanoribbon; Mean Free Path; Intercalation Doping; Staging; Kinetic Inductance*

## INTRODUCTION

The VLSI industry presently is suffering from reliability issues owing to the nanoscale dimension of the on-chip devices and interconnect circuits integrated in the chip. Besides, passive components like resistor, capacitor and inductor consumes around 70-80% of the chip area, among which inductor takes up the maximum area. The size of inductor does not scale with process technology. Conventional copper (Cu) inductor is becoming ill fitted for integrated circuits in the nanoscale regime as a result of their bulky nature and is strenuous to integrate on a chip. Therefore, need to minimize the area consumption along with using a light material to design an inductor is a prime focus for on chip circuit designers. Graphene nanoribbon (GNR) is gradually becoming potential as an alternative material for on-chip devices and interconnect circuits superseding Cu.

GNR, the 2D structure of graphene, has been found to be the hardest yet thinnest material till date. GNR exhibits extraordinary current carrying capability, high mobility leading to high mean free path (MFP), exceptional thermal and electrical conductivity [1-3]. When stacked in layers, the GNR is called as Multilayer GNR (MLGNR). Performance enhancement of multilayer over single layer GNR has been demonstrated in various works [4-8]. Despite this, a key challenge of using MLGNR in its most intrinsic form revealed much lower conductivity. MLGNR intercalated with different doping materials has affirmed an enhanced performance owing to larger interlayer spacing that leads to low scattering, high MFP and higher conductivity [9]. It has been demonstrated earlier [10-12] that the resistance of MLGNR can be much alleviated with intercalation doping, subsequently increasing the conductivity. In our previous work, we have demonstrated the effect of intercalation doping upon the effective resistance of an MLGNR considering with and without Fermi screening [13]. However, most of the work has been emphasised upon the determination of the effective resistance.

The present research work, focuses on determining the on chip effective inductance by exploiting the unique characteristics of intercalation doped MLGNR. A comparative analysis for the kinetic inductance has been carried out for pristine and intercalation doped MLGNR for different width and thickness. It has been observed that the kinetic inductance for pristine and intercalation doped MLGNR appears to be progressively dominant with a reduction in thickness and width.

The framing of the remaining part of the paper is as follows. Section II emphasizes on the methodologies followed to evaluate the kinetic inductance of pristine and intercalated MLGNR. The results of the evaluation are integrated in section III. The conclusion of the work has been drawn in Section IV.

## METHODOLOGY

The effective inductance ($L_{efct}$) of an inductor is the aggregate of the magnetic inductance ($L_{Mg}$) and kinetic inductance ($L_{Kn}$). However, as the chip dimension is scaled down, inductance density degrades. Subsequently, the effect of $L_{Mg}$ becomes insignificant [1,14], and the effective inductance calculated equals approximately $L_{Kn}$. The constraint of area exhaustion can be defeated with evaluation of $L_{Kn}$ for on chip application. Also, unwanted coupling due to mutual inductance can be avoided while determining $L_{Kn}$ [15-16]. On chip inductance is being calculated based on the mobility of the material being used. It has been mentioned above that GNR possess high mobility compared to Cu. Subsequently, the momentum relaxation time of GNR in order of picosecond allow it to possess higher $L_{Kn}$. Along with this, the electrical conductivity property is influenced by number of layers ($N_L$) in a MLGNR stack [5-7]. For pristine and intercalation doped MLGNR number of conducting channels ($N_{ch}$) also regulates the electrical conductivity. Per layer and per conducting channel the kinetic inductance for pristine MLGNR has been calculated to be 8nH/µm [1].

As stated earlier, with intercalation doping, the Fermi energy ($E_f$) as well as the interlayer spacing rises. Besides, intercalation doped MLGNR has a higher MFP owing to their large momentum relaxation time [15-16]. Different doping materials have been used to analyse the performance of MLGNR. We have focused our observation with $AsF_5$, $FeCl_3$, and Bromine ($Br_2$) intercalated MLGNR to determine the kinetic inductance and design the on-chip inductor.

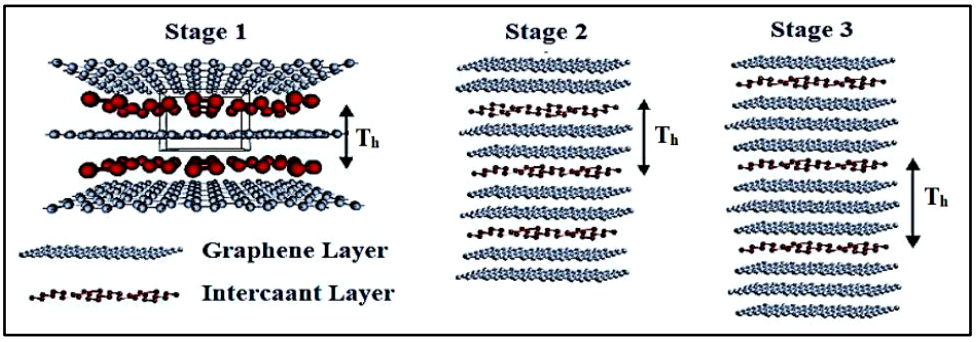


**Figure 1** Intercalation doping of MLGNR with staging [15]

Per layer per conducting channel the $L_{Kn}$ for pristine MLGNR has been calculated to be 8 nH/µm. With intercalation doping $N_L$, $N_{ch}$, and $E_f$ also increases. $N_{ch}$ bears a linear relation with $E_f$ and width of MLGNR and calculated as $N_{ch} = \alpha\, w_d\, E_f$ where the fitting parameter α equals $1.2eV^{-1}\, nm^{-1}$ [17]. Hence the kinetic inductance can be calculated as

$$L_{kn} = \frac{8}{\alpha w_d E_f} nH/\mu m \qquad (1)$$

Again, GNR possess a substantial momentum relaxation time ($\tau_m$) at very smaller dimension. τm can be determined from the Fermi energy and mobility of MLGNR as

$$Ef = \frac{e\, v_f^2 \tau_m}{\mu} \qquad (2)$$

where $v_f$ is the Fermi velocity, µ is the carrier mobility and $\tau_m$ is the relaxation time. With increase in Fermi energy, as a consequence of intercalation doping, the relaxation time also increases. Subsequently the MFP is enhanced. Banerjee et. al. has calculated the kinetic inductance based on the level of doping concentration and conductivity.

LKn has been evaluated considering the MFP and conductivity of the pristine and intercalation doped MLGNR given as [15]

$$L_{kn} = \frac{v\,\lambda_{efct}}{\sigma\, w_d T_h} \qquad (3)$$

where $\lambda_{efct}$ is the MFP derived from the momentum relaxation time, $\sigma$ is the conductivity, $w_d$ and $T_h$ are respectively the width and thickness of MLGNR inductor. It can be observed that with increase in conductivity, as a result of intercalation doping, the kinetic inductance tends to go down. Decreasing the conductivity can lead to increase in effective resistance. A trade-off has been done to keep the resistance low while increasing the inductance. One way to achieve higher inductance is to scale down the width of the inductor in micrometer range instead of nanometer range. The need to maintain aspect ratio of width to thickness for intercalated MLGNR is not essential. This will thus avoid bulky inductor design. Secondly, staging of MLGNR intercalation need to be considered while determining the kinetic inductance. As depicted in Figure 1 the number of GNR layers present in between two intercalant layers refers to staging [18]. Thickness of intercalated MLGNR is calculated based on the stage number, however, staging does not affect the width of the layer. Banerjee et.al [15] have demonstrated that for a 500 nm thick MLGNR, LKn for pristine and intercalated MLGNR are found to be 37nH/m and 86nH/m respectively. As inductance varies inversely to the cross-sectional area, stage-I intercalation doping gives the maximum inductance.

## RESULTS AND DISCUSSION

A comparative analysis for on chip inductance calculation revealed that compared to Cu, pristine and intercalation doped MLGNR bestows higher kinetic inductance at lower widths. **Figure 2** demonstrates the kinetic inductance of Cu, pristine and intercalated MLGNR. It is being observed that Br2-intercalated MLGNR exhibits the highest inductance across varying widths, making it a promising candidate for power electronics applications. Unlike resistance, which explicitly depends on the number of conducting layers, the inductance of MLGNR is dependent on the stage of intercalation, operating frequency and effective width. Another important aspect to obtain higher inductance is the intercalation time and level of carrier concentration as doping is considered to be a process of charge transfer that influence the mobility, subsequently, the relaxation time of the intercalation doped MLGNR.

In our present model, the thickness is considered as 500 nm. As displayed in **Figure 2(a)** the width is varied from 4 μm to 20 μm. Stage of Br2 intercalation is taken as I while for AsF5 and FeCl3 stage II is considered. Carrier concentration after intercalation is also an important criterion for determination of the interconnect conductivity. **Figure 2(b)** depicts that for pristine MLGNR, the present calculated values almost equal the values determined by Zhao [16]. However, for intercalation doped MLGNR, the kinetic inductance for smaller width has been calibrated which is an order higher than those proposed in [16]. This deviation is due to the increased carrier concentration after intercalation doping. The time and quantity of doping carrier concentration is a notable factor to determine the on chip inductor values. It has been observed that the kinetic inductance becomes progressively dominant with alleviated width and thickness.

**Table 1** Kinetic Inductance (nH/m) for pristine and different Intercalation doped MLGNR for different width. The thickness is taken as 500 nm and frequency 30GHz.

| Width (um) | Pristine MLGNR | $AsF_5$ Intercalated | $FeCl_3$ Intercalated | $Br_2$ Intercalated | Cu |
|---|---|---|---|---|---|
| 4 | 37.5 | 4 | 2.8 | 40 | 0.48 |
| 8 | 18.7 | 2 | 1.4 | 25 | 0.24 |
| 12 | 12.5 | 1.3 | 0.95 | 13.3 | 0.16 |
| 16 | 9.3 | 0.97 | 0.7 | 9.95 | 0.12 |
| 20 | 7.5 | 0.78 | 0.56 | 7.9 | 0.09 |
| 25 | 6 | 0.62 | 0.45 | 6.3 | 0.07 |

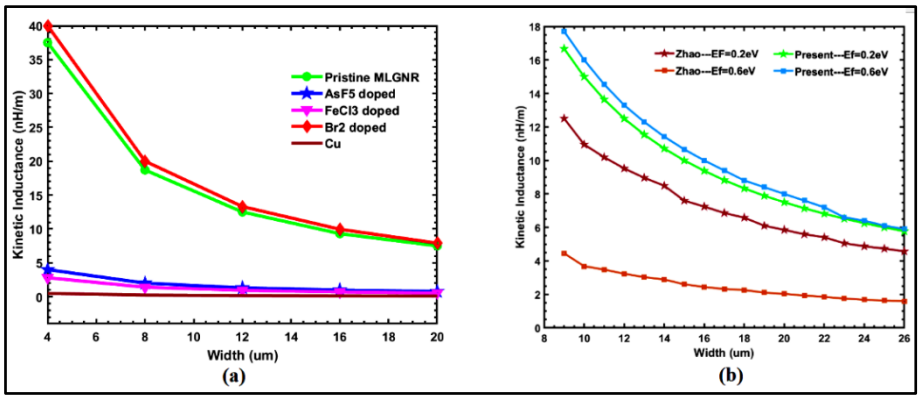


**Figure 2** (a) Variation of Kinetic Inductance with varying width (b) Validation of Kinetic Inductance with data by Zhao et al [16]

## CONCLUSION

Different intercalation doping was used to investigate the kinetic inductance of an on chip inductor using MLGNR. The unique attribute of exploiting intercalation doped MLGNR played an important factor in enhancing the inductance of the on chip inductor. The Fermi level shift with increased carrier concentration for Br2 intercalated MLGNR compared to pristine and other intercalants evinced a better inductance at higher frequency. Trade off in thickness and width improved area efficiency. Besides, intercalation doping is used to alleviate high resistance too. Higher value of on chip inductor with lowered resistance is the call for time as power electric load. For VLSI circuits, use of intercalation doped MLGNR paves a way to obtain smaller dimension, higher inductance value on chip inductors.

## ACKNOWLEDGMENT

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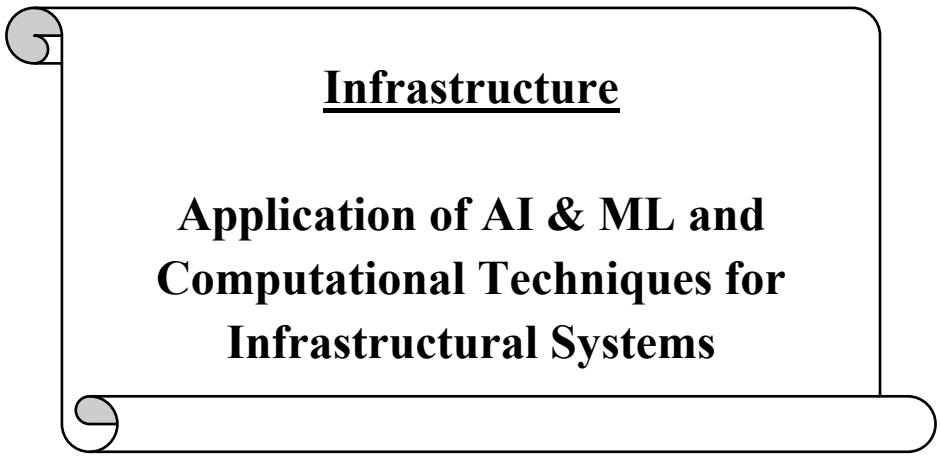
Infrastructure
Application of AI & ML and
Computational Techniques for
Infrastructural Systems

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# BARF — A Web-based/Terminal Application for Multi-Objective Optimization of Pinned and Rigid Building Frames using Evolutionary Algorithms

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***Abstract:*** *Minimum weight design optimization of 2d and 3d trusses and minimum cost design optimization of reinforced concrete plane frames and beams using genetic algorithms and particle swarm optimization methods via a web/terminal based stand alone program (Bar Force Analyzer (BARF); hosted online and on github) written in Go is presented in this paper. A few standard problems in structural design optimization are modeled using the program and the results are compared with those in the references.*

***Keywords:*** *Genetic Algorithm; Particle Swarm Optimization; Structural Optimization; Cost Optimization; Building Frames*

## INTRODUCTION

To quote W.H. Mosley, a satisfactory and economic design of a building structure rarely depends on a complex theoretical analysis. Hence, though multiple powerful, mature and fully-featured structural analysis and design programs exist today, both open source and commercial, there seems to be a space for simple web-based design and optimization routines for common building members and use cases.

There exist detailed manuals for computer-based analysis (Kassimali 2012[9], Harrison 1990[10]) and design of structural members in concrete (Hulse 1986[12], Shah 1988[13]) ,timber (Abel 2017[14]) and steel (Mosley 1984[11]).

The effectiveness of basic evolutionary algorithms such as the genetic algorithm (GA) and particle swarm optimization (PSO) in multi objective structural optimization problems has been demonstrated multiple times in literature (Rajeev & Krishnamoorthy 1992[1], 1998[2]; Govindraj & Ramasamy 2005[3], 2006[4]; Li, Peng & Zhou 2013[7])

This paper outlines the methodology of a web/terminal based program (written in Go) for the analysis, design and optimization of RCC frames and members with svg/dxf drawing output (using Gnuplot).

The program is tested on a few classic structural optimization problems (minimum weight of 2d and 3d trusses; cost optimization of concrete continuous beams and frames) and the results are compared with those in the references to show that the code outputs economical and constructable solutions.

The program is available on github at the url given in Ref. [15].

## METHODOLOGY

The program is split into separate modules; one for structural analysis of the six basic frame forms (beams, 2d and 3d trusses, grids and space frames); one for evolutionary algorithm based optimization routines and the rest for individual member design.

The program was written in Go (www.go.dev) due to the language's simplicity; Gnuplot (www.gnuplot.info) was used to generate vector/CAD drawings. All entry functions have a struct with named (integers/floats/arrays) fields for input; this also allows for JSON I/O via terminal/HTML and simple encoding of optimization problems.

The analysis module follows the steps and general structure laid out in Kassimali, 2011[9] and has been tested on all the examples in the source(see github[15] for more details). A few routines for analysis of beams and frames with non-prismatic members, elastic-plastic analysis of frames and analysis of bolted and welded connections are based on the steps and tested on the examples outlined in Harrison, 1990[10].

The RCC design module is based on Hulse, 1986[12] and Shah, 1998[13] and contains routines for design of RCC columns, beams, slabs and footings.

Optimization routines based on the simplex method, simulated annealing, genetic algorithms (GA) and particle swarm optimization (PSO) methods have been tested on standard problems such as the one-max and knapsack problem and minimization of sphere and rastagrin functions (see tests in the "opt" module for details[15]).

Minimum-weight optimization of 2d and 3d trusses and cost optimization of continuous beams and 2d frames by GA and PSO is the main focus of this paper. These are modeled as discrete combinatorial optimization problems; with an array of design variables and an objective function to minimize/optimize subject to a set of constraints.

The GA used for these problems is real (integer) coded (Kusum Deep, 2009[6]) with an (optional) adaptive probability of 1-point crossover and shuffle mutation (Srinivas, 1994[5]) with a population range of 40-60 and a generation range of 40-75.

The PSO used is again adaptive with the improvement criteria proposed in Wang, 2002 and later refined in Li, 2013 [15]. The continuous PSO float64 array is converted into discrete steps by float-integer conversion (Eberhart, 2001[8]). The number of particles is 20 and the number of generations is 30.

**TRUSS OPTIMIZATION**

2d and 3d trusses are modeled as an analysis model struct subjected to a certain set of loads with a list of discrete cross-sectional areas as design variables and the permissible (working) stress, base material unit weight and the maximum permissible deflection as inputs. The input JSON text for the 10-bar truss problem is given below:


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[3,1,1,2],[6,4,1,3],[4,2,1,4],[4,3,1,5],[2,1,1,6],[4,5,1,7],[6,3,1,8],[2,3,1,9],[4,
1,1,10]],
"Dims":[[1045.16, 1161.29, 128386.84, 1374.19, 1535.48, 1690.32, 1696.77, 1858.06,
1890.32, 1993.54, 2019.35, 2180.64, 2238.71, 2290.32, 2341.93, 2477.41, 2496.77,
2503.22, 2696.77, 2722.58, 2896.77, 2961.28, 3096.77, 3206.45, 3303.22, 3703.22,
4658.06, 5141.93, 7419.34, 8709.66, 8967.72, 9161.27, 9999.98, 10322.56, 10903.2,
12129.01, 12838.68, 14193.52, 14774.16, 17096.74, 19354.8, 21612.86]],
"Jloads": [[2,0,-445374.0],[4,0,-445374.0]],
"Fy":172.25, "Pg":2.77e-6,"Dmax":50.8}
```


Above, the model geometry is represented by an array of xy(z) coordinates ("Coords")of which the restrained nodes are indicated by (i+1) indexing in the "Supports" field and the members are represented by start and end node indices and material and cross-section array indices. Nodal loads are represented by node indices and force components in xy(z) directions. The "Dims" field lists the available sectional areas; "Fy" is the maximum allowed stress, "Dmax" is the maximum allowed deflection and "Pg" is the unit weight of the material; all in consistent units (here N-mm). The optimization method is controlled by the "Opt" field, with different integer values for different optimization methods (1 - GA, 2 - PSO, 11 - adaptive GA, 21 - adaptive PSO, 12 - "n" runs of GA and so on).

The objective function to be minimized is the total weight of the truss subject to deflection and stress constraints and can be stated as follows:

$$g(x) = f(x) * (1.0 + k * C)$$

where

$$f(x) = \Sigma \rho AL$$

for all truss members, and

$k, C =$

constant (10.0), sum of all violated constraints

**BEAMS AND FRAMES**

RCC beams and frames are modeled as an array of beam spans ("Lspans"; in meters) and floor-floor heights subjected to a set of dead ("DL"), live ("LL") and wind ("WL") loads (in kN) with (optional) individual partial safety factors (which are taken as per (IS 456/BS 8110) code defaults if none are given) which are then applied to the model to generate load envelopes with moment redistribution (Hulse, 1986[12]). The JSON text for the third example in Govindaraj, 2006[3] is given below:


```
{"Title":"Govr3",
  "Nspans":3,
  "Fck":20.0,
  "Fy":415.0,
   "Code":1,
    "DL":25,
    "LL":10,
 "Selfwt":true,
 "Bfcalc":true,
"Lspans":[10.0,8.0,7.0],
 "Nomcvr":30.0,
  "Lsxs":[300],
  "Dslb":150.0,
    "Styp":6,
     "Opt":2,
"Kostin":[2500.0,32.0,100.0],
  "Term":"svg"}
```


Above, "Fck" and "Fy" indicate the grades of concrete and steel; the "Code" field indicates the design code (1 - IS 456, 2 - BS 8110), the width of supports and depth of slab/flange are given in MM by the "Lsxs" and "Dslb" fields and the nominal cover in MM and the section type (6 - T beam, 7 - L-beam) are given by the "Nomcvr" and "Styp" fields. The "Kostin" array has the unit cost of concrete (in Rs/$m^3$), steel (in Rs/kg) and formwork (in Rs/$m^2$). The "Bfcalc" boolean if set to "true" will calculate the effective breadth of the (T/L- defined by "Styp"(6/7)) flange based on end conditions and span length as per codal provisions.

The objective function to be minimized is the total cost of the beam/frame subject to codal provisions and can be stated as:

$$g(x) = f(x) * (1.0 + k * C)$$

where,again

$k, C =$

constant (10.0), sum of all violated constraints

and

$$f(x) = Vck * Kck + Wstl * Kstl + Afw * Kfw$$

in which

$Vck, Wstl, Afw =$

(total) volume of concrete (m3), weight of steel (kg), area of formwork (m2)

$Kck, Kstl, Kfw =$

cost of concrete (Rs/m3), steel (Rs/kg), formwork (Rs/m2)

After model and load case generation based on the above geometry and matrix analysis and load envelope generation (moment redistribution has not been carried out here for comparison with the source), frame member results are then sorted for ultimate values of bending moment, shear and axial forces.

Beams are first designed and detailed (area of steel/rebar n1-n2 dia combinations) for depth and ultimate bending moment and shear at three critical sections (face of left and right support, mid span) and are then checked for deflection (span/depth ratios for an area of tension steel and shear) at those sections. Columns are first classified based on effective height calculations and are then designed and detailed for the load case combination of maximum major (x) axis bending moment and axial force.

The overall quantities of concrete, steel and formwork are estimated from the above details and the objective function is then evaluated.

**RESULTS**

The GA and PSO were run with a total number of 9 cycles with different initial seeds on the problems and the results are summarized below in **Table 1**. These are not the absolute minimum values reached by the program; they rather serve to illustrate the fact that a few runs of these routines with different starting seeds are sufficient to arrive at near-optimal solutions (with detailed tables and drawings) to building design problems with multiple load cases and constraints in a few seconds.

To be noted is the fact that the 25 bar problem's minimum weight is based on multiple load cases and buckling compressive stress limitations; here these were ignored as in [2] and for simplicity.

The terminal output of the continuous beam optimization test written for this paper is given below:

```
c:/Users/Admin/junk/barf/mosh $ go test -run OptCBmIEC -v
=== RUN   TestOptCBmIEC
    cbeamopt_test.go:22: starting ex no. 1 - govr1 opt - ga
    cbeamopt_test.go:36: optimized cost - 2.2973 rs
    cbeamopt_test.go:37: volume of  rcc 0.1696 m3 weight of steel 70.91 kg area of
formwork 2.508 m2
    cbeamopt_test.go:39: optimized section vec - [[1627 275 240 120]] rs
    cbeamopt_test.go:22: starting ex no. 1 - govr1 opt - pso
    cbeamopt_test.go:36: optimized cost - 2.2918 rs
    cbeamopt_test.go:37: volume of  rcc 0.1970 m3 weight of steel 62.42 kg area of
formwork 2.736 m2
    cbeamopt_test.go:39: optimized section vec - [[1627 300 240 120]] rs
    cbeamopt_test.go:22: starting ex no. 2 - govr2 opt - ga
    cbeamopt_test.go:36: optimized cost - 13.2069 rs
    cbeamopt_test.go:37: volume of  rcc 1.3954 m3 weight of steel 370.05 kg area of
formwork 14.774 m2
    cbeamopt_test.go:39: optimized section vec - [[1837 375 300 120] [1603 375 300
120] [1487 375 300 120]] rs
    cbeamopt_test.go:22: starting ex no. 2 - govr2 opt - pso
    cbeamopt_test.go:36: optimized cost - 13.2061 rs
    cbeamopt_test.go:37: volume of  rcc 1.5322 m3 weight of steel 335.68 kg area of
formwork 15.686 m2
    cbeamopt_test.go:39: optimized section vec - [[1837 400 300 120] [1603 400 300
120] [1487 400 300 120]] rs
    cbeamopt_test.go:22: starting ex no. 3 - govr3 opt - ga
    cbeamopt_test.go:36: optimized cost - 41774.5180 rs
    cbeamopt_test.go:37: volume of  rcc 7.0015 m3 weight of steel 626.56 kg area of
formwork 42.210 m2
    cbeamopt_test.go:39: optimized section vec - [[2542 700 475 150] [2308 700 475
150] [2192 700 475 150]] rs
    cbeamopt_test.go:22: starting ex no. 3 - govr3 opt - pso
    cbeamopt_test.go:36: optimized cost - 31923.8541 rs
    cbeamopt_test.go:37: volume of  rcc 3.1657 m3 weight of steel 643.51 kg area of
formwork 34.170 m2
    cbeamopt_test.go:39: optimized section vec - [[2292 675 225 150] [2058 675 225
150] [1942 675 225 150]] rs
--- PASS: TestOptCBmIEC (50.54s)
PASS
ok     barf/mosh     50.961s
```

**Table 1** truss optimization (minimum weight)

| | | |
|---|---|---|
| **10 bar plane truss** | **lit. result [1]** | **2546.4 kg** |
| opt type | weight | sections |
| GA | 2722.5 kg | [19354.80] [2961.28] [14774.16] [10903.20] [2019.35] [4658.06] [8709.66] [14774.16] [10903.20] [2961.28] |
| PSO | 2710.7 kg | [19354.80] [2180.64] [21612.86] [8967.72] [2496.77] [2180.64] [12129.01] [14774.16] [10322.56] [3703.22] |
| GA (adaptive) | 2665.1 kg | [19354.80] [1161.29] [17096.74] [10322.56] [2290.32] [1161.29] [12129.01] [9999.98] [14774.16] [1161.29] |
| PSO (adaptive) | 2527.6 kg | [21612.86] [1045.16] [21612.86] [8709.66] [1045.16] [1045.16] [5141.93] [14193.52] [12838.68] [1161.29] |
| **25 bar space truss*** | **lit. result[2]** | **247.9 kg** |
| opt type | weight | sections |
| GA | 235.5 kg | [129.03] [903.22] [1677.42] [322.58] [903.22] [516.13] [580.64] [2193.54] |
| PSO | 223.5 kg | [387.10] [64.52] [2193.54] [64.52] [1032.26] [709.68] [451.61] [2193.54] |
| GA (adaptive) | 232.5 kg | [129.03] [322.58] [2193.54] [129.03] [1677.42] [580.64] [451.61] [2193.54] |
| PSO (adaptive) | 220.7 kg | [129.03] [258.06] [2193.54] [64.52] [1096.77] [645.16] [451.61] [2193.54] |
| **rcc continuous beam optimization (minimum cost)** | | |
| **1 span beam (4m)** | **lit. result [4]** | **Rs. 2.38 (325mm depth)** |
| opt type | cost | sections (flange width, total depth, web width, flange depth) |
| GA | Rs. 2.297 | [1627 275 240 120] |
| PSO | Rs. 2.291 | [1627 300 240 120] |
| GA (adaptive) | Rs. 2.291 | [1627 300 240 120] |
| PSO (adaptive) | Rs. 2.291 | [1627 300 240 120] |
| **3 span beam 1** | **lit. result [4]** | **Rs. 12.79 (400mm depth)** |
| opt type | cost | sections (flange width, total depth, web width, flange depth) |
| GA | Rs. 13.207 | [1837 375 300 120] [1603 375 300 120] [1487 375 300 120] |
| PSO | Rs. 13.206 | [1837 400 300 120] [1603 400 300 120] [1487 400 300 120] |
| GA (adaptive) | Rs. 13.206 | [1837 400 300 120] [1603 400 300 120] [1487 400 300 120] |
| PSO (adaptive) | Rs. 13.206 | [1837 400 300 120] [1603 400 300 120] [1487 400 300 120] |
| **3 span beam 2** | **lit. result [4]** | **Rs. 26447 (650mm depth)** |
| opt type | cost | sections (flange width, total depth, web width, flange depth) |
| GA | Rs. 41774.5 | [2542 700 475 150] [2308 700 475 150] [2192 700 475 150] |
| PSO | Rs. 31923.8 | [2292 675 225 150] [2058 675 225 150] [1942 675 225 150] |
| GA (adaptive) | Rs. 37458.5 | [2417 625 350 150] [2183 625 350 150] [2067 625 350 150] |
| PSO (adaptive) | Rs. 31923.8 | [2292 675 225 150] [2058 675 225 150] [1942 675 225 150] |
| **rcc 2d frame optimization (minimum cost)** | | |
| **3 bay 4 storey frame** | **lit. result [2]** | **Rs. 20737 ([200 250] [200 500] [200 500])** |
| opt. type | cost | sections (edge column, mid column, beam) |
| PSO | Rs. 26899 | [200 250] [200 500] [200 525] |
| **2 bay 6 storey frame** | **lit. result [3]** | **Rs. 22966 ([200 200] [200 550] [200 575])** |
| opt. type | cost | sections (edge column, mid column, beam) |
| PSO | Rs. 25216 | [200 225] [200 425] [200 475] |

The RCC cost function values will vary as the rebar quantity calculations in the program vary from those in the source; also steel combinations here are calculated for a given area of steel, nominal cover and width while those in the source are based on predefined templates. The sectional dimensions are quite comparable with source results. The cost of example 3 in the source was arrived at by considering unequal depth for individual beam spans.

These problems are also available as Go unit tests in the source code(see github for more details). The beam and column details output as svg from the program (which can be imported into almost any CAD program) for the two bay six storey frame are shown below in **Figure 1** and **Figure 2** for reference. It can be seen that these are practical, ready-to-construct solutions.

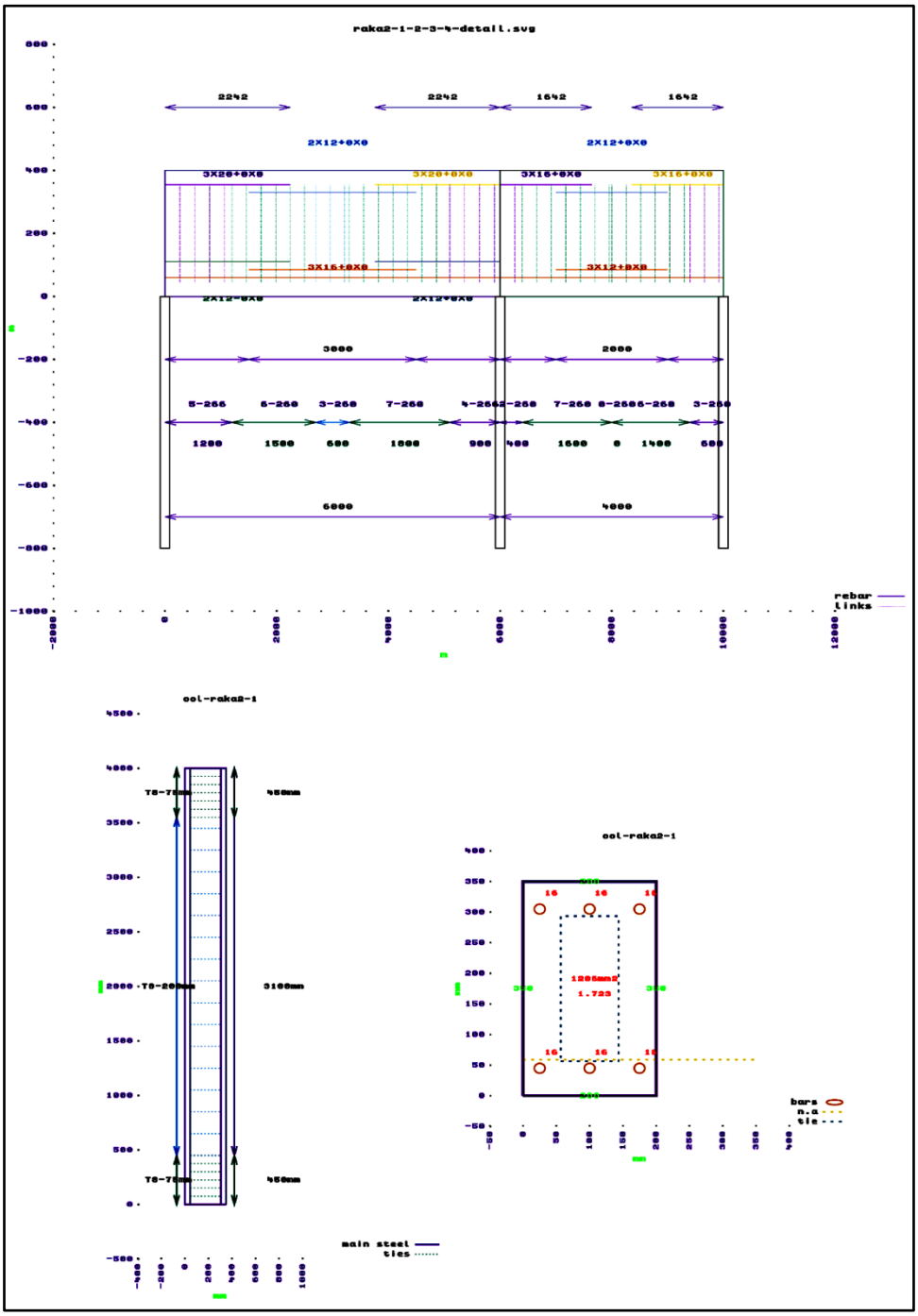


**Figure 1**

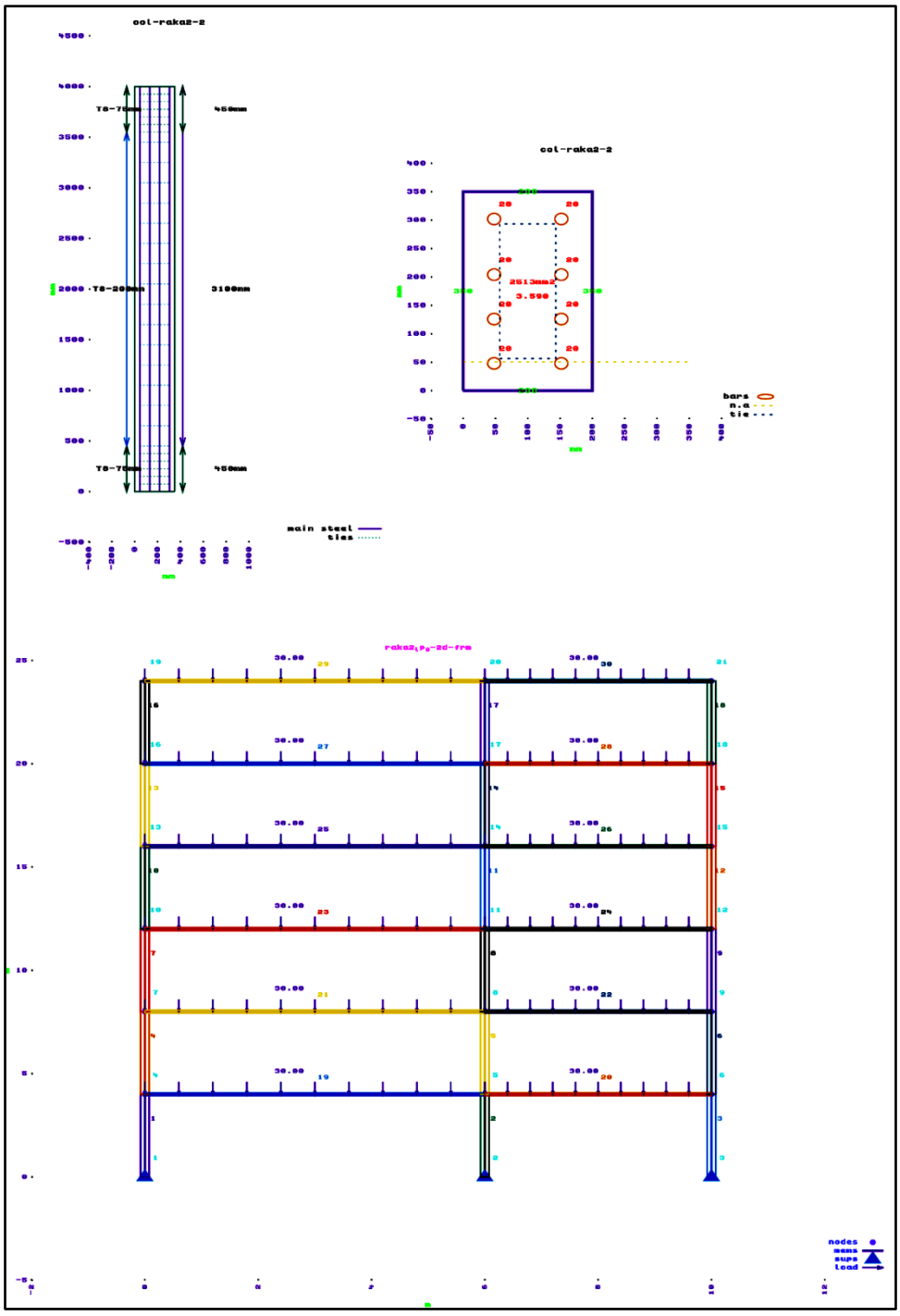


**Figure 2**

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212_IEC32392

# Automated Arc Welder's PPE Object Detection System using YOLOv8 Large Model

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***Abstract***: *The arc welding process provides strong and durable joints and hence is primarily used in manufacturing, construction, automotive industries, shipbuilding, etc. The arc welding process can cause hazards to the welder if precautions are not taken. However, sometimes, due to discomfort and inconvenience, perception of low risk, lack of training knowledge, time pressure or productivity concerns, cultural or peer influence, resistance to change, or psychological factors, workers neglect to wear Personal Protective Equipment (PPE) and violate industry safety guidelines which may result in danger to the workers' physical safety. The remedy to ensure adherence to safety guidelines is automatically detecting the presence of PPE on workers' bodies via surveillance videos and giving feedback to comply with safety protocols if violated. Essentially, detecting an arc welder's PPE is an object recognition task. The literature study on YOLOv8 showed that it can detect multiple objects with fewer trainable parameters while retaining good accuracy. Through this study a model developed an automated arc welder's PPE object detection system using a lightweight YOLOv8 DL model. The model was deployed on Nvidia Jetson and tested for real-time performance, and the result was highly accurate. The dataset was created using multiple sources to detect multiple objects simultaneously. The dataset contains images where more than one safety gear is on workers' bodies. The system accurately detected four PPE objects, even when tested on average-quality images acquired from video streams.*

***Keywords:*** *Arc Welding; Safety Gear; Deep Learning*

## INTRODUCTION

The arc welding process provides strong and durable joints and hence is primarily used in manufacturing, construction, automotive industries, shipbuilding, etc. The arc welding process can cause hazards to the welder if precautions are not taken. Personal Protective Equipment (PPE) protects welders from various dangers that were mentioned previously. Therefore, wearing PPE is necessary for workers' safety in industries and jobs requiring arc welding. The typical PPE used in arc welding includes welding helmets, welding gloves, fire-resistant clothing, safety glasses, welding boots, welding fume masks, hearing protection, and apron. The strategies followed by industries for workers' safety include forming clear safety policies and procedures, conducting training and awareness programs, supervision and enforcement, and regular audits and inspections. Therefore, traditionally, the industry manually ensures that workers follow safety guidelines and PPE. However, sometimes, due to discomfort and inconvenience, perception of low risk, lack of training knowledge, time pressure or productivity concerns, cultural or peer influence, resistance to change, or psychological factors, workers neglect to wear PPE and violate industry safety guidelines which may result in danger to the workers' physical safety. The remedy to ensure adherence to safety guidelines is automatically detecting the presence of PPE on workers' bodies via surveillance videos and giving feedback to comply with safety protocols if violated. Further, automatically detecting safety gears for arc welding jobs is relatively unexplored in literature and needs further attention.

Essentially, detecting an arc welder's PPE is an object recognition task. The state–of–the–art models for object detection are machine learning (ML) or deep learning (DL) models that detect the presence of safety gears using convolutional neural networks (CNN), recurrent neural networks (RNN), single-shot detection models, etc. [2]. These models require extensive resources and hardware for implementation. Therefore, doing real-time analysis using such models is time-consuming. Moreover, their deployment may become incompatible with edge or mobile devices.

Further, no object detection models for arc welders detect multiple PPE objects [5,7]. The literature study on YOLOv8 showed that it can detect multiple objects with fewer trainable parameters while retaining good accuracy[6,7,12]. Therefore, it is suitable for deployment on real-time mobile devices. The work presented in this study, which is inspired by [7], uses a YOLOv8 large model for detecting arc welder's safety gears.

The following is a summary of our key contributions.

- We have developed an automated arc welder's PPE object detection system using a lightweight YOLOv8 DL model. The model was deployed on Nvidia Jetson and tested for real-time performance, and the result was highly accurate.
- We created our own dataset from multiple sources to detect multiple objects simultaneously. The dataset contains images where more than one safety gear is on workers' bodies.
- Our system accurately detected four PPE objects, even when tested on average-quality images acquired from video streams.

## METHODOLOGY

### Data Collection and Organization

The first step to ensure that our model performed well was to collect a comprehensive dataset. To ensure this, the photos of PPE objects were collected using a camera under various conditions, including different angles, lighting scenarios, and helmet types. Also, the images were collected from multiple sources to account for all the possibilities and varied conditions. To add more diversity to the dataset, images were also collected from publicly available datasets. The resultant dataset covers the possibility of various combinations of safety gears present on workers' bodies. Using this dataset, we were able to build a model that provides good predictions under more realistic situations.

The created dataset was divided into the training and validation sets using a standard ratio. The training and validation folders each had two folders in them, one for images and another for labels. Every image had its corresponding label, containing information about the classes of the four objects. This was done to ensure that our dataset was compatible with YOLOv8.

### Data Annotation

For data annotation, LabelImg tool was used. The annotations are saved in the labels folder. The LabelImg tool's intuitive interface allowed us to manually draw bounding boxes around the PPE objects such as helmets, aprons, shoes and earmuffs. Each object was denoted by a different class. The label files were stored as text files.

### Model Development and Training

During model development, we ensured that it was trained iteratively to enhance accuracy. With the high number of epochs (100 epochs), high-power GPU services provided by Google Colab were used to train the model and handle the extensive computational tasks

## RESULTS

The model performs really well considering the two factors, i.e. precision and recall. It can be said that our model is very reliable and works excellently. Our model gives very minimal false positives with almost no missed detections. However, for aprons, the precision value is the least, which denotes slightly false positives, whereas earmuffs have the highest precision, thus making it the most perfectly detected class. It was observed that the system can accurately detect multiple PPE objects simultaneously. Our model's F1 score for all classes is 0.99 at a confidence level of 0.762. The snapshot of the objects detected by our system is provided in an appendix. **Table 1** below summarizes the results of our experiments.

**Table 1** Performance Summary

| Class | No. of Images Tested for | Total number of Instances of detection | Precision | Recall |
|---|---|---|---|---|
| **All** | 43 | 54 | 0.989 | 0.999 |
| **Helmet** | 20 | 20 | 0.990 | 1.000 |
| **Gloves** | 9 | 11 | 0.994 | 1.000 |
| **Earmuffs** | 18 | 18 | 1.000 | 0.996 |
| **Apron** | 5 | 5 | 0.970 | 1.000 |

## CONCLUSION

This study proposed an end-to-end system to detect multiple PPE objects simultaneously on a worker's body. We tested our model when two or more safety gears were worn by the worker. Even under these conditions, the model provided good accuracy. This system will help maintain safety guidelines and protocols for arc welders. The model showed the capability to adapt to different lighting conditions, environments and PPE kits while being tested on live video feeds. The model was easily deployed on Nvidia Jetson. The system is a transformative step in enhancing workplace safety for arc welders by using the power of deep learning.

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**APPENDIX**


**Figure 1** Testing screen shots

253_IEC67358

# Higher Order Accurate Finite Difference Method for Solving Level Set Equation for Moving Interface Problems

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***Abstract:*** *In this work, we introduce a new scheme to solve the viscosity relation of the Hamilton-Jacobi equation (also known as the Level Set equation) in domains with discontinuities across time-dependent moving interfaces. This scheme is fourth-order accurate in time variables as well as in space variables. For the time variables, we use the fourth-order Runge-Kutta scheme, and for the space variable, we use the Higher-order Compact(HOC)[2] finite difference scheme. HOC scheme gives very accurate results in the convection-diffusion problem for the two-dimensional incompressible navier-stokes equation. The outcomes of the present scheme are very closed to the existing analytical and numerical results, as the compactness of the present discretization allows us for efficient computing, as it reduces the number of grid points to achieve high accuracy. Overall the scheme is found to be reliable, efficient, and accurate.*

***Keywords:*** *HOC, WENO, Runge-Kutta, Level Set Equation, ENO*

## INTRODUCTION

The area of moving interface problem is of huge importance and makes a remarkable impact in our daily lives. It has huge applications in the medical field like MRI, CT Scan, etc. Due to the complexity from physical as well as numerical point of view, various techniques are developed to capture the interface with at most accuracy like an Essential non-oscillatory scheme, level set method, front-tracking method, etc. Although, the idea behind these methods is almost similar, but the numerical results differ.

## MATHEMATICAL MODEL AND NUMERICAL DISCRETIZATION

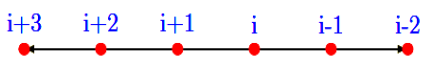
To capture the interface, we use the fourth-order Runge-Kutta method for the time variables and in space variables, we use successive differentiations with respect to space variables to get a higher order accurate discretization on a compact stencil of nine points. The generalized 2D convection-diffusion equation is as follows

$$-\nabla^2\phi + c\frac{\partial\phi}{\partial x} + d\frac{\partial\phi}{\partial y} = f(x,y)$$

semi-discrete form of this equation is

$$-\partial_x^2\phi_{i,j} - \partial_y^2\phi_{i,j} + c\partial_x\phi_{i,j} + d\partial_y\phi_{i,j} - \tau_{i,j} = f_{i,j}$$

Where $\tau_{i,j}$ is the truncation error. Because of compactness, this scheme surely gives us better results as compared to other higher order accurate schemes. Currently, we have captured the gradual deformation of a single vortex in a closed cavity using the Weighted ENO scheme [4]. But this scheme is not compact, it uses a six-point stencil in a direct line



To solve, the Hamilton-Jacobi equation,

$$\frac{\partial \phi}{\partial t} + \vec{u}.\nabla\phi = 0$$

The semi-discrete form of the WENO scheme is

$$\frac{\partial \phi_{i,j}}{\partial t} + u(i,j)\phi^{\pm}_{x,i,j} + v(i,j)\phi^{\pm}_{y,i,j} = 0$$

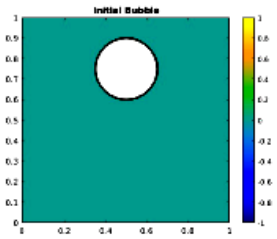
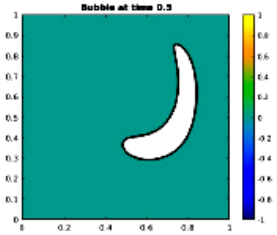
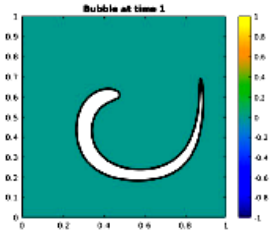
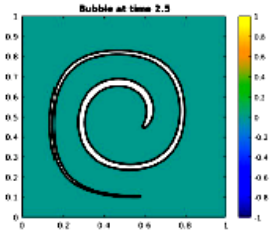
where $\phi^{\pm}_{x,i,j}$ , $\phi^{\pm}_{y,i,j}$ are the 1D approximations.

**RESULTS**

We already have captured the gradual deformation of a vortex inside a closed cavity using the WENO scheme[4] for a single vortex flow, where an initially circular bubble of radius 0.15 unit centered at (0.5, 0.75) is evolved by a single vortex flow field. We calculate this up to T = 8 sec. The flow field is given by

$u(x, y) = -2\sin^2(\pi x)\sin(\pi y)\cos(\pi y)$; $v(x, y) = 2\sin^2(\pi y)\sin(\pi x)\cos(\pi x)$ (3)

**Table 1** Single vortex deformation of a circle

| Time | Figures in different time |
|---|---|
| t=0.0 sec |  |
| t=0.5 sec |  |
| t=1.5 sec |  |
| t=2.5 sec |  |

Now, we are solving this problem using our proposed scheme. Primary results are very interesting and we shall incorporate our new results in the main manuscript.

## CONCLUSION

In this study, we proposed a new scheme to solve the viscosity relation of the Hamilton-Jacobi equation (also known as the Level Set equation) in domains with discontinuities across time-dependent moving interfaces. To discretise the time variable, we use the fourthorder Runge-Kutta scheme, and for the space variable, we use the Higher-order Compact (HOC) [2] finite difference scheme. Our proposed scheme very accurately reproduces the bubble deformation flow inside a closed cavity. Overall, our present study add new insights in this complex flow problem.

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257_IEC62315

# Exploring Flow Patterns around Bluff Bodies using Physics-Informed Neural Networks

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***Abstract:*** *Partial Differential Equations (PDEs) play a fundamental role in Scientific Machine Learning and Applied Mathematics, particularly in the modeling of physical phenomena. Although deep learning has seen a wide range of applications, its recent use in solving PDEs has become a trending topic. Traditionally, meshbased numerical solvers such as the Finite Difference Method (FDM), Finite Volume Method (FVM), and Finite Element Method (FEM) have been employed to solve PDEs. However, these methods can face challenges with mesh generation, particularly for complex geometries, and are computationally expensive. In contrast, Physics-Informed Neural Networks (PINNs) offer a meshless alternative, providing flexibility and reduced computational costs for handling intricate domains. PINNs also take advantage of modern machine learning techniques, such as automatic differentiation, to ensure that solutions inherently satisfy governing physical laws without requiring labeled data. In this work, we create a PINN to solve the two-dimensional incompressible laminar flow, governed by the Navier-Stokes equations, with an emphasis on flow past bluff bodies such as squares and other shapes. The results demonstrate that PINNs not only provide a viable alternative to traditional numerical methods but also offer computational advantages in solving fluid flow problems with intricate geometries.*

***Keywords:*** *Physics-Informed Neural Networks; Navier–Stokes Equations; Bluff Bodies; Deep Learning; Automatic Differentiation*

## INTRODUCTION

Physics-Informed Neural Networks are a relatively young subfield in deep learning. Instead of only representing the difference between the predicted and labeled data, PINNs alter the loss function to reflect the residuals of governing equations. Physical rules are followed since the trained neural network automatically fulfills the governing equations by minimizing these residuals. Additionally, the network reduces the need for labeled data even more during training by including boundary and starting conditions.

Various proof-of-concept studies marked the beginning of PINN research in 2018. By using PINNs to solve a number of PDEs, including Burger's equation, the Korteweg-de Vries (KdV) equation, and the Kuramoto-Sivashinsky equation, Raissi et al. [1] established the foundation for PINNs. The PDE residuals, which are employed in the loss function, were computed in these works using Automatic Differentiation (AD). The network was given boundary conditions and beginning conditions to guarantee unique convergence of the solution. Subsequently, other PINN-based frameworks have been suggested [2–8] to handle a variety of PDE issues.

Considerable progress has been made in numerous research that concentrate on the Navier-Stokes equations. With the use of an encoder-decoder structure, Sun et al. [9] created a surrogate model for incompressible Navier-Stokes equations in which the boundary and beginning conditions were strictly enforced. NSF-net was first introduced by Jin et al. [10] to solve three-dimensional Navier-Stokes equations in both turbulent and laminar regimes. A method for solving mixed-form incompressible Navier-Stokes equations that included stream functions and Cauchy stress was presented by Rao et al. [11]. Convolutional neural networks (CNNs) were used in the Gao et al. [12] developed PhyGeoNet, which handled discretized Navier-Stokes equations. Furthermore, Ranade et al. [13] used approximations based on the Green-Gauss cell theorem to discretize Navier-Stokes equations using finite volume approaches.

The goal of this work is to develop a PINN framework for solving steady-state, two-dimensional incompressible Navier-Stokes equations. For validation, square and circular particles are employed as benchmark cases. Estimating the drag coefficient from the Reynolds number (Re) is another goal of the study. The PINN framework, with its

meshless design, presents a viable substitute for conventional approaches that depend on discretization techniques, such the finite element and finite volume methods.

## PINN MODEL

### Methodology

There are two main parts to the Physics-Informed Neural Network (PINN) technique. The first uses a multi-layer perceptron (MLP) to anticipate a possible solution, represented by u, at given positions. For this suggested solution, the second phase computes the terms linked to the partial differential equation (PDE) and creates a loss function that is minimized by gradient descent optimization. We shall examine these techniques' inner workings using the following example. Take a look at this one-dimensional PDE:

$$\frac{\partial u}{\partial t} + \frac{\partial^2 u}{\partial x^2} = 0, \quad \forall x \in \Omega, \forall t \in [0, T]. \tag{1}$$

$$u = 0 \quad \text{in}\, \Gamma_2, \, \forall t \in [0, T], \tag{2}$$

$$u(t = 0) = u_0, \quad \forall x \in \Omega \tag{3}$$

Applying the PINN to the preceding equation results in a candidate u as the output after the neural network receives x and t as inputs. The following loss function must be minimized in order to find the solution:

$$\text{MSE}_u = \text{MSE}_0 + \text{MSE}_b + \text{MSE}_f, \tag{4}$$

where,

$$\text{MSE}_0 = \frac{1}{N_0} \sum_{i=1}^{N_0} \left| u(0, x_0^i) - u_0^i \right|^2 \tag{5}$$

$$\text{MSE}_b = \frac{1}{N_b} \sum_{i=1}^{N_b} \left| u(t_b^i, x_b^i) - u_b^i \right|^2 \tag{6}$$

$$\text{MSE}_f = \frac{1}{N_f} \sum_{i=1}^{N_f} \left| f(t_f^i, x_f^i) \right|^2 \tag{7}$$

Let $\{x_0^i, u_0^i\}_{i=1}^{N_0}$ be the set of data points that reflect the problem's initial circumstances. The number of data points is denoted by $N_0$. With $N_b$ being the number of points, the set $\{t_b^i, x_b^i\}_{i=1}^{N_b}$ represents the collocation points on the border. Collocation points on f(t, x) are also indicated by the set $\{t_f^i, x_f^i\}_{i=1}^{N_f}$.

The average of the squared differences between the expected and actual values is determined by the mean squared error, or $\text{MSE}_u$. Within the present framework, the MSE metric explicitly linked to the problem's initial circumstances is denoted as $\text{MSE}_0$. In a similar vein, $\text{MSE}_f$ is a loss function that guarantees the solution satisfies the equation inside the domain, and $\text{MSE}_b$ is the MSE metric linked to the boundary conditions.

$$f(t, x) = \frac{\partial u}{\partial t} + \frac{\partial^2 u}{\partial x^2} \tag{8}$$

To accurately solve the given problem, the combination of these three loss functions is essential. With a few exceptions for more difficult issues where adjustments to the loss function and neural network topologies could be required, this method can be used to a variety of PDEs.

PINN to Solve 2-D Navier - Stokes Equation

A prominent study[2] solved the 2D Navier-Stokes Equations (NSE) using the PINN method. In order to approximate the u and v components of the equation of incompressibility, the authors assumed that a stream function φ would be useful:

$$u = \frac{\partial \varphi}{\partial y}, \quad v = -\frac{\partial \varphi}{\partial x} \tag{9}$$

As the neural network's output, the stream function φ is computed, much like the pressure p. Examine the two functions $f_1$ and $f_2$ in order to determine that:

$$f_1(t,x,y) = \frac{\partial u}{\partial t} + \beta\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) + \frac{\partial p}{\partial x} - \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \tag{10}$$

$$f_2(t,x,y) = \frac{\partial v}{\partial t} + \beta\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) + \frac{\partial p}{\partial y} - \nu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) \tag{11}$$

The following loss functions are used to train the model using the previously defined functions (10) and (11):

$$\text{MSE} = \frac{1}{N}\sum_{i=1}^{N}\left(\left|u(t^i,x^i,y^i) - u^i\right|^2 + \left|v(t^i,x^i,y^i) - v^i\right|^2\right) \tag{12}$$

$$+ \frac{1}{N}\sum_{i=1}^{N}\left(\left|f_1(t^i,x^i,y^i)\right|^2 + \left|f_2(t^i,x^i,y^i)\right|^2\right) \tag{13}$$

where the collection $\{t^i, x^i, y^i, u^i, v^i\}$ denotes precise data taken from measurements made in the actual world or from PDE simulations.

The data used to train the model came from studies where an incompressible fluid flowed around a circular cylinder. A numerical solver known as Nektar++ is used to create the data. It discretizes the solution domain into triangular parts and approximates the solution as a linear combination of semi-orthogonal, tenth-order hierarchical Jacobi polynomial expansions at the tenth order. In this study, the 2D NSE was solved using the approach outlined in this section.1

Although the PINN method has shown useful in handling this challenging issue, present research is concentrated on enhancing the model's performance. The upgraded models, which are meant to enhance the employed approach, are fully described in the following section.

2-D Navier - Stokes Equation PINN Flowchart

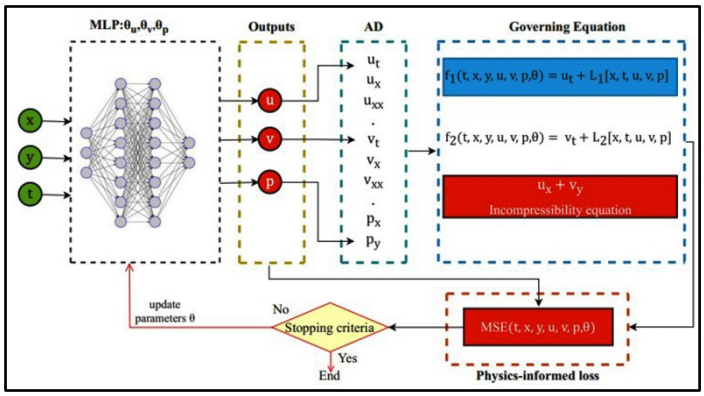


**Figure 1**

## RESULTS

Using the DeepXDE library, we were able to replicate the flow past a circular cylinder results reported by Raissi et al. [1]. There are eight hidden levels in the neural network architecture, and each layer has twenty neurons. The model was trained for 60,000 epochs and the L2 error loss was employed for the optimization.

Using Google Colab, the model training process was carried out, utilizing the T4 GPU to maximize computing efficiency. The duration of the session was almost 1.30 hours. The accuracy and convergence of the PINNs model were demonstrated by the final test and training losses, which were $1.57 \times 10^{-4}$.

The behavior of the fluid flow around the cylinder is clearly shown by the epoch versus loss graph that is presented below, along with the anticipated u-velocity field derived from the PINNs model. Important flow properties like vortex shedding were captured by the model in a way that was in line with the findings of Raissi et al.'s initial research.

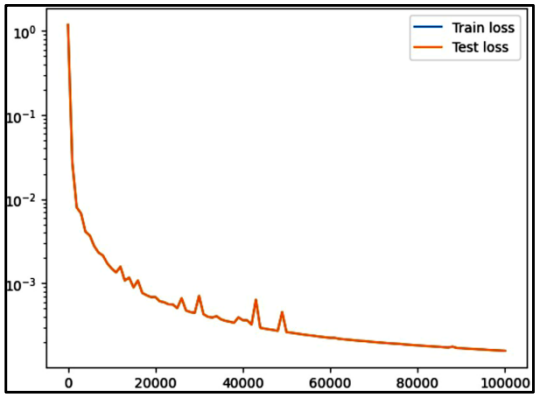


**Figure 2** Loss versus epoch graph

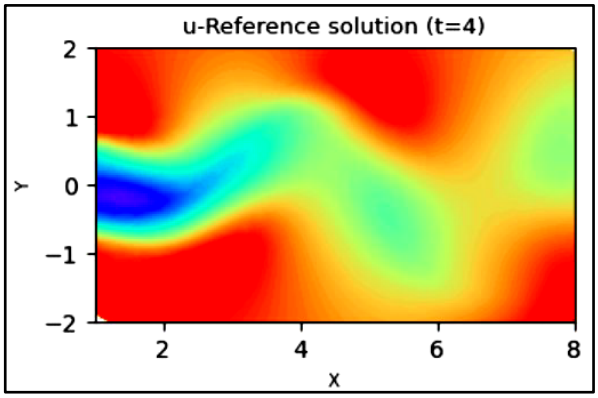


**Figure 3** U-velocity calculated by using PINNs

**Figure 4** loss and u-velocity graph

## CONCLUSION

I want to expand on this study in the future by looking into more intricate situations, such the flow past two tandem circular cylinders and the flow past a square-shaped cylinder. These more thorough investigations will enable a better comprehension of how well PINNs handle various geometries and flow interactions.

## ACKNOWLEDGMENT

I express my gratitude to the Institute for offering the HTRA fellowship for scientific objectives.

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# Infrastructure

## Disaster Resilient Infrastructural Systems

218_IEC57391

# Unique Steel Concrete Composite for Most Demanding Civil Engineering Applications in Infrastructural System

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***Abstract:*** *The system refers to the combination of two widely used materials It is a well-known fact that steel members are susceptible to buckling, while their tensile strength is remarkable. Conversely, plain concrete members can withstand a large magnitude of compressive force, though , their tensile strength is very low. Therefore, the simultaneous use of steel and concrete allows to take advantage of steel and concrete and neutralize each material's drawback by the advantage of the other material. The steel concrete-steel(SCS) composite sandwich panel comprises two parallel steel plated fixed in their relative positions by an array of transverse bar (preferably reinforcing bar obtained as off cuts from construction sites or plain mild steel bars whichever is easily available) connectors that are welded at each end to the steel facing plates. The individual panels may be bolted/welded together and can be fabricated in several sizes either flat or curved. The individual panels may be prefabricated in a workshop and erected on site with relative ease owing to their unfilled light weight, the space between the plates may be filled with concrete in-situ after erection has been completed. The composite system opens up new opportunities to design and build infrastructure projects in ways that were once practically, structurally or financially impossible. Safeguarding infrastructure facilities built for public, against the threats of terrorism has assumed significant importance. The inherent blast resistance characteristics of this composite can provide unrivalled protection from explosions. The system excels where speed of construction as in infrastructure projects is of vital importance. This article focuses on presenting the composite structure and, at the same time, introduces the potential and applications to the current construction practice, suggested manufacturing and installation process along with the mechanism of the proposed system.*

***Keywords****: Composite; Blast; Sandwich; Panel*

## INTRODUCTION

The system combines two of the world's two widely used materials to make use of their strongest assets the tensile strength of steel with the compressive strength of concrete. The system opens up new opportunities to design and build infrastructure projects in ways that were once practically, structurally or financially impossible.

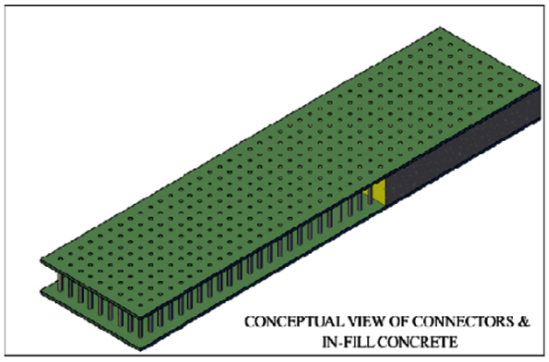
Safeguarding infrastructure facilities built for public, against the threats of terrorism has assumed significant importance . A steel concrete composite construction system has an inherent blast resistance characteristics and can provide unrivalled protection from explosions. The system excels where strength or speed of construction are of vital importance such as road tunnel sections, port roads, railway bridges/culverts and small bridges. The suggested system also finds applications in numerous other areas like bank vaults, lift cores in multistoried buildings where it can act as a shear wall. These composite system can resist high magnitude earthquake forces successfully.

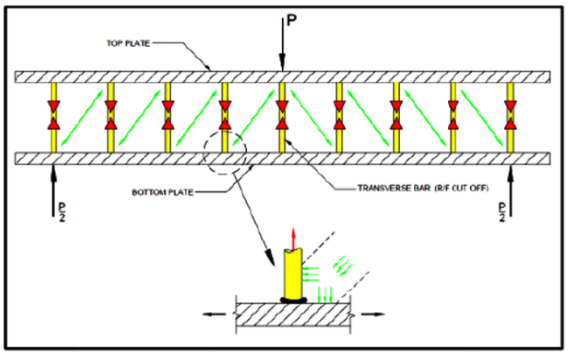
The steel-concrete-steel (SCS) composite sandwich panel comprises two parallel steel plated fixed in their relative positions by an array of transverse bar (preferably reinforcing bar obtained as off cuts from construction sites or plain mild steel bars whichever is easily available) connectors that are welded at each end to the steel facing plates, these bars are closely spaced and arranged in a regular pattern (array). The individual panels may be bolted/welded together and can be fabricated in several sizes cither flat or curved. These individual panels may be prefabricated in a workshop and erected on site with relative case owing to their unfilled light weight, the space between the plates may be filled with concrete in-situ after erection has been completed. This composite action of the steel and concrete is responsible for the high strength of the arrangement.

The paper discusses the concept of this composite system, suggested manufacturing process and installation process along with the mechanism of the system proposed.

## METHODOLOGY

The composite action is developed through the bar connectors. The welding of both sides of the bar connectors to the steel plates is done in a fabrication shop, thereby allowing for a quick and efficient assembly on the site with no difficulty in maintain the plates during concreting. The basic concept on which the steel-concrete-steel sandwich panel works on can be understood by comparing an analogy with a truss. A sectional view of a SCS composite sandwich panel undergoing simple bending is shown along with the truss phenomenon which is given below:



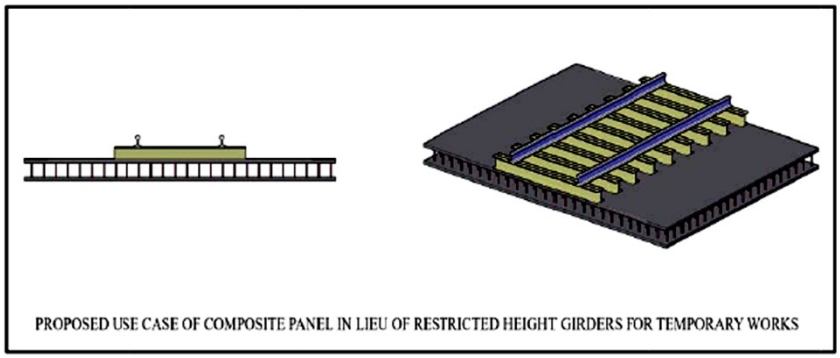




The possible failure modes of SCS can be related to each of the elements in the truss analogy -

**Compression failure of the top chord: Failure of transverse bars in tension: Concrete compressive strut failure: Yielding of bottom plate: Transverse bar to plate junction failure**

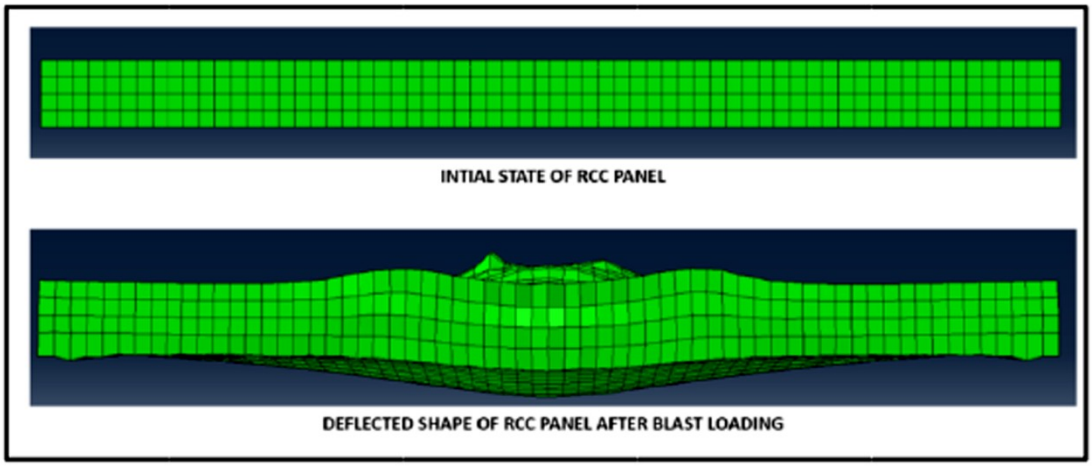
The composite action of the concrete filled Composite Panels can be effectively used as a replacement of Restricted Height (RH) Girders for construction of Limited Height Subways (LHS) & Road Under Bridges (RUBS) for Temporary Works.

- These composite panels may be utilised in place of the existing RH Girders that are in use on the Indian Railways such as RDSO/B-11040 RH Plate Girder Welded Type for Temporary Works of 20.4 m Overall Length.
- The panels by virtue of their composite action of steel and concrete, provide very effective utilisation of section, and may allow for a significantly reduced depth of construction compared with that of RH Girders currently in use, ie, additional bottom clearance is obtained by the low profile compared to that of conventional systems.
- This combined with the reduction in weight allows for greater versatility in construction of LHS/RUBS, entailing lesser depth of excavation, reduced block requirement for installation and dismantling of temporary works, and faster construction progress of the LHS/RUB through Box/Air Pushing Methodology.
- The track laid for the temporary work can be connected to the composite panel by modifying the top plate for connection with HBeam Sleepers with Zero-Toe Load Fastening (ZTLF).
- They may also be utilised for quick resumption of traffic in case of washouts/floods/subsidence.

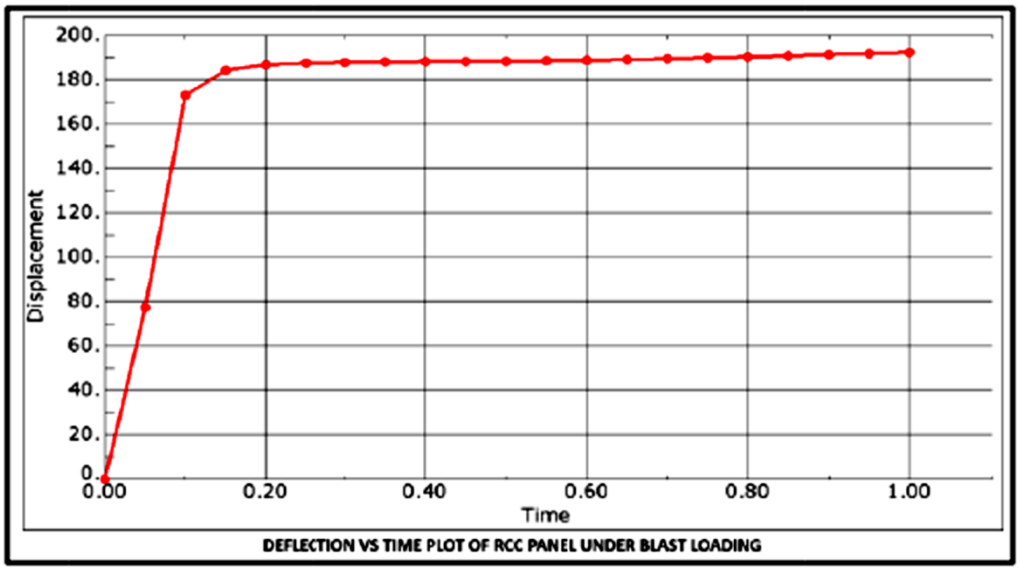


**Blast Resistance**

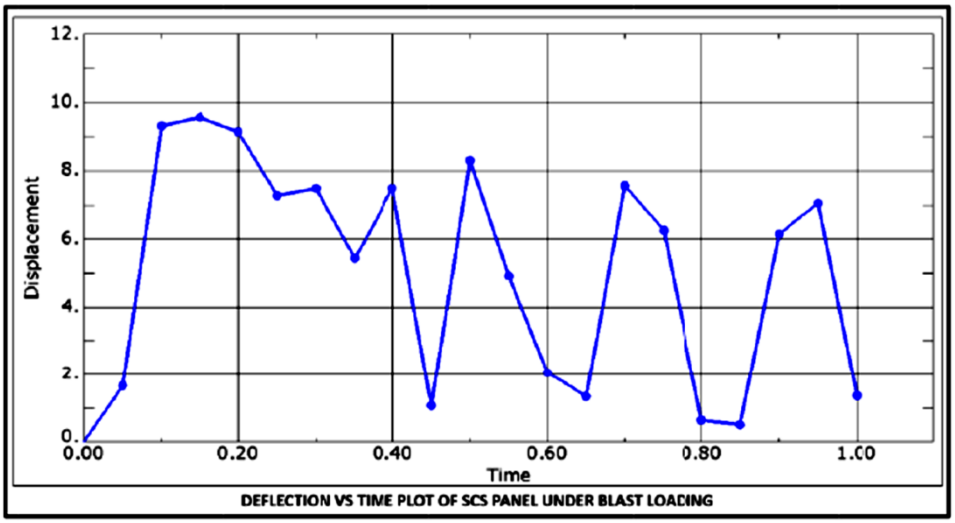
The composite panels exhibit high ductility and energy absorption through plastic deformation, the fixing of the two plates together by the bar connectors prevents spalling of concrete fragments, since Blast resistant structures dissipate the energy by large deformation. Steel and concrete are the most commonly used materials in construction. Steel is ductile in nature, while concrete is brittle. The major disadvantage of concrete is the chance of spalling on being subjected to blast loading. Loss of material caused by spalling of concrete affects the integrity of the structure. The steel concrete steel composite system combines the advantages of steel and concrete to provide defence against impact and blast.




Finite Element Analysis (FEA) 'was conducted in ABAQUS software comprising of 6400 × 2200 mm steel concrete steel composite panel comprising of E250 grade (As per IS:2062-2011) 10 mm top & bottom steel plates,400 mm thick fill of M25 concrete, and Fe-500 grade 25 mm diameter steel bars at 300 mm C/C spacing in both directions This was compared with a separate model comprising of a 6400 × 2200 × 420 mm M25 grade.




Reinforced concrete (RCC) slab having top & bottom reinforcement in the form of Fe 500 grade 25 mm diameter steel bars at 200 mm C/C spacing in both directions, similar to that of a doubly reinforced slab. Both the panels were subjected to blast loading considering a simply supported condition with the distance between the supports as 6000 mm, the panels were subjected to an air blast loading of 100 kg Trinitrotoluene (TNT) at a distance of 500 mm using the built-in CONWEP model in ABAQUS for simulating the air blast loading on the structural element without needing to model the medium of transmission of the ballast wave.



DEFLECTION VS TIME PLOT OF SCS PANEL UNDER BLAST LOADING

## CONCLUSION

Further detailed study including sophisticated Finite Element Modelling and Analysis (FEM/FEA) along with prototype studies including construction of field scale models and subsequent load, blast, fatigue analysis and testing is required to arrive at practical applications including corresponding modifications/improvements in the various fields of application. In addition to this, Rail Structure Interaction (RSI) studies are required for the suitability of this system for the continuation of Long/Continuously Welded Rails (LWR/CWR) over bridges. Utilisation of these composite panels may allow for innovative approaches for the construction of ROB/RUB/LHS for LC Gate Elimination along with providing further avenues for rebuilding of distressed bridges also. The advantages of such composite panels are 'manifold, allowing for reduction in sectional depth, reduced construction times, lesser disruption to rail traffic, blast resistance, and better construction quality.

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266_IEC2817

# Seismic Behaviour Assessment of Conventional and Hybrid Reinforced Concrete Buildings

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***Abstract:*** *Due to rapid urbanization, many cities have witnessed significant changes in building structures, including the emergence of hybrid structures, such as mixed concrete and steel frames. However, the current seismic code regulations provided by the Bureau of Indian Standards (BIS) do not offer specific guidelines for determining the appropriate design seismic forces and capacities for these hybrid multi-story buildings. Therefore, assessing their structural behaviour under seismic forces is critical to ensuring safe and effective designs. In this study, an attempt is made to evaluate the seismic behaviour of a hypothetical G+2 hybrid reinforced concrete (RC) building, compared to a conventional building, located in the Warangal district of Telangana state, which lies in a moderate seismic zone with a medium soil profile. The performance of these buildings is assessed based on base shear, horizontal displacement, inter-story drift ratio (IDR), and other key behavioural patterns. Furthermore, the study aims to analytically determine the design seismic forces required for earthquake-resistant hybrid buildings in urban environments, taking into account various structural configurations.*

***Keywords:*** *Urbanization; Hybrid RC Building; Seismic Performance; IDR; Horizontal Displacement; Base Shear*

## INTRODUCTION

Earthquakes represent a major and unavoidable natural hazard that can lead to significant damage and disrupt the economy of a nation. The National Disaster Management Authority (NDMA) of India estimates that over 59 percent of the Indian subcontinent is at risk of experiencing moderate to severe earthquakes [1]. Historical data supports this, with notable seismic events including the Bihar-Nepal border earthquake (M6.4) in 1988, the Uttarkashi earthquake (M6.6) in 1991, the Killari earthquake (M6.3) in 1993, the Jabalpur earthquake (M6.0) in 1997, the Chamoli earthquake (M6.8) in 1999, the Bhuj earthquake (M6.9) in 2001, and the Kashmir earthquake (M7.6) in 2005 [2,3,4]. In light of urbanization and lessons learned from past natural disasters, many urban areas have undergone significant changes in the construction of their buildings. In practice there is a rise of hybrid structures (e.g., mixed concrete and steel frames). However, the current seismic code regulations provided by the Bureau of Indian Standards (BIS) do not offer specific guidelines for determining the appropriate design seismic forces and capacities for these hybrid multi-story buildings. Consequently, there is a pressing need to assess the structural behaviour of these hybrid buildings under earthquake forces at specific site locations to ensure safe and efficient design configuration.

To resist earthquake loads, the analysis and design of buildings must comply with codal provisions. Although hybrid-building structures are becoming more commonly constructed for commercial and office buildings across all seismic zones in India, there are no specific code provisions for the analysis and design of such hybrid structures. Similarly, building codes from other countries also do not provide specific values for seismic factors to be used in the design of hybrid buildings. In this study, an attempt has been made to analyse and design a hybrid (mixed concrete/steel) building, and compare its performance with that of a conventional building of the same number of storeys.

## METHODOLOGY

In this study, two special moment-resisting frames (SMRFs) have been considered (Conventional RC building and hybrid RC building) which represent the building configurations relevant to moderate seismic zone III (PGA of 0.16g) with medium soil profile. The typical hypothetical G+2 (ground + two floors) building configurations (regular & hybrid) comprises of 5 × 3 bay of 5m and 4m in X & Y-direction respectively with the story height of 3.0m. The hybrid-building configuration comprises of RC moment resisting frame for G+1 followed by steel frame (with zero length element connections) supporting the floor above with deck slab, as depicted in **Figure 1**. The material specifications for the buildings considered are M30 grade concrete, Fe415 grade reinforcement steel, and Fe345 grade

steel for the hybrid structure. The structural elements for the conventional RC building include columns of 500 x 500 mm, beams of 300 × 500 mm, and slabs with a thickness of 130 mm. In contrast, for the hybrid RC building, the structural elements consist of ISWB550 steel columns, ISMB500 primary beams, ISLB300 secondary beams, and a 90mm thick deck slab. The commercial structural analysis programme software (ETABS V21) has been used as a tool to perform Non Linear Static (Pushover) analysis for these structural configurations under gravity loads and Zone III seismic forces [5,6]. The design loads are considered in accordance with IS 875-Parts I and II (1987), IS 456 (2000), and IS 1893 (2016) [7,8,9]. The slab's dead load (including floor finish) was calculated, and the slab's live load was assessed to be 3 kN/m$^2$. The partition walls' self-weight - 230 mm for the exterior walls and 115 mm for the interior walls, where applied as an evenly distributed load to the adjacent beams. The structural elements (beams and columns) were modelled with concentrated plastic hinges, i.e., the beams were modelled with only moment (M3) hinges, and the columns with axial load and a biaxial moment (P-M2-M3) hinges as per ASCE 41–17 (2017) [10,11].

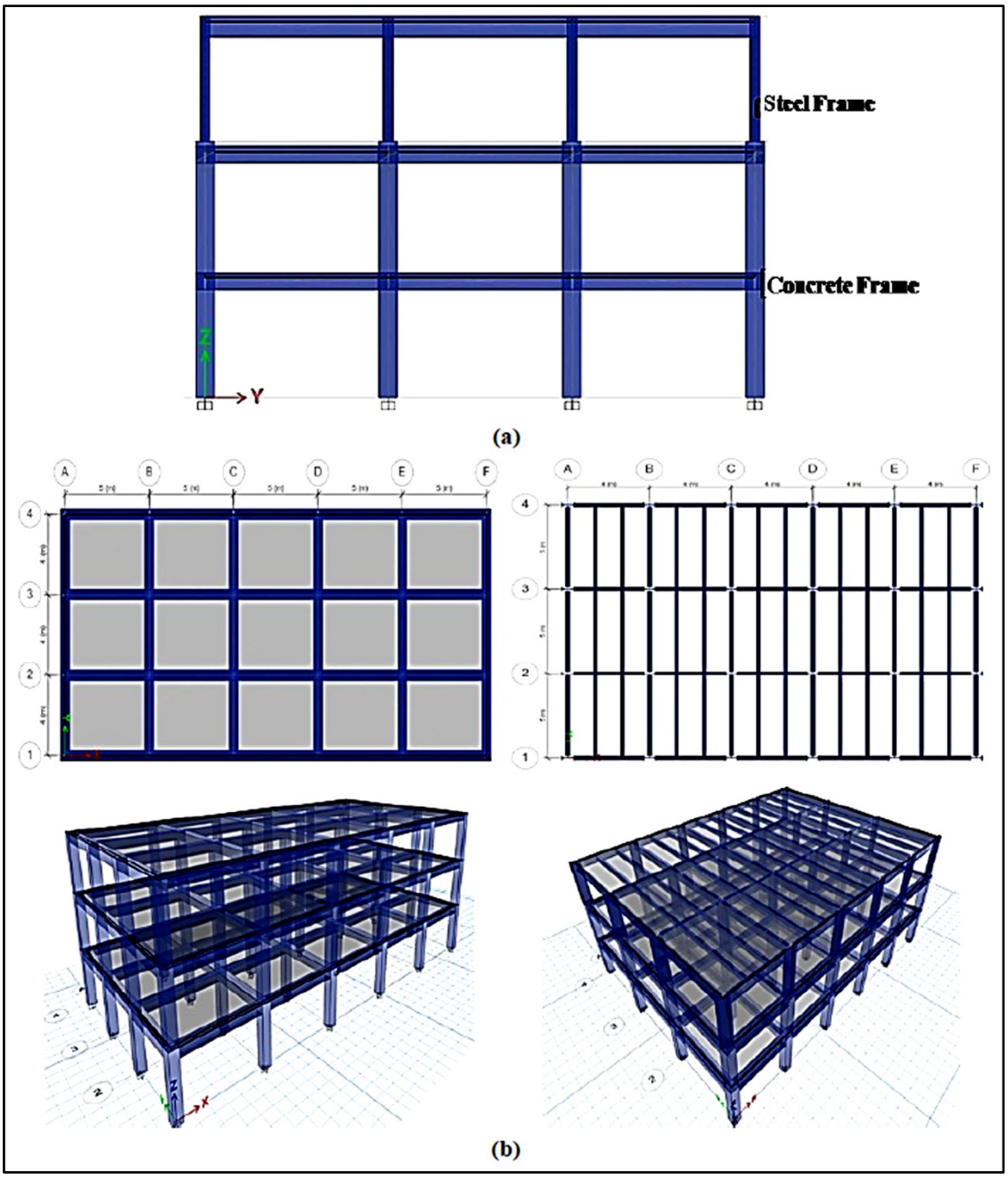


**Figure 1** (a) Elevation of hybrid building (b) plan and 3D model of conventional and hybrid structure

## RESULTS

**Table 1** Time period of conventional and hybrid building

| Mode Number | Time Period (sec) | | Mode Number | Time Period (sec) | |
|---|---|---|---|---|---|
| | Conventional Building | Hybrid Building | | Conventional Building | Hybrid Building |
| 1 | 0.29 | 0.36 | 7 | 0.048 | 0.056 |
| 2 | 0.28 | 0.276 | 8 | 0.048 | 0.047 |
| 3 | 0.253 | 0.262 | 9 | 0.044 | 0.046 |
| 4 | 0.087 | 0.141 | 10 | 0.03 | 0.021 |
| 5 | 0.086 | 0.086 | 11 | 0.028 | 0.02 |
| 6 | 0.077 | 0.078 | 12 | 0.025 | 0.019 |

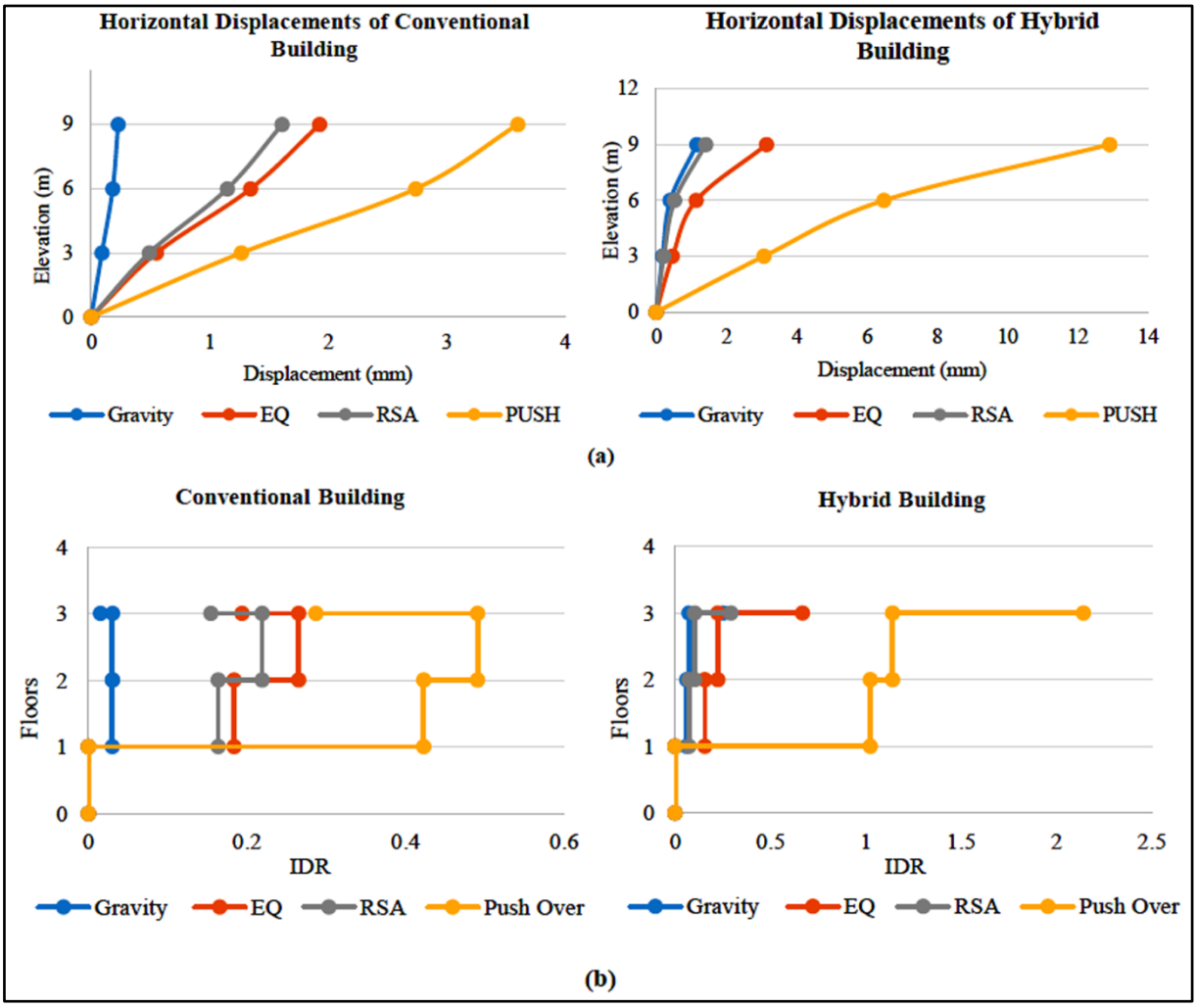


**Figure 2** (a) Horizontal displacement of conventional and hybrid building (b) comparative inter-storey drift ratio (IDR) of conventional and hybrid building

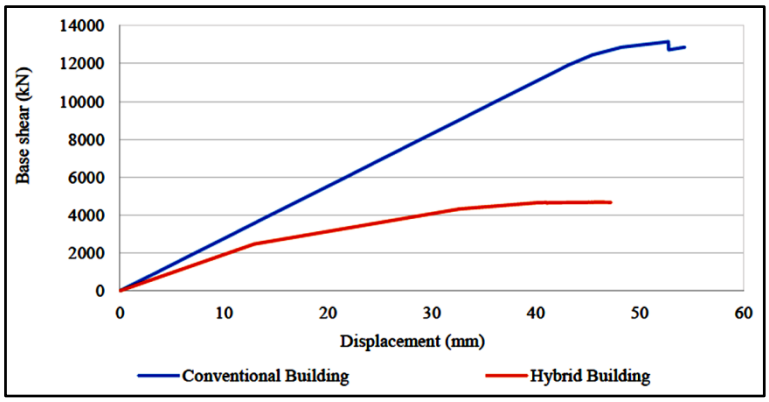


**Figure 3** Capacity curve of conventional and hybrid building

## CONCLUSION

The present study focused on performance assessment of hybrid RC building in comparison with the conventional RC building. Hypothetical G+2 building models representing both conventional and hybrid building models were analysed and designed using the software package (ETABs V21). Equivalent static, Response Spectrum and Pushover analyses were conducted to evaluate the structural behaviour, focusing on engineering decision parameters. Based on the outcomes, the following can be observed:

- The variation in the modal time period between the conventional and hybrid buildings is more pronounced in the X direction, with a difference of about 20%, while in the Y direction, it is almost the same, at 1.4%. This suggests that the X direction is the critical axis influencing the building's flexibility and response behaviour.
- The building plan and overall height are kept constant for both the conventional and hybrid building models. However, analysis shows a significant increase in base shear values for the hybrid-building model compared to the conventional model. This is primarily due to the increased mass in hybrid building model.
- The hybrid building exhibits significantly higher storey displacements (about 72%) and inter-storey drifts (about 86%) along the critical direction as depicted in **Figure 2**, highlighting the increased flexibility of the hybrid-building model compared to the conventional one.
- The capacity curves for both building models reveal that the hybrid-building model has a lower strength capacity than the conventional building model. Additionally, the curves indicate reduced stiffness in the hybrid model, which could lead to premature structural failure.
- The hybrid building exhibits higher ductility in both directions when compared to the conventional building model. However, its lower strength may increase its susceptibility to damage during seismic events.
- The over strength factor of the hybrid building model is higher than that of the conventional model, indicating that the hybrid structure possesses greater reserve strength.

Based on the outcomes, it is evident that hybrid structures are seismically deficient according to current standards and may be highly vulnerable to severe damage during an earthquake. To ensure the safety and functionality of these hybrid structures, it is crucial not to rely on traditional analysis methods. Instead, detailed and specific analysis and design approaches should be adopted. Given that hybrid-building models combine several structural types into a single system, determining their dynamic characteristics is complex. Therefore, detailed or specialized analysis is essential to accurately determine the seismic design forces and ductility required for earthquake-resistant design, ensuring safety and functionality throughout the structure's service life without risk of collapse.

## ACKNOWLEDGEMENT

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277_IEC43305

# Removal of Chloride from Wastewater using Anion Exchange Resin: Fixed Bed Column Study

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***Abstract:*** *This study presents the evaluation of a fixed bed column for removing chloride ions from water using various adsorbents. Chloride contamination is a significant environmental issue, primarily caused by industrial effluents, agricultural runoff, and de-icing salts. High chloride concentrations can deteriorate water quality, harm aquatic ecosystems, and cause infrastructural corrosion. The fixed bed column was tested under various operational conditions to optimize its performance in removing chloride ions. Breakthrough curve analysis was performed to determine the system's efficiency, and different adsorption models were applied to understand the kinetics and dynamics of the process. Results show that the fixed bed column, when packed with suitable adsorbents, is an efficient method for chloride removal.*

***Keywords:*** *Chloride Removal; Column Study; Break Through Curve; Resin; Infrastructure*

## INTRODUCTION

The removal of chloride from water is essential for ensuring drinking water quality[1], protecting infrastructure, supporting industrial operations, and safeguarding the environment. Increasing chloride concentrations in water resources pose a pressing global environmental issue, as they lead to problems such as pipe deterioration, salinization of freshwater and soil, and impaired agricultural productivity. Chloride also accelerates the corrosion of reinforcement steel in concrete, compromising the durability of structures. The corrosion process involves chloride ions combining with $Fe^{2+}$ ions on the surface of rebars, forming $FeCl_2$, which further reacts to produce $Fe(OH)_2$ precipitates[2]. This corrosion not only weakens concrete structures but also threatens aquatic ecosystems when water containing high chloride levels is discharged into natural bodies[3, 4]. Consequently, technologies for chloride removal are critical to prevent environmental harm and ensure water treatment meets regulatory standards[5]. In India, high chloride concentrations in water used for construction have led to infrastructure damage, with chloride-induced corrosion of rebar being a significant cause of building collapses in cities like Delhi and Gurugram. The Bureau of Indian Standards (BIS) mandates strict limits on chloride content in construction water, with a maximum of 500 ppm for reinforced concrete and 200 ppm for prestressed concrete. However, many regions, including Delhi, Chennai, and Mumbai, report chloride levels far exceeding these limits. Ion exchange is an effective technology for removing chloride from water, providing quantitative removal and long-term cost efficiency through resin regeneration[6]. Researchers have explored various ion exchange resins and adsorbents, here DOSHION GA-13 (OH) proving effective in studies. Ongoing research focuses on developing low-cost adsorbents and improving regeneration techniques to make chloride removal more sustainable and feasible for large-scale applications. Analytical studies on adsorption kinetics, isotherms, and thermodynamic parameters support the effectiveness of these methods in water treatment. A fixed bed column system provides a promising approach for continuous water treatment. This study investigates the potential of anion exchange resin as a adsorbents within a fixed bed column for the removal of chloride from water under various operating conditions. The work aims to optimize the system and analyze its kinetics and breakthrough behavior to understand the factors influencing its performance.

## MATERIALS AND METHODS

A fixed bed column was fabricated and the schematic diagram of the same is shown **Figure 1**. The column was packed with anion exchange resin between two supporting layers of glass wool. The resin was added from the top of the column and allowed to settle by gravity force. The upper portion of the adsorbent was covered with glass beads.

The resin used is DOSHION GA-13 (OH) anion exchange resin were tested for their chloride adsorption capacities. Specification of the resin is given in **Table 1**.

**Table 1** Specification of the ion exchange resin used in the experiments

| | |
|---|---|
| Matrix | Polystyrene Gel |
| Functional group | Quaternary ammonium Expansion Type-I |
| Physical form | Hard moist bead |
| Ionic form as shipped | -OH (Hydroxyl form) |
| Moisture content | 45-50% |
| Particle size (mm) | 0.30-1.20 |
| Operating pH | 0-14 |
| Bulk density (gm/L) | 690-720 |

Experiments on Chloride removal efficiency were studied to investigate the effects of initial chloride concentration, bed height, and flow rate on removal efficiency. Resin particles (0.30-1.20 mm in size) were packed into a glass column. Prior to the experiments, distilled water was passed through the column for 50 to 60 min minutes to remove any fine particles from the resin. Flow rates (Q) were varied between 1.5 and 3.5 mL/min. The experiments were performed at a pH of 8.5 and room temperature. The column was operated under down-flow conditions, with synthetic water containing chloride ions at concentrations ranging from 800 to 2000 mg/L. The effluent was collected at regular intervals, and chloride concentrations were measured via titration. Breakthrough curves were generated by plotting the ratio of effluent to influent chloride concentration ($C/C_0$) against time. The adsorption capacity of each material was determined from the area under the breakthrough curve, and kinetic models, including the Thomas models, were applied to evaluate the process dynamics.

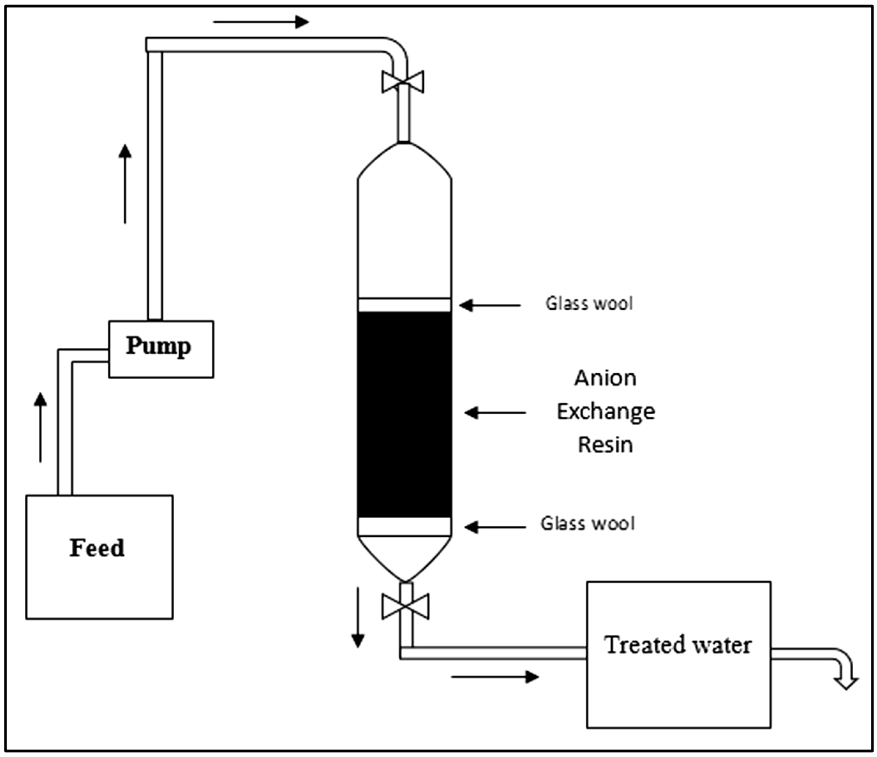


**Figure 1** Continuous fixed bed water reactor

## RESULTS AND DISCUSSION

Initial chloride ion concentration is an important parameter affecting the ion exchange process. In order to study the effect, three different initial concentrations were used. The experiments were conducted at 800, 1000, and 2000 mg /L of chloride concentrations. The **Figure 2** shows that with time final concentration increases.

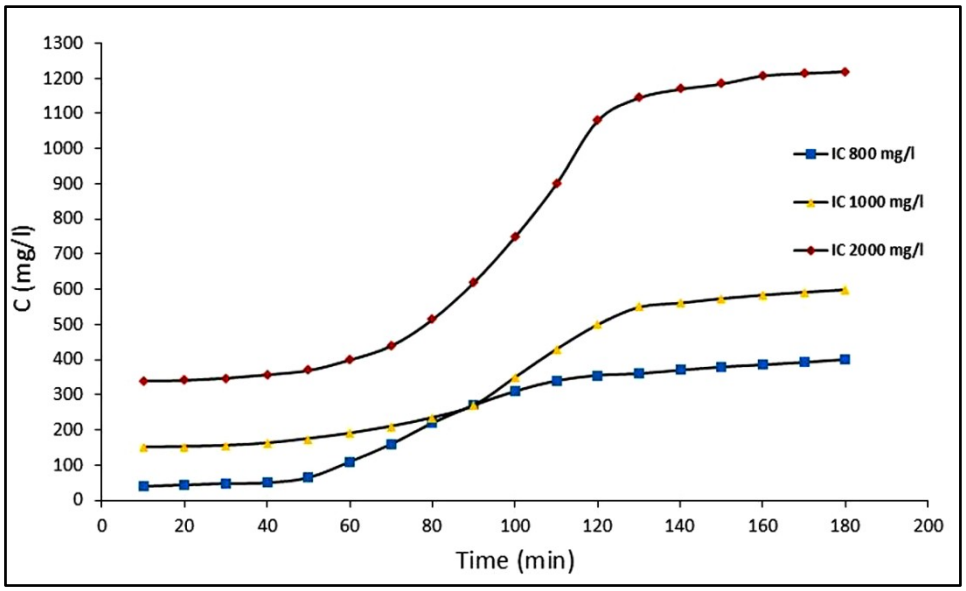


**Figure 2** Change of chloride ion concentration with time at different initial concentrations

**Figure 3** illustrate breakthrough curves for solutions with varying chloride concentrations with bed depths 10 cm, at a flow rate of 3.5 mL $min^{-1}$. The sorption parameters are outlined in **Table 2**. The curves show that either increasing the solution concentration led to faster breakthrough and saturation points, resulting in a smaller volume of solution being treated at breakthrough. This is because the resin's adsorption capacity is limited and was reached more quickly at higher inlet concentrations. These findings support the viability of using a fixed bed column to continuously remove chloride from water. The system's efficiency depends largely on the selection of adsorbent material and operational conditions, which influence the contact time and adsorbent saturation rate.

**Table 2** Breakthrough time and properties of ion exchange for different initial concentration

| Initial concentration (mg/L) | Bed height (cm) | Breakthrough Time (min) | Saturation Time (min) |
|---|---|---|---|
| 800 | 10 | 50 | 150 |
| 1000 | 10 | 70 | 130 |
| 2000 | 10 | 60 | 120 |

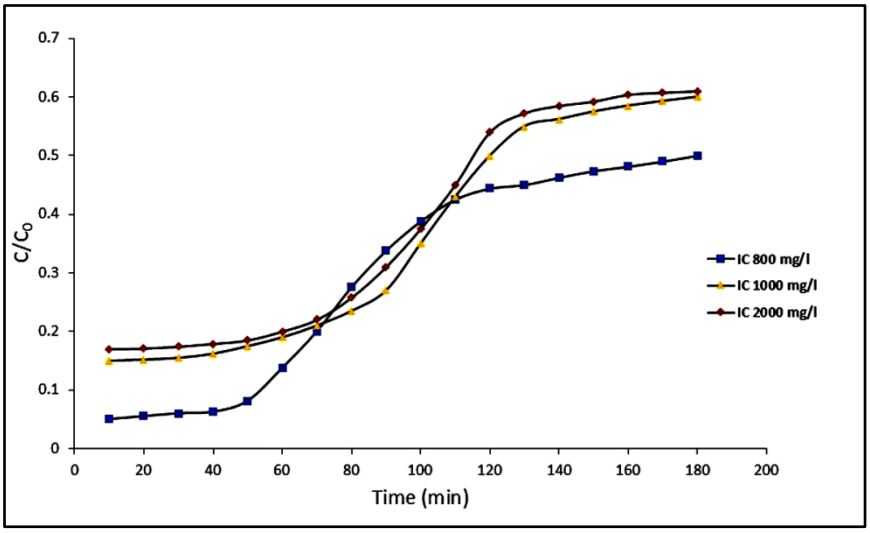


**Figure 3** Breakthrough curve of Chloride at different initial concentrations

## CONCLUSION

This study demonstrates the effectiveness of the anion exchange resin DOSHION GA-13 (OH) for chloride removal, marking its first application for this purpose. Through a comprehensive evaluation of parameters impacting chloride sorption efficiency, the resin was shown to have promising characteristics for water treatment. Although its adsorption capacity is lower compared to strong base resins, it can be successfully regenerated using sodium hydroxide solutions, making it a viable option for continuous use in both batch and fixed-bed column systems. The resin's ability to function efficiently without interference from chloride ions further supports its suitability for industrial effluent treatment. The fixed-bed column experiments proved particularly effective, especially when combined with lower flow rates and optimal bed depths, which maximized the resin’s performance. This research highlights the potential for DOSHION GA-13 (OH) resin to be integrated into scalable, cost-effective water treatment systems, offering a viable alternative to more costly methods like reverse osmosis. Future studies should focus on exploring the resin’s regeneration potential over multiple cycles and its real-world application in industrial settings, ensuring the long-term feasibility of this solution for addressing chloride contamination in water treatment.

## ACKNOWLEDGEMENT

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# Infrastructure

# Health Monitoring and Retrofitting of Infrastructural Systems

32_IEC22319

# Health and Performance Monitoring for Reducing Infrastructural Downtime: Intelligent & Predictive Maintenance with Retrofittable Onboard Diagnostic and Remote Monitoring Systems

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***Abstract:*** *THCM (Tata Hitachi Construction Machinery Private Limited) has been the market leader for Construction Equipment in India. The company manufactures equipment like Excavator, Wheel Loader, Backhoe loader etc. These equipments use various systems including engine, hydraulics and transmission. The overall operation of the machine is integrated by the electronic system. With the increasing customer demand and to maintain the leadership position in the market, there is a need to maintain the product quality and machine performance, to the highest standard. The performance & basic function of the machine was earlier monitored from the mechanical gauges on dashboard fitted inside the operator's cabin. The operator used to take corrective action based on the fault indication available on the dashboard. But with the increase in fleet size with a greater number of machineries, it has become essential to go for the latest on-board and remote monitoring of machine performance. This feature enhances machine diagnostics system with the help of faults & alarms. The cloud based remote tracking system can be retrofitted at the job site, which allows the fleet owners to automate their processes and shift from semi-autonomous systems to fully autonomous systems. This, not only enhances safety, but also is essential for proper running of the machines. The system enhances machine intelligence by increasing productivity and reduces the cost & downtime of operation.*

***Keywords:*** *Predictive Maintenance; Real Time Data; Retrofittable; Onboard Diagnostic; Remote Monitoring*

## INTRODUCTION

Monitoring and analysis of machine performance data accounts for a major part in maintaining the quality of product. A robust analysis of the performance report will lead us to have better machine availability by reducing downtime at job site. Earlier, we used to face lots of difficulties to understand the cause of failure. This used to affect customer Satisfaction index, in a greater way. Currently, with the introduction of On-board Diagnostic & Remote Monitoring system, the machine owner & service engineer can easily download the data to have machine information on a Real Time basis as shown in **Figure 1** below. This not only helps with trouble-free machine operation, but also increases the machine availability at customer site by 10-20%. Moreover, a proper study of machine Utilization Report (generated from the system) would help to take measures to reduce Carbon Footprint by 20-40%.

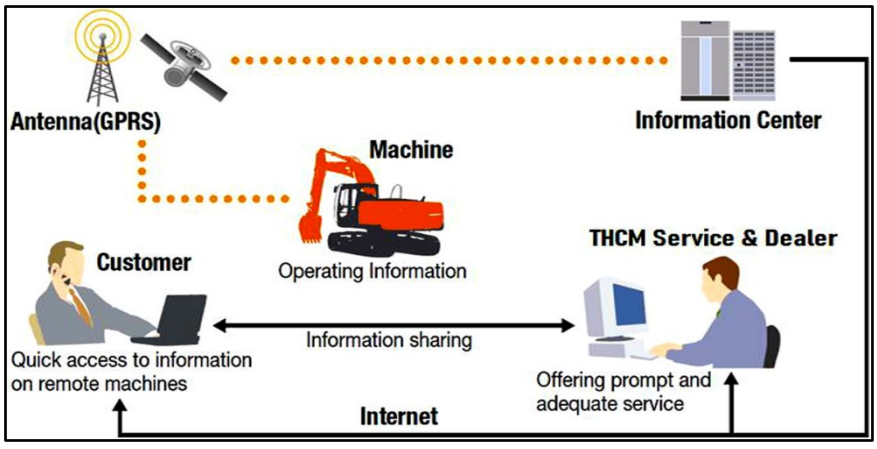


**Figure 1** Real time machine performance monitoring

## METHODOLOGY

Both On-board Diagnostic & Remote monitoring system helps with predictive & preventive maintenance of the machine and reduces the downtime by increasing the productivity of operation. The On-board Monitoring system, shown below in **Figure 2**, is accomplished through the dashboard fitted in the operator's cabin. Machine parameters from various systems including engine, hydraulics & transmission are transmitted to the dashboard controller.

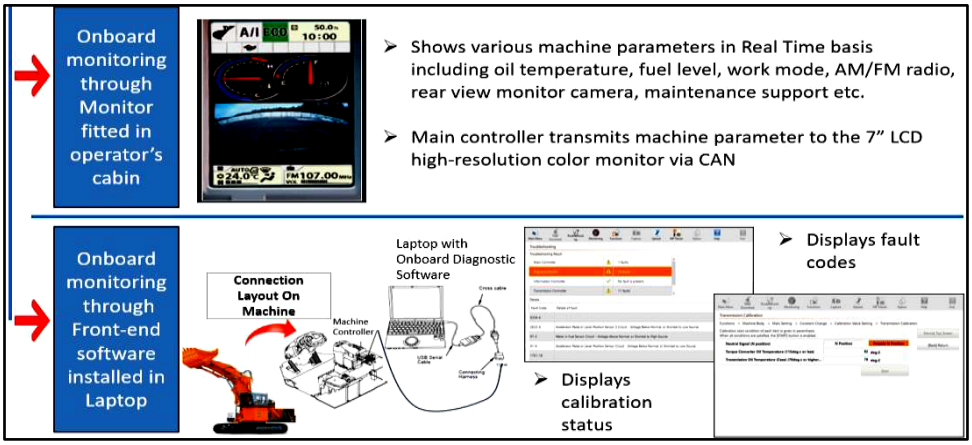


**Figure 2** Performance monitoring using on-board diagnostic system

For the Remote Monitoring system, a mobile communication controller is integrated with the main controller through CAN communication. The mobile communication controller is a GPS based tracking device, which uses the GSM / GPRS communication protocol for data transfer through mobile carrier. Machine data from various systems including engine, hydraulics, transmission etc. are transmitted to a remote location through Mobile Communication Terminal. This helps the dealers and machine owners to identify and resolve machine problems. The cloud data is available in a remote location which helps the machine owners to identify and resolve problems in a faster way. Apart from Health Monitoring system (HMS), the remote tracking system also helps in Productivity Management System (PMS) for the machine fleet owners.

Moreover, the remote monitoring system links the customers to their machines in the work sites in two ways:

1. Alarm Report or emergency notifications via email & SMS
2. Consolidated Monthly Report.

The system sends an alarm when abnormality is detected (not after breakdown) for proactive solution as shown in **Figure 3**. The data from machine controller is transmitted to the cloud through Mobile Carrier and stored in the server. The information on machine Faults is then transmitted to the owner via email or SMS.

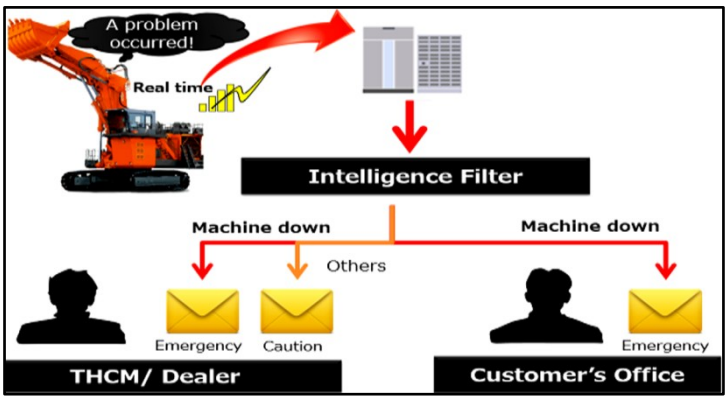


**Figure 3** Alarm report mechanism

Also, the monthly report is generated, which can be downloaded in pdf format for analysis, as shown in **Figure 4**. The Report contains the data related to Performance Management System (PMS) and Health Monitoring System (HMS).

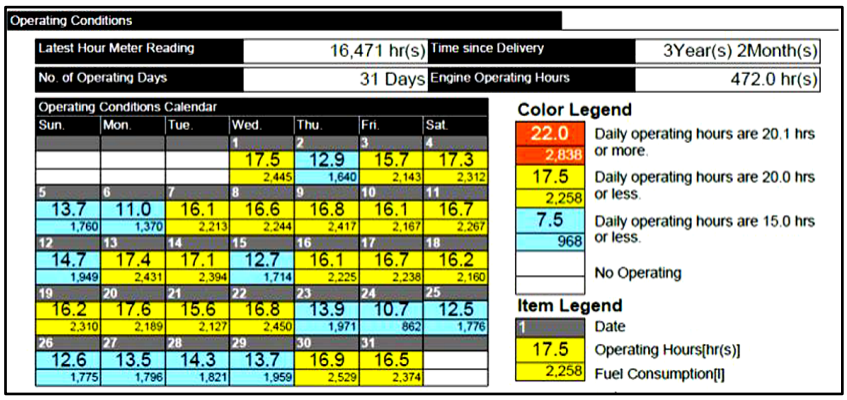


**Figure 4** Monthly report mechanism

The machine's live data is available in a web portal and customized mobile application.

The Remote Monitoring system can also be retrofitted in the machine based on requirement. The **Figure 5** shows the block diagram and component required for retrofitment.

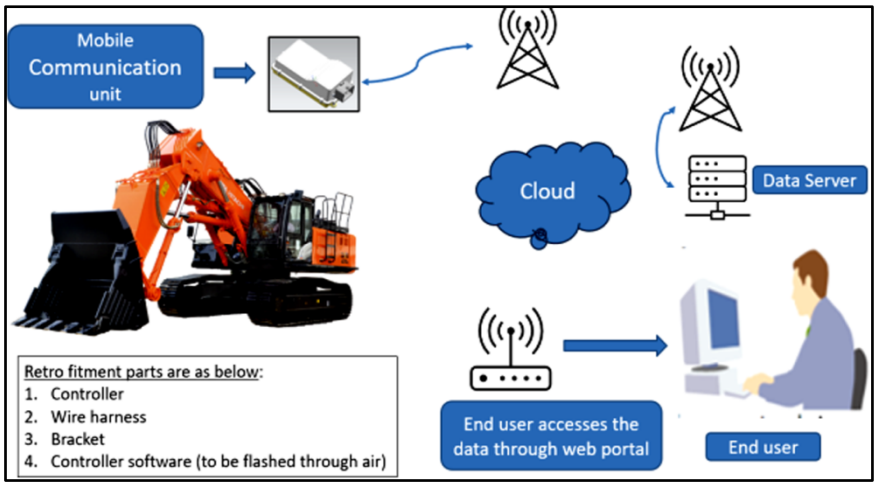


**Figure 5** Retro-fitment option for onboard & remote monitoring system

**RESULTS**

With the above system installed in our machine, we can achieve the following:

(a) Basic machine information including machine serial no., model name.
(b) Machine location (co-ordinates) on Google Maps
(c) Fault code and alarm details
(d) Recommended preliminary action
(e) Detailed step-by-step troubleshooting and problem-solving procedure for the service engineer.

The above helps to meet customer satisfaction in terms of the following ways (2-examples shown):

1. Increase in components and overall machine life expectancy by 30-40% due to preventive maintenance and early fault detection. Below online report analysis as shown in **Figure 6**, helps in determining engine over-

heating pattern & thus taking proactive action to restrict major failure.

2. Light blue cells show idling in the Machine Utilization Report in **Figure 7** as below. As per the Report, the Idling loss shows around 17%, which is High! Several customers have controlled this to 8-10% after Report Analysis.

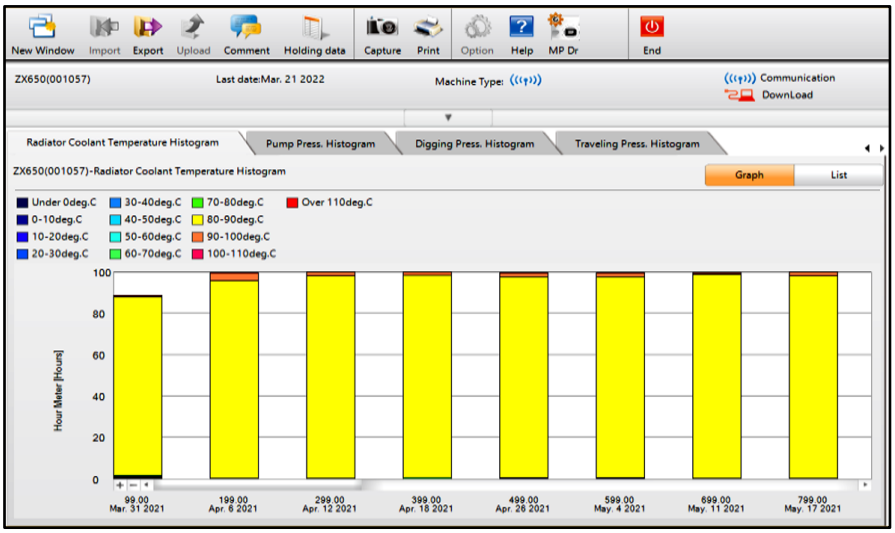


**Figure 6** Engine overheating trend: for enhancing engine life

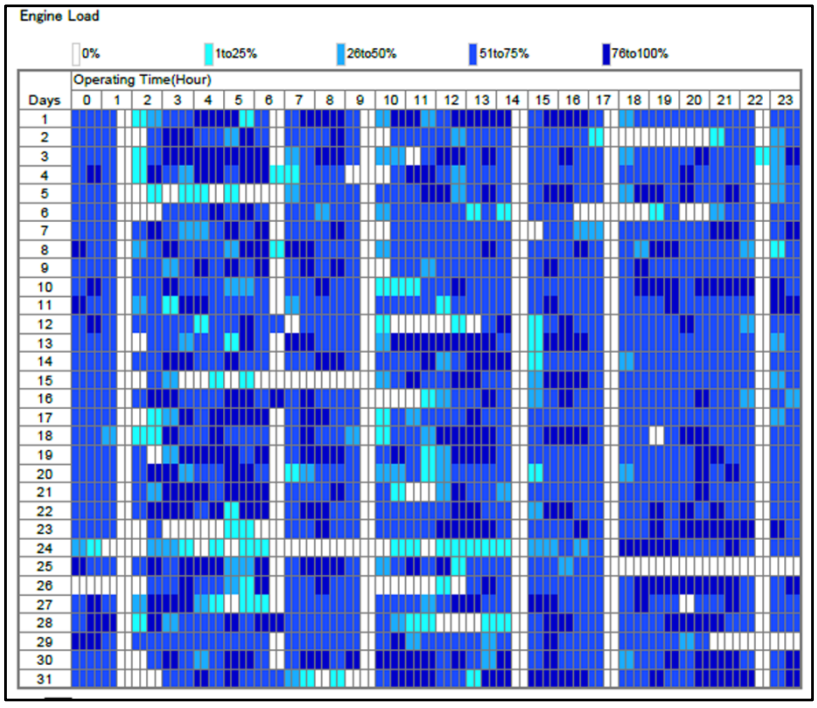


**Figure 7** Machine utilization report

## CONCLUSION AND FUTURE SCOPE

The latest mobile network technology & faster scanning rate of THCM server enables us to get Real Time machine data. Real Time information helps to initiate trouble shooting process without any delay. The system Enhances Availability of machine by 10-20% by reducing the Down Time. This increases component and overall machine life expectancy by 30-40% due to preventive maintenance and early fault detection. The system also helps to reduce the carbon footprint by 20-40%.

**Future Scope**

- ✓ In future, we would like to apply Remote Communication Technology for machine operation using ICT (Information and communication technologies) platform with minimum operator interventions for accurate digging, fuel consumption reduction & increase of safety.
- ✓ The above will help to map a particular work site accurately through Machine Guidance System (MGS), by using various sensors. The inbuilt Automation with MGS will help to plan and optimize the operation by predicting the time & resources required for a job site.

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120_IEC67763

# Dynamic Behaviour and Numerical Analysis of a Supportive Transportation Infrastructure: A Case Study

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***Abstract:*** *The maintenance of infrastructure, especially bridges, is a global challenge, and India, with around 150,000 bridges, is no exception. Many of these are aging, making regular upkeep and monitoring crucial. Spatial Information Technology (SIT) has transformed bridge management by integrating sensor technologies for vibration data analysis. Historically, bridges have evolved from basic materials to modern designs built to endure environmental forces. Today, bridge health monitoring (BHM) systems use sensors to track temperature, humidity, wind, and traffic loads, with real-time data processing. Non-destructive evaluation (NDE) methods, such as acoustic analysis and vibration testing, are vital for assessing structural integrity. A study on two foot-over-bridges (FOBs) in Hyderabad — Lingampally and HITEC City — demonstrates the efficacy of vibration analysis in ensuring safety. SIT enhances the prediction and prevention of structural deterioration, improving maintenance and helping prevent disasters.*

***Keywords:*** *Spatial Information Technology; Numerical Modeling; Sensors; Vibration Analysis; Goodness of Fit*

## INTRODUCTION

The safety and longevity of bridge infrastructure are critical concerns, with the maintenance of bridges posing unique challenges globally. In India alone, approximately 150,000 bridges require continual inspection, maintenance, and monitoring to ensure public safety. Many older bridges are deteriorating, while new ones require advanced technologies for regular assessment. Spatial Information Technology (SIT) and the use of sensors to monitor vibrations have emerged as key tools for assessing the structural health of bridges. These technologies enhance precision in detecting and predicting deterioration by measuring dynamic factors such as traffic-induced loads and environmental stresses.

Given the complexity of modern transportation infrastructure, Structural Health Monitoring (SHM) has become indispensable. The Morbi bridge collapse in India serves as a tragic reminder of the potential consequences of neglected infrastructure, underscoring the importance of regular and timely inspections.

Each structure has unique vibrational properties that vary based on its material composition, geometry, and overall integrity. Any alterations in stiffness or mass, or changes in damping mechanisms, affect a structure's natural frequency and mode shapes. Vibration analysis is particularly effective for identifying localized damage and evaluating structural integrity, especially for bridges subjected to dynamic forces. The development of sensor-based monitoring, particularly in bridge health, aims to enhance real-time assessments, predict future issues, and manage the growing challenges posed by highway bridge degradation.

### Code books of National and International Codes for Structural Assessment and Monitoring

In India, structural health is assessed using specific codes, including Non-Destructive Testing (NDT) and vibration analysis. **Table 1.1** outlines the relevant codes:

| S.No | Assessment Method | IS Code | Year |
|---|---|---|---|
| I | Visual Inspection | - | - |
| II | NDT | IS 1331.1 (Part 2): 1992 | 1992 |
| | 1. Rebound Hammer | IS 1331.1 (Part 2): 1992 | 1992 |
| | 2. Ultrasonic Testing (UT) | IS 1331.1 (Part 2): 1992 | 1992 |
| | 3. Radiographic Testing | IS 1331.1 (Part 2): 1992 | 1992 |
| | 4. Magnetic Particle Testing | IS 1331.1 (Part 2): 1992 | 1992 |
| III | Vibration analysis | Not applicable (In progress) | - |

## LITERATURE REVIEW

Over the years, various methods for identifying structural damage have been explored, ranging from static to dynamic assessments. Lifshitz and Rotem (1969) first noted the correlation between frequency shifts and structural damage [3], while Cawley and Adams (1979) developed a framework for using vibration analysis to detect damage[2].

Recent advancements, including the use of artificial neural networks (ANNs) and genetic algorithms (GA), have improved the accuracy of these methods for large structures. Hybrid approaches that combine GA with modal strain energy (MSE) provide more reliable identification of structural issues. Frequency-based methods, enhanced with AI, continue to improve the precision of damage detection.

### Spatial Information Technology (SIT) in Structural Health Monitoring (SHM)

Sensors are central to SHM, recording structural responses to dynamic loads and environmental conditions. These include accelerometers, strain gauges, displacement sensors, and tilt meters. Wireless sensors, which integrate data processing and transmission capabilities, are particularly valuable due to their low cost and flexibility. Wireless SHM systems can transmit real-time data to remote monitoring centers, facilitating continuous surveillance of critical infrastructure without the need for manual inspections [6].

The key parameter in SHM is the resonant frequency, which changes with structural damage. By monitoring shifts in this frequency, engineers can pinpoint areas of concern. Modern SHM systems, equipped with data archiving and analytical software, provide engineers with a comprehensive overview of a bridge's health, reducing the need for frequent manual inspections [6].

## METHODOLOGY

This study focuses on vibration analysis of two foot-overbridges (FOBs) in Hyderabad—Lingampally and HITEC City—using wireless sensors to assess their condition. Vibration tests were conducted with the assistance of the National Geophysical Research Institute (NGRI), employing TitanSMA and TitanEA sensors under traffic and non-traffic conditions. Numerical models were used to simulate the dynamic behavior of the structures, and frequency vs. amplitude graphs were plotted to identify the mode shapes with the highest amplitude. Data analysis was performed using Python.

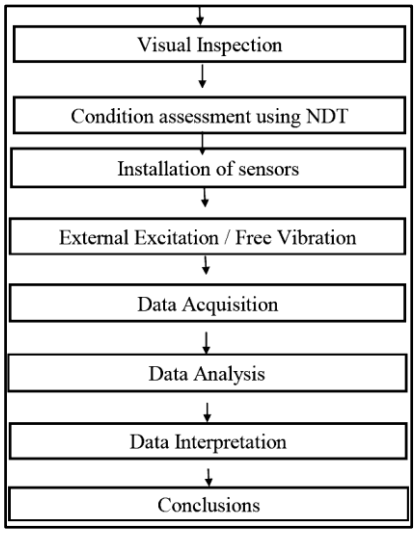



**Figure 4.1** Stages of the methodology

## NUMERICAL AND EXPERIMENTAL INVESTIGATIONS

Numerical modal analysis simulates the dynamic behavior of structures without physical testing, allowing engineers

to calculate natural frequencies, mode shapes and damping ratios. This aids in design optimization, identifying critical areas susceptible to resonance, and predicting potential failures.

**Numerical Modal Analysis**

Numerical modal analysis simulates structural behavior calculating natural frequencies, mode shapes, and damping without physical testing. It aids in design optimization, predicting resonance, and identifying critical areas. Finite Element (FE) models, updated for Structural Health Monitoring, improve damage detection by aligning model responses with real structures, enhancing diagnostic accuracy.

**Experimental Investigations**

Two types of sensors were deployed:

- TitanSMA: A high-precision motion accelerograph used for monitoring civil structures. It provides real-time data and supports both standalone and networked deployments.
- TitanEA: An Ethernet-based accelerograph for large civil structures, offering precise synchronization and real-time monitoring capabilities.

TitanSMA Sensor

The TitanSMA is a powerful motion accelerograph for high-precision structural engineering, offering remarkable dynamic range and low noise. It supports both solo and networked deployments, featuring easy data recovery, continuous streaming and browser-based configuration. Ideal for civil defense applications, it facilitates real-time earthquake monitoring, early warnings and ultra-low latency event detection. [5]

TitanEA Sensor

The TitanEA is a powerful motion Ethernet accelerograph designed for large civil structures like bridges and dams. It features Power-over-Ethernet, network timing and a triaxial sensor. With single-cable Ethernet connectivity, it provides precise time synchronization via Precision Time Protocol (PTP) or Network Time Protocol (NTP), enabling real-time structural monitoring from any internet-connected device [4].


**Figure 5.1** TitanSMA Sensor [5]


**Figure 5.2** TitanEA Sensor [4]

**Fly Over Bridge at HITECH City Hyderabad**

Case study: Fly over bridge at HITEC City, Hyderabad

The HITEC City FOB in Hyderabad is 0.85 km long with a 13.10 m carriageway and 15 spans. GPS coordinates were recorded using the DGPS Model-18 system.

**Case Study : HITEC CITY FOB**

The HITEC City foot-over-bridge (FOB) in Hyderabad, measuring 0.85 km in length with a 13.10 m carriageway, was chosen for detailed analysis. GPS coordinates were recorded using the DGPS Model-18 system. Vibration analysis of the bridge revealed slight frequency variations, indicating minor structural deterioration.

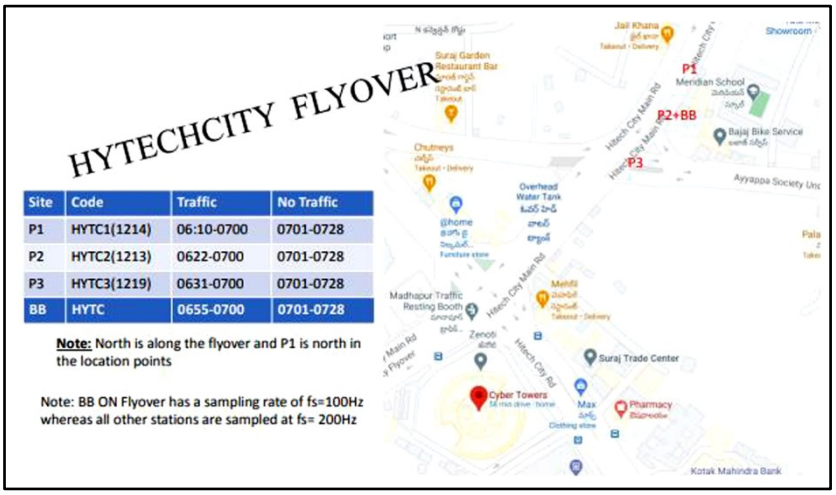



**Figure 5.3** GIS location of HITEC City FOB with latitude of 17°27'11.8"N, longitude 78°22'57.9"E and elevation 587.881m

**DETAILS OF HITEC CITY FOB**

**1. Bridge Geometric**

(a) Length 0.85 km
(b) Carriage way 13.10 meters
(c) Number of spans 15

**2. Material Properties**

(a) Young's modules of elasticity of steel 2×10^11N/m^2.
(b) Young's modulus of elasticity of concrete = 5000√fck = 5000√45 = 33541 N/m^2
(c) Poisson's ratio 0.30

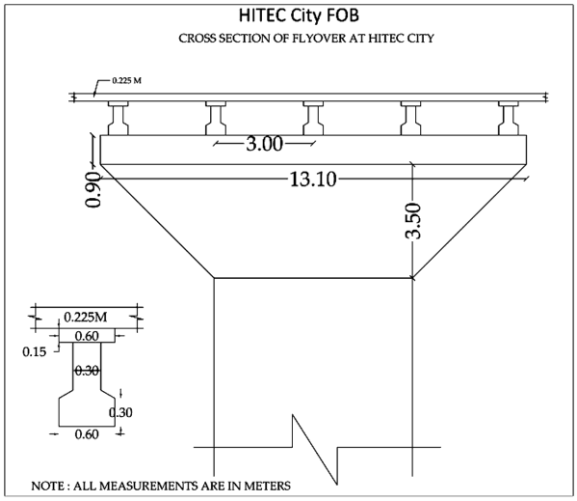



**Figure 5.4** Cross-section of HITEC City FOB

**Table 5.2** Co-ordinates of HITEC City FOB in degrees, minutes and seconds

| Point | Latitude | Longitude | Elevation |
|---|---|---|---|
| P1 | 17°27'12.8"N | 78°22'58.7"E | 586.374 |
| P2 | 17°27'11.8"N | 78°22'57.9"E | 587.881 |
| P3 | 17°27'10.8"N | 78°22'57.0"E | 589.486 |
| Base1 | 17°27'17.9"N | 78°23'01.5"E | 578.423 |

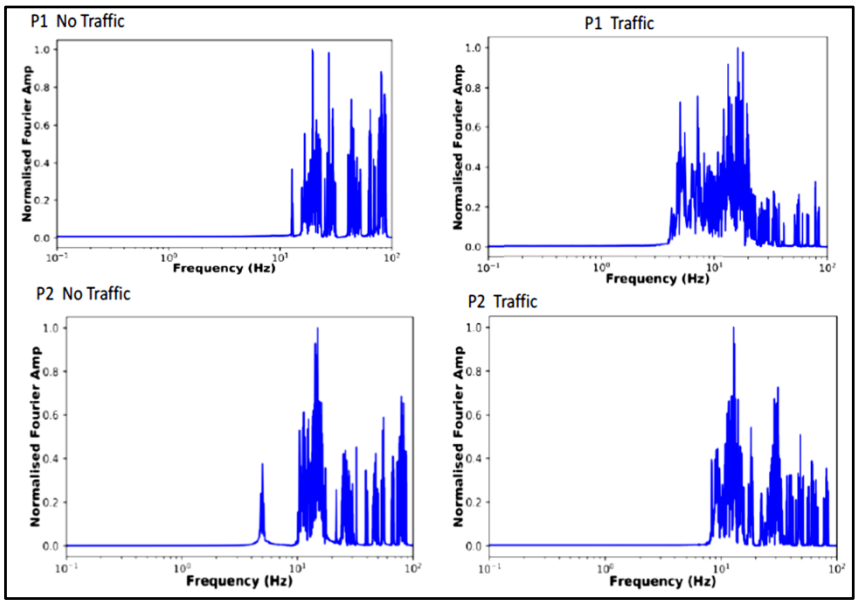



**Figure 5.5** Frequency vs amplitude of P1- P2

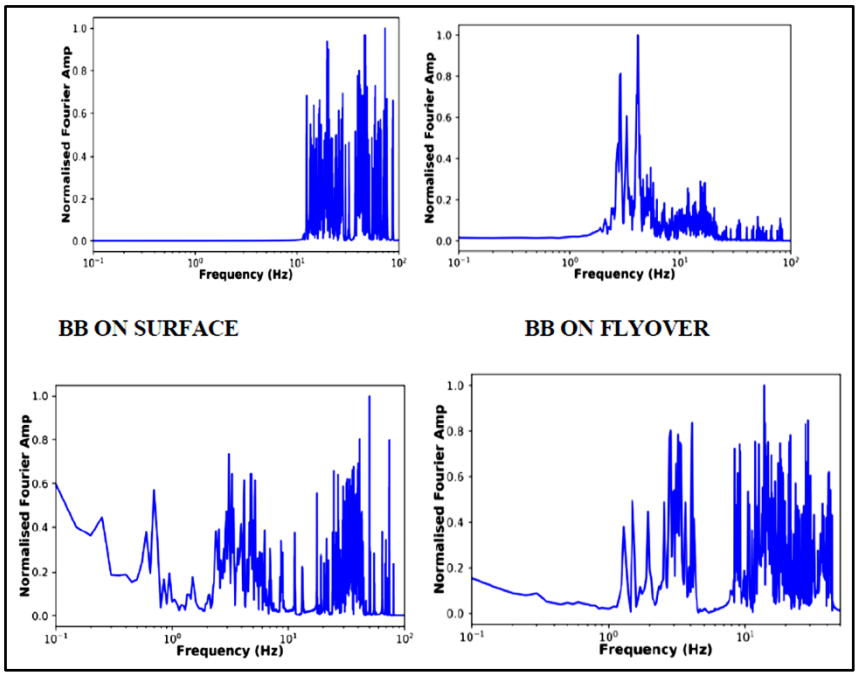



**Figure 5.6** Frequencies vs amplitude on surface and flyover at HITEC City FOB

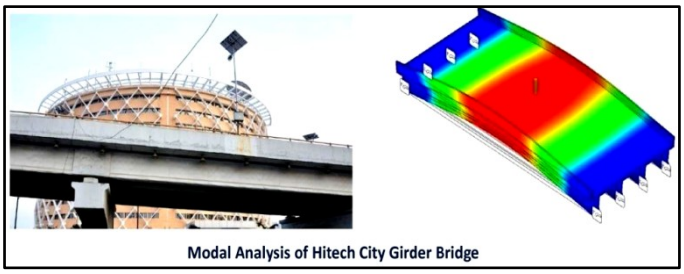



**Figure 5.7** Modal analysis of HITEC City FOB

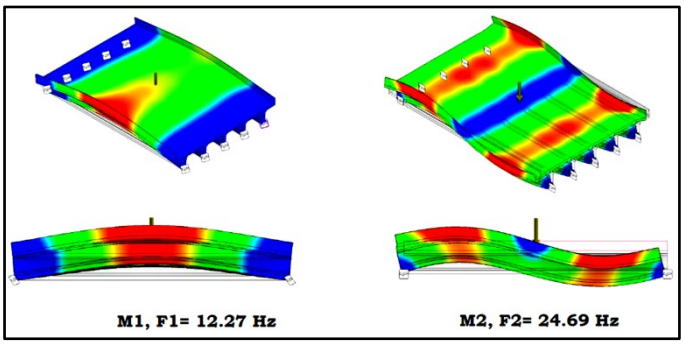



**Figure 5.8** Numerical modal analysis

**Comparative Analysis**

Case study : Analysis of FOB at HITEC City

**Hitech City FOB**

**Table 5.8: Comparison of frequencies (Hz) of first two vertical modes at P1**

| Mode | Induced Vibration / Forced Vibration | Ambient Vibration Testing and Free Vibration | Analytical results from Numerical model | Variation in Frequency compare to undamage | |
|---|---|---|---|---|---|
| | (Traffic) | Traffic No | | Traffic | Traffic No |
| 1st mode | 16.60 | 12.55 | 12.27 | 4.33 | 0.28 |
| 2nd mode | 23.26 | 20.26 | 24.69 | 1.43 | 4.43 |

**Hitech City FOB**

**Table 5.9: Comparison of frequencies (Hz) of first two vertical modes at P2**

| Mode | Induced Vibration / Forced Vibration | Ambient Vibration Testing and Free Vibration | Analytical results from Numerical model | Variation in Frequency compare to undamage | |
|---|---|---|---|---|---|
| | (Traffic) | Traffic No | | Traffic | Traffic No |
| 1st mode | 12.40 | 12.45 | 12.27 | 0.13 | 0.18 |
| 2nd mode | 25.21 | 26.51 | 24.69 | 0.52 | 1.83 |

**Hitech City FOB**

**Table 5.10: Comparison of frequencies (Hz) of first two vertical modes at P3**

| Mode | Induced Vibration / Forced Vibration | Ambient Vibration Testing and Free Vibration | Analytical results from Numerical model | Variation in Frequency compare to undamage | |
|---|---|---|---|---|---|
| | (Traffic) | Traffic No | | Traffic | Traffic No |
| 1st mode | 12.50 | 12.10 | 12.27 | 0.23 | 0.17 |
| 2nd mode | 25.86 | 20.66 | 24.69 | 1.17 | 4.03 |

Similar study was also made Lingampally FOB at Hyderabad and results was analyzed on simpler grounds and the results confirm that both bridges are structurally sound.

Goodness of Fit

Goodness of fit in bridge condition assessment measures how well a model aligns with observed frequency data over time. Engineers compare predicted vibration frequencies to actual data, refining models to ensure accuracy. This process helps detect anomalies, forecast issues and plan maintenance, ensuring bridge safety and performance.

**Statistical Analytics**

A statistical analysis was performed using data from the HITEC City FOB. Paired t-tests, correlation, regression, and ANOVA were employed to ensure the consistency and accuracy of the experimental data. The data was found to be normally distributed, and ANOVA confirmed homogeneity across six variables.

Charts

The data generated is tested for consistency and it is found that the data is normal in nature, without any error and the same is visualized in the histogram below histogram.

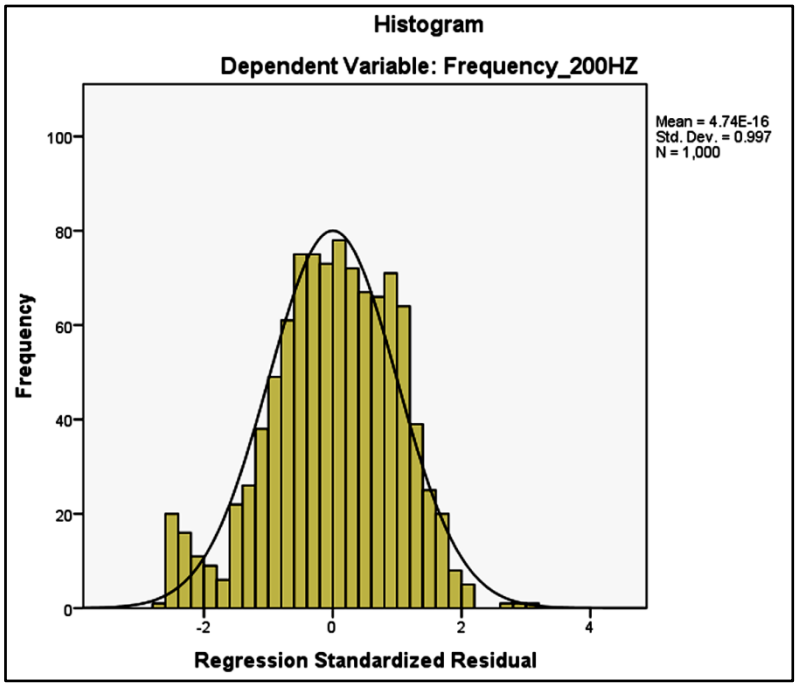


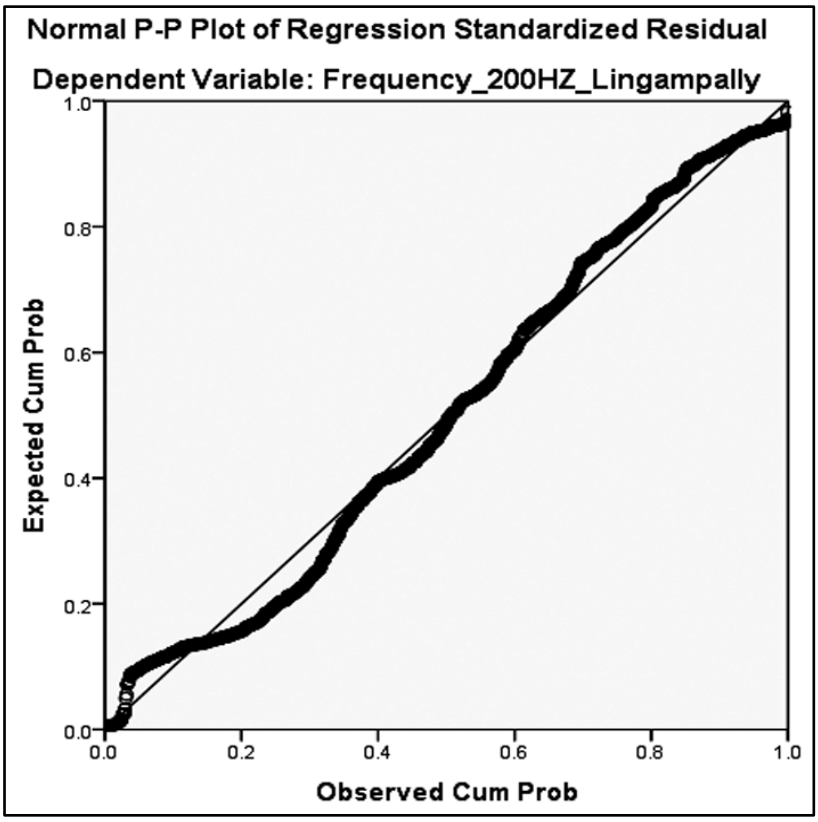

**Figure 5.9** Histogram based on experimental data of fs = 200Hz at HITEC City FOB

Mean = 4.74E -16 = 0
Standard deviation = 0.997 or say 1
Normal ANN (0,1)

Also, the visualizations are done for the actual 'Y' and the predicted 'Y' by considering error equals to Y (actual data - Y^ (predicted data)). Based on this visualization, it's apparent that the actual data and the predicted values align closely, displaying a good fit with minimal discrepancies or errors.

Charts

The data is consistent, error-free, and visualized as normal below.




One-way ANOVA confirmed homogeneity across six variables, showing vibrations occur on bridges regardless of traffic presence or absence. Analysis details are below.

Descriptives

| | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound | | |
| P1_Traffic | 1000 | 0.06128230 | 0.128765768 | 0.004071931 | 0.05329178 | 0.06927281 | 0.000321 | 1.000000 |
| P1_NoTraffic | 1000 | 0.06229912 | 0.141198691 | 0.004465095 | 0.05353708 | 0.07106116 | 0.002310 | 1.000000 |
| P3_Traffic | 1000 | 0.05958153 | 0.135490715 | 0.004284593 | 0.05117370 | 0.06798937 | 0.000648 | 1.000000 |
| P3_NoTraffic | 1000 | 0.05137574 | 0.095312147 | 0.003014035 | 0.04546117 | 0.05729030 | 0.000260 | 1.000000 |
| Total | 4000 | 0.05863467 | 0.126477168 | 0.001999780 | 0.05471399 | 0.06255535 | 0.000260 | 1.000000 |

**Table 5.11** Test of homogeneity of variances

P1_Traffic

| Levene Statistic | df1 | df2 | Sig. |
|---|---|---|---|
| 19.218 | 3 | 3996 | .000 |

**Table 5.12** ANOVA

P1_Traffic

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 0.074 | 3 | 0.025 | 1.543 | 0.201 |
| Within Groups | 63.896 | 3996 | 0.016 | | |
| Total | 63.970 | 3999 | | | |

**Table 5.13** Post hoc tests

Multiple Comparisons
Dependent Variable: P1_Traffic
LSD

| Target Variable (I) | Target Variable (J) | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| P1_Traffic | P2_NoTraffic | -0.001016829 | 0.005655079 | 0.857 | -0.01210394 | 0.01007028 |
| | P2_Traffic | 0.001700763 | 0.005655079 | 0.764 | -0.00938635 | 0.01278787 |
| | P2_NoTraffic | 0.009906559 | 0.005655079 | 0.080 | -0.00118055 | 0.02099367 |
| P1_NoTraffic | P1_Traffic | 0.001016829 | 0.005655079 | 0.857 | -0.01007028 | 0.01210394 |
| | P2_Traffic | 0.002717592 | 0.005655079 | 0.631 | -0.00836952 | 0.01380470 |
| | P2_NoTraffic | 0.010923387 | 0.005655079 | 0.053 | -0.00016372 | 0.02201050 |
| P3_Traffic | P1_Traffic | -0.001700763 | 0.005655079 | 0.764 | -0.01278787 | 0.00938635 |
| | P2_NoTraffic | -0.002717592 | 0.005655079 | 0.631 | -0.01380470 | 0.00836952 |
| | P2_NoTraffic | 0.008205796 | 0.005655079 | 0.147 | -0.00288131 | 0.01929290 |
| P3_NoTraffic | P1_Traffic | -0.009906559 | 0.005655079 | 0.080 | -0.02099367 | 0.00118055 |
| | P2_NoTraffic | -0.010923387 | 0.005655079 | 0.053 | -0.02201050 | 0.00016372 |
| | P2_Traffic | -0.008205796 | 0.005655079 | 0.147 | -0.01929290 | 0.00288131 |

**Table 5.14** Coefficients[a]

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. | 95.0% Confidence Interval for B | |
|---|---|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | | Lower Bound | Upper Bound |
| 1 | (Constant) | 30.099 | 0.420 | | 71.747 | 0.000 | 29.276 | 30.922 |
| | P1_Traffic | -33.905 | 4.123 | -0.302 | -8.223 | 0.000 | -41.997 | -25.814 |
| | P1_NoTraffic | -20.274 | 3.899 | -0.198 | -5.200 | 0.000 | -27.925 | -12.623 |
| | P3_Traffic | -15.066 | 3.699 | -0.141 | -4.073 | 0.000 | -22.324 | -7.807 |
| | P3_NoTraffic | -16.997 | 4.213 | -0.112 | -4.035 | 0.000 | -25.264 | -8.730 |

## DISCUSSION OF RESULTS

The Latitudes and Longitudes of Lingampally and HITEC City FOBs were identified using GIS-based sensors. TitanSMA and TitanEA sensors were installed for vibration testing and frequencies were recorded. Results showed close alignment between experimental and numerical data, confirming bridge safety. However, some deterioration was noted. Further research is needed.

Based on the previous studies, the frequency vs amplitude of vibration is given by the following figure.

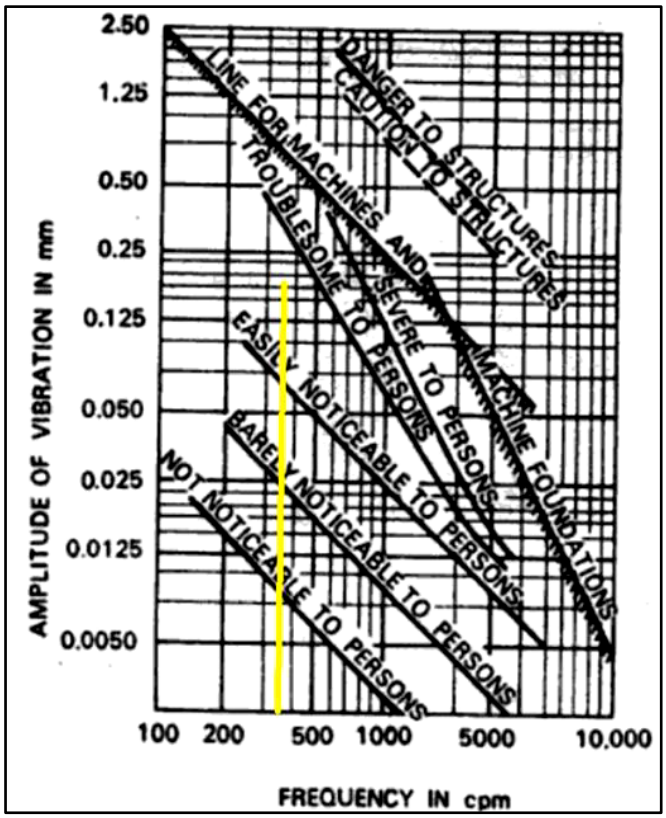



**Figure 5.6** Allowable limits for vertical vibration amplitudes (After Richart, F. E., Jr. et al., Vibration of soils and foundations, Prentice-Hall Inc., New Jersey, USA, 1970; with permission) [1]

## SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

### Summary

Bridges face increasing stress due to rising traffic loads, making routine monitoring essential for identifying early signs of deterioration. Vibration-based damage assessment, coupled with advanced SIT tools, allows for accurate predictions of structural health and maintenance needs.

### Conclusions

This study focused on the vibration analysis of two FOBs in Hyderabad. The results confirm that both bridges are structurally sound, although minor deterioration was observed. SIT plays a crucial role in improving the accuracy of condition assessments.

### Recommendations

1. Establish clear guidelines for visual inspections.
2. Enhance the use of NDE methods in SHM.
3. Implement automated data collection systems for real-time monitoring.
4. Further research should focus on improving wireless sensing technology and developing standardized SHM models. adaptable to different bridge types.

## FURTHER RESEARCH /INVESTIGATIONS NEEDED

1. Develop a comprehensive procedure for bridge assessments.
2. Address technical limitations of wireless sensors.
3. Create adaptable SHM models for diverse bridge structures.

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121_IEC36045

# Numerical Analysis of Existing Bridge Infrastructure

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***Abstract***: *The assessment and maintenance of existing bridge infrastructure are critical to ensuring public safety, optimizing economic resources, and prolonging the lifespan of these essential structures. Numerical analysis, incorporating computational tools and techniques, plays a pivotal role in evaluating the structural integrity, load-carrying capacity, and performance of bridges. This paper discusses key methodologies in numerical analysis, explores its application in bridge condition assessment, and highlights case studies demonstrating its effectiveness in addressing challenges associated with aging bridge infrastructure. A recent study of two foot-over-bridges (FOBs) in Hyderabad, Lingampally and HITEC City, highlights the effectiveness of vibration analysis in detecting potential issues and ensuring safety. By integrating SIT with predictive maintenance strategies, engineers can better anticipate and mitigate structural deterioration, reducing the risk of failures and improving overall safety. This proactive approach helps extend the lifespan of bridges and prevent catastrophic disasters*

***Keywords***: *Existing Bridge Infrastructure; Numerical Model Analysis; Computational Tools and Techniques; Software Packages; Bridge Condition Assessment*

176_IEC88585

# Retrofitting of Structural Members with Post-Tensioned CFRP Strips

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***Abstract:*** *This research focuses on assessing the effectiveness of retrofitting structural members with post-tensioned Carbon Fiber Reinforced Polymer (CFRP) strips, employing both experimental and numerical approaches. Firstly, a comprehensive three-dimensional finite element model is developed in Abaqus to simulate post-tensioned CFRP beams. The validated model accurately captures the behaviour of the composite system, providing valuable insights into its applicability. Subsequently, experimental investigations are conducted in laboratory on beam samples, including a control Reinforced Concrete (RC) beam, a RC beam with CFRP wrap and a RC beam with post-tensioned CFRP strip. Through four-point bending tests, load was applied and deflections were measured using dial gauges. The experimental results revealed that there was a significant enhancement in flexural strength with post-tensioned CFRP strips compared to both control and CFRP wrapped samples. The study demonstrates the effectiveness of post-tensioned CFRP strips in retrofitting concrete structures, highlighting the improved properties of the CFRP strengthened beams as compared to CFRP wrap applications.*

***Keywords:*** *Retrofitting; Post-tensioning; Carbon Fibre Reinforced Polymer (CFRP); Finite Element; Flexural Strength*

## INTRODUCTION

As infrastructure ages, structures are subjected to various loads and environmental factors, leading to deterioration. Traditional solutions like demolition and reconstruction are costly and time-consuming, making retrofitting a more efficient alternative for enhancing structural stability, strength, and load-bearing capacity.Fiber Reinforced Polymer (FRP) has become a popular retrofitting material due to its ability to increase load-carrying capacity, durability, and resistance to degradation. However, conventional FRP wrapping does not fully utilize its strength. Post-tensioning, where tension is applied after the concrete has set, maximizes FRP's potential, significantly improving flexural strength and overall structural performance. While steel tendons have been commonly used for post-tensioning, the application of Carbon Fiber Reinforced Polymer (CFRP) remains underexplored. Given CFRP's high strength-to-weight ratio and corrosion resistance, this research investigates the effectiveness of post-tensioned CFRP strips in retrofitting structural members, offering a promising approach to extending the lifespan of aging infrastructure.

A brief review of literature is discussed here. Choi et al. (2005)[1] investigated the behavior of reinforced concrete (RC) beams strengthened with externally post-tensioned Carbon Fiber Reinforced Polymer (CFRP) strips, focusing on the effects of post-tensioning levels and bonded versus unbonded systems. Kim et al. (2015) [2] presented a numerical investigation on the effects of post-tensioning near-surface mounted (NSM) Carbon Fiber Reinforced Polymer (CFRP) strips on precast concrete (PC) beams.Amran et al. (2018) [3]reviewed the properties and applications of fiber-reinforced polymer (FRP) composites in strengthening and rehabilitating reinforced concrete (RC) structures, highlighting the mechanical properties, types of FRP materials, and their effectiveness in various civil engineering applications such as beams, columns, and joints. Sujivorakul (2020) [4] explored the strengthening of reinforced concrete slabs using post-tensioned carbon fiber reinforced polymer (CFRP) strips. Marwein and Maitra(2021) [5] investigated the use of Fiber-Reinforced Polymer Stay-in-Place (FRP-SIP) formwork systems for concrete construction. It examines the flexural behavior of beams and slabs with glass FRP permanent formwork through experimental and numerical analysis.

## METHODOLOGY

The methodology employed in this study involved both experimental and numerical approaches to assess the effectiveness of retrofitting structural members using post-tensioned CFRP strips.

### Finite Element Modelling

A three-dimensional finite element model was developed in Abaqus to simulate the behavior of reinforced concrete beams under various retrofitting scenarios. The model included a control beam (RCC beam), RCC beams with CFRP wrap, and RCC beams retrofitted with post-tensioned CFRP strip. The concrete was modeled using 8-noded linear brick elements (C3D8R), while the CFRP was represented by using 4-noded doubly curved shell elements (S4R). The reinforcement was modeled using 2-node linear beam elements (B31). The interface between concrete and CFRP was modeled as a cohesive surface. Material properties were assigned based on experimental data. Concrete had an elastic modulus of 27,340 MPa and a Poisson's ratio of 0.15, while the CFRP had an elastic modulus of 160 GPa and a tensile strength of 2800 MPa. The finite element models were validated using analytical methods, literature, and experimental results to ensure accuracy.

### Laboratory Experiments

The experimental study involved several key activities.

### Sample Preparation

Several steps are involved for the preparation of samples for conducting the experiments.

Concrete Mix Design: The concrete mix design was done following IS 10262:2009 standards and the mix ratio was obtained as Cement: FA: CA as 1:1.743:2.5762 and a water-cement ratio of 0.42. A slump test was conducted to ensure workability, yielding a value of 95 mm.

Formwork & Reinforcement: Wooden formwork for beam with dimensions 3000 mm length x 400 mm width x 200 mm depth was prepared having three 12 mm diameter bars as bottom tension reinforcement and three 10 mm diameter bars as hanger bars on the compression face. Stirrups of 8 mm diameter bars were used.

Casting: Concrete was poured into the formwork and vibrated using a vibrating rod to eliminate air pockets. The samples were cured using the gunny bag method to maintain moisture levels for 28 days.

CFRP Wrap Application: For the CFRP-wrapped beams, the CFRP strip (50 mm wide and 1.4 mm thick) was applied to the beam surface using adhesive. The surface was double layered primed, and the adhesive was allowed to cure for 7 days.

Post-Tensioned CFRP Application: The application of post-tensioned CFRP strips in the retrofitting of structural members is a critical component of this study. The following steps outline the detailed procedure: -

### Surface Preparation

The surface of the reinforced concrete beam where the CFRP strip is to be applied was thoroughly cleaned to remove any dust, debris, or loose particles. This step is essential to ensure a strong bond between the concrete and the CFRP strip. A moisture meter was used to assess the moisture content of the concrete surface, ensuring it was below 5% before proceeding with the application of the primer and adhesive.

### Positioning of Bolts

The bolt holes were drilled at designated locations on the beam using a profometer to ensure they did not intersect with any reinforcing bars. The chemical adhesive was applied to the holes, and the bolts were inserted. The adhesive was allowed to cure to ensure a secure bond.

**Primer Application**

A layer of primer was applied to the prepared concrete surface. The primer was allowed to penetrate the surface, filling any pores and creating a smooth, adhesive-friendly layer. The primer was left to cure for 24 hours before the application of the adhesive.

**CFRP Strip Placement**

The CFRP strip was aligned along the bottom surface of the beam. The adhesive was applied evenly along the entire length of the CFRP strip. The adhesive acts as the bonding agent between the CFRP strip and the concrete surface.

**Post-Tensioning Setup**

A hydraulic jack was set up at one end of the beam, connected to the CFRP strip through a specially designed clamping system. The opposite end of the CFRP strip was securely anchored. The hydraulic jack was used to gradually apply tension to the CFRP strip. The amount of tension was carefully controlled to achieve the desired level of prestressing, typically ranging between 20% to 40% of the CFRP's tensile strength. The CFRP strip was then pressed firmly onto the concrete surface, ensuring full contact and alignment. The assembly was left undisturbed for 14 days to allow the adhesive to cure fully.

**Laboratory Testing**

The control and the retrofitted beams were subjected to four-point bending tests to evaluate their flexural strength. A frame was prepared for carrying out the experiments in the laboratory (**Figure 1**). The load was applied at a consistent rate of 2.5 kN/min, and deflections were measured using dial gauges. The cracking load, failure load and the failure mode of the beams were noted. The experiments enabled an investigation of the performance of RCC beams retrofitted with post-tensioned CFRP strips, providing valuable insights into the potential of this technique for structural retrofitting.

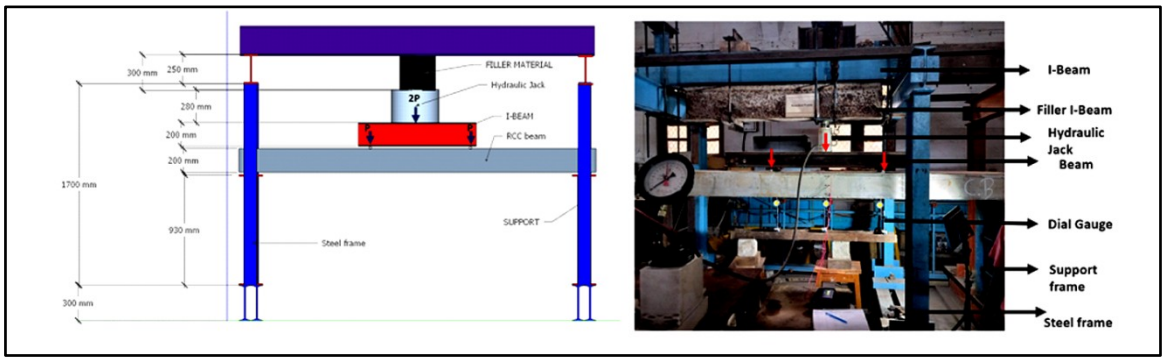


**Figure 1** Test setup

**RESULTS**

The results of the tests were compared across the control, CFRP-wrapped, and post-tensioned CFRP-retrofitted beams to determine the effectiveness of the retrofitting techniques. The experimental results revealed significant improvements in the flexural strength of beams retrofitted with post-tensioned CFRP strips compared to both control beams and those strengthened with conventional CFRP wraps as given in **Table 1**.

CFRP application boosts the load-carrying capacity of beams by roughly 32% more than the control beam. In comparison, post-tensioning with CFRP strip further elevates capacity by 22.42% as compared to CFRP-wrapped beam and 61.6% when compared with control beam. The FEM simulations indicated a substantial reduction in stress levels, with a 66.63% reduction for post-tensioned CFRP beams and a 21.08% reduction for CFRP-wrapped beams. The integration of CFRP strips with varying levels of post-tensioning demonstrated a notable increase in the flexural

capacity of the beams, with improvements of approximately 63% and 96% for 20% and 40% post-tensioning, respectively. **Table 2** shows the results of FE analysis.

**Table 1** Experimental results

| Prepared beam Samples | Experimental Results | |
|---|---|---|
| | First Cracking Load (kN) | Failure Load (kN) |
| RCC beam | 27.5 | 62.5 |
| CFRP Wrap RCC beam | 32.5 | 82.5 |
| RCC beam with post-tensioned CFRP Strip | 48 | 101 |

**Table 2** FEM results

| | Simply Supported beam | Reinforced Simply Supported beam | Reinforced Simply Supported beam with CFRP wrap | Reinforced Simply Supported beam with post-tensioned CFRP Strip |
|---|---|---|---|---|
| Deflection (mm) | 0.778 | 0.716 | 0.6523 | 0.3272 |
| Bending Stress in the beam section (MPa) | 2.481 | 2.428 | 1.958 | 0.8278 |
| Bending Stress in the reinforced section (MPa) | - | 14.5 | 12.25 | 4.72 |
| Bending Stress in the Strip section (MPa) | - | - | 11.96 | 560 |

The results of experiments and FE analysis indicate that, the post-tensioned CFRP strips provided enhanced resistance to crack propagation, delaying the onset of failure compared to the control and CFRP-wrapped beams. However, the primary failure mode observed in post-tensioned CFRP beams was debonding and splitting of the CFRP near the anchoring devices. Load-deflection plots of all samples, as obtained from the FE analysis, are shown in **Figure 2**.

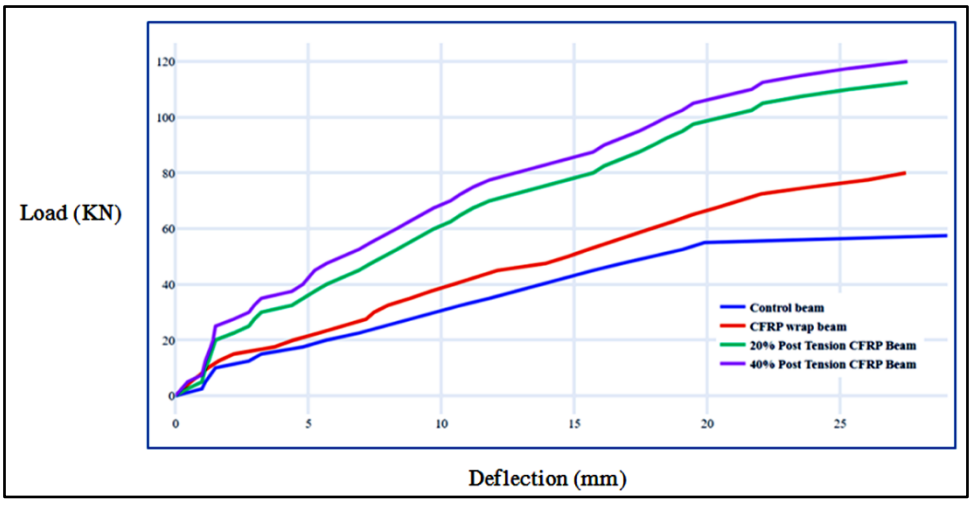


**Figure 2** Load v/s Deflection graph of all samples obtained from FE analysis

## CONCLUSION

This study demonstrates the effectiveness of post-tensioned CFRP strips in retrofitting reinforced concrete beams. The use of post-tensioned CFRP strips significantly enhances the flexural capacity and durability of the beams, offering a more efficient solution compared to traditional CFRP wrapping methods. The findings highlight the

potential of post-tensioned CFRP as a superior retrofitting technique, particularly for aging infrastructure requiring increased load-bearing capacity and extended service life.

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220_IEC39417

# New Technique for Evaluating Concrete Strength through Non-Destructive Testing

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***Abstract:*** *Non Destructive testing (NDT) of concrete is one of the important methods to assess the strength of concrete without causing any damage to the concrete structure. Schmidt Rebound hammer is used to calculate concrete surface hardness which is a widely used non-destructive testing (NDT) method to predict strength of concrete with the statistical correlation between strength of concrete and rebound index reading. Decades of practice and research in assessing strength using Schmidt Rebound hammer for an assessment of concrete strength remains a controversial issue as the test results are inconsistent by assuming the universal correlation model is correct.*

*The new Non Destructive testing approach is a pendulum based prototype designed to assess the concrete strength gain evaluation based on the principle of coefficient of restitution. The prototype tested on different types of materials used in the construction sector. Rebound angle calculated using prototype is different for different construction material and structural elements and there is increase in the rebound angle with increase in the days after casting of concrete from day 3 to 28 days. The increase in the rebound angle on concrete as the days of casting increases has a correlation with the strength gain of concrete.*

***Keywords:*** *Schmidt Rebound Hammer; Coefficient of Restitution; Rebound Angle; Strength Estimation*

## INTRODUCTION

The assessment of concrete quality is crucial in both new construction and the evaluation of existing structures, especially in contexts requiring retrofitting to meet modern standards. The rebound hammer test, developed by Schmidt in the early 1950s, has become one of the most prevalent NDT methods due to its simplicity and affordability. The goal of Schmidt rebound hammer tests on concrete structures is typically to establish a connection between compressive strength and surface hardness with a tolerable margin of error. The rebound index and concrete's compressive strength are correlated using the curve supplied for the rebound hammer. There hasn't been a general theory that can explain the relationship between recorded hardness values and compressive strength for the rebound method. The rebound hammer (Schmidt hammer) test is one of the most extensively used methods, and its calibration is still based on the original Schmidt curve from the early 1950s. Analyzing the relationships between concrete core strength and NDT test findings has been the subject of extensive research, both in the lab and on actual structures. After years of research and expertise, the use of NDT technologies for a quick and accurate evaluation of concrete strength is still a contentious topic. NDT techniques are frequently applied in daily practice. Yet, not every issue is always handled properly, either due to a lack of understanding, expertise, or training addressing this complex topic.

1. There is inconsistency in test results by assuming the universal correlation model is true.
2. There is a lack of consideration of the effects of the ingredient of concrete on test results.
3. The lack of consideration for the effects of external factors (e.g. carbonation and moisture content of concrete

The issues related to the using NDT techniques and assessing the strength of concrete need to be addressed by modifying the correlation model or by introducing the new technique to assess the concrete. In this paper a New method is proposed to assess the strength of concrete using a pendulum based prototype to assess the strength gain of concrete based on the principle of coefficient of restitution.

## METHODOLOGY

In the Proposed prototype **Figure 1** is a string attached with a hard plastic ball having weight 83 gm (m1) is attached with a plywood with screw. The length of the pendulum is L mm. It was kept at initial angle 900 with the test specimen having mass ($m_2$). When we release the ball it will strike on the test specimen and rebound.

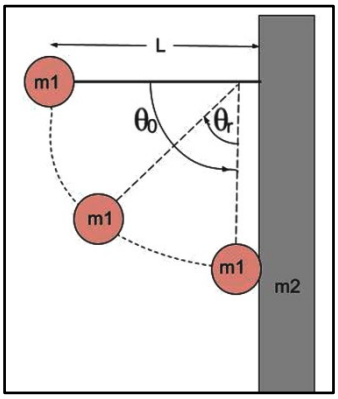


**Figure 1** Schematic diagram of prototype

The first angle of rebound is measured. Prototype is used to take the readings at different undergoing construction works. There are different specimens tested including RCC Beam, RCC Column, AAC Block, Wood etc to determine their rebound angle to understand the behavior of the different material.

## RESULTS

Prototype is used to determine the rebound angle of different RCC elements and construction materials. The test was conducted on four under construction sites having different dates of casting and construction materials such as AAC blocks, Wood Door frame, plywood etc. The details of the site and the results of the specimen tested is as per the below table.

### Testing of Different construction Materials

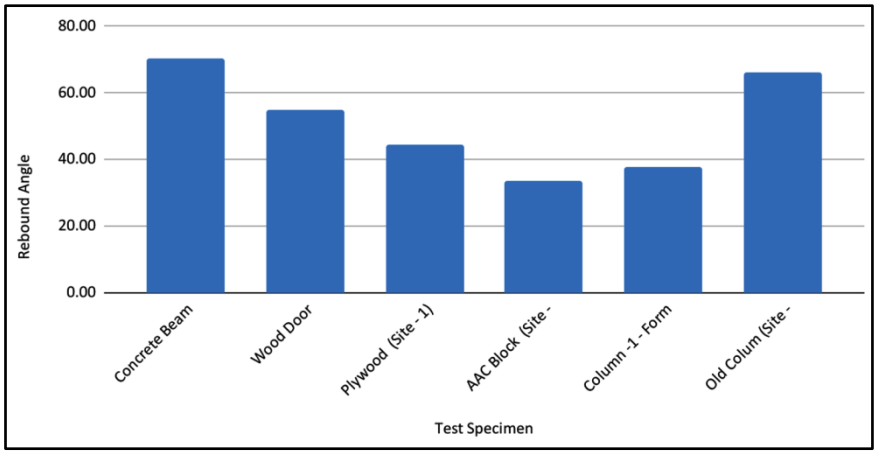


**Figure 2** Graph of test specimen vs rebound angle

Average rebound angle is different for different test specimens. The AAC block has less rebound than a RCC column due to its light weight and the voids in it. There is increase in the rebound angle of the wood door frame as compared with AAC block. The column age of 4 Days is having 42.71 % less rebound than a column having age more than 28 days. The round angle of an RCC column having age more than 28 days is different at different sites due to different mix design.

**Testing of RCC Column**

The test procedure and tests were conducted on RCC columns for different sites on 3, 7, 14, 21, 28 Days.

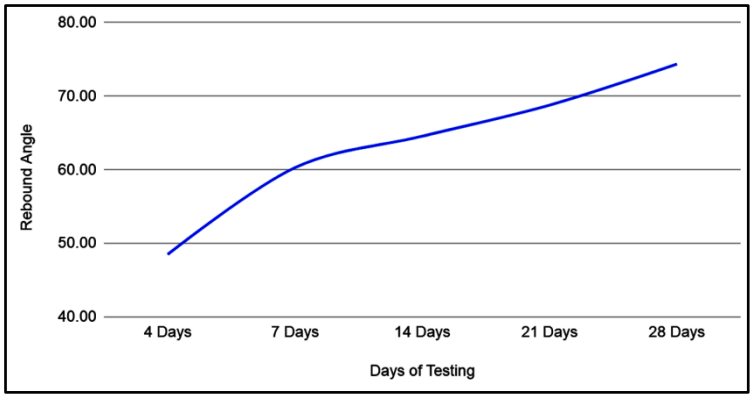


**Figure 3** Graph of days of testing vs rebound angle

The average lowest angle recorded on 3 days of casting along a longer span is for column-5 5 is 43.23° and maximum average angle recorded is 52.17° for column -3. The maximum angle is 75.27° for column-4 and lowest is 73.57° for column-2 on 28 Days of casting. The average rebound angle for a shorter span for 3 Days – 47.25° and on 28 Days – 74.41°. There is progressive gain in rebound angle as the days of testing increases.

**Testing of Concrete Cube**

Concrete cube were tested with Prototype by recording the rebound angle on the surface of the cube, then same cube were tested with Rebound hammer rebound to record the Rebound angle and corresponding compressive strength, later the cube were tested with compression testing machine to get exact compressive strength of cube. The readings are as shown below

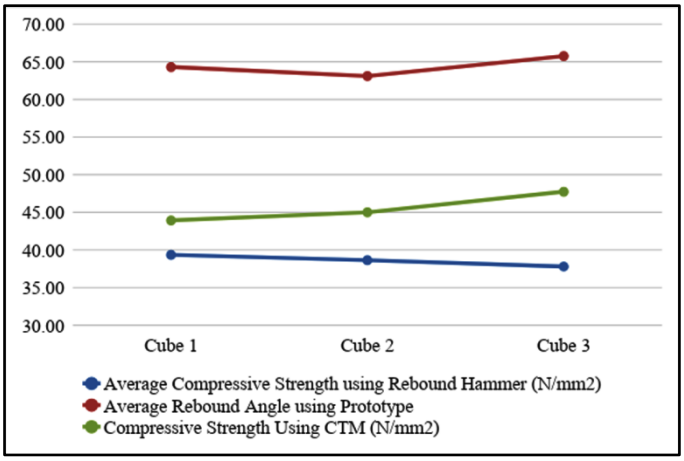


**Figure 4** Graph

The average compressive strength for cube set-1 using the rebound hammer is 38.60 N/mm$^2$. Average prototype rebound angle is 64.380 and the actual compressive strength after testing cube with compression testing machine is 45.55 N/mm$^2$.

**CONCLUSION**

1. Rebound angle calculated using prototype is different for different construction material and structural

elements.

2. Prototype gives progressive rise in angle from 3 Day to 28 Day of casting of column related to strength gain of concrete.
3. Rebound hammer used for testing of concrete having age 14 Days and assessing strength more than 10 Mpa
4. Proposed prototype can be used to record the reading from 1 Days of concrete casting.
5. It has been observed that Prototype shows consistent results as compared with rebound hammer.

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# Inclinometer-based Health Monitoring and Digital Twin Development for Simply Supported Beam Subjected to Point Load

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***Abstract:*** *Structural Health Monitoring (SHM) is essential for ensuring the safety and integrity of structures by providing real-time insights into their condition. This project focuses on the SHM of beams using accelerometers as inclinometers to measure angular displacements at supports. Two ADXL345 accelerometer sensors are utilized to accurately capture rotation data, which is sufficient to determine the magnitude and location of point loads relative to the supports. The collected data is processed using ESP32 and ESP8266 microcontrollers and transmitted to a real-time IoT dashboard for visualization and analysis. Experiments conducted on tubular steel sections demonstrated high accuracy, particularly when point loads were applied at critical locations, underscoring the potential for broader applications in bridge and beam health monitoring. This cost-effective and efficient system improves structural audits and provides timely warnings to enhance infrastructure safety.*

***Keywords:*** *Structural Health Monitoring; IoT; Structural Audit; Digital Twin*

## INTRODUCTION

Structural Health Monitoring (SHM) is essential for ensuring the safety and integrity of structures by providing real-time data on their condition. It enables early detection of potential failures, optimizing maintenance efforts and reducing costs. SHM supports informed decision-making, ensures regulatory compliance, and enhances performance assessments. Additionally, it fosters public confidence in infrastructure safety, extends the lifespan of structures, and helps mitigate risks related to environmental changes, making it a critical component of modern engineering practices. IoT-based SHM can help improve structural safety by detecting damage early and enabling timely maintenance or repair [1]. Flexural members, such as beams and slabs, play a critical role in structural engineering by distributing loads, maintaining structural integrity, and controlling deflection. They enhance safety and efficiency while absorbing dynamic forces, making them essential for versatile and resilient designs in various construction applications. There is a need for reasonably reliable and easy-to-implement health monitoring schema for general beams and bridge structures.

This project has attempted doing real-time structural audit of simply supported steel beams loaded under moving point load by measuring rotation of beam at supports. Structural health monitoring of these flexural members requires decisions regarding appropriate types of sensors. Deflection measurement requires a fixed datum/ reference line, which is not practicable. Rotation measurement of the beam does not require an external reference line, and rotation measurements at the support of a simply supported beam are sufficient to map the position and magnitude of a point load. This was achieved by incorporating a real-time, IoT based embedded system to measure angle using ADXL345 accelerometers. Digital twin for deflection, shear force and bending moment diagrams are generated using support rotation values in real time. Digital twin is a concept that utilizes digital technologies to mirror the real-time states of physical assets and extract the hidden yet valuable information of physical assets for optimization, decision-making or scheduling [2]. The advent of digital twin technology, coupled with advances in sensing, data processing, and communication techniques, has presented new opportunities for enhancing SHM systems in civil structure [3]. Getting early warning regarding the real time integrity and serviceability of structures is crucial for manufacturers, maintenance teams, and operators [4].

This is a simple application of available sensor technology and cost effective microcontroller to demonstrate digital twin for simply supported beam under moving point load. Combined structural health monitoring with digital twin

provides a comprehensive and easy to understand state of the structural component. This concept can be used in long term monitoring of numerous bridge structures, buildings and infrastructure.

## METHODOLOGY

The stresses in the simply supported beam, deflection, bending moment, and shear force can be correlated with the support rotation using a simple formulation as given in equation

$\theta_A = Pab(L+b)/6\ LEI$

$\theta_B = Pab(L+a)/6LEI$

Where, $\theta_A$ - Rotation of support A (radian); $\theta_B$ - Rotation of support B (radian); P - Point load acting on a beam (N); a - Distance of point load from support A (mm); b - Distance of point load from support B (mm); L - Span of beam (mm); E, I - Modulus of elasticity ($N/mm^2$) and moment of inertia of cross-section ($mm^4$).

Rotation has been chosen as the basis for further analysis and postprocessing. The system can map the deflection of the beam (theoretically) under single point load using two sensors. Linear distance measuring sensors are generally used to monitor the deflection, which requires a reference line. This problem is solved by using rotation measurement near supports. Shear force and bending moment can be evaluated from the magnitude of force and the location of force calculated from the angular displacement values.

Embedded system has been made to measure real-time rotation data of the simply supported beam. The embedded system as shown in **Figure 1** has been formed with the help of:

1. ESP32 and ESP8266 microcontroller board
2. ADXL345 accelerometers

The simply supported beam will deflect on application of point load. Angular displacement of support is measured using an accelerometer ADXL345. The ADXL345 accelerometer has been used to measure angles with high sensitivity (3.9 mg/LSB) and range of +2g. This data is then averaged over a few readings to get a reliable rotation reading. The rotation is measured at the points on the beam nearest to the supports. The microcontrollers have been programmed using the Arduino Cloud platform which allows for easy integration and real-time data visualization. This allows the user to see real-time angular displacements. Long-term data helps in identifying gradual changes or trends that could indicate structural degradation, enabling predictive maintenance and timely interventions. The ADXL345 sensors measure angular displacements, which are then processed in real time using advanced algorithms. This processing converts rotation data into valuable insights about the forces acting on the beam including location of force, Magnitude of force (point load), Shear force diagram and Bending moment diagram The algorithm then checks whether the current bending moment and shear force are under the permissible limits or not. If the limits have been violated the user/resident will be given an alarm so as to alert them of potential danger. The system has been tested on a steel beam having a tubular section. The section was loaded at various points with varying magnitude of load. The following were the results **Tables 1** and **2**.

## RESULTS AND CONCLUSION

The system demonstrates strong accuracy, as observed from low percentage errors in angular displacement measurements at supports A and B, with most errors under 1.5%. This confirms the reliability of the developed inclinometer-based SHM system for beam subjected to point load. The highest error (5.10%) was observed at support B when the load was positioned at 1000 mm from support A, indicating potential sensitivity in measurements based on load location.

The inclinometer-based system provides highly accurate point load calculations, with errors mostly under 1.5%, showing strong consistency with calibrated load values. Test 4 and 5 show higher errors (5.86% and 4.01%), which may indicate minor calibration requirement or measurement deviations at specific load points.

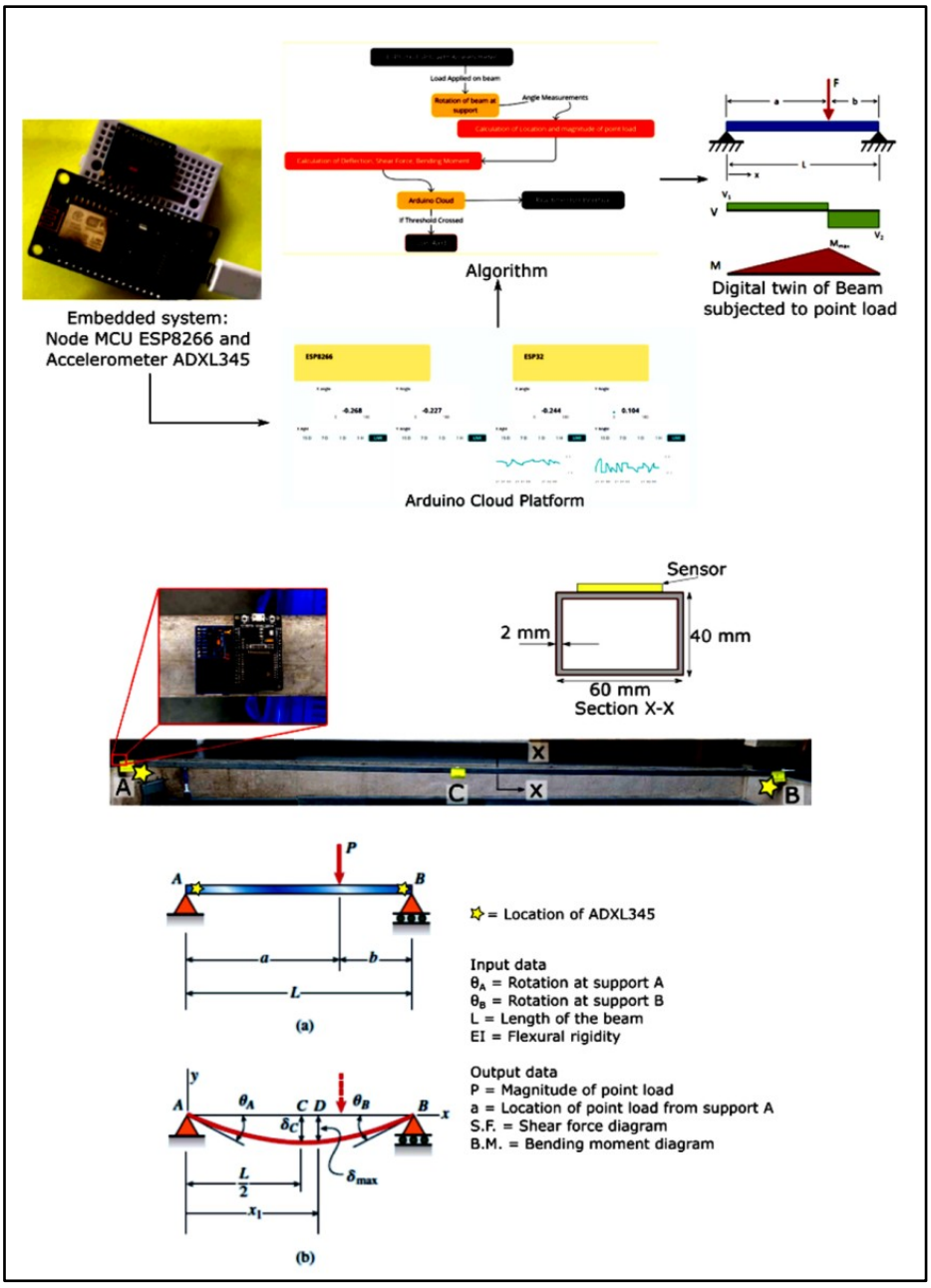


**Figure 1** Indicative sketch showing arrangement of test and location of sensor

**Table 1** Theoretical vs measured values: angular displacement (8)

| Test No. | Loading location from support A (a) | Loading location from support B (b) | Angular displacement at support A ($\theta_A$) | | | Angular displacement at support B ($\theta_B$) | | |
|---|---|---|---|---|---|---|---|---|
| | mm | mm | Degree (°) Theoretical | Degree (°) Measured | Error (%) | Degree (°) Theoretical | Degree (°) Measured | Error (%) |
| 1 | 2485 | 2485 | 3.33 | 3.30 | 0.80 | 3.33 | 3.30 | 0.80 |
| 2 | 2485 | 2485 | 2.52 | 2.50 | 0.97 | 2.52 | 2.50 | 0.97 |
| 3 | 2485 | 2485 | 2.96 | 3.00 | 1.28 | 2.96 | 3.00 | 1.28 |
| 4 | 1000 | 3970 | 2.56 | 2.60 | 1.38 | 1.71 | 1.80 | 5.10 |
| 5 | 1800 | 3170 | 3.36 | 3.40 | 1.30 | 2.79 | 2.70 | 3.27 |

**Table 2** Measured vs calibrated values: magnitude of point load (P) and Location of point load from support A (a)

| Test No. | Magnitude of point load (P) | | | Distance of point load from support 'A' (a) | | |
|---|---|---|---|---|---|---|
| | Calculated from the inclinometer-based system (N) | Calibrated load (N) | Error (%) | calculated from the inclinometer-based system (mm) | Actual distance (mm) | Error (%) |
| 1 | 710.41 | 716.13 | 0.80 | 2485 | 2485 | 0 |
| 2 | 538.19 | 543.47 | 0.97 | 2485 | 2485 | 0 |
| 3 | 645.83 | 637.65 | 1.28 | 2485 | 2485 | 0 |
| 4 | 674.20 | 716.13 | 5.86 | 1000 | 1129 | 12.95 |
| 5 | 744.87 | 716.13 | 4.01 | 1800 | 1629 | 9.47 |

The inclinometer-based system provides accurate results for calculating the distance of the point load from support 'A' in most cases, with no error for tests 1, 2, and 3. However, higher errors are observed in test 4 (12.95%) and test 5 (9.47%), suggesting that at specific distances, the system may have limitations or require further calibration. Overall, the system shows strong potential for structural health monitoring, but further calibration may be needed for certain configurations.

## IMPLICATIONS AND LIMITATIONS

This concept has the potential to be extended to bridge structures, enabling them to become smart and responsive to real-time forces, improving safety and performance. Given its simplicity, the system offers an economical solution for transforming regular structures into responsive ones, minimizing costs while enhancing safety and monitoring capabilities. It enables immediate interventions during critical structural changes, allowing authorities to respond promptly to unsafe conditions. By collecting and analyzing long-term data, the system could predict future issues, offering a proactive approach to structural health monitoring.

The current system is limited to simply supported beams under a single point load. It will need modifications to accommodate more complex loading scenarios like distributed loads or multiple points of force. The system is restricted to flexural members, meaning it needs further modification to monitor structures experiencing torsion, compression, or other types of forces beyond bending. Currently tested only on steel beams, it may not accurately predict behavior for beams of different materials such as reinforced concrete or timber.

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# Non-Linear Comparative Study of Retrofit Schemes for a Real-Life Vertically Misaligned RCC Over Head Reservoir based on Seismic Vulnerability Assessment

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***Abstract***: *Overhead Reservoirs (OHRs) are crucial infrastructures for public health by providing potable water and firefighting resources; thus, must be operational, even after seismic events. However, constructional defects, often due to poor workmanship, can weaken these structures against earthquakes. Nowadays, a common issue is vertical misalignment, leading to increased seismic vulnerability due to developed eccentricity. Hence, proper retrofit of these structures is of common concern. While extensively used Non-Destructive Tests mainly assess concrete quality, these may not fully capture global behavior of such misaligned structures. The present study focuses to assess effectiveness of different retrofit schemes proposed for a real-life OHR over vertically misaligned RCC frame staging; using Non-Linear Push-Over Analysis of the structure, developed in Finite Element (FE) Platform. Vertical misalignment and different retrofit strategies are duly considered in numerical models for seismic vulnerability assessment, as applicable. Results show a significant effect of these retrofit schemes to reduce seismic vulnerability of such vertically misaligned RCC OHRs, as evident from global responses of the structure. This paper seems to have a great scope for seismic evaluation of potential retrofitting strategies, ensuring safety of existing RCC OHRs with similar defects.*

***Keywords***: *Finite Element Platform; Non-Linear Push-Over Analysis; Over Head Reservoir; Seismic Vulnerability; Vertical Misalignment*

## INTRODUCTION

Over Head Reservoirs (OHRs) are important for modern water supply systems, providing a steady flow of potable water to both urban and rural areas [1]. These must be stable enough to withstand environmental and structural challenges to remain functional. Among these challenges, constructional imperfections-such as deviations from design, material deficiencies, and structural misalignment pose significant risks [4] to the structures. These imperfections can reduce the stability and durability, further imparting seismic vulnerability to such OHRs over vertically misaligned RCC frames. Retrofit of such top-heavy inverted pendulum type important infrastructures thus seems to be very much essential for making these sustainable.

The current research compares the global responses of a real-life RCC 150 m3 torch type OHR supported on vertically misaligned RCC-frame staging (**Figures 1(a)** & **1(b)**); before and after different types of proposed retrofit schemes. The current state of the concerned existing OHR is assessed using visual inspection and Non-Destructive Tests (NDTs). Measurements have been taken using a plumb-bob to quantify the vertical misalignment of the RCC frame staging. Two types of retrofit schemes have been proposed; i.e., strengthening by CFRP jacketing at beam column joints, and RCC jacketing of the columns. Previous studies have indicated nonlinear static analysis [1, 11] as an important tool to evaluate the seismic vulnerability [11] of such OHR structures subjected to constructional imperfections [4]. The effectiveness of retrofit schemes can also be assessed using the same [11]. Based on the plumb-bob measurements and NDT results, numerical models are developed in the FE platform of SAP2000. FE models considering the said retrofit schemes have also been analysed; and the structural responses have been compared with that of the responses of the numerical model having constructional defect. Results indicate CFRP jacketing as more effective retrofit strategy to maintain long-term safety and reliability of vertically misaligned OHRs; by reducing seismic vulnerability, without hampering the mass & stiffness distribution.

**Figure 1** (a)-(b) Real-life RCC OHR subjected to constructional imperfection, (c)-(e) visual inspection & non destructive tests

## METHODOLOGY

Various steps for non-linear comparative study of the retrofit schemes and step wise calculation of Seismic Vulnerability Index is presented below (**Figure 2(a)** & **2(b)**).

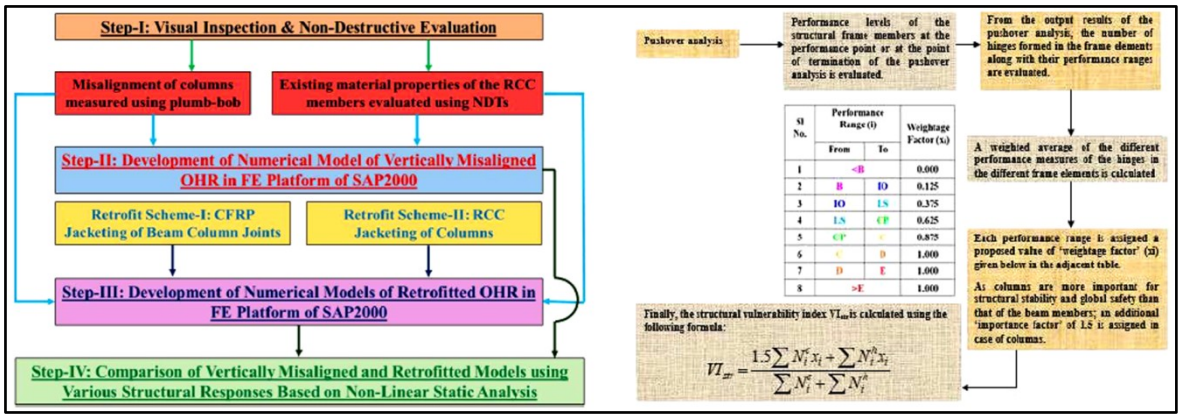


**Figure 2** (a) Step-by-step flowchart for seismic evaluation of the retrofit schemes (b) Calculation of Vulnerability Index [11]

## VISUAL INSPECTION AND NON-DESTRUCTIVE-EVALUATION

Vertical misalignment in columns, misaligned column-bracing joints, necking, bulging and beam-column offsets are observed; and these are measured using a plumb-bob (**Figure 1(c)**). The measurements are given below in **Figure 3**.

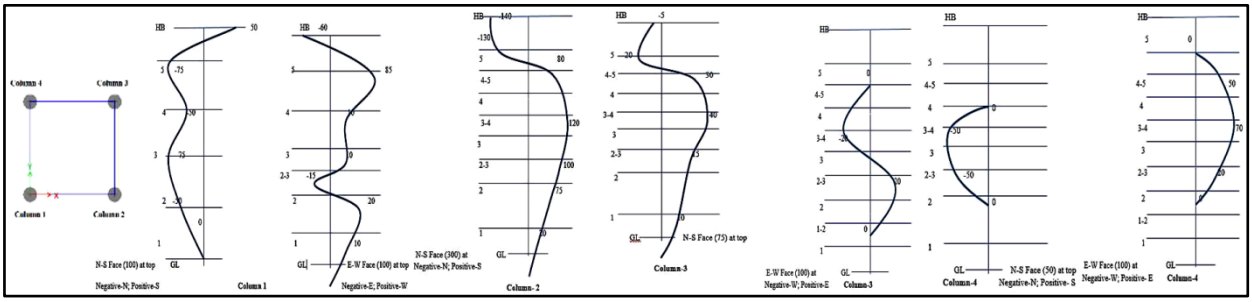

**Figure 3** Measurements of vertical misalignment of different RCC Columns

Schmidt Rebound Hammer and Ultrasonic Pulse Velocity tests were conducted on RCC frame elements to assess existing mechanical properties of the materials (**Figure 1(d)** & **1(e)**). Summary of NDTs is given in **Figure 4**.

| Sl. No | Location of Members | Schmid't Hammer Test Result (*Horizontal Direction*) | | | | |
|---|---|---|---|---|---|---|
| | | Average Hammer Reading | Standard Deviation | Most Probable Least Value at 95% Conf. level | Equivalent Comp. Strength (MPa) | |
| | | | | | Hammer Reading | MPLV |
| **COLUMN** | | | | | | |
| 1 | Ground Level | 30 | 2.65 | 26 | 25.7 | 19.2 |
| 2 | First Level | 33 | 3.86 | 26 | 30.6 | 19.2 |
| 3 | Second Level | 31 | 3.63 | 25 | 27.2 | 17.7 |
| 4 | Third Level | 31 | 3.33 | 26 | 27.2 | 19.2 |
| 5 | Fourth Level | 30 | 2.50 | 26 | 25.7 | 19.2 |
| 6 | Fifth Level | 30 | 2.90 | 25 | 25.7 | 17.7 |
| **Overall at Columns** | | **30** | **3.01** | **26** | **25.7** | **19.2** |
| **BRACING** | | | | | | |
| 7 | Second Level | 33 | 4.56 | 26 | 30.6 | 19.2 |
| 8 | Third Level | 31 | 3.78 | 25 | 27.2 | 17.7 |
| 9 | Fourth Level | 30 | 2.19 | 27 | 25.7 | 20.8 |
| 10 | Fifth Level | 33 | 3.81 | 26 | 30.6 | 19.2 |
| **Overall at Bracings** | | **32** | **3.77** | **26** | **28.9** | **19.2** |

| Sl. No. | Location | Ultrasonic Pulse Velocity Test (Semi-Direct Method*) | | | | |
|---|---|---|---|---|---|---|
| | | Average Value (Km/Sec) | Standard Deviation (Km/Sec) | Range (Km/Sec) | | Remarks on Avg. Quality of Concrete |
| | | | | Max. | Min. | |
| **Column** | | | | | | |
| 1 | Ground Level | 4.24 | 0.37 | 4.53 | 3.30 | Good |
| 2 | First Level | 4.25 | 0.21 | 4.41 | 4.10 | Good |
| 3 | Second Level | 4.03 | 0.07 | 4.08 | 3.99 | Good |
| 4 | Third Level | 3.78 | 0.09 | 3.84 | 3.72 | Marginally Good |
| 5 | Fourth Level | 3.76 | 0.08 | 3.82 | 3.71 | |
| 6 | Fifth Level | 3.79 | 0.09 | 3.86 | 3.72 | |
| **Overall at Column** | | **4.07** | **0.34** | **4.53** | **3.30** | **Good** |
| **Bracing** | | | | | | |
| 7 | Second Level | 3.52 | - | - | - | **Doubtful** |
| 8 | Third Level | 3.96 | 0.18 | 4.12 | 3.76 | Good |
| 9 | Fourth Level | 3.96 | - | - | - | Good |
| 10 | Fifth Level | 3.23 | - | - | - | **Doubtful** |
| **Overall at Bracing** | | 3.77 | **0.34** | **4.12** | **3.23** | **Marginally Good** |

**Figure 4** (a) Summary of Schmid't Hammer Test, (b) Summary of Ultrasonic Pulse Velocity Test

## NUMERICAL MODELLING

The existing OHR over vertically misaligned RCC framed staging of 20 m height is modelled using RCC frame and thin shell elements, as per site condition. Bracing beam, heel beam and ring beam are of size 450 mm × 700 mm, 600 mm × 700 mm and 275 mm × 275 mm respectively. Circular RCC columns are of 600 mm diameter. Top dome, bottom dome and conical shell have shell thickness of 125 mm, 150 mm and avg. 175 mm respectively. Mechanical properties of concrete are taken as per NDT results (**Figure 4(a)** & **4(b)**), and grade of reinforcement is Fe-500D. Loads and combinations are used as per relevant BIS codes [9]. Detailed numerical modelling is given in [4].

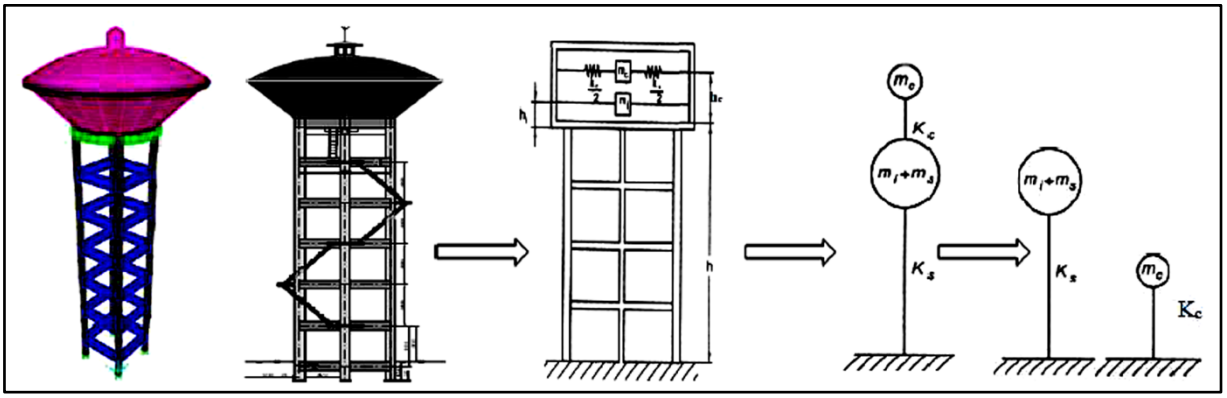


**Figure 5** Numerical Model, Elevation view and 2-Mass Idealization [9] of 150 m3 RCC OHR with vertical misalignment

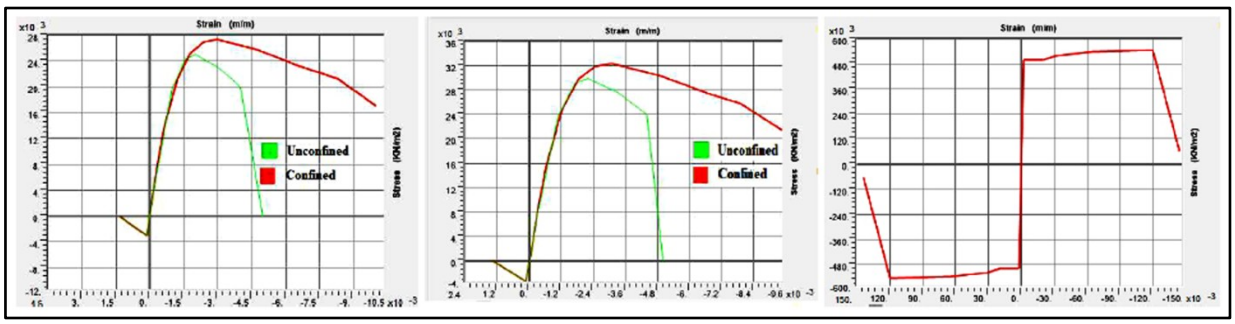


**Figure 6** Stress-Strain Curves [10] of (a) M25 Grade Concrete, (b) M30 Grade Concrete, and (c) Fe500-D Grade Reinforcement

## PROPOSED RETROFIT SCHEMES

Numerical models have revealed that vertical misalignment significantly increased column reinforcement demands [4]. Two retrofit schemes are thus proposed for comparison. Firstly, CFRP jacketing (**Figure 8(b)**) using high-strength carbon fiber sheets and specialized encapsulating resins for beam-column joints from 1st to 5th bracing levels, offering lightweight and superior shear and flexural performance. Secondly, RCC jacketing (**Figure 8(c)**) of columns with flow-able, low-shrink micro-concrete to enhance strength and durability. Mechanical properties of CFRP sheets and micro-concrete are given here.

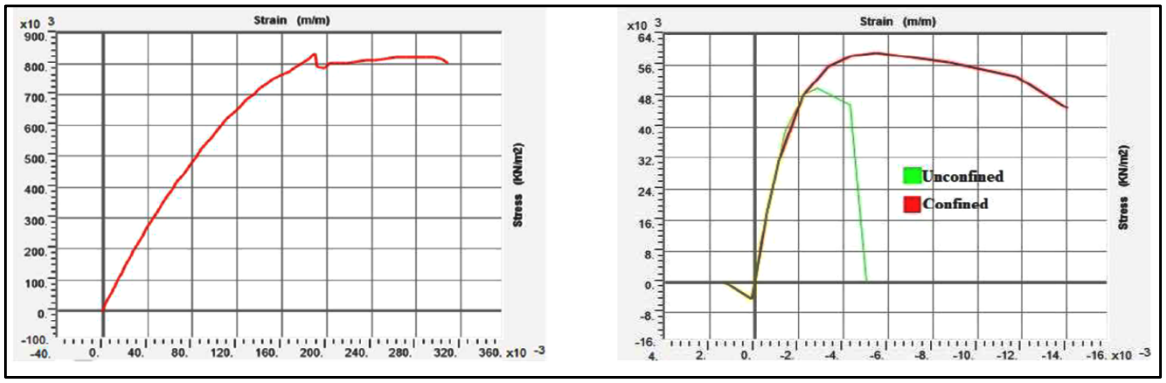


**Figure 7** Stress-Strain Curve of (a) CFRP Fabric [5] and (b) Flow-able-low-shrink Micro-Concrete

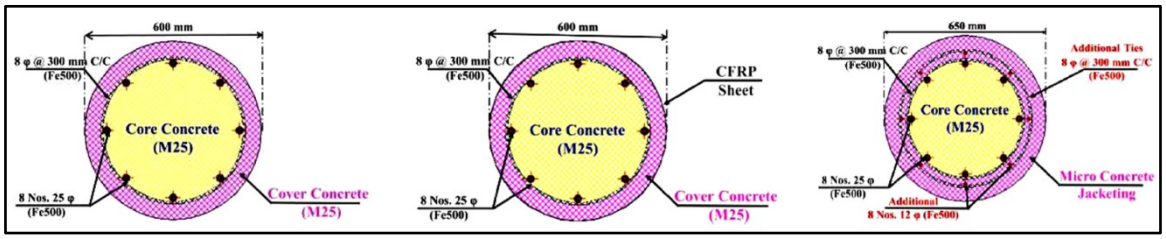


**Figure 8** (a) Existing RCC Column Section, (b) CFRP Jacketed Column, and (c) RCC Jacketed Column

## SEISMIC VULNERABILITY ASSESSMENT USING NON-LINEAR PUSHOVER ANALYSIS

Pushover analysis, a performance-based method, applies incremental lateral loads to assess seismic resilience, revealing weak points, failure modes, and post-yield force redistribution; key for collapse prevention. Various standards define different performance levels [2, 3, 6-8] to ensure safety against varying earthquake intensities (DBE & MCE). Nonlinear Static Pushover Analysis (NLPOA) evaluates global stiffness, global ductility, and damage states to meet life safety (LS) and collapse prevention (CP) standards. Seismic Vulnerability Index (SVI) [11] estimates structural vulnerability to earthquake using NLPOA; using plastic hinge performance under varying intensities, helping to plan retrofit strategies for such OHRs with constructional defects.

## RESULTS AND DISCUSSIONS

Vertical misalignment reduces base shear capacity, inelastic crown top displacement, and global ductility of OHR models, indicating deteriorated structural performance. Performance of the aforesaid retrofit schemes are evaluated by comparing these parameters for the retrofitted models w.r.t. the vertically misaligned models. Both retrofits have increased the base shear capacities compared to the misaligned case, with RCC jacketing providing a higher capacity due to its greater strength and stiffness. Inelastic crown top displacement has been improved for both the methods, though CFRP jacketing resulted in higher inelastic displacement than RCC jacketing. Global ductility has increased for both the retrofitted models, more significantly with CFRP jacketing. The seismic vulnerability index has increased for numerical models with vertical misalignment due to formation of more critical column hinges, but retrofitting reduces this vulnerability, especially the CFRP jacketing. The Fundamental Natural Period of Vibration is another

crucial parameter to indirectly assess the global stiffness and structural stability of OHRs over RCC frames. Additionally, vertical misalignment decreases Fundamental Natural Period of Vibration, indicating reduced global stiffness. RCC jacketing has effectively increased structural stiffness of lateral load-resisting frame more than that of the CFRP jacketing, as evident from the Fundamental Natural Period of Vibrations of the numerical models. Overall, RCC jacketing offers superior enhancements in base shear capacity and global stiffness, while CFRP jacketing provides greater improvements in global ductility and reduces the seismic vulnerability more effectively.

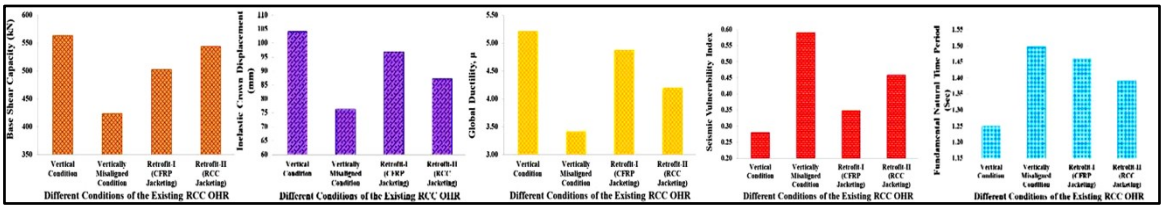


**Figure 9** Variation of (a) Base Shear Capacity, (b) Inelastic Crown Displacement, (c) Global Ductility, (d) Seismic Vulnerability Index, and (e) Fundamental Natural Time Period w.r.t. Different Conditions of RCC OHR

## CONCLUSIONS

The present paper studied the effect of vertical misalignment of RCC OHR structure with respect to its seismic vulnerability based on non-linear numerical analysis. Subsequently, comparative study of two proposed retrofit schemes have also been performed. Following conclusions can be drawn based on the presented results. Vertical misalignment reduces base shear capacity, inelastic crown displacement, global ductility; indicating about global stiffness degradation and increased seismic vulnerability. Both the retrofit schemes improve base shear capacity, increases inelastic crown displacement and global ductility; and also lowers down the vulnerability index. RCC jacketing imparts more strength and stiffness than CFRP jacketing, as evident from base shear capacities. CFRP jacketing enhances inelastic crown displacement and global ductility more effectively than RCC jacketing. CFRP jacketing results in greater reduction of seismic vulnerability caused by vertical misalignment. RCC jacketing improves global stiffness more effectively, as indicated by the Fundamental Period of Vibration. Overall performance indicates CFRP jacketing as the better choice; as it improves ductility and reduces seismic vulnerability, while RCC jacketing enhances global stiffness, but increases structural mass and seismic demand. Thus, this study seems to be crucial for selection of proper retrofit scheme for such real-life misaligned OHRs.

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# Experimental Study of RCC T-Girder under Fatigue Loading Adopting Ambient Vibration Technique

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***Abstract***: *The current study emphasizes the importance of Structural Health Monitoring (SHM) for bridges using Ambient Vibration Techniques, particularly in RCC girder-type bridges. This method is advantageous as it operates without disrupting traffic or requiring artificial excitation forces. The research focuses on a laboratory model RCC T-girder subjected to cyclic loading to simulate real-life fatigue from traffic. Using Operational Modal Analysis (OMA), the study analyses dynamic responses, extracting modal parameters at each stage of loading through seismic accelerometers and a multi-channel data acquisition system. The results show that fluctuations in the modal vectors increase with repeated loading cycles, indicating internal damage. These fluctuations align symmetrically with numerical models and are consistent with experimental data for the first five modes. This suggests that changes in modal vectors can serve as a reliable indicator of internal damage caused by repetitive loading. The findings highlight the potential of OMA with ambient vibration data for practical SHM of bridges, though further experimental studies on real-life structures are needed to confirm and refine its application.*

***Keywords***: *Ambient Vibration Technique; Cyclic Loading; Operational Modal Analysis; RCC Girder Bridges; Structural Health Monitoring.*

## INTRODUCTION

Bridges are one of the most important parts of transportation infrastructure. In a developing country like India, nearly one in every four bridges are over a century old. Furthermore, around 2130 bridges (excluding culverts and pedestrian bridges) failed to service or collapsed during various stages of construction in the last four decades (from 1977 to 2017) [3]. Bridges in India have an average lifespan of 34.5 years, which is extremely short when compared to the intended design life [3]. In recent past, it is observed that there are growing incidents of premature distress; even catastrophic failure of bridges (**Figure 1**). Failure of RCC bridges is often associated with the failure of RCC girders subjected to repetitive wheel loads, leading to fatigue of the structural members.

**Figure 1** (a)-(b) Catastrophic failure of bridges, (c)-(d) Distress in bridge deck slab and bearings [4]

Structural Health Monitoring (SHM) is crucial for improving structural performance, durability, and timely damage repair of various infrastructures. Civil engineering structures equipped with SHM demonstrate superior lifespan,

safety, and reliability compared to those without it. In bridge structures, dynamic responses are governed by mass stiffness, and damping; where stiffness deteriorates over time due to wear, damage, or localized failures. This affects the structural response to dynamic forces, as stiffness directly influences dynamic behavior.

Among various dynamic analysis methods, the ambient vibration method stands out as it uses vibrations from moving traffic and does not disrupt bridge operations. Advanced response-measuring devices [5] now enable precise detection of these changes [1, 2]. The current paper highlights those changes in a model bridge girder's dynamic response,

caused by ambient forces, to identify stiffness reduction and subsequent presence of damage. The present research focuses on the response of an RCC T-Girder under repetitive cyclic loading in a laboratory setting. It employs Operational Modal Analysis (OMA) to extract modal properties; and variations of modal frequency and mode shapes are assessed to check the presence of damage. By comparing these properties, the study demonstrates how ambient vibration methods can effectively monitor and analyze structural health in bridges, emphasizing their practicality in real-world scenarios.

## METHODOLOGY AND EXPERIMENTAL STUDY

The experiment is conducted in two stages. In the first stage (**Figures 2(a)** & **2(b)**), cyclic loading is applied to the T-beam using hydraulic press (HEICO make) after it is securely positioned on the loading platform using a chain pulley system. In the second stage, the T-beam is tested using an accelerometer (Brüel & Kjær make) setup to determine its mode shapes and frequencies using OMA (Brüel & Kjær). Various steps are shown below (**Figure 2** & **Figure 3**).

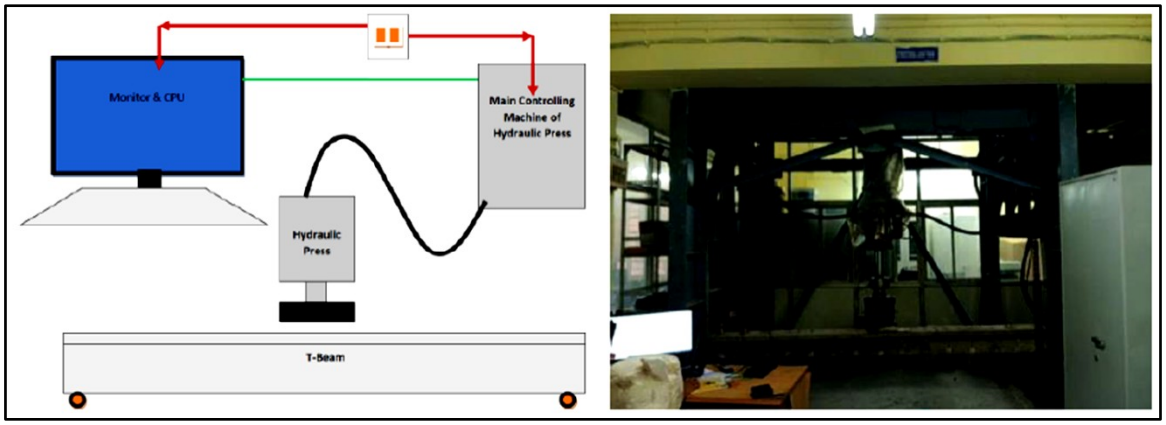



**Figure 2** (a) Schematic diagram, and (b) photograph of experimental set-up for applying cyclic load on T-beam

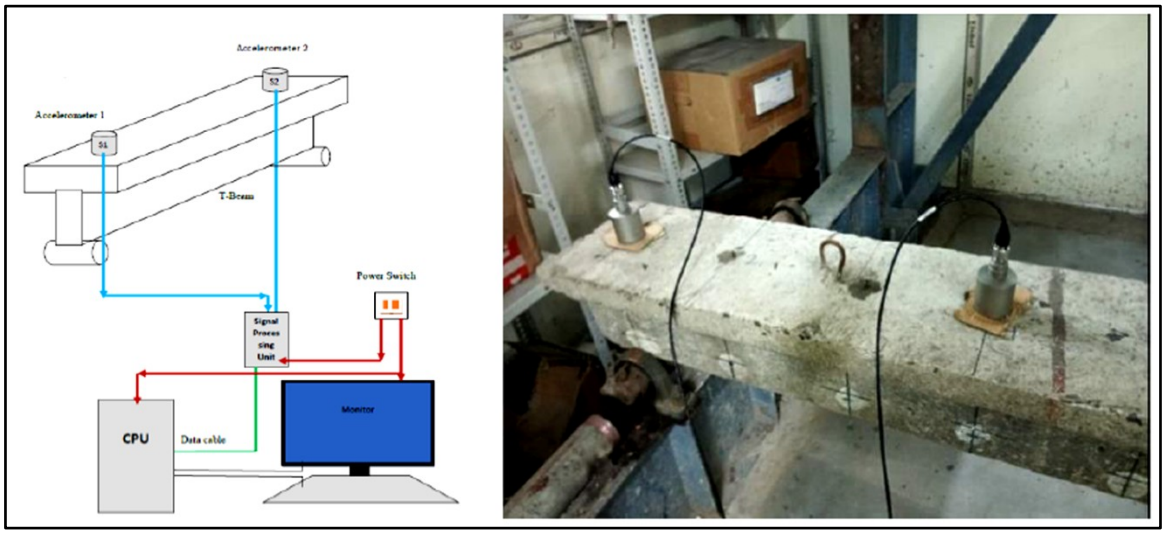
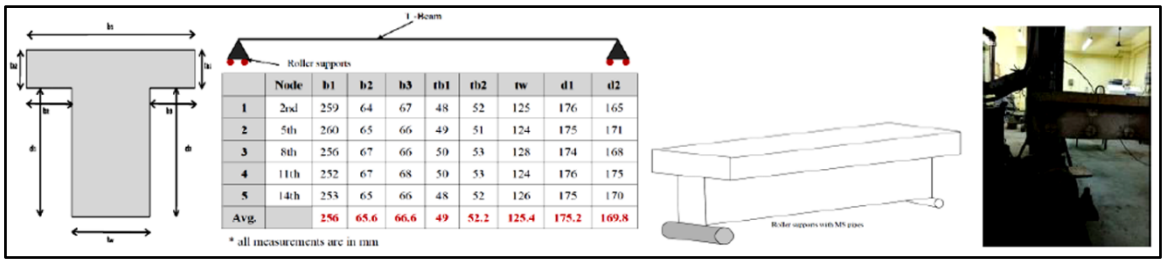



**Figure 3** (a) Schematic diagram, and (b) photograph of experimental set-up for OMA using accelerometers

The RCC T-beam is made up of M25 grade of concrete and Fe500 grade of steel; resting over two MS pipes, resembling roller supports at both the ends. The beam is of 3000 mm length between the supports and 100 mm as overhangs at both sides. The span is divided into 15 nos. of equidistant points to place the accelerometers for testing. All the details of the RCC T-Beam specimen are presented in **Figure 4(a)** & **4(b)**.




| | Node | b1 | b2 | b3 | tb1 | tb2 | tw | d1 | d2 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2nd | 259 | 64 | 67 | 48 | 52 | 125 | 176 | 165 |
| 2 | 5th | 260 | 65 | 66 | 49 | 51 | 124 | 175 | 171 |
| 3 | 8th | 256 | 67 | 66 | 50 | 53 | 128 | 174 | 168 |
| 4 | 11th | 252 | 67 | 68 | 50 | 53 | 124 | 176 | 175 |
| 5 | 14th | 253 | 65 | 66 | 48 | 52 | 126 | 175 | 170 |
| Avg. | | 256 | 65.6 | 66.6 | 49 | 52.2 | 125.4 | 175.2 | 169.8 |

**Figure 4** (a) RCC T-Beam Cross-Section with Measurements, and (b) Schematic Diagram & Photograph of Roller Supports

## EXTRACTION AND INTERPRETATION OF MODAL PARAMETERS

Extraction and interpretation of experimental data is very much important for a successful experimental study. The main steps for this study are as follows: i) Generation of Acceleration Time History Data, ii) Enhanced Frequency Domain Decomposition (EFDD) in OMA Software, and iii) Modal Parameters Extraction. Afterwards, the modal characteristics are compared for undamaged and various damage states.

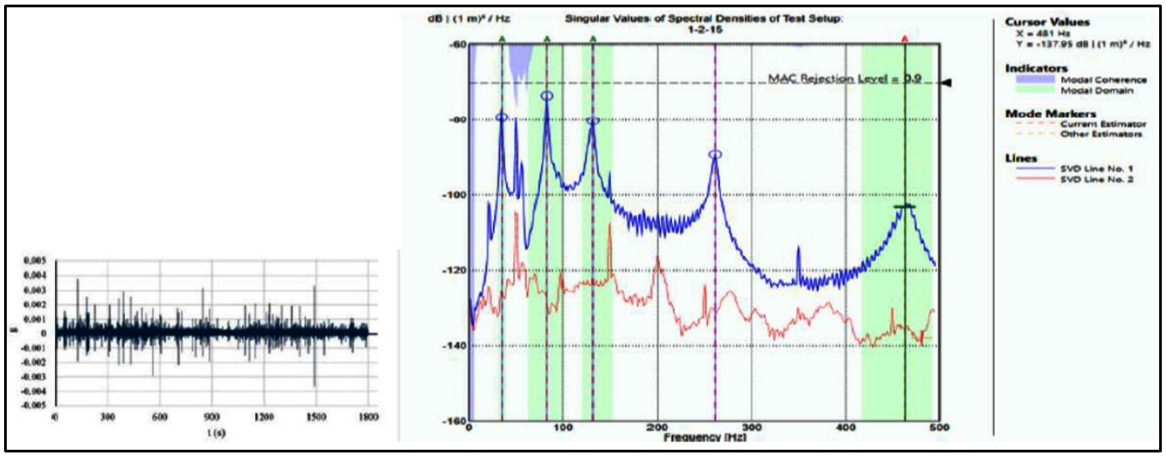



**Figure 5** (a) Generation of Typical Acceleration Time History Data, and (b) Frequency Extraction using OMA Software

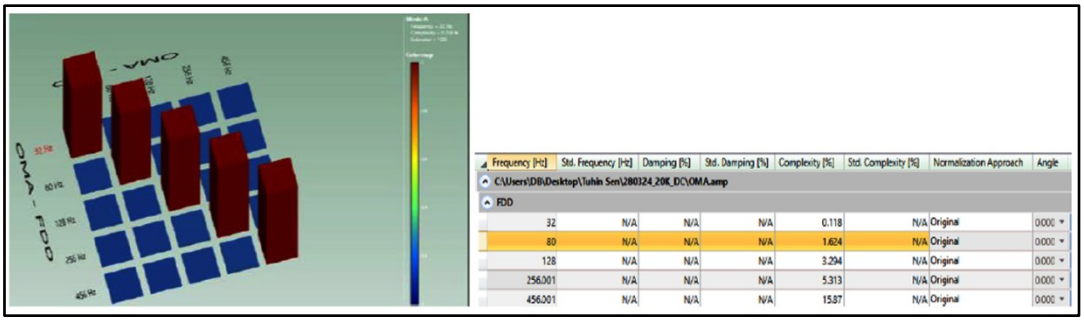



**Figure 6** (a) Checking for Modal Assurance Criterion, and (b) Typical table of extracted Modal parameters using OMA Software

## RESULTS AND DISCUSSIONS

The analysis of frequency changes across different mode shapes reveals the progression of damage and stiffness reduction in the RCC beam under cyclic loading. Initially, the first mode shape shows a frequency of 35 Hz in an undamaged state, dropping to 32 Hz after 20K load cycles, indicating initial damage. Beyond 100.5K cycles, visible

cracks appear, but the frequency remains stable until 117.5K cycles; further it drops to 28 Hz, signifying significant loss of stiffness. The second mode shape starts at 132 Hz and decreases to 120 Hz after early load cycles, reflecting initial damage. Frequencies then fluctuate slightly due to increased rigidity caused by surface abrasion and changes in support conditions, dropping significantly to 108 Hz at 117.5K cycles, indicating stiffness and strength reduction. Similarly, the third mode shape frequency drops from 261 Hz to 236 Hz initially, reflecting early damage, then increases slightly before dropping to 240 Hz after 117.5K cycles, aligning with stiffness changes.

The fourth mode shape shows a similar trend, with an initial frequency of 463 Hz dropping to 424 Hz due to early damage and fluctuating until a permanent drop to 428 Hz after cracks appear. Lastly, the fifth mode shape also follows this pattern, starting at 711 Hz and dropping to 660 Hz early on. It stabilizes briefly before a significant decrease to 652 Hz after 100.5K cycles, highlighting a loss of flexural strength. These findings confirm the progressive nature of stiffness reduction and damage accumulation, with each mode shape offering insights into structural changes under repetitive loading.

The analysis of mode shape curves under cyclic loading highlights general consistency across modes but identifies certain deviations likely due to experimental errors. In the first mode shape, all curves follow the expected pattern except for the 80K load cycle, where a notable drop occurs at the 7th node point, potentially due to accelerometer reading errors. The first and last nodes also show non-zero amplitudes, suggesting free vibration instead of ideal simply supported conditions; which is in tune with the laboratory testing scenario. For the second mode shape, most curves superimpose well, crossing the x-axis twice, except for minor deviations at nodes 10 and 14 under 0K and 60K load cycles, again attributed to accelerometer inaccuracies.

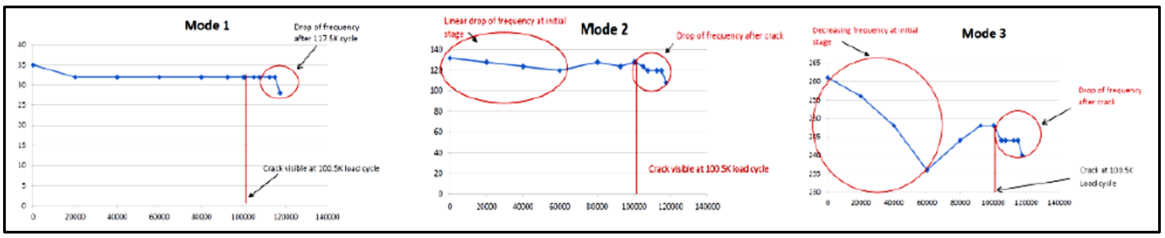



**Figure 7** Frequency (Hz) vs. load cycle for (a) 1st mode, (b) 2nd mode, and (c) 3rd mode of vibration

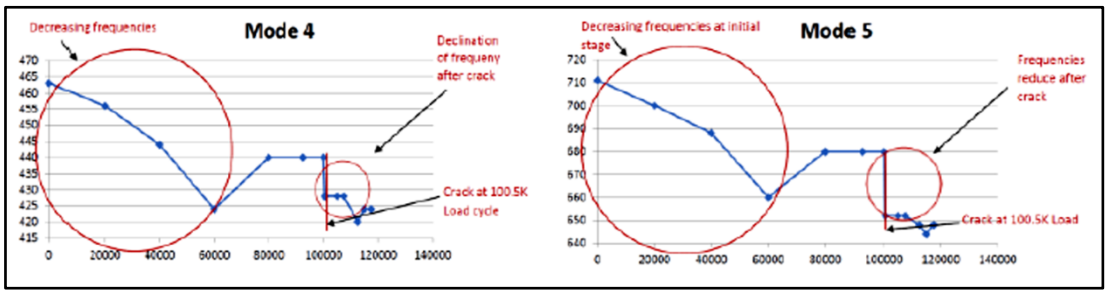



**Figure 8** Frequency (Hz) vs. load cycle for (a) 4th mode, and (b) 5th mode of vibration

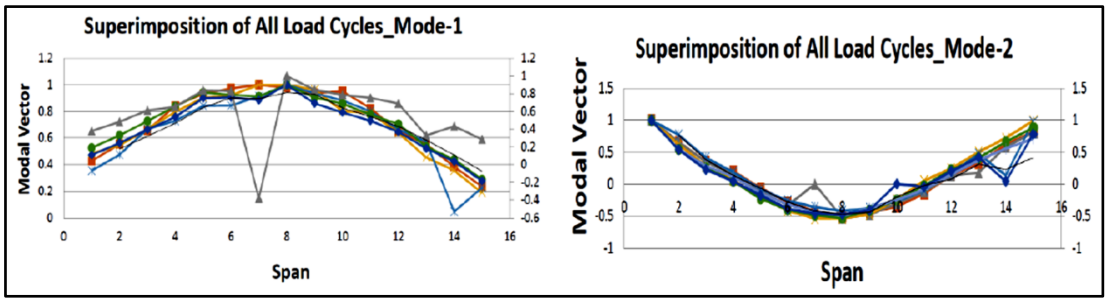



**Figure 9** Different Mode Shapes (1st and 2nd) of the RCC T-Beam for undamaged and various damaged cases

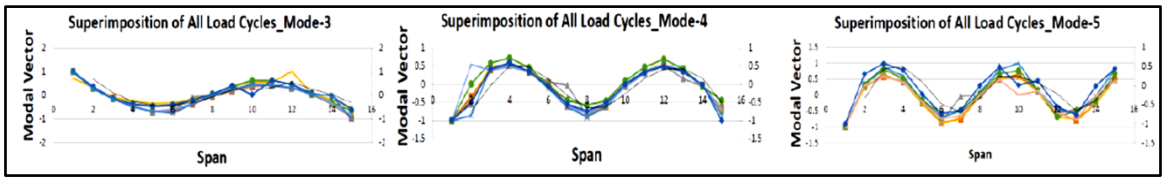



**Figure 10** Different Mode Shapes (3rd, 4th, and 5th) of the RCC T-Beam for undamaged and various damaged cases

The third mode shape exhibits similar issues, with deviations at nodes 10 and 14 for 0K and 80K cycles, although overall adherence to the standard pattern, crossing the x-axis three times, is maintained. The fourth mode shape curves generally align well, crossing the x-axis four times, with minor inconsistencies observed at the first three nodes under 60K, 100.5K, and 107.5K cycles. These differences may arise from slight experimental errors. The fifth mode shape shows the greatest variability, with more pronounced deviations from the standard pattern. Although the curves cross the x-axis five times as expected, they display moderate alignment, requiring normalization and scaling for further analysis. Across all mode shapes, errors are attributed to the beam vibrating more freely than anticipated due to support conditions shifting from simply supported to partially hinged, likely caused by surface erosion at the beam's soffit during repeated loading. These findings underscore the need for careful calibration and normalization of experimental data for accurate modal analysis. Despite these limitations, the mode shape curves provide valuable insights into the beam's dynamic behavior under cyclic loading.

## CONCLUSIONS

The present experimental study demonstrates possibility of extracting modal parameters adopting Ambient Vibration Technique. The possible progressive damage with stiffness reduction of the RCC T-beam may occur due to increasing load cycles, which is attempted to identify with the changes in frequency and mode shapes. Initial frequency drops across all modes signify damage, while significant reductions after 100.5K to 117.5K load cycles due to visible crack. Deviations in mode shape curves, attributed to experimental uncertainties and due to change in support conditions resulted from surface erosion at supports. Despite these limitations, the mode shape curves effectively reveal the beam's dynamic behavior which are in tune with the expectations confirming the potential of Operational Modal Analysis for SHM in real life bridge under fatigue loading.

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# Infrastructure

## Planning and Design of Infrastructural Systems

51_IEC65812

# Addressing Systemic Challenges in the Construction Industry: Pathways to Sustainable Improvement

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***Abstract:*** *Successful completion of various projects and schemes constitutes one of the most significant conditions for development. Effective coordination judiciously matched with regular monitoring thus becomes an important element in ensuring their successful completion with improved efficiency at greater speed and at reduced cost. However, seldom infrastructure projects are completed within the originally planned timelines or costs. Projects continue to be plagued with delays and cost overruns for several issues. The present paper intends to highlight the various challenges faced by infrastructure projects in India through a case study approach. The paper aims at the reforms required in the prevailing system/ areas, right from concept to commission for any infrastructure project by citing those areas that are affecting the project execution in time and cost. The paper aims to highlight the areas that need attention and measures that can be taken up by the project stakeholders that shall ensure the improvement in the efficiencies of project execution and the construction industry.*

***Keywords:*** *Infrastructure; India; Challenges; Delays; Sustainability; Development*

## INTRODUCTION

The word “Infrastructure” first appeared in the 1880s, derived from the French with “INFRA” meaning “BELOW”, and “STRUCTURE” meaning BUILDING. Thus, it means Infrastructure is the foundation upon which the structure of the economy is built. Infrastructure is the basic requirement serving a country/region/ community that covers Housing, Mass transit, Road connectivity for fast transport, connectivity to ports, airports, mines, logistics with warehouses for storage of not only manufactured goods but also agricultural produce to protect from damages in rains, medical and pharma industry, educational institutions, power projects, telecommunication networks & IT coverage across the country etc.

The Indian economy in the recent past has been in the limelight, as one of the fastest-growing economies in the world. Presently, the fifth largest economy, it is expected that the Indian economy will soon surpass Japan and Germany to be recognized as the third largest economy next only to USA and China. Towards this, India has made a document on Vision for Viksit Bharat @2047 and it was discussed in NITI Aayog, 9th Governing Council held on 27th July 2024. The one main point of this vision is to build the economy from the present 3.4 trillion USD to 30 trillion USD by 2047. The per capita income is planned to be raised from 2392 USD to 18220 USD by 2047 [1]. In addition, it is reported that the urbanization in India which is presently around 37% with 450 Million people is expected to double over the next 15 years [2]. The cities of India need an anticipated capital investment of USD 840 billion in urban infrastructure and municipal services over the fifteen years from now till 2036 (in 2020 prices), equivalent to 1.18% of expected GDP over this time [3]. All of this requires building and adding Infrastructure, that too at enormous speeds and it necessitates the servicing of this need with the building of mega infrastructure projects within the targets.

However, this rapid delivery is far from reality. Infrastructure projects in India are plagued with delays, cost overruns, disputes and numerous challenges [4,5]. The statistics of project delays and cost overruns in India as reported by the Ministry of Statistics and Programme Implementation (MOSPI) over the last two decades are presented in **Figure 1**.

As can be seen from **Figure 1**, out of a total of 1831 projects (project size greater than 1.5 Billion INR), a staggering 831 projects (46%) are delayed with respect to the original contract duration. The delayed completion of these projects naturally amounts to an escalation in the cost of the projects and it is reported that 5710.8 Billion INR. This is huge from the perspective of the infrastructure funding challenges and amounts to nothing less than a criminal

waste of taxpayer's money. The report also highlights the generic reasons for this deplorable and miserable state of project implementation viz., land acquisition, environmental clearances, financial issues, contractual/internal issues, manpower shortage and litigation issues. Given the need for rapid infrastructure developments highlighted earlier, this performance requires deeper introspection and immediate corrective measures. The present paper intends to unearth the implementation challenges and possible solutions to cut down / mitigate the delays, and cost overruns and thereby an improvement in the performance of the projects. It has been reported that A recent statement as reported in the article [8] highlighted that The front-end and concept development stage has to improve. The extent of time and effort invested in the initial phases of design or DPR is substantially lower in India in comparison to the worldwide averages, and this leads to inadequate definition of the projects, eventually leading to delays and cost overruns. One of the main reasons for the award of projects is on account of political compulsions such as approaching elections which results in overlooking the right assessment in completing the survey and investigation, acquiring the lands, getting encumbrance-free forest, tribal lands with paying the compensation to landowners etc. This results in an Ineffective Detailed Project Report (DPR) and thereby tender documents. The estimated construction schedule containing lapses gives a shady picture of the project concept, for completion. In the end, nobody is held responsible for delays which contribute to huge losses to the exchequer and loss in estimated revenues from the project apart from claims made by the agencies for reasons not attributable to them.

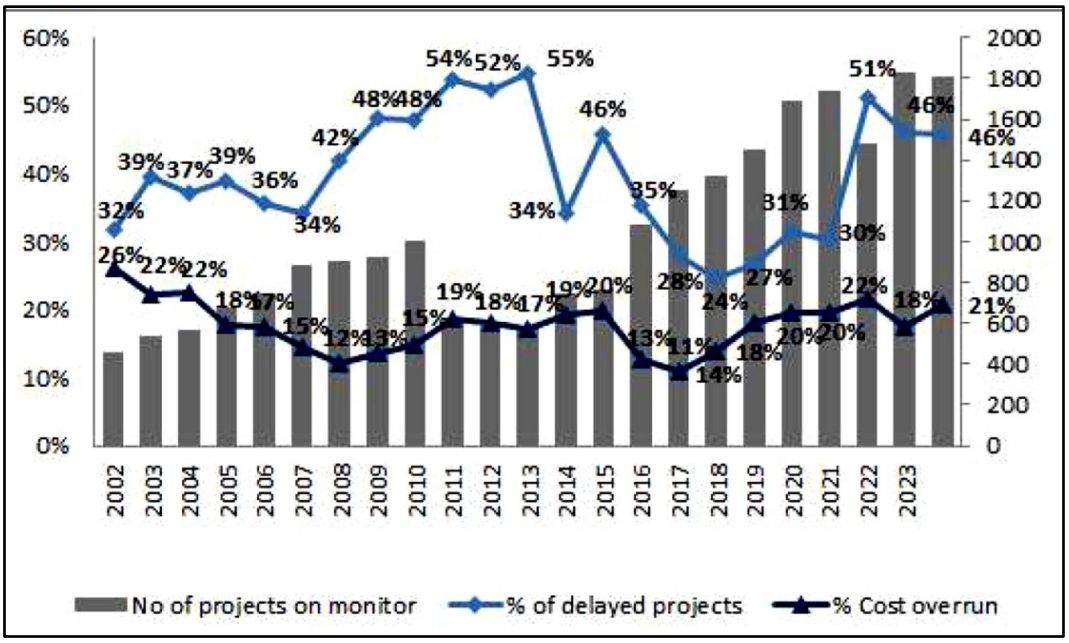


**Figure 1** Extent of delays and cost overruns in India's projects [6,7]

## METHODOLOGY

To fulfil the objectives of the present study, a mixed method has been adopted. To explain the systemic challenges in the construction and infrastructure projects, a case study approach is adopted. The case study approach has been widely regarded as one of the most preferred research methods as it enables a deeper investigation of the problem, providing sufficient opportunity to understand the root cause for a given problem and therefore identify the right solution to the problem. Secondly, to recommend solutions to address these challenges, the authors have chosen the learnings from projects executed (the first author has an experience of more than five decades in the execution and delivery of construction projects), and a literature review on the latest technology, methods and practices, which are revolutionalizing the project implementation.

## CASE STUDIES

The present section of the paper details the various issues and challenges faced in construction projects with the help of several case studies on different types of projects.

**Case I**: **A Case Study of the First EPC Project, Awarded in the State of Andhra Pradesh**

Case Project 1 is a project involving major lift and transport of water to a distance of 137 km from Godavari River at El 70 to EL 338 through intermediate four pump houses (Stage Pumping) and historical tanks by embedded 1.5 m steel pipeline for which land acquisition is inevitable not only through villages but also agriculture fields, forest and tribal land. The EPC contract was awarded to be completed in 18 months but took 50 months for the following reasons.

- The contract has no provision for Arbitration and provides 5% escalation only no matter whatever be the price of material is beyond 5%. Only up to Rs 50,000 claims will be settled by Project engineers. Beyond this, the contractor had to go to court.
- Delay in acquiring the forest, and tribal land was the main cause and delay in resolving disputes and paying compensation to landlords.
- Delays in resolving the dispute for compensating the exorbitant price rise of steel Rs. 18000/MT which went up to Rs 32000/MT.
- Consequent delays in the survey of land and submission of designs and approval. Delays in getting the approval for designs submitted due to inadequate staff in the Central design organization of the Government. (Client)
- Naxals threat at Intake structure
- Delay in releasing the bill payments as the client was awarded about Rs 1.40 lakh crs. projects across the state with fund arrangements not in place.
- The delays on account of the above reasons were overlooked by the client and made the tender/ contract for 18 months with harsh terms on the cost incurred to not compensated.

**Case II: A Case Study of Hydro Electric Project with Tunnels /Caverns**

The client had proposed an entire fleet of imported equipment under an Inter-Government agreement from India to Canada against a loan with a condition that the contractor has to utilize this equipment on hire charges. The contractor agencies with local Engineers & crew were new to the technology and equipment operation and maintenance.

- About one year was lost in learning and training the crew for reasonably expected productivity as the crew was inducted.
- The Tender document specified the different rock classifications with corresponding rock support treatment, but the extent of different rock classes encountered surprises assumed that misfired the construction schedule.
- In caverns and deep shafts, despite the methodology followed as per the Engineers recommendation, even after completion of rock treatment with long rock bolts/wire mesh/shotcrete in the crown and after lowering the bench for quite a depth, rock movement was observed in the crown resulting cracks. It called for rework with tailor-made methodology by imported rock bolts of 50 mm dia. and 5/6-m length with quick setting grout after insertion.
- On the side walls of the cavern 32 mm diameter. 12-to-18-m rock bolts were employed. client/contractor, which was not foreseen.

- A lack of qualified and expert geologists either from the client or contractor in each front to assess the rock class encountered in every blast or advancement and thereby apply corresponding support treatment tunnel treatment was experienced which was the main reason for delays on account of rework, particularly in water table zones.

**Case III: A Case Study of India's Landmark Sea Link Project**

The case project is one of Mumbai's most prominent infrastructural projects. It is more than 5.6 km long and has a 4-lane double carriageway with diamond-shaped pylon towers in the centre. On one side, you can see the Worli settlement, and on the other, the wide Arabian Sea. It is regarded as a lifeline by Mumbai residents because of the speed with which it connects Bandra and Worli. The project was originally planned to be completed in 30 months, eventually completed in 114 months (a time overrun by 380%). The major causes of the delay on this project were –

- Frequent disruption due to PILs filed, and protests by environmentalists, fishermen and residents.
- Delay on account of residents' demand not to connect the bridge to the sea face.
- Delay in handing over of jetty and land for casting yard by client and other agencies
- Change in the alignment of the entire bridge due to fishermen's demands
- Revision in the design of the cable-stayed bridge
- Shift of bridge alignment towards the sea in the Worli zone
- Additional variations to the scope of work & delays in the resolution of issues related to variations such as the introduction of the additional span of 150 m of Worli Cable-stayed bridge to accommodate passage of fishermen's boats
- Delay in appointment of engineer to the contract and change of project management consultant during the project
- Delay in payments at various stages
- EOT claims submitted was settled after a lengthy process that took seven years after completion. How an agency toiled to complete the project against all odds by investing, pending settlement can sustain?

**REFORMS REQUIRED**

It calls for reforms in our process and systems from project inception to commission that involves the following steps.

**A. Procedures**

- Investigation – survey of the location and alignment including geological survey wherever required of the strata for the tunnels and roads/Bridges, Hydro projects etc. areas encountered with forests, villages, tribal areas, roads, River /Rail crossings, Tanks, and Historical structures.
- Preparation of Detailed Project Reports by competent agencies based on Investigation documents and identifying the availability of resources at economical lead for a realistic estimate.
- Preparation of Tender / Contract documents with all specifications; schedule for construction including mobilization of resources and the acquisition of encumbrance-free land and accesses with clearances from forest, tribals, mining and so on.
- The PQ evaluation has to be done carefully thoroughly accounting for the successful accomplishment of earlier projects and not based on a non-executing / name lending partner.

- Obligations for the client, project monitoring & certifying Agency (Independent Engineer) and contractor are required to be specified with clarity.

- Construction Engineering & Methodology document - It defines the methodology of execution equipment & resources deployed with productivity and time cycle that varies with rock classification along with mix design etc. This document needs thorough review before approval.

**B. Improvement in Practices**

- Adoption of the latest state-of-the-art technologies. Technologies such as BIM, and AR-VR have proven to yield significant benefits to construction projects in the planning stage of the project [9]
- Organizations practising the lean philosophy in construction have been able to harness substantial benefits in project timelines, costs, reduction of defects & rework [10,11]
- Improved means of technology-enabled contract management such as Smart Contracts help provide proactive triggers to contractual parties and minimize project disputes.

## CONCLUSION

The three case studies presented in brief throw light on the problems to address the hidden points or areas overlooked before awarding work with logical reasonable assessment by effective investigation and covering all aspects for timely completion of the project and saving the cost incurred for an extended period and loss of revenue. The paper has also presented practical recommendations to address the challenges faced in projects and how these could be systematically addressed. The authors believe that these recommendations if considered appropriately during the lifecycle of the project from conceptualisation to close out shall yield the optimal results and improve the speed, and agility of the industry.

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60_IEC22309

# Design of Transfer Beam for Torsion & it's Analysis in Different Seismic Zones

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***Abstract:*** *This research explores the design and analysis of transfer beams subjected to torsional forces across various seismic zones, adhering to the guidelines established by IS 1893:2016. The study's main aim is to ensure that transfer beams, essential for load redistribution in high-rise structures, can effectively withstand the combined effects of torsion and seismic activity. The research focuses on developing robust design methodologies in compliance with Indian standards, particularly IS 456:2000 and IS 13920:2016. The methodology employed in the study involves the use of structural analysis tools such as STAAD. Pro to simulate the behavior of transfer beams under different seismic conditions. The analysis concentrates on critical aspects like torsional stresses, shear forces, and bending moments, with an emphasis on optimizing reinforcement strategies. By evaluating the performance of beams across various seismic zones, the research identifies key design parameters that are crucial for maintaining structural integrity. The study's findings suggest that transfer beams located in higher seismic zones require increased reinforcement to adequately manage torsional stresses. It provides practical design recommendations aimed at enhancing the resilience and safety of buildings in earthquake-prone regions. These insights make a significant contribution to seismic design practices, helping to ensure the durability and reliability of transfer beams under complex loading conditions.*

***Keywords:*** *Transfer Beam; Torsion; Seismic Zones; Vertical Irregularity*

## INTRODUCTION

In the modern construction industry, despite the considerable technological advancements and innovative design practices, structural irregularity continues to be a significant challenge, especially in the context of high-rise buildings. One of the most critical aspects of this challenge is the management of vertical irregularity in seismic design, which is crucial for ensuring the stability and safety of tall structures. In specific architectural projects, such as hotel lobbies, conference centers, and banquet halls, there is a demand for large, unobstructed spaces. Similarly, healthcare facilities, including emergency rooms, operating theaters, and large wards, require expansive, uninterrupted areas to facilitate smooth operations and ensure patient care. Also, commercial spaces such as shopping malls, exhibition centers, and office buildings often require flexible floor layouts to accommodate various functions and activities.

To address these needs, transfer beams are strategically utilized. These horizontal structural elements are designed to transfer loads from columns or walls above to other supporting elements below, which may not be directly aligned. This transfer mechanism enables architects and engineers to create expansive open spaces by eliminating the need for intermediate columns, thus providing the desired layout flexibility without compromising structural integrity.

However, the use of transfer beams introduces additional complexities, particularly in the redistribution of loads and the management of significant torsional forces that arise from eccentric loading. These forces result from the misalignment of structural elements and can pose a challenge in maintaining the building's structural equilibrium. To ensure that transfer beams perform effectively under such conditions, their design must rigorously adhere to the guidelines outlined in IS 1893:2016, which addresses the seismic design of structures, and IS 456:2000, which covers the general design principles for reinforced concrete. The analysis and design process involves the careful application of the respective clauses and formulas, grounded in the limit state design philosophies. These philosophies, which encompass both the limit state of collapse and the limit state of serviceability, are fundamental to ensuring that the structure not only withstands extreme conditions but also remains functional, durable, and comfortable throughout its lifespan. The integration of these design principles is crucial in mitigating the risks associated with torsional forces and ensuring that the building's structural integrity is preserved over time.

Studies on transfer beams have underscored the critical impact of torsion, particularly concerning seismic activity. As seismic zones vary, the torsional effects on structural elements become more pronounced, leading to an increase in the effective shear forces on the beam sections. This phenomenon highlights the importance of incorporating a thorough analysis of torsional effects into the design process, especially for buildings located in seismically active regions. By understanding and addressing these challenges, engineers can develop more resilient structures capable of withstanding the dynamic forces associated with earthquakes. This approach not only enhances the safety and stability of the building but also ensures that it remains functional and secure for its intended use, even in the face of significant seismic events.

## METHODOLOGY

The research was conducted in two distinct phases. The first phase focuses on a comparative analysis of two reinforced concrete beams, each having the same span of 10 meters, cross-sectional dimensions of 300 mm × 750 mm, loading conditions, concrete grade M25, and steel grade Fe500D. The primary differentiating factor between the two beam sections is the presence of torsion in the second beam. The beam without torsional moment adheres to Clause 40, the Limit State of Collapse for Shear, as outlined in IS 456:2000. In contrast, the beam subjected to torsion follows Clause 41, the Limit State of Collapse for Torsion, in the same standard. Both beams are designed not only in accordance with the Limit State of Collapse criteria but also to meet the Limit State of Serviceability requirements, ensuring control of deflection and cracking. The comparative analysis examines the flexural reinforcement, shear reinforcement, and serviceability factors, thereby emphasizing the combined effects of shear and torsion, which sets the foundation for the subsequent phase.

The second and final phase of the study involves a torsional analysis of transfer beams in a G+4 structure, considering different seismic zones. This analysis is conducted using the advanced structural analysis software STAAD.Pro, which allows for a detailed examination of critical aspects such as torsional stresses, shear forces, and bending moments. The simulation environment replicates various seismic conditions to evaluate the structural performance, enabling an emphasis on the potential for further optimization of the reinforcement design. The transfer beams under investigation are located on the third floor of the G+4 structure, where the column height is twice that of the other floors. There are three transfer beams with spans of 24 meters and cross-sectional dimensions of 450 mm x 1300 mm, constructed with M25 concrete and Fe500D steel. Each transfer beam is divided into four sections of 6 meters each. The analysis considers ultimate loading combinations, including axial forces along the x-axis, shear forces along the y and z axes, torsional moments along the x-axis, and bending moments along the y and z axes. Based on the post-processing results of the analysis, each transfer beam section is evaluated as either passing or failing the design criteria. In the case of failure, the reasons are investigated in accordance with Clause 41 of IS 456:2000, and potential alternatives are explored to optimize the design of the failed sections.

## RESULTS

In the first phase of the study, the inclusion of torsion in the beam design (**Figure 1**) has a pronounced impact on its structural performance. Specifically, the presence of torsion leads to a 6.06% increase in tensile reinforcement and a 14.064% increase in compressive reinforcement, resulting in a significant overall rise in the required longitudinal reinforcement. Although both beams share identical transverse reinforcement, the beam subjected to torsion necessitates additional side-face reinforcement to counteract the combined effects of shear and torsion.

In accordance with IS 456:2000, the design includes equally distributed side-face reinforcement, amounting to 0.12% of the gross cross-sectional area. This meticulous consideration of both shear and torsion ensures the structural integrity of the beam, thereby requiring a more robust design than the beam without torsion.

In the second phase, the analysis of failed transfer beam sections within the G+4 structural frame (**Figure 2**) reveals a critical beam section that fails in both Seismic Zones IV and V. The study highlights a marked increase in torsional effects as the seismic zone intensifies, necessitating strategies to mitigate these adverse effects. For instance, a particular failed beam section (**Figure 3**) shows a torsional increase of 13.114% from Zone II to Zone III, 15.459% from Zone III to Zone IV, and 20.083% from Zone IV to Zone V. Under these torsional forces, the original beam

dimensions of 450 mm × 1300 mm result in an equivalent nominal shear that exceeds the maximum design shear strength of M25 concrete (3.1 N/mm²), leading to failure in Zones IV and V. To counteract the combined effects of shear and torsion, two optimization strategies are proposed:

I. Altered Dimensions: By increasing the beam dimensions to 500 mm × 1400 mm, the equivalent nominal shear is reduced by 19.688% in Zone IV and 20.053% in Zone V. This reduction brings the shear stress below the maximum design shear strength limit for M25 concrete, thereby ensuring the beam's structural integrity in these zones.

II. Altered Grade of Concrete: Upgrading the concrete grade to M30 in Zone IV and M35 in Zone V effectively lowers the equivalent nominal shear. This adjustment ensures that the shear stress remains within the maximum design shear strength limits for the respective concrete grades, maintaining the structural integrity of the beam across these seismic zones.

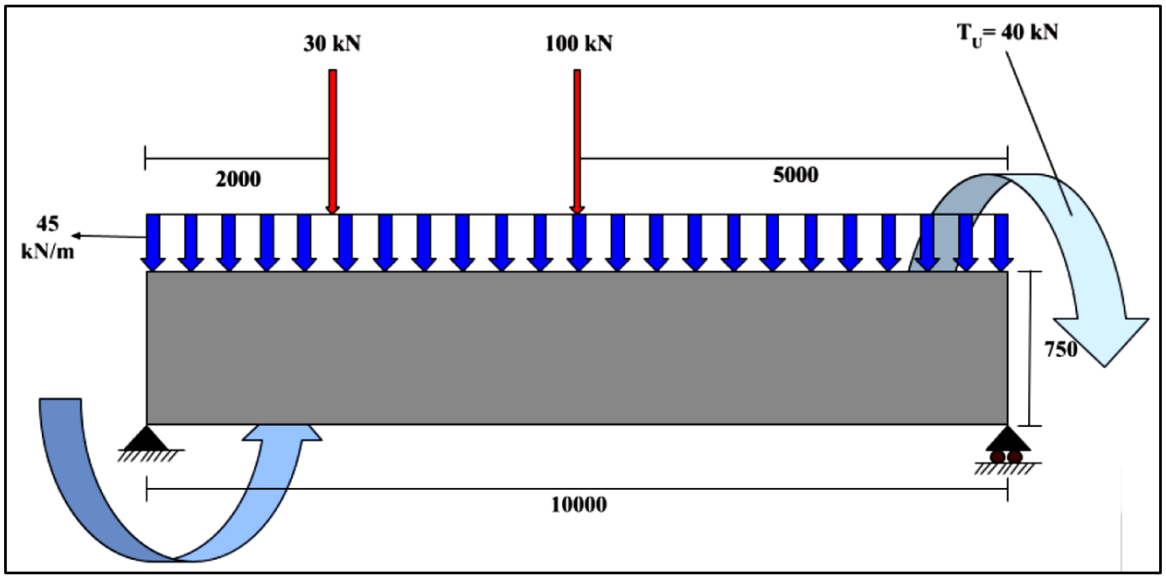


**Figure 1** Beam with Torsion (*All dimensions are in millimeters)

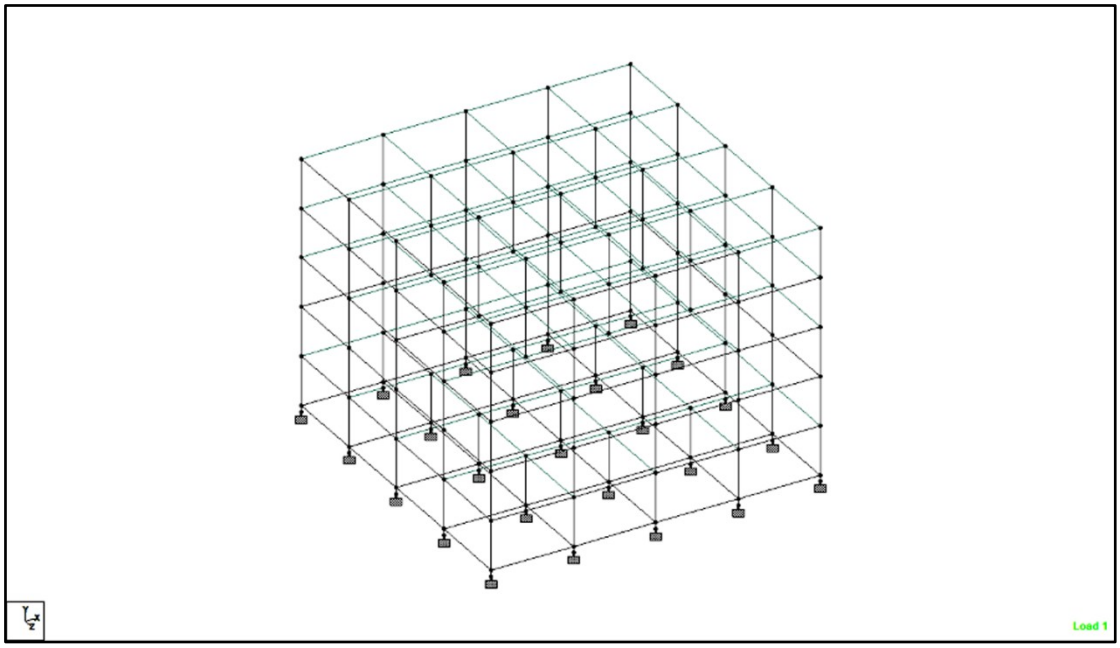


**Figure 2** G+4 Structural Frame

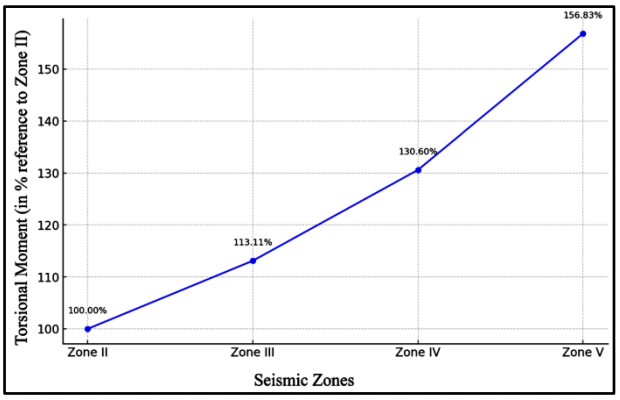


**Figure 3** Increase in Torsional Moment across Seismic Zones

## CONCLUSION

This study provides valuable insights into the impact of torsional forces on the design and performance of reinforced concrete beams, particularly in the context of high-rise buildings subjected to seismic activity. The first phase of the research demonstrated that when torsion is incorporated into the design of a beam, there is a significant increase in both tensile and compressive reinforcement requirements- by 6.06% and 14.064%, respectively. This necessitates the inclusion of additional side-face reinforcement to effectively manage the combined effects of shear and torsion, as prescribed by IS 456:2000. The results emphasize the importance of considering torsional effects in the structural design process to ensure the beam's overall integrity and to prevent failures under complex loading conditions.

In the second phase, the study focused on transfer beams within a G+4 structural frame, examining their behavior across different seismic zones. The findings reveal that torsional forces intensify as the seismic zone increases, leading to higher shear forces that, in some cases, exceed the maximum design shear strength of the concrete used (M25 in this case). The analysis of failed beam sections in Seismic Zones IV and V highlighted the need for optimized design strategies. Two effective methods were proposed: increasing the beam dimensions and upgrading the concrete grade. These adjustments were shown to significantly reduce the equivalent nominal shear forces, thereby enhancing the beams' capacity to withstand seismic loads, and maintaining their structural integrity.

The contributions of this study are significant in that they offer a clear understanding of how torsion interacts with other forces in reinforced concrete beams, especially in seismic contexts. The research presents practical design strategies that can be implemented to improve the resilience of structures, particularly in regions prone to earthquakes. Additionally, the study addresses the broader implications of vertical irregularities in buildings, which can exacerbate torsional effects and lead to structural instability.

However, the study has certain limitations. The analysis was based on specific beam dimensions and material grades, which may not be applicable to all structural designs. Furthermore, while the study explored the use of conventional design methods and materials, future research could investigate the potential benefits of advanced technologies such as Lead Rubber Bearings (LRB). These technologies could help reduce end moments at beam-column junctions and further optimize the performance of structures under seismic loads. Expanding the scope of research to include a wider variety of structural configurations, materials, and advanced seismic mitigation techniques would enhance the generalizability and applicability of the findings.

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62_IEC95497

# Design Concept, Optimisation Opportunities and Challenges of an Underground Station supporting a Flyover and Ramp

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***Abstract:*** *Urban transportation networks are acting nowadays like a lifeline of the city as well as main key drivers of sustainable development of any developing country like India. The underground constructions are gaining popularity by playing a key role in improving many more the urban space congestion problem. To provide multidimensional transportation system for busy road crossing at Radhakrishna Salai junction location of Chennai city, a highway flyover is planned above an underground metro corridor station. Design and construction of Radhakrishna Salai junction underground metro station from Chennai Metro Project Phase-II corridor 3 has been referred here for the present case study. 3D isometric view of Radhakrishnan Salai Junction Station with flyover running along the length of the station is shown Fig.1 The present paper describes the design concept, optimisation opportunities and challenges of this underground station supporting a flyover and ramp. The station comprises of three levels of slabs supported on two diaphragm walls on both sides. Diaphragm Walls are considered as external walls of the station with slabs forming a part of the internal framing. Entire underground station construction is planned with top-down sequence. Flyover and ramp parts have been planned to cast later once civil works of underground station be completed. As per plan, the flyover spans are supported on the station roof by means of 3 m (wide) × 2.4 m (deep) beams which in turn are supported on the 1000 mm thick diaphragm walls of the station. Besides this, the approach ramp of the flyover is also supported on the station roof. As a part of structural design of underground station and flyover, different types of stability analyses and construction stage analysis have been performed in finite-element-based software Plaxis 2D whereas service stage analysis has been done in STAAD Pro.*

***Keywords:*** *Urban Transportation; Underground Metro Station; Flyover above Unground Metro Station; Road Junction*

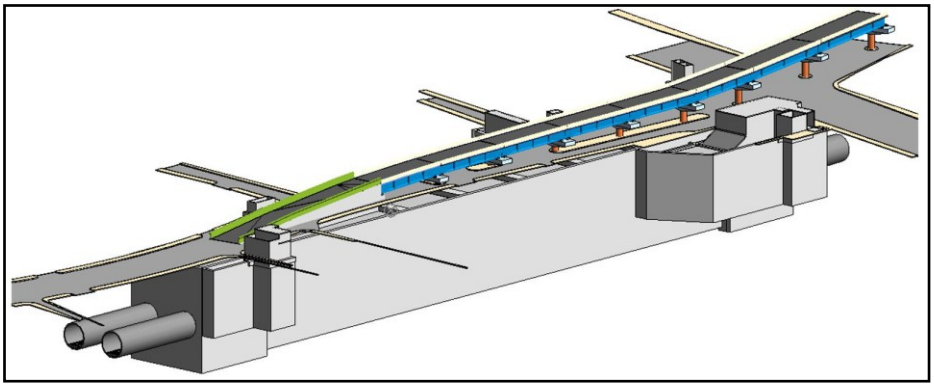

**Figure 1** 3D Isometric view of Radhakrishnan Salai Junction station with flyover running along the length of the station

105_IEC56565

# Development of Infra-structure for Measurement of Needle butt-Cam Interactive Force inside Knitting Zone of Double Jersey Knitting Machine

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***Introduction to Knitting and Needle butt-Cam Interacting Force:*** *Knitting is the second most popular technique of fabric or garment formation by inter looping from one or one set of yarn and its share in fabric production is about 25 %. In knitting, continuous length of yarn is converted into vertically intermeshed loops for producing the fabric. The loop length (length of yarn in a loop) is the most important parameter which governs the ultimate quality of the knitted fabric. The primary element for loop formation is Needle, which moves either vertically up and down or horizontally to and fro under the control of cam system, for looping and subsequently interloping. According to the direction of movement of yarn during loop formation, there are two types of knitting – Weft & Warp knitting. Moreover, weft knitting machines may be flat and circular, at the same time, both of them may be single jersey and double jersey. Similarly warp knitting can be also of two types – Tricot and Raschel.*

*The nature of yarn tension is an important parameter for knitting. Some minimum tension in knitting is essential for smooth flow of yarn from the package to the needle as well as for loop formation. At very high tension, yarn may break along with other knitting elements. The input yarn tension in the first phase is generally uniform and easily measurable, however the resultant yarn tension developed during loop formation inside knitting zone fluctuates to a great extent due to needle butt-cam interaction, the magnitude of the same mainly depends on the type of the machine, cam profile, quality of the yarn and the requirement of the end product. The extent of robbing back phenomenon is also influenced by the yarn tension developed inside knitting zone, generally it is higher at higher tension.*

***Keywords:*** *Knitting; Mechanics; Loop-Length; Cam-Force; Sensor*

## MECHANICS OF LOOP FORMATION IN WEFT KNITTING - BOTH SINGLE & DOUBLE JERSEY

The study of mechanics of loop formation through modeling and experimentation helps to understand the sciences of knitting. Such understanding is essential for optimizing input parameters for desired output and redesigning the machine parts in order to achieve higher productivity. Nineteen input parameters [Table1] were identified and necessary provisions were made in the programs to incorporate all those input parameters for studying their influence in the process of 1x1 rib loop formation on a dial and cylinder type double jersey knitting machine. It is obvious that if the variables governing the length of loop as well as the mutual interaction between the variables inside KZ are known, it would be possible

to produce a knitted fabric with a pre-determined loop length. Hence the length of loop decided and the yarn tension developed inside KZ are the two crucial parameters to be considered in studying the mechanics of the loop forming system.

## OBJECTIVE OF THE STUDY

For understanding the actual mechanics of loop formation in knitting, it is necessary to record and analyze the Needle butt-Cam interactive force inside the knitting zone for a complete loop forming cycle. Such understanding helps to evaluate the performance of the needles and cam for higher production and product developments. The critical analysis of these aspects helps to optimize knitting conditions as well as redesign the machine components. So, the main aim of this study is “Development of Infrastructure for measurement of Needle butt- Cam interactive force (yarn tension profile) inside knitting zone while knitting takes place”.

## DEVELOPMENT OF BACKGROUND

As the knitting zone is inaccessible for the probes or sensors of the yarn tensiometers available in the market, it becomes mandatory to develop some indirect technique to measure the yarn tension (cam force) inside the knitting zone. Before designing a force measuring device, it is essential to have knowledge of the nature and magnitude of the cam force for appropriate selection of the sensor. As per output of the computerized model, the cam force is periodic in nature, frequency of pulse is about 3000 Hz, while the magnitude ranges between 50 to 500 cN. Nineteen input parameters [Table1] were identified and necessary provisions were made in the programs to incorporate all those input parameters for studying their influence in the process of 1x1 rib loop formation on a dial and cylinder type double jersey knitting machine.

The measurement of cam force in single jersey machine was first attempted by Henshaw [1] for increasing machine speed and Peat & Spicer [2], initiated the study of yarn movement and tension during loop formation using pointed and flatbottomed stitch cams on circular single jersey machine.

## PROCEDURE

Ray & Banerjee [3] decided first to measure the needle butt-cam interactive force on a dial and cylinder type double jersey machine and to compare the same with the predicted cam force (out-put of the computerized model they [4] developed for the study of the mechanics of 1×1 rib loop formation) translated from yarn tension inside the knitting zone. Before designing the force measuring device, they studied in detail the nature and magnitude of the theoretical force, i.e., the output of the model to approximately select the natural frequency and strain sensitivity of the measuring instrument (transducer). Considering the merits and demerits of different types of transducers available worldwide and their suitability of application for the problem at hand, they decided to use a piezoelectric force

transducer, namely quartz force link of M/s. Kistler Instrumente AG, Switzerland. The sectional view of the quartz force link is shown in Fig.1, and a few of the specifications are – Measuring range = +2500 cN, Resolution = 0.1 N, Sensitivity = 3.57pC/N, Error due to eccentric loading = 2%, Weight = 12 gm.

As at any instant two or more needles act on the stitch cam, the resultant cam force would not represent the profile of yarn tension developed during a cycle of loop formation. Hence it was necessary to drive one or few needle(s) (measuring needle) in a separate cam track, replica of the main cam track, in such a way that this needle forms loop in sequence with the neighbouring needles running in the main track. The new cam track was made of pieces which were fabricated from mild steel and subsequently case hardened as well as smoothened in the workshop (**Figure 2**). For mounting the transducer, stitch cam is first fitted to a T-shaped metallic platform, which in turn is bolted to the Quartz Force Link, which remains suspended vertically inside a slot made on the cam jacket made of bakelite bar. In order to prevent the induced e.m.f. from the environment creating a noise (50 Hz) in the output, the transducer was electrically insulated from the machine by placing a polyester sheet in between T-shaped platform and stitch cam.

The signal in the form of charge (pc) generated by the quartz force link was conducted to a charge amplifier (**Figure 4**) for amplification and conversion in to voltage. Initially the signal in the form of voltage was observed in storage oscilloscope to gather basic information about the signal. Finally, signals were recorded in a Desktop computer through analog to digital conversion card (ADC) of Dynamic range = 0 to +5 Volts, Polarity = Unipolar, No. of bits = 12, No. of Channels = 16 multiplexed, Conversion time = 60 microseconds, Operative principle = Successive Approximation Method, Non-linearnity = 0.2%. A programme written in Turbo-Pascal (version 5) was executed for recording the digitized signals in the hard disk of the computer. The computer recording made it possible to record a large number of signals at a very fast speed with a minimum distortion of the signals as well as to process those signals afterwards.

The **Figure 3** demonstrates the installation of the transducer on the cam jacket. To evaluate the force measuring system critically, i.e., the following testing were performed.

(a) Linearity of the ADC was verified by passing different voltage (0 to +5)

(b) True reproduction of the nature and shape of the input signal (Rectangular, Triangular etc.) generated by function generator (first viewed on oscilloscope and then on the computer)

(c) Different known weights were placed over the transducer and recorded whether exactly same values were obtained in the computer with its linearity
(d) The transducer was subjected to sudden loading with a blob of putty as well as steel ball to observe the effect of step input and impulsive input.
(e) The effects of eccentric and angular loading on the transducer.
(f) Generation of any noise as well as its recording by the system and subsequently elimination of the same by using digital filter.

After ensuring all the requirements for the purpose of accurate and true measurement, the force measuring experiments were conducted. The digitized cam force signals were subsequently plotted in to analog curves with the help available graphic software to critically analyze the shape and nature of the signals. Repeated recording of the cam force for the same combination of the input parameters invariably leads to traces, exhibiting certain dispersion. Therefore, average values of cam force for each instant were calculated from eight different traces pertaining to the same set and the experimental cam force curves were the best fit curves drawn from the average values of the measured force signals. Confidence interval was calculated at 95% level to establish the dispersion of the individual values from the average. The nature of yarn tension profile (cam force) for a particular combination of input parameters under 2 needle delayed timing is shown in Fig. 2. In general, four peaks are found occurring at yarn catching point (CP), cast-off point (COP), cylinder knitting point (CKP) and one needle space away from cylinder knitting point (CKP2).

## CONCLUSION

(i) Both the developments – Computerized Model and Infra-structure for Needle butt-Cam force measurement were good enough for scientific studies.
(ii) The model, in general, slightly under-estimates loop length (up-to 9%). The higher values of cam setting are associated with more accurate prediction of loop length under both synchronized and delayed timings.
(iii) Higher loop length at lower cam force.
(iv) The measured cam force shows similar trend with the predicted one including number (4) of peaks. About 20% variation observed in two peaks (CKP & CKP2).
(v) The developed infra-structure was successfully used for Interlock knitting and can be applied to solve many real problems in the processing of textile materials.

**Table 1** Nineteen input parameters a dial and cylinder type double jersey knitting machine

| |
|---|
| a) Timing of knitting |
| b) Fabric take-down load |
| c) Yarn input tension |
| d) Gauge of the machine |
| e) Dial height |
| f) Yarn thickness |
| g) Cylinder stitch cam setting |
| h) Yarn relative rigidity |
| i) Dial stitch cam setting |
| j) Coefficient of yarn - needle friction |
| k) Cylinder needle resistance with bed |
| l) Coefficient of yarn - yarn friction |
| m) Dial needle resistance with bed |
| n) Needle hook dimension |
| o) Descending angle of Cyl. stitch cam |
| p) Horizontal gap between two beds |
| q) Ascending angle of Cyl. stitch cam |
| r) Descending angle of Dial stitch cam |
| s) Ascending angle of Dial stitch cam |

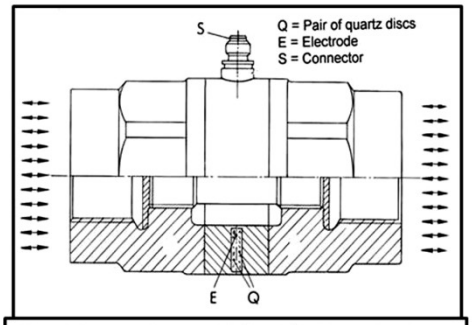


Fig. 1 Quartz Force Link with Cross Section


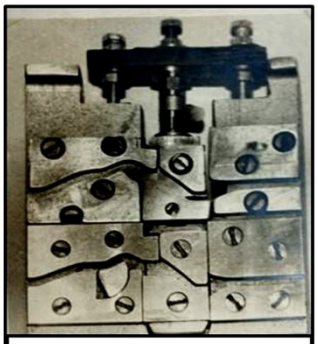

Fig.2 Modified Cam Track

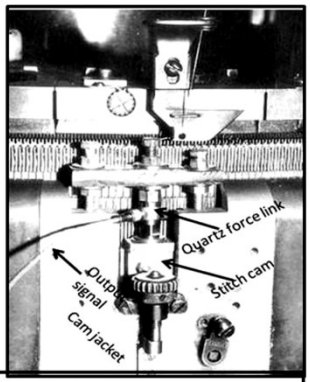


Fig. 3 Measurement System

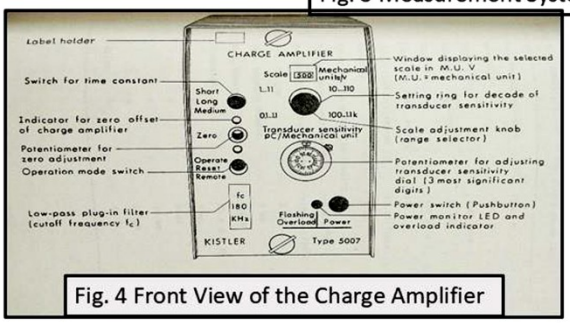


Fig. 4 Front View of the Charge Amplifier

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108_IEC1133

# Lift Irrigation – Re-Engineering of Irrigation Projects in the State of Telangana

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***Abstract:*** *Irrigation Engineering, primarily based on gravity storage (Dams) and gravity flows (contour canals) has remained stagnant for last one or two centuries due to no technological intervention on account of less revenue returns. Telangana State is a land-locked State located in the southern Indian peninsula on the Deccan Plateau. Though the region is drained by major rivers the Godavari and Krishna rivers, but these rivers flow at an average altitude of 100m above mean sea level whereas the habitations and lands are at about 500-600 m levels. The topography made providing irrigation difficult with conventional technologies which people of the region took as neglect. The aspirations of the people for irrigation and water forced the Central Government to carve out the region as a new State. The newly carved State had no option but to go for Lift Irrigations, made feasible with advancements in high capacity pumps to provide water and irrigation fulfilling the aspirations of the people. Lift irrigations broke the barrier of gravity and provided water and irrigation to much larger areas in the region giving opportunity for re-engineering of Irrigation projects. During the period 2014-15 to 2022-23, the Government has incurred an amount of Rs 1.61 lakh crore on irrigation projects in the State, which brought considerable prosperity to the State. The Paper describes re-engineering of a few Irrigation Projects made possible with lift irrigations. But Lift Irrigation has made irrigation waters very costly, and therefore, require high level of water use efficiency and restructuring of subsidy to make the water infrastructure sustainable.*

***Keywords:*** *Telangana; Irrigation; Lift Irrigation; Water Use Efficiency*

Telangana is a land locked region located in the southern peninsula. The people of Telangana had been perceiving injustices in the distribution of water, budget allocations, and jobs since decades right from re-organisation of States in India after independence. Within the state of Andhra Pradesh, 68.5% of the catchment area of the Krishna River and 69% of the catchment area of the Godavari River are in the plateau region of Telangana and flowing through the other parts of the state into bay of Bengal. Telangana and non-coastal parts of Karnataka and Maharashtra states form Deccan Plateau. While 74.25% of irrigation water through the canal system under major irrigation projects goes to the Coastal Andhra region, Telangana region prior to bifurcation got only 18.20%. The remaining 7.55% went to the Rayalaseema region. Though the region with a geographical area of 1,12,080 Sq.Km (112.08 Lakh Hectares) was drained by 2 major rivers of Godavari and Krishna and, owing to poorly designed projects, Agriculture Sector was mostly dependent on rainfall which caused large areas and districts being chronically drought affected and had driven many farmers frequently to suicide. Due to lack of sufficient surface water, some of the then combined Districts like Nalgonda & Mahabubnagar were seriously affected with fluoride problems and recurring droughts and drinking water shortages. Lack of water and irrigation were the prime reason, which resulted into huge unrest and political movements towards formation of a separate state Telangana, to which the Central Government finally succumbed announcing its intent to the creation of the Telangana State in December, 2013 and passage of the Andhra Pradesh Reorganisation Act, 2014 on March 2, 2014 with creation of the new State on 2nd June, 2014.

Telangana is situated on the Deccan Plateau, in the central stretch of the eastern seaboard of the Indian Peninsula. It covers 112,080 square kilometres (43,273 sq mi). The region is drained by two major rivers, with about 79% of the Godavari River catchment area and about 69% of the Krishna River catchment area, but most of the land is arid. Telangana is also drained by several minor rivers such as the Bhima, the Maner, the Manjira, the Musi, and the Tungabhadra. The annual rainfall is between 900 and 1500mm in northern Telangana and 700 to 900mm in southern Telangana, from the southwest monsoons. Though the region is endowed with good amount of rainfall, the topographical feature of land at about 500-600m elevation with river flowing at about 100m level made conventional irrigation of storing water against gravity dam and providing water through canals (gravity flows) very difficult.


**Figure 1** Map of India (Indicative) showing Telangana State

With the advancements of high-capacity pumps, it became feasible to lift large quantities of water from lower levels of river flows to higher levels of land in multiple stages. The aspirations and need of the people for water and irrigation forced the newly formed State to adopt lift irrigation, even at enormous costs. The state Government accordingly obliged. Lift irrigation broke the barrier of gravity and gave the opportunity for re-engineering of the existing and planned Irrigation Projects.

After formation of the state, Telangana Govt has given the highest priority for the creation of maximum possible irrigation facilities to the extent of 125 lakh acres under the caption "Creating Koti Yekarala Magani" with an assurance that all the rural assembly constituencies shall have atleast 1 lakh acres of irrigated ayacut from all sources. Major projects like Dr. B.R. Ambedkar Pranahita Chevella LIS, Indiramma Flood Flow Canal, J.Chokka Rao-Devadula LIS, Rajiv Dummugudem LIS & Indira Sagar Dummugudem LIS, Kanthanapally and the projects of Palamuru - Rangareddy and Dindi (Nakkalagandi) Lift Irrigation Schemes which were conceived and sanctioned in the erstwhile combined State of Andhra Pradesh were reviewed in detail and were comprehensively Re-engineered / Re-designed to suit the states requirements. Brief details of re-engineering carried out by the State Government in these Projects are described below;

1. **Dr.B.R.Ambedkar Pranahita Chevella Sujala Sravanthi Project** - Pranahita Chevella project was earlier conceived to utilize 160.00 TMC by erstwhile Andhra Pradesh by diverting the water at Thummidihetti on Pranahita River to benefit 16.40 Lakhs Acres in 7 Districts of Telangana. Maharashtra Government had objected to fixing the FRL of +152.00 due to a submergence of 1852 Acres and insisted to lower down the FRL to +148.00 to avoid submergence in Maharashtra. The Hon'ble Chief Minister of Maharashtra in October 2013 has sought the Hon'ble

Chief Minister of erstwhile Andhra Pradesh not to proceed with unilaterally decided layouts and control levels as it may lead to unfruitful expenditure. Several Efforts were made by the new Government of Telangana at Hon'ble Irrigation Minister and Hon'ble Chief Ministers Level of both the states to commence the Barrage work with originally proposed FRL +152.00. However the Maharashtra Government pleaded to lower down the FRL to avoid any submergence. In light of the Hydrology observations of the Central Water Commission the available flows at Thummidihetti being only 165.38 TMC as against 273 TMC, originally accepted 'In Principle' and a divertible flow being only 120 TMC in 77 days with FRL of +152.00. Further, with the reduced FRL of +148.00 as insisted by the Maharashtra Government, the divertible flow was coming to 44 TMC, which would had resulted into change of the entire scope of the project conceived for utilization of 160.00 TMC from the head works and the works taken up in the different reaches of the project would have become non functional. In order to make the project functional and achieve the contemplated benefits to effectively utilize the Telangana state's share of Godavari Basin, it had become essential to do the Re-engineering and revise the entire scheme. The location of the barrage was later proposed to be shifted further downstream after the confluence of the rivers Pranahita and Godavari to draw the entitled water for the planned utilization under the project. In light of the Limitations in the originally proposed scheme, the following were taken up;

Pranahita Project: By constructing a Barrage near Thummidihetti to irrigate an ayacut of 56,500 acres in East Adilabad District as originally proposed. Apart from it, it is proposed to irrigate an additional ayacut of 1.00 Lakh acres in East Adilabad as part of the re-engineering in Adilabad District in Bellampally, Siripur(T) and Asifabad Constituencies which was ignored by the erstwhile Government. With this, the total ayacut under the Pranahita Project would be 1,56,500 Acres in East Adilabad District, by utilizing 15 TMC.

Kaleshwaram Irrigation Project: By constructing a barrage across river Godavari after the confluence of Indravati river to divert the balance water for irrigating the ayacut 16.40 Acres. The location of the barrage were proposed after obtaining the LIDAR Survey Report. Proposals were made to enhance the present storage capacities of the reservoirs and also formation of new reservoirs under the system to cater to the needs of the drought prone districts by increasing the storage capacities of the reservoirs from 16.03 TMC to 124.32 TMC as suggested by Central Water Commission.

2. **Indiramma Flood Flow Canal (FFC) Project from SRSP**: FFC canal was envisaged for diverting 20 TMC of flood water from SRSP. The dependability of flood water is only 50%. Due to reduced inflows into SRSP in recent years and due to indiscriminate construction of series of barrages/check dams in the upstream by Maharastra state, even the availability of 20 TMC of flood water at SRSP came at stake. The earlier proposed Mothe reservoir couldn't be taken up due to strong resistance from the villagers in the submergence area for the last 7 years. However the contemplated ayacut of 20,000 acres could be irrigated under PCLIS (?) project. Thotapally balancing reservoir couldn't taken up till date and now it proposed to be dropped due to the economical considerations arising out of new LARR2013 Act. However the contemplated ayacut of 49,000 acres under gravity can be served by extending the canal by constructing 2 aqueducts across the streams. The capacity of Gouravelly reservoir was proposed to increase up to 9 TMC due to following reasons;

(i) Drought prone areas of Husnabad and Jangoan constituencies will be benefitted by assured water supply to the contemplated ayacut and also increase of ground water levels.
(ii) Less additional submergence of land and houses little submergence of 110 Houses and 1700 acres of land.because of topographical area due to which less cost for increase of capacity from 1.4 to 9 TMC
(iii) There are no big storage reservoirs beyond MMR. The capacity of Gandipally reservoir is proposed to increase up to 1 TMC in order to serve the new gap ayacut between IFFC and GLIS projects and also to stabilise the ground water levels in drought prone areas. It is also proposed to supplement the 2.00 lakhs acres of ayacut under GLIS project due to insufficient GLIS project pumping capacity and required water can be met from allocated water of GLIS through integrated MMR. Capacity of MMR R/S Canal and pump house were also increased from 2630 Cusecs to 4200 Cusecs to utilize 23 TMC additional water.

After the deletion of Thotapally (Ogulapur) Reservoir, two aqueducts were proposed to cross the Mohitummeda

Vaagu & Yellamagadda Vaagu for supplying water to 49000 Acres aycut beyond Thotapally . A 3.30 Km tunnel parallel to the existing tunnel was proposed to lift water to +350 level to supply 2400 cusecs of water through the gravity canal to RS Ghanpur Tank.

3. **J.C.R. Devadula Lift Irrigation Scheme**: The Duty of 15,000 Ac/TMC earlier proposed for the Project was found un-practicable to irrigate the 5.437 Lakh Acres with 35.34 TMC. Generally it is adopted 10,000 Ac/TMC for irrigation of I.D/Wet crops. Pumping of JCR-DLIS is proposed for 170 days (from July to Middle of December). But as per actual, the feasibility is for about 120 days due to lack of pondage facility. The quantum of water that can be lifted in 120 days is 27 TMC only against proposed 38.18 TMC due to restricted pumping facility. Hence Re-Engineering of the JCR-DLIS project was carried out for achieving the contemplated benefits.

JCRDLIS ayacut was earlier to be restricted up to Dharmasagar Reservoir (+303 M) to utilize 27TMC water. With adoption of Lift Irrigation Scheme, an ayacut of 1,79,741 acres from Dharmasagar Reservoir, and fresh (gap) ayacut of about 48,780 acres in Bhupalapally & Mulugu Constituencies would get covered and ayacut under Ramappa, Laknavaram & Pakhala lakes will get be supplemented. (All together 2,47,000 Acres).The balance ayacut of JCRDLIS is to be supplemented by IFFC and Pranahitha Chevella project systems.

4. **Re-Engineering of Indira Sagar Rudramakota LIS**: The lift point from the River Godavari in Velerupadu was merged in to Andhra Pradesh after the re-organization of the State which has made the projects an Inter-State projects. This has necessitated opting for the alternative proposals duly shifting of lifting point within the state of Telangana. In Rajiv Sagar LIS, there were 6 reservoirs having capacity of 1.088TMC only. Subsequently, it was re-designed to provide additional storage capacity of 14.712 TMC by raising the capacities of Marrelapadu, Rollapadu and Bayyaram balancing reservoirs. The demand for the ayacut as per redesign is 27.00 TMC against 15.80 TMC earlier provided, which facilitates smooth functioning of the system and early start of Khariff . Due to redesign a new ayacut of 16,000 Acres and additional 55,000Acres under DBM 60 of SRCP II in Khammam District. With this 71,000 Acres of extra ayacut in addition to the earlier 2,00,000 Acres can be irrigated under this scheme. Further, both Indira Sagar Rudramakota LIS and Rajiv Sagar Dumugudem LIS get integrated with utilisation 67.05 TMc to create 1.68 lakh Acres new ayacut and stablise 1.5 lakh Ha ayacut including ayacut under wyra, paleru and other minor irrigation Projects of Nagarjun Sagar.

**BENEFITS**

Due to above re-engineering and considerable investment by the State Government, the Gross Irrigated Area (GIA) significantly increased by 117% (from 62.48 lakh acres in 2014-15 to 135lakh acres in 2021-22). This impressive growth in irrigated area has resulted in an increase in paddy production by 342% between 2015-16 and 2021-22 (from 45.71 lakh MTs to 202 lakh MTs) and the State has emerged as the second largest supplier of Paddy. This along with other initiatives have led to an increase in the share of Agriculture and Allied sectors in the total current-price Gross State Value Added(GSVA) of the State – from 16.3% in2014-15 to 18.2% in 2022-23 resulting into consistent double digit growth rate making Telangana State rank third in terms of the growth rate of nominal GSDP (Provisional Estimates) among the thirteen General states in the country.

**WAY FORWARD**

However, the above re-engineering has also been criticized as that would require considerable pumping cost and therefore may bleed the State. One should never forget that Technology is driven by economics. Irrigation engineering remained stagnant since there were no economic returns. No doubt lift irrigation and re-engineering of irrigation Projects have brough tremendous progress in the field of irrigation and consequently to the Telanagana State, but the enormous costs associated with it should not be lost sight of. As the Compltroller and Auditor General for India has pointed out taking example of Kaleshwaram Lift Irrigation Project that that these re-engineering of Projects would bleed the State Government. Therefore, the State Government should work concurrently on water efficient irrigation incorporating piped distribution network with micro irrigation techques, so that economic returns are obtained on this costly water. The People and the State should realize that there is no free lunch and in order to sustain availability of power and/or water and irrigation, water must be utilized judiciously with high degree of

efficiency. Water spread can also be utilized for floating solar panels for generating solar energy as well as reducing evaporation losses. Pressurized Pipe distribution system coupled with micro irrigation techniques are inevitable to sustain these Lift Irrigation Projects. Water deficit States like Rajasthan and Madhya Pradesh have already resolved that only piped distribution irrigation system would be adopted in their States. Since paddy/Rice is a staple food in the region, the State Government must disseminate and encourage use of Systematic Rice intensification (SRI) system to drive maximum value from lifted water. After lot of struggle, the people of Telangana has got Statehood and consequent re-engineered Irrigation Projects and there is an imperative need to make those sustainable. The State of Telangana may also evolve innovative ways to price the water, noting that it is not the water which need to be priced but the services to lift the water and making available to farms is required to be adequately priced. The farmers may be compensated through commensurate increase in the Minimum Support Price. This will allow economic principles to maximise value from water ensuring adequate income from farming. The money proposed to be spent on electricity in lifting of water can be used to supplement farm income by diverting towards increased Minimum Support Price and subsidise farm produce to keep inflation in check. Such economic packaging would alone make these Lift irrigation Projects viable and sustainable.

**DISCLAIMER**

The views expressed by the Author are his personal views and does not represent or indicate the views of Godavari River Management Board and/or the Government of India.

112_IEC19999

# Project Execution Marvel in Refinery, Petrochemical, Fertilizer, and Similar Chemical Plants – Leverage Modularization

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***Abstract:*** *Modularization is revolutionizing project execution in refinery, petrochemical, fertilizer, and similar chemical plants by offering a more efficient, cost-effective, and time-saving alternative to conventional stick-built construction methods. This paper explores the significant advantages of modularized construction—such as improved project timelines, cost reductions, and enhanced quality control — and presents a significant recent case study made in India that showcase its global adoption. Particular attention is given to the true partnership required among stakeholders and the logistical and engineering challenges that arise. The analysis highlights how modularization facilitates faster project commissioning and better return on investment while addressing the complexities of large-scale chemical plants, making it a critical growth driver in the industry.*

***Keywords:*** *Project Cycle C2C (Concept to Commissioning); Chemical Plants; Stick-Built Construction; Modularized Construction; Engineering; Operationalization; Modularization*

## INTRODUCTION

Improvements in conventional project implementation process by reducing cost and time to build a project, while ensuring high quality, operability & maintainability with desired reliability and in-built fail-safe processes is the ideal aim.

In achieving this aim, this paper shows how modularization can ensure overall manifold improvements in all these factors.

## CONVENTIONAL STICK-BUILT PROJECT IMPLEMENTATION

Conventional method of project implementation consists of building plant components followed by assembly on-site. While it offers design flexibility, it also generally takes more time and resources than usually available and profitable to all parties involved.

Practically the project construction goes on in series sequentially, with potential for multiple bottlenecks and unexpected contingencies.

## MODULARIZED PROJECT IMPLEMENTATION

Modular construction involves building entire plants in controlled fabrication yards, generally away from the erection site, with major chunks executed in-parallel.

All project stakeholders decide in true partnership the project's objectives, and crucially their individual roles and responsibilities in advance, which they then constantly monitor and adjust during the entire project duration, to facilitate the project objective.

This is a parallel detailed engineering, procurement and construction process.

### Modularization is Globally a Growth Driver in Plant Construction

Modularization method of making plants is experiencing significant growth.

In 2023, the market size was valued at $95.68 billion, and is projected to grow to $102.52 billion in 2024,

representing a CAGR (compound annual growth rate) of 7.2%. Construction Institute has projected a CAGR of 9.6% until 2027.

This trend reflects the increasing adoption of modular construction methods, driven by their advantages in terms of speed, cost-effectiveness, quality control, and sustainability.

**Modularization Involves Conceiving a Plant as Plug-and-Play Sections**

First, conceptualize multiple sections, each erected separately, and pre-fitted with all necessary connectivity and bespoke equipment.

Then these modules transported to the site for assembly and erection on foundation, on a plug-and-play basis.

**Modularization Rests on True Partnership among Multiple Stakeholders**

A typical project cycle (whether refinery, petrochemical, fertilizer, or other similar process plants) from C2C (concept-to-commissioning) takes 5-10 years based on criticality of the plant being built.

The lower the C2C time, the greater the commercial RoI (returns on investment) on the plant.

Depending on the criticality of the plant following, several stakeholders are involved:

(i) Owners – who own the plant, conceive the project, and expect healthy RoI across the plant's lifecycle
(ii) Management – responsible to convert the project from C2C, including obtaining statutory clearances
(iii) Technology supplier(s)
(iv) Feed preparation agency(ies)
(v) PMC (project management company) – appointed by owner to implement the project, usually on EPCC (Engineering, Procurement, Construction, and Commissioning) contracting basis
(vi) Various EPCC contractors – executing full or per-division plant build per PMC and/or owner
(vii) Several manufacturers, suppliers, and subcontractors
(viii) Operating personnel and/or contractors of the owners
(ix) Inspection and maintenance personnel and/or contractors of the owners

For the success for a project, it is critical all stakeholders coordinate in true partnership.

**Examples of Modularized Projects**

Existing modular project examples span across the domestic, military, and industrial spaces, with the common plug and play concept.

- Domestic – modular kitchens
- Military – belly bridges used by armed forces
- Industrial – commercial kitchens; readymade housing; petrochemical and refinery heaters and furnaces, etc.

Among refineries, several modularized plants exist world-over, particularly in the US and recently in China. L&T, an Indian origin company, has in the Middle East, there is one in Sohar, Oman, and another in Jubail, Saudi Arabia.

Thus far, in India, L&T owns two such modular-built plants, one at Hazira in Gujarat and another in Kattupalli in Tamil Nadu,.

## ADVANTAGES AND CHALLENGES OF MODULARIZATION

While the advantages in adopting modular fabrication of a plant are many, there are several challenges associated. Leveraging the best of this methodology of plant construction, needs awareness of and planning for all of these.

**Advantages**

The three key benefits of modularization over traditional stick-built construction are:

(i) Efficient construction process, at a self-sustained fabrication yard
(ii) Drastically faster commissioning and completion time
(iii) Reduction in capital costs

Other benefits include:

(iv) Streamlined erection process
(v) Enhanced competitive bidding

We'll explore the key benefits in some depth below.

Efficient Construction

One of the primary capital requirements for adopting modularization methods, especially as a MFY (modular fabrication yard) is to have a dedicated large fabrication yard having detailed EPCC facilities at one place, providing a controlled and coordinated environment.

**Photograph 1** LTEH (L&T, Energy and Hydrocarbons) MFY (Modular Fabrication Yard) at Hazira

Geographical and co-location benefits

Dedicated fabrication yards yield geographical and co-location benefits:

- Extended construction windows: Uninterrupted year-round weather-agnostic operation of fabrication yards.
- Parallel construction enabled: While piling and civil foundation jobs are carried out at site, the modularization process starts simultaneously, if not even earlier, thereby allowing drastic reduction in total construction time.
- Efficiency in building and transportation: Building the entire plant at a dedicated fabrication yard improves efficiency and safety while ensuring desired overall quality, operability, and maintainability.

Overall transportation challenge is dealt with below.

Labor benefits

Detailed engineering and construction being co-located unlocks the advantage of having and mobilising required

amount of personnel with desired skills.

- Capacity limitations reduced
- Elevating labour skill levels
- Increasing worker productivity in the MFY
- Safety improved and risk of accidents minimised in MFY

Fabrication yard personnel are enabled to upskill and refine skills in a controlled environment, with safer and improved outcomes.

Faster Commissioning

Parallel progression at site and at MFY reduces project completion time drastically.

Compared to a typical stick-built project, which on-average can last approximately 70 months, modular projects can be completed in on-average around 58 months. (Kluck & Ouk Choi, 2018)

This average 12-month faster operational start-up enhances return on investment in the project for the owners.

Reduced Capital Spends

Building in a fabrication yard can be nearly six times cheaper than building on-site. (Kluck & Ouk Choi, 2018)

Additional indirect cost savings are:

- Efficiency gains: Processes are more efficient, wastages reduced, and time is saved.
- Predictable expenses: Modular approach provides better budget and timing predictability, with fewer unexpected costs, compared to traditional construction methods.

However, in modular construction, additional costs primarily arise from logistics (e.g. land and sea transport).

**Challenges**

There are few key challenges to overcome in realising these benefits:

(i) Engineering challenges; requiring full coordination of the several stakeholders involved
(ii) Logistical challenges, especially of transportation
(iii) Increase in complexity, needing coordinated partnership

We'll also explore these in some more depth below.

Engineering Challenges

This is the most important item to plan for and manage in leveraging the benefits of the modularized process.

It is resolved best by co-locating and carefully coordinating the engineering teams, operational personnel, and preferably procurement groups, across stakeholders and partners at the MFY.

Logistical Challenges

Another key challenge of modularization is related to logistics compared to traditional stick-built methods, especially the transportation of modular plants.

Complete route survey must be carried out and troubleshooting achieved in advance and in real-time, and incorporated in engineering design specifications.

Requirements of SPMTs (self-propelled modular transporters) and ramps to connect the fabrication yard's quay to the transport vessel must be studied in detail and incorporated in the engineering design specifications before starting construction at MFY.

Typical modular plant being transported, at loading, and in transit, are shown in the photographs below.

**Photograph 2** Modular plant being transported, at loading port of LTEH, Hazira

**Photograph 3** Typical modular plant being transported, in transit

Complex Coordination

Success in modularized project implementation depends on anticipating, identifying, and mitigating all foreseeable critical issues, and being responsive to unexpected contingencies, with mitigation processes, planning, and preparedness in advance; and integrating them in detailed engineering.

**Partnership and Coordination are Key to Achieving Modularized Process Success**

Critical to unlocking the advantages of modularization is to assemble, align, and coordinate the several stakeholders

listed above, across multiple organizations, divisions, processes – to work in unison and row together towards the goals of the project's objectives.

Clarity and accountability in collective and individual roles and responsibilities across all players, will keep the modularized project on the tracks.

## CASE STUDY OF A RECENT MODULARIZED APPROACH

The Thai oil refinery at Sriracha, Thailand underwent a massive upgrade and expansion project from 2018, to ensure cleaner hydrocarbon fuels by improving production processes and expand refining capacity.

TOPC (Thai Oil Public Company), a subsidiary of the state-owned oil and gas company PTT (Petroleum Authority of Thailand), is the owner and operator of the refinery at Sriracha.

Salient features of the project are laid for below.

### Objectives

Capacity increase from 275 kbpd to 400 kpbd (kpbd is capacity of a refinery, in thousand barrels daily). Plus, new provision to process heavier crude oil

### Investment

£3.6 bn ($4.8 bn)

### Project Timelines

Approved in August 2018; completion phases from 2023.

### Location

Sriracha, Thailand; 125 km southeast of Bangkok; over 910 acres – near lean Chabang port, on Eastern coast of the gulf of Thailand.

### History of this Refinery

Started in 1964, with 35 kbpd capacity.

### Existing (Pre-Project) Capacity and Units

- 3 CDUs (Crude Distillation Units): they separate crude oil into different fractions based on their boiling points – a significant capacity already
- 3 VDUs (Vacuum Distillation Units): post CDUs, VDUs process the heavier residual fractions under vacuum conditions to extract more valuable products like vacuum gas oil (VGO) and residual fuel oil
- Isomerization Unit: used to convert straight-chain hydrocarbons (typically light naphtha) into branched-chain hydrocarbons, improving the octane number of gasoline
- 2 CCRs (Continuous Catalytic Reformers): these units upgrade naphtha into high-octane reformate (for blending into gasoline) and produce hydrogen as a by-product, which is essential for other refining processes like hydrotreating
- 1 FCCU (Fluid Catalytic Cracking Unit): this unit breaks down heavier hydrocarbon molecules into lighter, more valuable products like gasoline, diesel, and LPG. The FCCU is one of the primary conversion units in most refineries
- 2 HCUs (Hydrocracking Units): these use hydrogen and catalysts to crack heavy oils into lighter, more valuable products like diesel, kerosene, and jet fuel
- 1 TCU (Thermal Cracking Unit): which, unlike catalytic cracking, uses high temperature to break down heavy

oils into lighter fractions, such as gasoline and diesel, often producing less valuable by-products compared to FCC or hydrocracking

**New Facilities Conceptualized and Commissioned in this Modularized Project**

- 2 existing CDUs will be replaced by 2 new CDUs at 220 kbpd
- 1 new high vacuum distillation unit (VDU)
- 2 new hydro treating units
- 1 new FCCU
- 1 new TCU
- Additional ERUs (Energy Recovery Units) – to capture and repurpose waste heat from various processes within the refinery to improve overall energy efficiency, which can then be re-used, reducing the refinery's reliance on external energy sources, furthering sustainability goals

**Heavier Crude Processing Enabled**

NCI (Nelson Complexity Index, where the higher index number indicates a greater ability to process heavier, lower-quality crudes; and convert them into lighter, more valuable products – typically with units like catalytic crackers, hydrocrackers, and coking units, ranging between 1 to 15) – improved for this refinery from 9.8 to 12

**Multiple Contractors and Agencies Involved**

- Amec Foster wheeler (Wood Group): feed preparation
- Consortium of Petrofac (leader), Saipem, and Samsung: EPCC @ £3 bn ($4 bn), appointed in October 2018
- Sub agencies
  - McCconnel: earthwork and civil engineering, appointed in July 2020
  - Sunpower group: supply of heat exchangers @ £ 7.5 mn ($ 9 mn), appointed in August 2019
  - BT Wealth: steel structures, metal pipe assembly, electrical equipment, cable installation
  - ATB Group: pressure vessels, main process units
  - Worley: EPCC, appointed in May 2019
  - Haldor Topsoe: to provide SNOX air quality control technology for the eru in April 2020. The scope of the contract includes the supply of proprietary equipment and catalyst. Three parallel snox lines will be used to remove sulfur oxides (sox), nitrogen oxides (nox), and dust from the circulating fluidized bed boilers.
  - Larsen and Toubro (L&T), Energy and Hydrocarbon (LTEH): awarded in 2020

<u>LTEH Contribution</u>

- Process unit modular manufacturing, testing, and supply, of 99 refinery modules, consisting of pre-assembled-racks, units, pipe-bridge racks, weighing 26000 mt (metric tons)
- Scope involved detailed engineering of entire plant, procurement of all required materials including fireproofing, coating, insulation, jacketed piping, electrical, instrumentation, installation of pre-insulated tubes for steam tracing, testing, pre-commissioning, weighing, and loadout
- Involved fabrication of 13,000 metric tons of structural steel, 200,000 inch-diameter pipe fabrication, 1,250,000-inch diameter piping erection and testing, in-situ welding of 130,000 inch-diameter piping and 77,000 square meters of insulation
- Largest single module was 1030 meters wide and 32 meters high
- Job was carried out at L&T Hazira MFY during the Covid period.
- More than 4000 workers worked during the peak of the project round-the-clock
- Upon completion of the module works, pipes were cut, beveled and protected for transportation
- Completed modules were loaded onto ocean-going vessels in multiple shipments starting from September 2021 using self-propelled modular transporters – with sea-fastening carried out to ensure safe transit journey

from Hazira for an onward journey of 4,600 nautical miles to Thailand's Laem Chabang port

- L&T fabricated the modules at its Hazira facility as per actual layout of the Sriracha refinery site, to avoid any mismatch of coordinates at hook up points at the refinery site
- Project completed in October 2022 (approximately 28 months). 16 million lost-time-injury-free manhours
- Bectel was the PMC for the L&T EPCC work
- Photographs 1 and 2 show modularized consignments loaded on the ocean-faring vessels

**Results**

Quality, operation, and maintenance delivered. Project-completion time was reduced by 20%+. Cost benefit of 50%+ realized.

This case study illustrates how this new modular construction approach helped achieve drastic reduction in the time of EPCC phase of the project in India for a Global client enabled faster realization of returns on the investment.

## CONCLUSION

Global adoption of modularization in refinery, petrochemical, and other chemical plants represents a paradigm shift in project execution, driving significant improvements in RoI for the owners. This is realized largely via much faster project completion time, enabling faster commissioning of a plant – while enabling better quality, safer, and more cost-effective construction and operation. Success crucially hinges on true partnership and real-time agile coordination among all stakeholders aiming for a clear objective, anticipating and mitigating challenges.

The case study and industry growth trends highlight in this paper underline modularization's potential to become the standard approach for large-scale industrial projects globally and in India, positioning this modular approach as a key growth driver for future plant construction projects.

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# Infrastructure

## Safety and Reliability of Infrastructural Systems

20_IEC50391

# An Assessment of the High Mast Poles' Reliability with Corrosion Contemplated

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***Abstract:*** *Steel structures like high mast poles are often subjected to fatigue failures. The fatigue strength of these structures is impacted by degree of loading, type of loading – static, dynamic and the environment surrounding the structures. Maintenance of such structures becomes key in lengthening the life of overall system. Also considering the growing impact of prognosis, remaining useful life calculation of the product/ system becomes the key matrix especially for the high mast poles as they help create optimized schedule for the maintenance thereby minimizing the inspection and repair cost. This paper deals with introducing a remaining useful life (RUL) curve for the high mast pole based on physics-based approach which includes wind and thermal loads in initial calculations. Paper details how corrosion can be major factor and how it can impact the reliability. Incorporation of the corrosion as a separate factor in the RUL curve is studied in this paper. Application of this study is performed on the one of the high mast pole situated in the USA and detailed study was conducted. Finally, this study was concluded with the help of map charts for qualitative denouement.*

***Keywords:*** *Reliability Analysis; Fatigue; High Mast Poles; Corrosion Damage; Remaining Useful Life*

## INTRODUCTION

Failure of any kind in an industry set up or working equipment can cause severe inconvenience. In a world where we are currently leaving in, any delay would cause wastage of dollars and time. For products specifically designed to operate in open environment, any mechanical failure can cause fatalities or damage to the surroundings. To avoid such failures, usually maintenance checks are scheduled. For this, predictive maintenance strategy can be very useful. Predictive Maintenance (PdM) can be defined as conducting maintenance, not on scheduled time, but based on predicted failures where reliability analysis comes into the picture. An important aspect of PdM [1] is to know much of a life a product or system has before failure. RUL is a critical metric and essential for failure prediction [2]. The method by which various failure modes are determined and RUL is estimated is called as prognosis [3]. There are multiple ways of predicting RUL which are used to manage systems, structures or infrastructures. Physics based models are dependent on extensive understanding of the mechanics and dynamics interactions with the system [4]. These models are built based upon multiple variables and are difficult to build initially. These models work on finding a degradation function over time as a function of model parameters to predict future failure. If a system is well studied and all loading conditions are well-known Physics based models can be applied without any modifications. Therefore, physics-based algorithms are always recommended when the physical model that describes the damage is available [5]. In a system subjected to failure, following degradation mechanisms are widely predominant: Fracture, Wear, Corrosion and Deformation [6]. With the accurate knowledge of loading pattern and necessary analytical equations to calculate degradation, life of a system can be utilized to calculate RUL.

The system under consideration is combination of luminaire and pole assembly erected on ground and exposed to variety of external environment. Generically, pole assembly design remains constant irrespective of external environment and shipped to multiple extreme terrains such as: high daily temperature cycling, constant wind

galloping, heavy wind gusts and coastal terrain with different humidity ratios. It has been observed that same pole assembly has different overall life and seems to be function of environmental stressors. We compiled the failure data from different regions for pole assemblies and observed that in few areas' poles are more susceptible to failures. Pole assembly failures in the dense population area can cause fatal incidents causing life loss and lawsuits which eventually can harm financial health of organizations designing these products.

## LIFE CALCULATION MODEL

Pole assemblies in its lifetime face combination of different environmental loads. The more dominant of them is wind. Wind loadings create oscillating flow and pressure zones across the poles which is called as the vortex shedding [7]. The approach associated with the modelling requires probabilistic modelling of wind distribution which then is converted into wind loads using analytical models. Detailed modelling of vortex shedding is performed and the Fatigue life obtained from these models is used to calculate the overall life estimation. Second environmental stressor which significantly affects the total life of the system is thermal cycling. Thermal cycling stresses are prone to add up with alternate stresses of wind and reduce the life more. These are location specific. High delta in daily temperature routine can significantly reduce the remaining life. $S_{RE}$ is the effective stress representing the cumulative impact of all the stressors. Calculations involving and combining effects of wind and thermal cycling is beyond the purview of this paper.

For a given cluster of poles, analytical treatment assumes that each pole has a same life as calculated above. But every pole has a variability associated with the material properties, weld properties and initial crack lengths. To account for these variabilities, reliability analysis plays an important role. In the current report reliability analysis framed by Chung el at (2003) [8] is followed. According to this framework, probability of failure $P_f$ can be defined in terms of reliability index β as (1)

$$P_f = 1 - \phi(\beta) \quad (1)$$

ϕ is cumulative distribution function of standard normal variable β. Reliability index is a function of two log normally distributed variables A ($\mu_\Delta$, $\delta_\Delta$) and Δ ($\mu_A$, $\delta_A$). $\mu_A$ and $\delta_A$ represent variability in welding techniques also material variability of weld and accounted in S-N curve for the weldment. Δ is modelled similarly as A with $\mu_\Delta$=1 and $\delta_\Delta$= 0.3. β values can effectively guide us through number of years in service. For the pole assembly under consideration, β value, eventually a function of effective stress can be calculated using (2) [9] as below.

$$\beta = \frac{\left\{\left[ln(\mu_\Delta) - \frac{ln\left(1+\delta_\Delta{}^2\right)}{2}\right]\right\} - \left\{\left[ln(\mu_A) - \frac{ln\left(1+\delta_A{}^2\right)}{2}\right]\right\} - 3\,ln\,S_{RE} - ln\,N}{\sqrt{ln\left(1+\delta_A{}^2\right) + ln\left(1+\delta_\Delta{}^2\right)}} \quad (2)$$

Humidity induced corrosion also plays a huge role in coastal belt areas on fatigue life. The life calculation model mentioned above is the vector summation of these stressors. At any given time, environmental conditions are bound to vary at every different place. Life calculations should comprehensively take care all the variations in the environmental conditions and can be effectively used across different terrains and conditions. As the focus of the paper is on the induction of the corrosion into the RUL model, wind and thermal load considerations are explained in brief in the upcoming sections.

### Calculation of the Effective Stress from the Wind Loads

As vortex shedding is a dynamic phenomenon, a simulation approach was designed and utilized. This approach is used to calculate generated forces due to vortex shedding on the pole. To simulate this system, it is important to understand derivation of forces using the analytical equations. The vortex shedding force is calculated using (3)[7] mentioned below.

$$F = \frac{\rho V^2 C_L D \sin 2\pi f t}{2} \quad (3)$$

### Calculation of the Effective Stress from the Thermal Loads

It has been observed that thermal stress changes very slowly as compared to stresses due to vortex shedding. The dynamic value of the wind stresses needed to be updated for non-zero mean. This can be done using Goodman criteria. Combinational value of stress is used eventually to estimate effective stresses.

**Impact of Corrosion on Reliability of Poles**

Steel structures are often subjected to fatigue failures accelerated by corrosion. The fatigue strength of these structures is impacted by degree of corrosion defined by corrosion rate. Once initiated at the critical areas crack propagation rate can increase based on environment factors. Corrosion is measured quantitatively using a term called corrosion rate measured in mm/year. Corrosion rate is dependent on multiple factors such as relative humidity, temperature, chloride ions and sulphate precipitates. Literature mentions that a coupling effect between the temperature and relative humidity on the corrosion rate is also immense [10]. Corrosion rate determination is provided by few standards and standard EN ISO 9223 is one of them. EN standards provides an equation for corrosion rate as a function of Sulphur dioxide, temperature, relative humidity and chloride ions. This equation is also called as a dose-response functions. These equations are determined from the corrosion rate of samples under outdoor atmospheric corrosion in cooperating with measuring of climatic data [11].

There are few literatures which calculate corrosion rate using empirical formulae as well. RE Melchers [12] explains that local structural details are prone to corrosion particularly in the welded HAZ of stiffeners. There is no official data available on how corrosion changes stresses at the critical area. Relatively very less data available for steel structures paves way for the empirical models. Few authors have concluded that allowable corrosion rate of 6µm should be used for steels. Author also suggests that best fit law for the atmospheric corrosion is not available and hence clearly gap is visible in this space.

Major corrosion modelling studies have produced empirical equations which specifically customized for an application. Few studies have given standard corrosion rates in mm/year for selected steel alloys. As explained corrosion is a function of temperature, humidity, chlorides, and sulphates. Hence, corrosion rates should be different for each place. As in a current study, corrosion is to be studied along with the effect of wind and thermal loads on pole, a comprehensive method needs to be developed which will align with the earlier RUL method and will incorporate effects of corrosion. This study has utilised a model which calculates corrosion rate as a function of atmospheric variants. Based on the corrosion rate, simulation model is developed with the corrosion impacted geometry. This will result into the amplified stress at the pole base location. The amplified effective stress is then used in the reliability calculations for the RUL calculations to assess the impact.

Application of Dose Response Function to Calculate Corrosion Rate

Corrosion damage can be determined by actual standard EN ISO 9223. This standard describes the equations, called dose-response functions given by (4)[13]. for calculation of the corrosion rate rcorr for standard materials like carbon steel. Input parameters on calculation of the dose-response functions are Sulphur dioxide, temperature, relative humidity, and chloride ions.

$$rcorr = [SO2]^{0.52} e^{(0.02_{Rh} + f(t))} + 0.102[Cl-]^{0.62} e^{(0.033_{Rh} + 0.04.T)} \quad (4)$$

Where,

$f(t)$=0.15$(T-10)$……$T$<10 $degree\ celsius$

$f(t)$=0.054$(T-10)$……$T$>10 $degree\ celsius$

To utilize **Equation 4**, data was extracted from National Atmospheric Deposition Program [14]. Based on these values, average corrosion rates were calculated. Based on corrosion rates and material removal calculations, FEA models were prepared to calculate amplified stress. This procedure is represented by **Figure 1**.

**Figure 1(a)** shows the uniform fillet in the absence of corrosion while **1(b)** shows removed material calculated according to corrosion rate respective to location. Using finite element analysis after reapplication of wind and thermal loads, effective stress was recalculated, and reliability index was reassessed. As the number of years in service for a pole increases, the reliability indices decrease. The diagrammatic comparison between corrosive environment and without corrosive environment is shown below in the **Figure 2**.

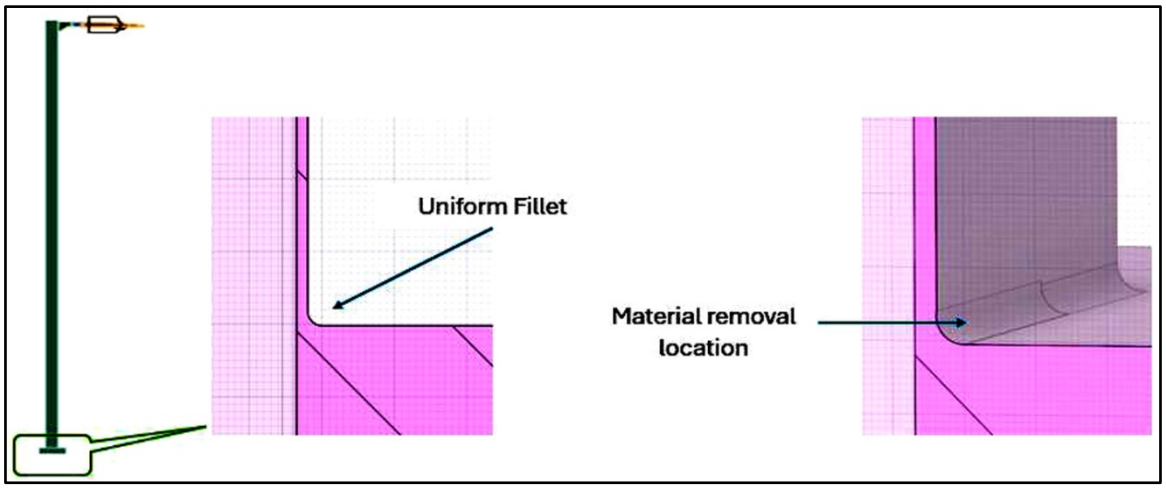


**Figure 1** a. original fillet at the base of the pole b. Removed material for the updated geometry

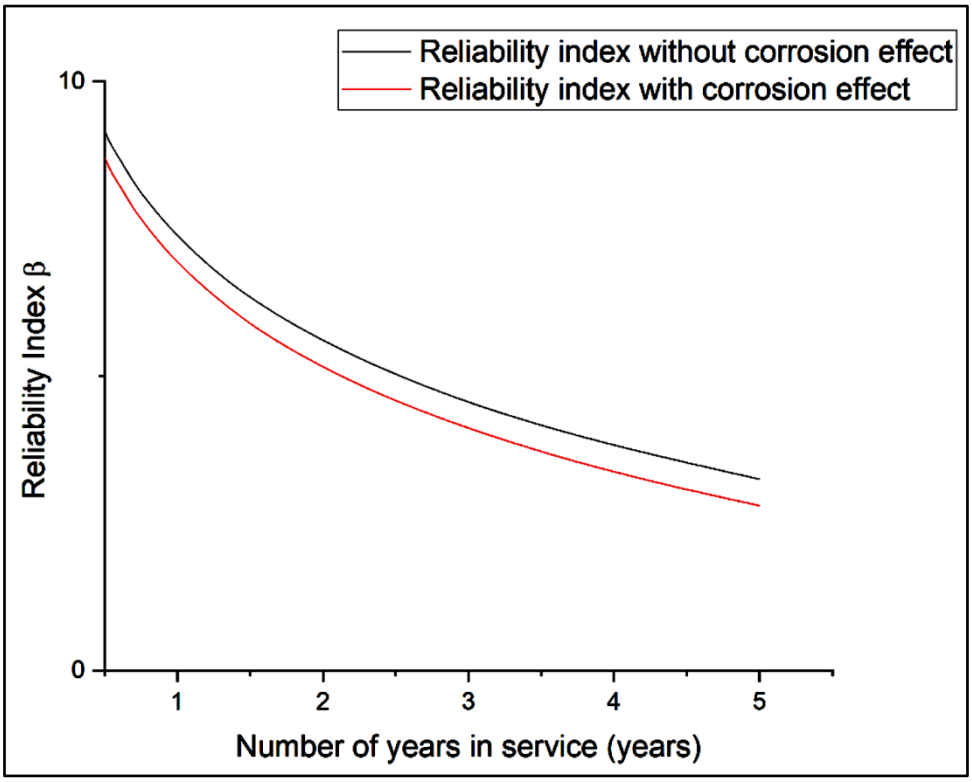


**Figure 2** Comparison of reliability indices due to corrosion impact

It is observed from the **Figure 2** that reliability index curve shift downwards when corrosive environment impact is included in the analysis. Though very small at the initial years, this gap increases more towards the increase in years in service. Considering the impact corrosive environment does it is advisable to inspect the system for the reduction in the material and corelate it with actual corrosion rate.

Expansion of Approach to Obtain Map Chart for Qualitative Risk Understanding

Typically, a state can have multiple wind zones, multiple humidity zones which can significantly change the probability of failure for a pole in a same state. To address this, we ran the whole analytical method for the state of Georgia. We selected multiple cities in the different wind zones to address the whole state. Considering all the data failure probability was calculated for each zone and map charts are prepared. These map charts provide failure

probability at the end of 5 years of service in field. Coastal area shows more probability of failure due to: Humidity induced corrosion and wind gusts which is reflected in map chart. These observations are evident from the **Figure 3**.

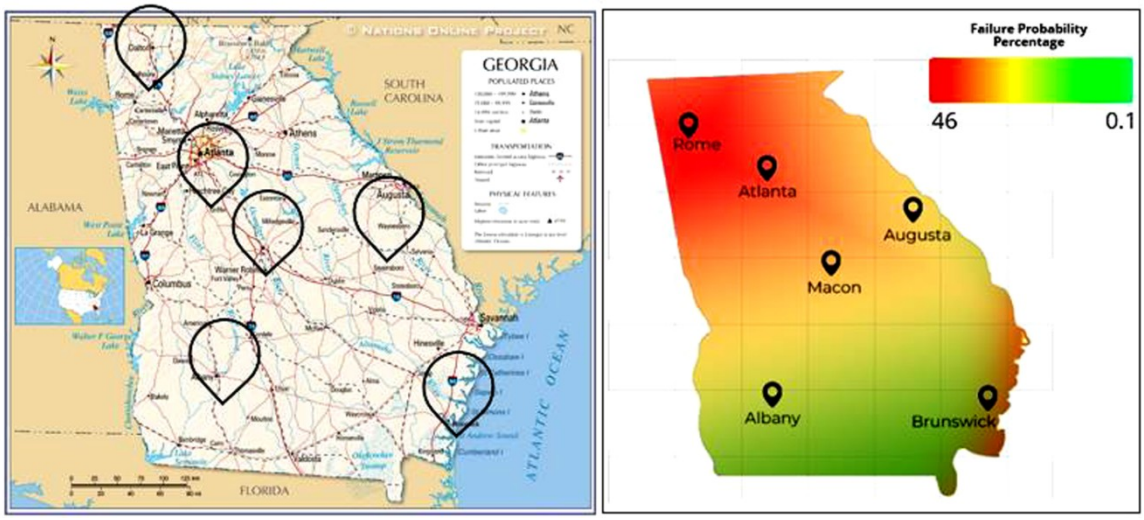


**Figure 3** Map charts for the probability of failure of a state Georgia

## CONCLUSIONS

This study encompasses impact of 3 major environmental factors that hamper the useful life of a luminaire-pole assembly namely wind, thermal cycling, and corrosion. From observation of actual failure specimen, it was observed that corrosion cracking is significantly affecting the life of the assembly. Effect of corrosion was observed and modelled and used in the reliability modelling in this paper. Once the available life potential is derived using the RUL curve, pole assemblies can be clustered into multiple zones based on inspection frequency required. Inspection frequency is a function of failure probability and hence separate inspection routine can be set up for different zones. Decision between Strengthening of the members (that is repairs) or replacement of the pole can also be taken based on time for which pole assembly is in the service. This whole procedure gives us the opportunity to optimize inspection incurred cost as well. This papers also provided qualitative areas for the selected state where more precaution for the system is needed. This information is provided through a map chart. Overall prognosis of a system which includes qualitative risk assessment to quantitative risk measurement can be understood from this paper will help engineers plan their inspection schedule accordingly.

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# Infrastructure

## Special Infrastructural System and New Technologies

36_IEC91205

# Evaluating the Structural Integrity of Gabion Walls under Repeated Lateral Loads using Alternative Infill Materials

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***Abstract:*** *Gabion walls are wire mesh boxes filled with broken rocks of suitable size. These boxes are stacked together to form a wall of large self-weight which can resist lateral loads. Gabion walls are usually used in the form of retaining walls and they prove to be a quicker and economical solution compared to the traditional reinforced concrete retaining walls. The present study aims to evaluate the engineering behavior of gabion walls under lateral repeated loading with infill combination of broken rock with construction and demolition waste. Double twisted factory manufactured gabion boxes with different wire diameters and mesh opening sizes are used in the study. The gabion specimen is tested using a reaction retaining wall which houses the specimen as well as allowing for lateral testing. The gabion box was tested for its load carrying capacity and deflection resistance against lateral monotonic and repeated loading. The results showed that the gabion wall has high ductility but comparatively low elasticity. The structural behavior depends on the dead load of the gabion and the arrangement of infill inside it. Also, it was seen that partially replacing infill stone with construction and demolition waste did not alter the strength of the gabion to a large extent.*

***Keywords:*** *Gabion Wall; Lateral Monotonic Loading; Lateral Repeated Loading; Deflection; Wire Mesh; Stone Infill*

## INTRODUCTION

A gabion is defined as a wire mesh container of different sizes, unvaryingly divided into internal compartments, interconnected with other similar components and filled with stone at the job site to form permeable, uniform structures for earth retaining and erosion control purposes, retaining walls, sea walls, channel facings, revetments, offshore bunds, dykes and weirs [1]. The different components of the gabion box are double twisted wire mesh, selvedge wire, edge wire and lacing wire. The tensile strength of wire used for lacing wire, double-twisted mesh and stiffener will be 350-550 MPa at a minimum elongation of 10%. The experiment is performed on a gauge length of test specimen as 200 mm. The specifications of gabion boxes are given in IS 16014:2012 [2].

In recent years, the interest in gabion structures is increasing drastically. This interest has been generated by the gabion's environmentally aesthetic features but additional interest is being developed by the versatility and advantages of gabion structure. Gabion structures are essentially cages made up of wire mesh which is filled with stones, rocks or sand. A gabion wall is a retaining wall made up of stones or rocks stacked layer by layer and confined inside a tied wire mesh. They can be stacked in any shapes from stepped walls to battering wall. As they dissipate energy from the flowing water, they allow water to pass through them but do not get washed away. As time passes the voids between the stones may get filled with silt, vegetation etc. This may increase the

strength of the gabion wall in some cases by reinforcing it with filled debris. One of the main aspects of a gabion retaining wall is its durability. The durability of the gabion wall mainly depends on the lifespan of the wire rather than the durability of the filler material. The wire mesh can be made up of galvanized steel wire or stainless-steel wire whose life expectancy can reach up to 60 years. The filler material should chiefly comply with the dimensional and structural characteristics.

It has been a long time since gabion walls have turned into an actual technical solution in the design, construction and conservation of a range of protective flexible assemblies. Gabions, by benefit of their outstanding strength, excellent engineering adaptability and dependability, have developed into selected building material for various construction works such as river training, road construction, weirs, control and training of natural and flood waters, earth retaining structures, water recharge dams, rock slide fortification, soil erosion protection and bridge protection.

## METHODOLOGY

The gabion specimen was tested on a reaction retaining wall platform which allows the specimen to be housed with bottom fixity and to be tested for lateral loading as well. Each gabion box was 1m in length, 0.3 m in width and 0.5 m in height. Two such gabion boxes were connected side by side to make one gabion specimen making the total size of 1 m × 0.5 m × 0.6 m. This gabion specimen was placed on the anchor bolts in the reaction retaining wall to make the bottom of the gabion fixed. A typical arrangement of the specimen test setup is shown in **Figure 1**. Different wire mesh diameters and mesh opening sizes are used to form gabion specimen. Also, two infills are used namely, stones and combination of stones and construction and demolition waste. Based on the above variables, the number of specimens were tested as given in **Table 1**.

Each gabion specimen type was tested for lateral monotonic and lateral repeated loading using a mechanical jack to apply load and proving ring to measure the same. The strain at the bottom of the specimen was measured using studs. The change in the known distance between two studs connected at the bottom of the specimen was used to calculate the strain. Also, deflection of the specimen at the top was noted for each load cycle.

**Figure 1** A typical testing setup for gabion wall

**Table 1** Details of various specimen tested in the study

| Specimen | Dia | Opening | Infill | Loading |
|---|---|---|---|---|
| S1_2.2ZN_STN_6x8_M | 2.2 Zinc | 60x80 | Stones | Monotonic |
| S2_2.7ZP_STN_10x12_C | 2.7 Z+P | 100x120 | Stones | Cyclic |
| S3_2.2ZP_STN_6x8_M | 2.2 Z+P | 60x80 | Stones | Monotonic |
| S4_2.2ZP_STN_6x8_C | 2.2 Z+P | 60x80 | Stones | Cyclic |
| S5_2.7ZN_STN_6x8_M | 2.7 Zinc | 60x80 | Stones | Monotonic |
| S6_2.7ZN_STN_6x8_C | 2.7 Zinc | 60x80 | Stones | Cyclic |
| S7_2.7ZN_STN_10x12_M | 2.7 Zinc | 100x120 | Stones | Monotonic |
| S8_2.7ZN_STN_10x12_C | 2.7 Zinc | 100x120 | Stones | Cyclic |
| S9_2.7ZP_STN_10x12_M | 2.7 Z+P | 100x120 | Stones | Monotonic |
| S10_3.0ZN_STN_10x12_M | 3.0 Zinc | 100x120 | Stones | Monotonic |
| S11_3.0ZN_STN_10x12_C | 3.0 Zinc | 100x120 | Stones | Cyclic |
| S12_2.2ZN_SCD_6x8_M | 2.2 Zinc | 60x80 | Stones+C&D | Monotonic |
| S13_2.2ZN_SCD_6x8_C | 2.2 Zinc | 60x80 | Stones+C&D | Cyclic |
| S14_2.2ZP_SCD_6x8_M | 2.2 Z+P | 60x80 | Stones+C&D | Monotonic |
| S15_2.2ZP_SCD_6x8_C | 2.2 Z+P | 60x80 | Stones+C&D | Cyclic |
| S16_2.7ZN_SCD_6x8_M | 2.7 Zinc | 60x80 | Stones+C&D | Monotonic |
| S17_2.7ZN_SCD_6x8_C | 2.7 Zinc | 60x80 | Stones+C&D | Cyclic |
| S18_2.7ZN_SCD_10x12_M | 2.7 Zinc | 100x120 | Stones+C&D | Monotonic |
| S19_2.2ZN_STN_6x8_C | 2.2 Zinc | 60x80 | Stones | Cyclic |
| S20_2.7ZN_SCD_10x12_C | 2.7 Zinc | 100x120 | Stones+C&D | Cyclic |
| S21_2.7ZP_SCD_10x12_M | 2.7 Z+P | 100x120 | Stones+C&D | Monotonic |
| S22_2.7ZP_SCD_10x12_C | 2.7 Z+P | 100x120 | Stones+C&D | Cyclic |
| S23_3.0ZN_SCD_10x12_M | 3.0 Zinc | 100x120 | Stones+C&D | Monotonic |
| S24_3.0ZN_SCD_10x12_C | 3.0 Zinc | 100x120 | Stones+C&D | Cyclic |

## RESULTS

The gabions specimens were tested and the respective deflection, strain and residual strain after each load cycle for cyclic loading were calculated. The typical variation of load with deflection are shown in **Figure 2** and the test results are shown in **Table 2**. Variation of deflection, load capacity and residual strain disclosed that gabion specimen of both infill types show similar behavior for 50% partial replacement of stones with construction and demolition waste.

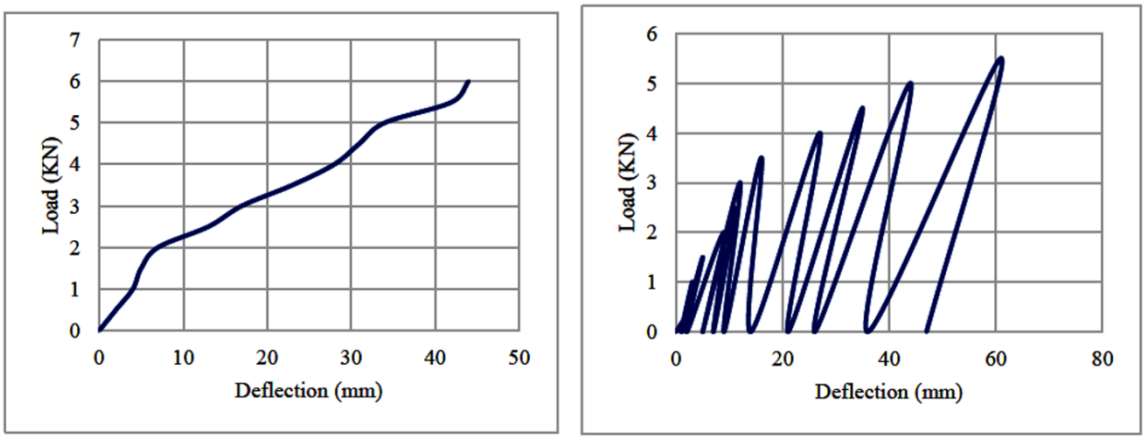


**Figure 2** Typical load v/s deflection variation for monotonic and cyclic loading

**Table 2**

| Specimen | Density (kg/cum) | Maximum load (KN) | Maximum strain | Maximum deflection (mm) | Residual strain |
|---|---|---|---|---|---|
| S1_2.2ZN_STN_6x8_M | 1523.333 | 5.333 | 0.061 | 57 | - |
| S2_2.7ZP_STN_10x12_C | 1458.333 | 5.500 | 0.042 | 124 | 0.03074 |
| S3_2.2ZP_STN_6x8_M | 1470.000 | 5.333 | 0.039 | 52 | - |
| S4_2.2ZP_STN_6x8_C | 1516.667 | 5.167 | 0.045 | 55 | 0.02027 |
| S5_2.7ZN_STN_6x8_M | 1481.667 | 5.667 | 0.045 | 55 | - |
| S6_2.7ZN_STN_6x8_C | 1495.000 | 5.167 | 0.042 | 55 | 0.02615 |
| S7_2.7ZN_STN_10x12_M | 1456.667 | 4.833 | 0.034 | 120 | - |
| S8_2.7ZN_STN_10x12_C | 1483.333 | 4.667 | 0.030 | 130 | 0.01631 |
| S9_2.7ZP_STN_10x12_M | 1486.667 | 5.000 | 0.045 | 143 | - |
| S10_3.0ZN_STN_10x12_M | 1431.667 | 5.333 | 0.048 | 128 | - |
| S11_3.0ZN_STN_10x12_C | 1418.333 | 5.667 | 0.066 | 137 | 0.03228 |
| S19_2.2ZN_STN_6x8_C | 1465.000 | 4.833 | 0.066 | 87 | 0.05464 |
| S12_2.2ZN_SCD_6x8_M | 1336.667 | 5.667 | 0.045 | 156 | - |
| S13_2.2ZN_SCD_6x8_C | 1405.000 | 5.667 | 0.078 | 141 | 0.05444 |
| S14_2.2ZP_SCD_6x8_M | 1330.000 | 5.000 | 0.040 | 132 | - |
| S15_2.2ZP_SCD_6x8_C | 1383.333 | 4.833 | 0.054 | 134 | 0.03604 |
| S16_2.7ZN_SCD_6x8_M | 1388.333 | 5.167 | 0.029 | 145 | - |
| S17_2.7ZN_SCD_6x8_C | 1358.333 | 6.167 | 0.047 | 113 | 0.04730 |
| S18_2.7ZN_SCD_10x12_M | 1341.667 | 5.500 | 0.043 | 125 | - |
| S20_2.7ZN_SCD_10x12_C | 1376.667 | 4.833 | 0.027 | 98 | 0.02117 |
| S21_2.7ZP_SCD_10x12_M | 1336.667 | 5.000 | 0.052 | 151 | - |
| S22_2.7ZP_SCD_10x12_C | 1371.667 | 4.833 | 0.035 | 150 | 0.02005 |
| S23_3.0ZN_SCD_10x12_M | 1340.000 | 5.000 | 0.036 | 135 | - |
| S24_3.0ZN_SCD_10x12_C | 1375.000 | 5.167 | 0.037 | 133 | 0.02560 |

## CONCLUSION

- It is seen from the results of various types of specimens that the load carrying capacity and resistance to deflection depends on the arrangement of infill material inside the gabion box.
- It is seen that the density of the gabion has no significant correlation with the performance of the gabion wall. For the same density of infill, the change in arrangement of infill could result in change in structural behavior of the gabion. Thus, the performance of gabion depends more on arrangement than the density achieved.
- It is seen that during monotonic and repeated loading tests, the infill of the gabion rearranges itself on application of load. This rearrangement depends on the amount of voids and the location of voids in the infill. Thus, during filling of the infill material inside the gabion, care has to be taken so that the stones do not have chance of filling up the nearby voids. This can be achieved by utilizing the shape of the stones.
- During repeated loading tests, it was seen that after each cycle of loading and unloading, there would be some amount of residual strain and deflection in the specimen. This is due to the fact that the rearranged infill cannot come back to its previous position completely on unloading.
- In general, the gabion walls with smaller opening size (60x80mm) performed better compared to gabion walls with larger opening size (100x120mm) and higher wire dia specimens performed better than lower wire dia specimens.

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86_IEC68132

# Self-Healing Nano Additives for Augmenting the Durability and Sustainability of Cement Composites

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***Abstract:*** *Self-healing nano additives are nanomaterials that can improve the durability and sustainability of cement composites by repairs at the nano-level. Nano titania, also known as nano-$TiO_2$, has a distinctive self-healing capacity whereby it not only increases the mechanical strength of cement composites and also concrete composites but also enhance the environmental remediation of cementitious systems by degrading organic pollutants thereby making it more durable & ultimately sustainable. Our paper reports the effect of adding hydrophobic 40 nm dia. nano-sized Titania (NT) particles by functionalizing them to hydrophilic via. surface modification or wrapping by new generation pH neutral polymeric admixtures & added them to cement: sand ratio of 1:3 with a water-cement ratio of 0.4. Mechanical strength results of the cementitious composites were taken at all terms up to 365 Days(D). The optimized quantity of NT as found in cement composites is then added to M-40 Grade concrete composites for compressive strength testing at both shorter & longer terms following Indian standard protocols. Results reveal that the application of NT in cementitious systems has an improved effect when compared with non-NT cementitious systems and also the former is more durable & sustainable. Photocatalytic NT is also time durable and the microstructural investigations disclose the crystallographic nature of NT, which is the main reason for their favourable mechanical impacts.*

***Keywords:*** *Cements; Self-healing; Nano-$TiO_2$; Sustainable*

## INTRODUCTION

The self-healing property of concrete is defined as its inherent aptitude to resist aggressive chemical attacks, weathering actions, abrasion, or any other progression of depreciation. Insufficient self-healing leads to many harmful impacts like, damage of strength, durability, and serviceability, corrosion, amplified cost of repairs, improved cost-benefit ratio, etc. While there are many elements affecting self-healing properties, the main being existence of advanced nanomaterials, cement types and water quantity/quality, manifestation of sulfate and chloride attacks, permeability, etc. Sulfate attack initiates from the presence of sewage in soil or soil foundation comprising excessive fertilizers or industrial wastes or automobile expends while chloride attacks arise from the salty sea environment within 100Kms of the coast. India has a huge coastline of more than 7500 kms with a harsh marine climate while out of the 30 most polluted cities in the world, 21 were in India [1]. So, the self-healing study of concrete demands the need for the hour. This paper discourses the consequence of adding nano-sized $TiO_2$ particles both in cement and concrete composites along with its self-healing influence on concrete from the harsh attacks of sulfates and chlorides.

Cement comprises of four principal clinker mineral phases: tri calcium silicate ($Ca_3SiO_5$), di calcium silicate($Ca_2SiO_4$),tri calcium aluminate($Ca_3Al_2O_6$) & tetra calcium alumino ferrite($Ca_4Al_2Fe_2O_{10}$)[2].Cement gets its strength from its reaction with water to form two products, viz. (i) Calcium-Silicate-Hydrate(C-S-H) gel which is responsible for its strength gain, and (ii) Calcium Hydroxide ($Ca(OH)_2$). This reaction(1) is also known as the hydration reaction due to the hydrated product formation is given below.

$$\text{Cement} + H_2O(\text{Water}) = \text{C-S-H (Calcium Silicate Hydrate)} + Ca(OH)_2 \quad (1)$$

Though C-S-H manifests its performances at the 10-9m (nano) levels, Calcium Hydroxide is treacherous as it serves as the main culprit for strength loss in the cement concrete matrix, through its reaction with outside chemical agents containing sulfate or chlorides.

In sulfate attack which is characterized by a whitish appearance on the concrete surface, this calcium hydroxide is

converted to calcium sulfate or secondary gypsum causing internal pressures in the cement concrete matrix due to its expanded volumes as shown in **Eqn.(2)**. Gypsum in turn reacts with hydrated calcium aluminates of cement to form ettringite (3) which is known for its extensive cracking and expansion. This results in loss of cohesion and cracks formation, thus making the concrete more porous and permeable. The reaction mechanism is shown below.

$$Ca(OH)_2 + Mg/Na_2SO_4 = CaSO_4.2H_2O(\text{secondary gypsum}) \quad (2)$$

$$CaSO_4.2H_2O + 2Ca_3Al_2O_6.12H_2O(\text{tri calcium aluminate}) = 3CaO.Al_2O_3.3CaSO_4.3H_2O(\text{Ettringite}) \quad (3)$$

Sulfate attacks the cement concrete matrix while chloride attack is characterized by corrosion on the steel reinforcements. Here, calcium hydroxide is converted to soluble calcium chloride (4) which in turn reacts with hydrated calcium aluminates of cement to form calcium chloro aluminates (5). The reaction mechanism is shown below.

$$Ca(OH)_2 + 2NaCl = CaCl_2 \text{ (soluble calcium chloride)} + 2NaOH \quad (4)$$

$$CaCl_2 + 2Ca_3Al_2O_6.12H_2O \text{ (tri calcium aluminate)} = 3CaO.Al_2O_3.CaCl_2.10H_2O \text{ (calcium chloro aluminates)} \quad (5)$$

**BRIEF DESCRIPTION**

All the above reactions are more predominant at the nanoscale levels than at micro-levels. Cement hydration yields more than 90% C-S-H products at 28 days but continues to hydrate in the long-term i.e.,1 year (365 days) albeit at a very small rate [3]. So, in our tests, we have measured results at 28 days and at long terms, i.e.,365 days. Optimized addition of nano-$TiO_2$ having mean particle size diameter in the range of 30-40nm has a unique self-healing capability, whereby it surges the mechanical strength of cement composites and concrete composites w.r.to the controlled samples due to supplementary C-S-H production as shown in **Figure 1**[4,5]. Also, the concrete samples cast with these nanomaterials resulted in increased workability and extra whitish appearances. However, this self-healing capacity of nano-$TiO_2$ is more palpable when it effectively peels off the aggressive chemical attacks of sulfate/chlorides as shown in **Figure 2**.

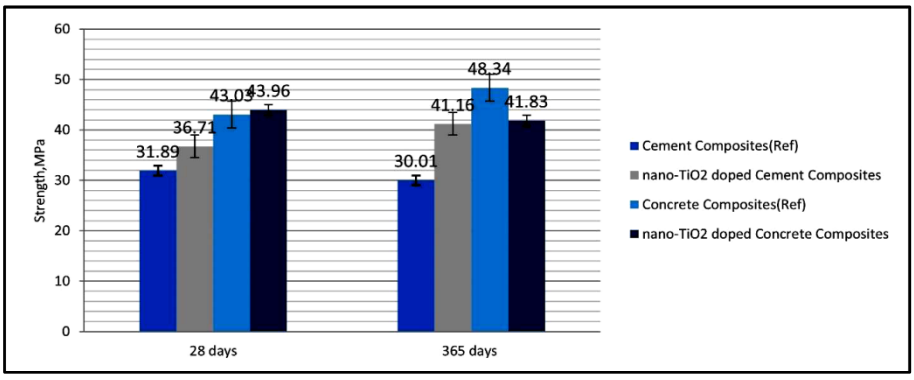


**Figure 1** Strength variations of cement & concrete composites with & without nano-$TiO_2$

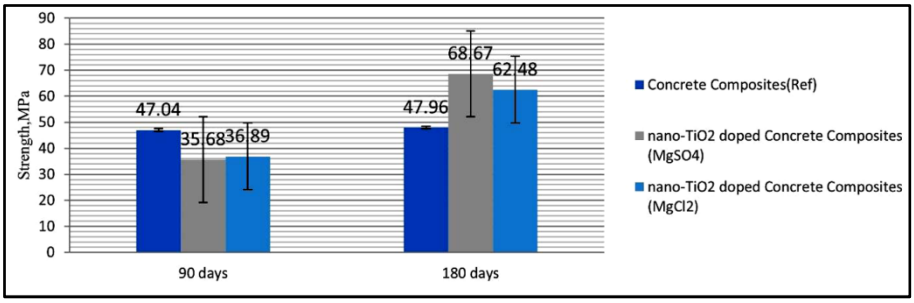


**Figure 2** Strength variations of cement & concrete composites with & without nano-$TiO_2$ in aggressive ($MgSO_4$/$MgCl_2$) exposures

It is to be noted from both the figures i.e., **Figure 1** & **Figure 2** that Nano-$TiO_2$ performs better in aggressive environments like $MgSo_4$/ $MgCl_2$ than in ordinary exposures, which may be attributed to its self-healing characteristics.

So, nano-$TiO_2$ could help in manufacturing high-strength concrete which in turn helps to make the concrete more durable, causing it to be more workable or flowable which is the main reason for its increased resistance to chemical attacks like $SO4^{-2}/Cl^{-1}$ hence with smoother exterior finish resulting in more deleterious substances decomposition thus making the end product greener. The photocatalysis mechanism of the self-healing materials has a disinfection mechanism which includes the decomposition of the cell wall and disinfection of novel viruses such as SARS-CoV and COVID-19[9].

The compound Titanium has applications in a wide range of industries from food coatings to construction to paints to sunscreen lotions. Its nano dimensions have proved to have more novel unique photo-catalytic properties than its parent bulk material as our Paper reports. This is due to the fact that when sunlight falls on nano-$TiO_2$ doped concrete, electrons are released which combine with $O_2$ in the atmosphere creating "$O^{2-}$" (Superoxide anion). As, a result of this discharge of electrons, nano-$TiO_2$ takes electrons from the moisture of the air and then returns to its original state. On the other hand, the moisture that lost the electron becomes a hydroxyl radical (•OH) resulting in a loss of moisture from the cement matrix system. As a result, chemical attacks of sulfate and chlorides could not be sustained in the second stage (see **Figure 3**), when the contribution of hydrated tri calcium aluminates from cement matrix comes into the picture due to the absence of moisture. Hence, hydrated products are not being attacked and the cement matrix continues to grow in strength.

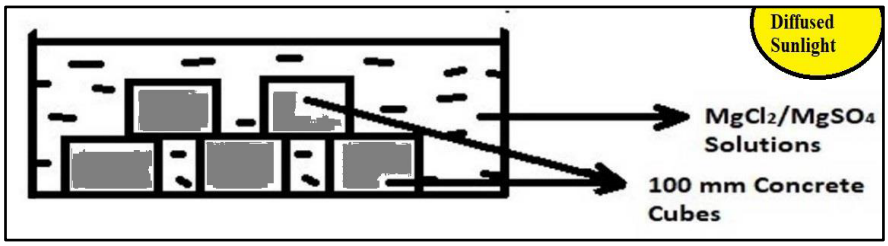


**Figure 3** Schematic representation of $MgCl_2$ and $MgSO_4$ exposure conditions for concrete

Energy conservation using the latest technology like Nanotechnology would help to conceptualize the principle of sustainability in today's climate change landscape, especially after the Covid-19 pandemic. Nanotechnology is said to have the potential to address the sustainability issues confronting the world and out of 17 Sustainability Development Goals (SDGs), it can directly influence 4 main themes namely – Sustainable resources, Safety, Healthcare, and Energy. Nanotechnology's Self-healing Nano Titania (NT) is an eco-friendly sustainable material as it can be synthesized from both agricultural by-products [8,9] and waste paints [10]. With differential rates of diffusion of nanotechnology, the world has been into a 'nano divide'- nano have & have-not countries. Nano-$TiO_2$ a product of nanotechnology has already been applied in many buildings as in the construction of Jubilee Church, Umberto Tunnel, and Ara Pacis archeological museum -Rome, Hotel-de-Police, Bordeaux-France [6,8]. The self-healing or cleaning properties have also been used to restore world-famous heritage paintings [7].


**Figure 4** Casted Nano Titania (NT) Cementitious Composites (left) and Reference Specimen (right)

## CONCLUSIONS

In conclusion, the study demonstrates that the incorporation of nano-$TiO_2$ into cementitious systems significantly enhances their self-healing capabilities. This is particularly evident in the ability of these systems to resist aggressive chemical attacks, such as those from sulfates and chlorides, which are common in harsh environmental conditions. The optimized addition of nano-$TiO_2$ not only improves the mechanical strength and durability of the composites but also contributes to their sustainability by increasing workability and providing a cleaner finish (see **Figure 4**). Furthermore, the photocatalytic properties of nano-$TiO_2$ offer additional benefits, including the potential for disinfection and environmental remediation. The findings suggest that nano-$TiO_2$ is a promising additive for developing high-performance, durable, and sustainable concrete for future construction needs

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119_IEC61765

# Autocross — an Automated Transit Shuttle System for Decoupling Pedestrians and Road Traffic

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***Abstract:*** *One of the prominent indicators of a country's growth is the consistency in infrastructural development and its engineering astuteness. Every country depends on its engineers to portray its capacity in building engaging solutions for the problems faced by its population. Advancement in technologies, world over, drives the engineers to work on enhancement over the existing solutions sometimes leading to path breaking outcomes. The success of an outcome of this nature is determined by the utility it provides to the users. Such a technology would primarily help overcome the problems faced by the existing solutions. As an unmistaken extension it would provide auxiliary benefits and set pathways for innovative solutions. In this paper, an automated technology to help pedestrians cross the roads involving heavy traffic is presented in detail to create awareness on the new technology. This paper is an extended arm of the Indian patent: 432636 granted on 23.06.2023[1]. The functionalities, salient features, advantages and auxiliary features are discussed in detail to spread the freshness and exquisite nature of such technologies.*

***Keywords:*** *Technology; Automation; Robot arm; Pedestrian; Traffic; Autocross*

## INTRODUCTION & BACKGROUND OF THE PROBLEM

The explosion in popularity of the automobile in the last 50 years has shifted the focus of street design from pedestrian traffic to automobile traffic. Even then, the congestion on roads has increased beyond capacity leading to delay, fuel loss, accidents and environmental pollution. Although motorization levels are increasing, still a large part of transport demand is met by walk in Indian cities. Walking has remained a vital means of transportation since long and is the most dependable and free of cost mode. The average walking trip length in kilometers in various city sizes varies from 0.8 km to 2.2 km [2-4]. Mumbai alone has 65 lakh pedestrians every day. So, the safety of pedestrians is an area of concern among current modes of transport [5].

Road accidents are a matter of great personal tragedy, tremendous social and economic costs in terms of valuable lives lost, medical treatment, insurance and damage to public and private property. In road transport, the number of fatalities has increased from 15,000 in 1971 to about 80,000 in 1999 [6]. Every road user is a pedestrian at some stage of the journey and is the main victim of fatal accidents. Even though the ninth five-year plan outlaid the broad items like engineering improvements, traffic control devices and wayside amenities, pedestrians share is above 40 percent of the total victims in Delhi [2,3,7]. On Mumbai roads 57 of every 100 people who die in accidents are pedestrians [5]. A few of the measures taken to enhance the safety of pedestrians for walking along the road and across the road are [4-9]:

- Provision of Footpath (Sidewalk)
- Foot over Bridges and Subways
- Traffic calming techniques
- Construction of Bypasses
- Delineators and Barricades
- Self-protection by Pedestrians
- Bus Shelters
- Pavement markings

**Problems Identified with the Existing Solutions for Walking Across the Road**

(i) **Subways**: It is unnecessarily huge. To cross a small stretch of the road a person must walk nearly 5 times the distance. People with health problems and physical challenges would find it hard to take the subways. It is not affordable by space and the cost involved. Most importantly it gets flooded during rainy season.

(ii) **Foot over Bridges**: The distance travelled is more than 5 times the actual distance climbing at least 60-100 steps on the stairway. Escalators are used in parallel these days but even this is open to atmosphere, dust and rain which would reduce their life [10, 11]. Both the subways and footpaths are not optimally utilized, since the pedestrians are reluctant to use them due to many reasons, like increase in travel time and distance, tiring when climbing the stairs, difficulty in carrying luggage, unsafe during non-peak hours, health reasons of old age people, etc. To install a subway or skywalk in front of every school, college, places of public transportation is practically not feasible.

(iii) **Zebra Crossing & Traffic Light**: There are about 338 pedestrian crossings without signal in Chennai alone. Even if there are proper signals, zebra crossings and police personnel regulating the pedestrian traffic, due to the exploding population, the constantly thickening traffic density helps only to bring the 'survival of the fittest' test even for a simple walk on the road. Pedestrians waiting for their "moment of luck" to cross the road at every school, college, places of public transportation and any other crowded junction are a common sight in our country. It is a "hurry-and-wait" scenario for everybody involved.

The provision of traffic signals for pedestrians in India is almost negligible though the studies show that users preferred the signalized crossings to the overpass or underpass crossings. It also shows that as the signal waiting time increases, pedestrians get impatient and violate traffic signals which place them at increased risk of being struck by a motor vehicle.

(iv) **Jaywalking**: Away from the signal points, pedestrians with no regulations to govern them, cross the road at multiple points and directions on the road. It is a scary adventure for the motorists when a person appears on the middle of the road out of nowhere. Even with all policemen on duty, vigilant youth and the unusual noble people there are moments when the pedestrians would be missing the oncoming high-speed vehicles just by a whisker.

Stretches of sidewalks are also not fully available for the pedestrians as they are being used for many other purposes such as operation of informal sector, parking of vehicles, movement of two-wheelers, extension of shops, etc. Other solutions are in the form of redesigning several of the city's busy junctions, creating refuge islands for pedestrians, installing dedicated pedestrian signals and encroachment-free walkways which face only minimum success in solving the problem.

**Objectives**

i. Develop an automatic transit shuttle system to move people across busy roads and junctions, through means of automation, without disturbing the vehicular traffic flow; by minimizing the total distance travelled in comparison to existing systems in a safe and modern way

ii. Minimize material usage and space occupied by the developed equipment leading to minimization of the cost of production and ease of installation

**PROPOSED SOLUTION**

To meet these objectives the proposed solution is presented as an outline in **Figure 1a**. The cross-sectional view of the invention is provided in **Figure 1b**. The paper presents in detail the Indian patent: 432636 granted on 23.06.2023 [1] as a solution to this problem.

It is a compact automatic transit shuttle system where rails are laid for carrying the wheeled mobile carriers over which the users make their transit under the road giving enough head clearance for people. At the place of boarding/alighting above the ground level a vertical transit mechanism travels downwards/upwards respectively, carrying people and gets locked on to the mobile platform for horizontal traverse. **Figure 2** shows the actual system intended, illustrating the major components and constraints.

- Apart from the regular operational and safety features this module should also be designed rain-proof with provisions for proper ventilation, air circulation, lighting and ambience.
- The entire mechanism could be made as an air-tight single unit that prevents water logging, allowing convenient entry and exit for the users. Apart from rails and boxed-chairs main system like motors, controllers and switches along with all the sub-systems like sensors, safety devices, lighting and other devices for comfort, power supply and associated ancillaries are also mounted inside the unit.
- Entire units could be brought readymade and put in place across the road inside the pit of required dimensions.

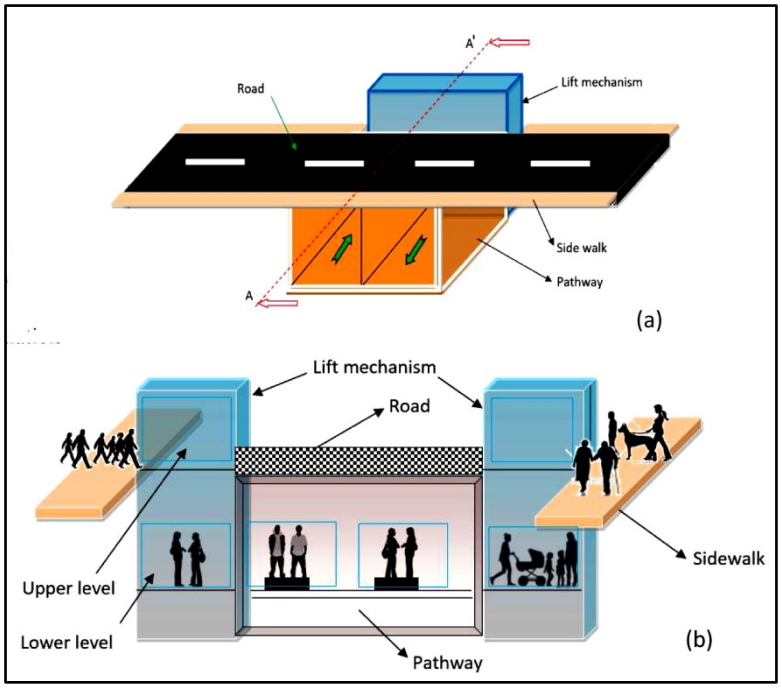


**Figure 1** Cross-section (A-A') of the automated mechanism pathway

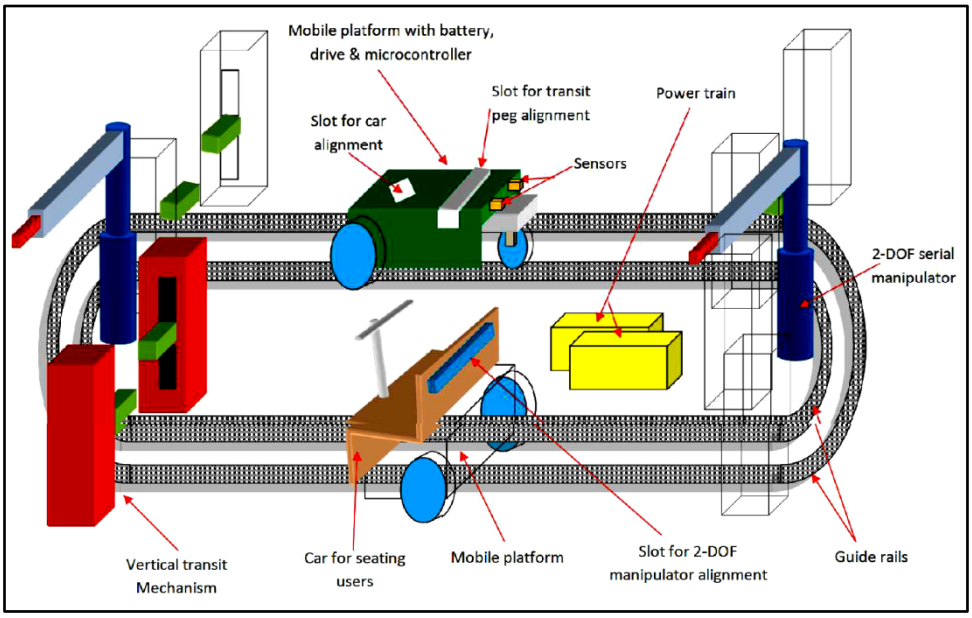


**Figure 2** Schematic representation of Autocross Mechanism

**Detailed Description**

The most important parts of this equipment Autocross are shown in the figure and are explained below:

(i) Vertical transit mechanism: The users embark and disembark through this entry and exit area provided above the road level. Once the doors are open the cars are available above the road level for the people to enter and sit/stand. The door shuts and the descent begin by lowering the car to the platform level for which a mechanism like that of fort lift vehicles or telescopic cylinder or of any Cartesian robot design could be used. The purpose of this mechanism on both sides of the road is to move up and down the road height carrying the car and mounting/unmounting the car on to the mobile platform. When the users board/alight the car, this mechanism holds it steadfast. Finally, it waits for the 2-DOF manipulator to transfer the cars to the adjacent transit mechanism and then moves to the opposite side of the road to repeat the tasks.

(ii) Cars: They provide the space for the users to sit/stand comfortably and move across the road in a safe manner. Cars are carried up and down the vertical transit mechanism and are carried across the road by the mobile platform. Once the users disembark the2-DOF mechanism shifts the cars to the adjacent transit mechanism for the next course of action. Handrails and other features are provided for safety. And provisions are also made for mating the forks of the transit mechanism and the arm of the 2DOF serial manipulator. Sensors like strain gauges are also added to avoid overload.

(iii) Rails: Two rails in parallel runs through the length across the road in both directions and are laid making an oval-shape. The distance between the rails stays constant. They are fixed to the floor providing the required support and not beyond the channel at the entry and exit. These guided rails carry and guide the mobile platform along the tracks. Position sensors in the form of LDRs, reed switches are also mounted for positioning the mobile platform for mounting and charging operations. Fig. 2 shows the track laid inside the channel.

(iv) Mobile platform: This is the carrier on which the users stand while holding the handlebar/rails as shown in Fig. 2. Two wheels at the back with a common axle are the driving wheels. Handlebar is connected to the single omni (Mecanum) wheel which can be turned left or right for steering. A lever could also be provided for controlling the speed of motor. The driving wheels are kept outside the tracks (Fig. 2) and the front wheel is kept in between the tracks. This allows the platform to take a turn along the direction of the laid tracks with the back wheel pushing it from behind.

- Sensors for proximity are provided in the front to avoid accidents. Other sensors like strain gauges, potentiometers and photodiodes (for stopping and positioning) are mounted as shown in the figure and are controlled by the microcontroller for various functions.
- Mechanical bumpers are also provided to avoid head on collision.
- It is on this platform, the car carrying the users is mounted to be ferried across the road horizontally.
- Slots are provided on this platform to align the car while mounting.
- Electromagnetic engagement and disengagement of the cars from the platform.
- Wheels that run on the side faces of the tracks are provided for alignment and safety.

(v) 2-DOF serial manipulator: As shown in Fig. 2, two serial manipulators with 2 degrees of freedom are provided at the two sides of the road in between the vertical transit mechanisms. This helps in shifting the cars from one side of the track to the other after the users have alighted at the exit. The height of the manipulator is above the road level and so could be mounted above the road level also. The payload capacity for this manipulator is very small since it carries only the empty car. The length of the arm is half the distance between the vertical transit mechanisms.

(vi) Microcontroller and Sensors: The brain of the platform controls the current to the motor based on user inputs and slows the motor when brakes are applied based on sensor inputs activated by the user while moving the corresponding lever. This microcontroller also senses the availability of platforms and based on that input the platforms would automatically follow the track and reach the other end. It also senses the availability of the cars at the entry and exit of vertical transit system. Other functions like overload, motor failure and emergency stop are programmed on to the microcontroller.

- A special function ‘Auto-mode’ can be used at the press of the switch when luggage is to be sent alone.
- PLC (Programmable Logic Controller) also could be used for its ruggedness in place of microcontroller.

(vii) Electric motor: Any electric motor with capacity to pull at least 150 kg on the track with an electronic drive is sufficient to move a person across the track.

(viii) On board battery: Since this equipment requires continuous power supply, an on-board battery is included to run the motor.

(ix) Charging by inductance: When the platforms are free from operation, they are positioned in places where they are charged by inductance method. Positioning in this case is controlled by the microcontroller.

(x) Regenerative Power: Vehicles constantly cross any busy junctions and their movement over an elastic speed breaker could be converted into current through a generator and could be used for lighting purposes after storing it in batteries

## WORKING AND THE CYCLE OF OPERATION & USAGE

The pedestrian approaches the entry, as the gates open takes the free space/chair/seat (along with his luggage) and presses the 'go' button which makes the car move down till it reaches the mobile platform and locks with it. The mobile platform carries the car with the load and crosses the road and reaches the vertical transit mechanism on the other side of the road which then carries the car to the exit, where it comes to a stop. The gate opens and the user walks out. The car is then shifted to the adjacent side for the cycle to continue.

Accordingly, a mechanism has been disclosed by which transportation of people and goods in places like heavy traffic junctions is made safe and easier by providing an automated shuttle based transit system below the road level in order to reduce traffic congestion and improve traffic flow, without mutual disturbance between the pedestrians and the oncoming vehicular traffic, and thus improving the living standards of urban based population while reducing the accidents caused by and on the pedestrians.

## CONCLUSION

Smart cities need smart infrastructure. To harness the benefits extended by the concurrent technologies innovations in infrastructure are to be embraced. The equipment would need only a minimum time for installation and would take minimum effort to install in comparison to the existing systems. From the commuters' point of view this is a hassle-free transport system with maximum safety, minimum efforts and minimum intervention. This would also help in segregating the pedestrian traffic from vehicular traffic either in time or space. In short, it would save lives, time, effort and money both in the shorter and longer run and most importantly bring peace of mind for the commuters both on legs and vehicles.

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# Manufacturing of Indigenous Tribal Bi-Component Fibres for Technical Textile Sector

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***Abstract:*** *Modern sportswear and activewear must incorporate both fashionable and functional elements. These are primarily meant for professional sports, where the pursuit of victory is paramount. [1–3]. Sports and activewear needs to have superior moisture transmission behaviour in order to be deemed comfortable. During an activity, sweat needs to evaporate quickly to keep the skin temperature stable. Improved moisture transmission properties of fabrics can be achieved by altering the cross-sectional shapes and morphologies of the fibres. The best way to address this is to modify the current fibre manufacturing process to produce fibres with different cross-sectional shapes and morphologies in order to achieve improved comfort and performance. The demand for more comfortable sports and activewear in India is driven by the country's youth and active population, and this demand is influenced by the country's climate. Trilobal cross-sectional fibres are superior to circular-shaped bicomponent fibres in terms of wicking or moisture transport, opacity, light weight, and specific surface area. By making modifications to a melt spinning machine and adding a spinneret and spin pack in the proper arrangement, these bicomponent fibres can be made. This article addresses the various forms of bicomponent fibres, their advantages and disadvantages, and applications. The construction of an indigenous melt spinning facility to create core-sheath trilobal bi-component fibres is also a topic of discussion.*

***Keywords:*** *Bi-Component Fibre, Tri-Lobal, Technical Fibre, Core-Sheath, Wicking, Melt-Spinning*

## INTRODUCTION

A wide variety of fibres with different cross-sectional shapes are produced by nature. Cotton has dog bone shapes, wool has oval shapes, jute has hexagonal shapes, and flax has polygonal shapes. Each of these cross-sectional shapes offers different levels of specific area that can be used for different purposes by changing its surface energy[1]. There are enough engineering opportunities in synthetic fibres to create trilobal-shaped fibres, and these opportunities should be carefully and methodically investigated. However, there are still issues with the shape factor of cross-sectional shapes in terms of their viability, application, and practicality. It is necessary to create fibre surfaces and/or fabrics with strong optical absorption, light-to-thermal conversion, and water transport capabilities. Then, these textiles can be efficiently combined with wastewater sinks to produce extremely high interfacial evaporation rates.

Mr. Upendra Kumar Gupta, Deputy Advisor at NITI Aayog, claims that the fastest-growing segment of the Indian textile industry is technical textiles. The nation's overall market share for technical textiles is 4-5% worldwide, considerably less than that of the United States (23%), the Western European Union (22%), China (11%) and Japan (7%).

The global market for technical textiles is projected to increase from USD 164.6 billion in 2020 to USD 222.4 billion by 2025 with a CAGR of 6.2% (https://www.marketsandmarkets.com /Market-Reports/technical-textile-market-1074.html) . In the worldwide technical textile market, India accounts for 5–10% of the market. Technical textiles account for 0.7% of the GDP of India and make up about 13% of the textile and apparel market there. With an average growth rate of 15-20%, the National Technical Textiles Mission aims to increase the domestic technical textile market to $40–50 billion by 2024. The Made in India initiative, international technical collaborations, investment promotions, market development, and market promotion will all be used to achieve this.

Over the past ten years, Asia has emerged as a major player in the production and consumption of technical textiles, with China at the forefront. Korea, Japan, India, and Taiwan are the other major players in the technical textile market on the Asian continent. Technical textile production requires the development of specialised high-performance fibre,

state-of-the-art production facilities, and cutting-edge technology.

Indian businesses have begun producing ballistic fabrics, safety-related textiles for soldiers at high altitudes, and technical textiles for autos. In 2018, India's technical textile export revenue was Rs. 14,013 crore. From January to June 2018, this sector's overall trade deficit was Rs. 1,100 crores, but by January to June 2019, it was only Rs. 523 crores. This suggests that India's technical textile industry is thriving and capable of reaching international markets.

Bi-component fibre is one of the most crucial raw materials used in the technical textiles industry for applications in clothing, home textiles, automotive, healthcare, and industrial textiles. In India, bi-component fibres are currently imported despite having a high demand on both the local and global markets due to a lack of manufacturing facilities in the country. There could be an in-house state-of-the-art melt spinning facility that manufactures bi-component products to cater to the textile industry in India. These days, in order to become self-sufficient in this area as well, our nation must produce its own equipment using domestic technology.

Thus, in order to achieve increased comfort, the current work is conceptualised for the development of the bi-component fibre manufacturing setup and the preparation of different fibres. Various cross-sectional shapes point to an undiscovered source of modified material that might be used to develop new, related products and, to some extent, enhance the functionalities of existing ones. If one looks closely at nature, one finds that forms are necessary for the completion of their activities and functions. Weaving, knitting, or braiding regular circular fibres cannot create the interconnected three-dimensional network that sponge gourds' diverse networks do. A crucial component of surface activities is the available surface area, which is increased by applying non-circular cross-sectional shapes. Several research groups worldwide are trying to construct various cross-sectional shapes for product development using such nature-inspired techniques.[4–6]. The literature indicates that the preparation of fibres and filaments with engineered functionalities is a result of proper spinneret, spinpack, and spinneret orifice design. Although there are a few basic design guidelines available, the knowledge base is not very large.

Our goal in this work is to create distinct trilobal cross-sectional shapes that can be used to develop various technical textiles with improved moisture transportation, filtration, opacity, controlled drug delivery, and so on. Additionally, a lab-scale prototype is to be developed to show off the melt spinning facility for these purposes.

**BICOMPONENT FIBRES**

Textile fibres are made of polymers with molecular orientation preferentially along the fibre axis. The polymers can be natural or synthetic polymers with certain fibre forming qualities. With enough potential, synthetic fibres can be engineered for a versatile application range, from complex composite materials to airbags. Depending on the desired fibre potential and the characteristics of the materials, melt, dry, or wet spinning can be used to produce fibres. The achievement of diverse cross-sectional shapes, tensile strength, modulus, and additional chemical properties is a likely outcome for manufactured fibres[5,7]. This definition of bicomponent fibres states that "a filament or fibres manufactured by extrusion of two different polymers from the same spinneret with both polymers contained within the same filament." The American Society for Testing Materials (ASTM) defined a bicomponent fibre as one that is made up of two polymers that differ either chemically or physically. Bicomponent fibres are extruded by combining two molten or dissolved different fiber-forming polymers, which converge at the spinneret exit and have different cross-sectional appearances, such as core/shell or core/sheath (C/S), an island in the sea (I/S), and side by side (S/S).Bicomponent fibres can be developed by selecting bicomponent polymers, and these fibres showed different conductivities, self-crimping, increased flame retardancy, piezoelectric effects, etc. Figure 1 illustrates how melt-spinning is used to produce the most common and widely produced core/sheath (C/S) type bicomponent fibres, in which the sheath polymer continues to be responsible for providing necessary functionalities while the role of the core polymer bearing themechanical properties.[8,9]. In addition to the two fiber-forming polymers, certain compatible additives are also combined with these polymers to expand the range of required physical attributes and desired functionalities. To create antimicrobial flame retardant fibre, flame retardant fillers should be combined with core polymer and antimicrobial fillers with sheath polymer. In addition to conventional microdenier fibres, nano diameter bicomponent fibres are also made for tissue engineering, controlled drug delivery, fine filtration, and other applications relating to medical textiles[10,11].

Nanofibers are made by centrifugal spinning, melt-blown, electrospinning, and electro-spraying techniques[12]. In order to create various kinds of bicomponent nanofibers with extra functions, electrospinning has undergone several changes in the modern era[13]. The production of core/sheath bicomponent nanofibers can be achieved through the use of both coaxial and emulsion electrospinning techniques (Tian et al., 2015). It is found that side by side (S/S) fibre configurations are easier to work with than core-sheath (C/S) bicomponent fibres[14].

**Bicomponent Fibre**

Developing bicomponent fibres has as its main goal exploring capabilities not available with a single polymer. No other method of manufacturing fibres can produce fibres with the cross-sectional shape that bicomponent fibres can. Bicomponent fibres are categorised below primarily on the basis of their cross-sectional shape.

**Side-by-Side (S/S) Bicomponent Fibres**

These kinds of bicomponent fibres, which are represented by S/S fibre in **Figures 1-3**, have two components that are positioned side by side. S/S fibres are typically produced by maintaining two or more components for the full length of the fibre. In order to successfully manufacture side-by-side bicomponent fibre, there must be enough adhesion between the two components to prevent any chance of disintegration. Typically, the two polymers are fed to the spinneret separately in the form of melt or solution and combined. Successful multilayer deposition requires the smooth or turbulence-free arrival of both polymer components. The orientation of the spinneret exit holes needs to cross the interfaces between different polymer layers.

The production of fibres with a broad range of compositions, from 100% of one component to 100% of the other through all intermediate compositions from 1 to 100%, is made possible by the holes in the polymer layers not precisely following the interfaces. The shrinkage behaviour of both polymers is altered in S/S fibre, making it suitable for self-crimping applications. On the other hand, a different method of producing self-crimping fibres is predicated on the distinct electrometric characteristics, both reversible and non-reversible, of the constituent polymers. The swelling behaviour of the components determines the crimp characteristics, which are reversible and non-reversible. The factors that affect the properties of S/S bicomponent fibres are thermal shrinkage, cross-sectional shape, shape and diameter of individual filaments, melting point, etc.

**Core/Sheath (C/S) Bicomponent Fibres**

As seen in **Figure 2**, these bicomponent fibres are those in which the second component, the sheath, envelops the first component, the core. For these fibres to remain intact, a high degree of adhesion is required. In order to preserve integrity, a highly countered core structure is recommended if the adhesion between the sheath and core polymer is relatively low. This kind of bicomponent fibre is needed when one of the polymers' properties, like stability, dyeability, or lustre, should be present on the surface and the core can add strength, lower cost, etc. When planning a C/S bicomponent fibre, the viscosity ratio of the polymers used to create the core and sheath is an essential factor to take into account; the viscosity of the core polymer should be higher than that of the sheath-forming polymer. The sheath, a high-tension zone, can be driven by the coaxial flow technique with a lower viscosity polymer[15]. With a single spinneret orifice, C/S bicomponent fibres can be produced thanks to the nature of these polymers. Since the non-woven industry uses polypropylene core and polyethylene sheath bicomponent fibres extensively to create thermally bonded non-woven sheets, they are the most widely used bicomponent combination from a production standpoint[16]. PET with a low melting temperature in the sheath and a high melting temperature in the core are also frequently used to create another well-liked bicomponent fibre[4].

**Citrus or Segmented Pie Structure**

As seen in **Figure 3**, this kind of fibre cross-sectional structure is created by extruding two distinct fiber-forming polymers that are each alternately divided into segments. Segmented pie structures and other polymeric combinations are successfully made with polyethylene terephthalate (PET) and Nylon 6 polymers. In general, there are an even number of segments. Segmented pie structure fibres are extruded, and then their web is split by a high-pressure air or

water jet. Using this method to manufacture hollow fibres becomes difficult and requires standard engineering manufacturing techniques.

Fibre cross sectional shape has a significant influence in wicking across the fabrics (**Figure 3**).

**Tri-Lobar Cross-Sectional Shape**

A trilobar cross-sectional shape with a low shape factor improves the fabrics' ability to wick away moisture [17]. When the trilobal shape is used, the equivalent fibre diameter increases proportionally for a given linear density (dtex). Less light may pass through the resulting nonwoven because of the large dimension fibre lobes, which increase fibre coverage. In comparison to round fibres, the amount of mineral charges (i.e., TiO2) added to the fibres can be greatly decreased to achieve comparable opacity levels in the related nonwovens. This results in a notable increase in production line efficiency and a subsequent decrease in system costs. When compared to regular round options, the trilobal bicpomponnet fibre nonwovens exhibit a greater nonwoven thickness when comparing the same Dtex fibres. A more open structure with improved air permeability is also associated with a higher nonwoven bulkiness.

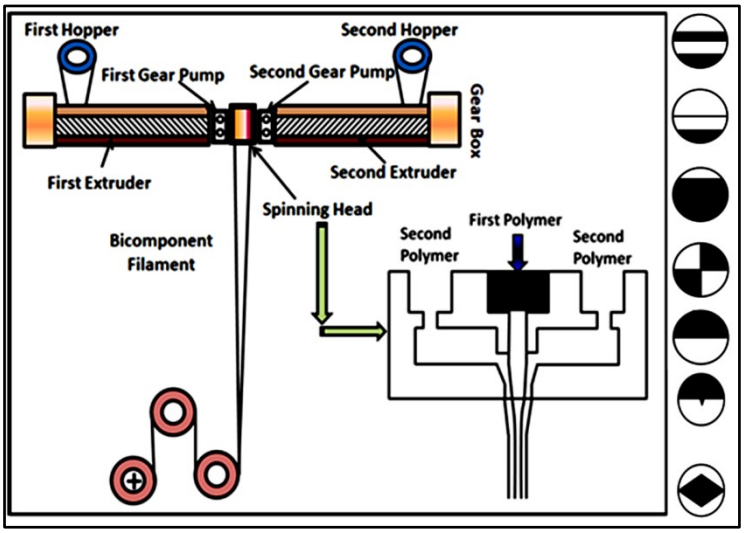


**Figure 1** Schematic diagram of bi-component melts spinning machine with various shapes of bi-component fibres (Right side)

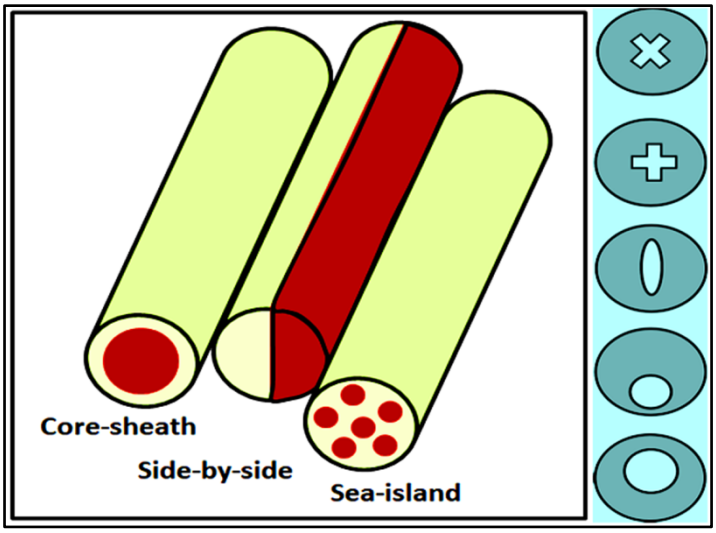


**Figure 2** Structures of Bicomponent Fibres and various core-sheath configurations

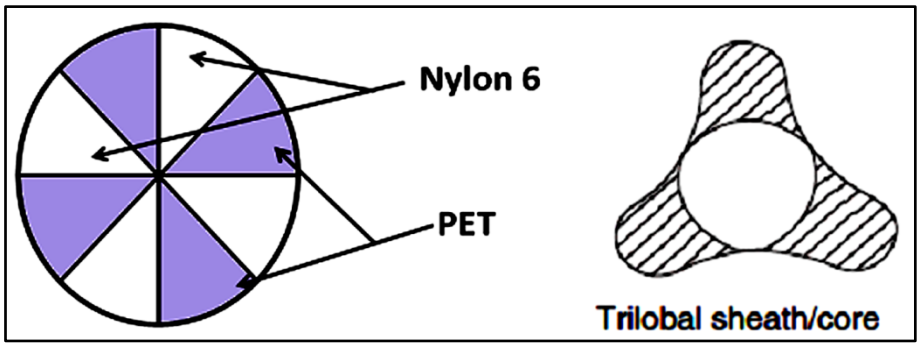


**Figure 3** Segmented Pie Structure and cross-sectional shape of a trilobal sheath-core bicomponent fibre

## CORE-SHEATH FIBRES

Two distinct polymers that travel through a spinneret are spun into bicomponent fibres. various bicomponent fibre cross-sections, such as C/S, S/S, and I/S. Although metals, cellulose, and other fillers can also be utilised in these fibres, synthetic polymers are the usual materials for fibre spinning. Although the production of C/S bicomponent fibres is more difficult than that of S/S, numerous reports and patents demonstrate their greater utility. C/S fibres can also be configured differently. One of the key factors in the fibres that has been previously studied with regard to the idea that the core material should have a higher viscosity ratio is the viscosity ratio of C/S materials. This indicates a tendency for higher viscosity polymers to settle in the core. Stated differently, in coaxial flow, the lower viscosity fluid is driven to the higher tension areas (sheath). Using this phenomenon, bicomponent fibres can be spun by passing mutual polymers—either dissolved or melted—through a single nozzle. Among bicomponent fibres, polypropylene (PP)/polyethylene (PE) fibres with a PP core and a PE sheath are currently produced in the greatest quantities. Because the shell material melts at a lower temperature, these fibres are used in the nonwoven industry for thermo-bonding. Bicomponent fibres also yield a low melting temperature polyester (LMPET) sheath and a high melting temperature polyester (HMPET) core, which makes them suitable for use in nonwoven, cleaning, and isolation products.

## APPLICATIONS

High-performance polymeric fibres are used in textile applications like cables that need to be stiff and strong in tension, rockets, bulletproof vests, composite structures, and firefighter apparel. Bicomponent fibres have many uses, as was previously mentioned. For example, spunbond nonwovens, self-healing composites, optics, electronics, etc. The largest market for bicomponent fibres is the nonwoven sector. Among these uses are cleaning, sports, and flooring products. Another common technique to give nonwoven fibres additional characteristics is to use different fillers. In order to create a new generation of artificial turf, C/S bicomponent fibres are developed. Additionally, they introduced liquid core fibres for new uses in optics, drug delivery, and damping. One important feature for bicomponent fibres in optics is the core/cladding structure of optical fibres. These fibres can also be utilised in the production of composites. Polyester (PET) composites have been reinforced by compression moulding using melt-spun LMPET/HMPET C/S bicomponent fibres. While the fibres are created through spinning, nanomaterials such as carbon nanotubes (CNTs), nanoclay, silver nanoparticles, etc., can be incorporated into the core or shell portion of nanocomposite fibres. Bicomponent fibres can be given new properties for use in electronic or smart clothing products by incorporating conductive or magnetic nanomaterials into the core section. Some of these sophisticated functional fibres could be employed to create artificial vessels or muscles. For bicomponent fibres in optics, the core/cladding structure of the optical fibres is an important feature. These fibres can also be used to make composites. By compression moulding, melt-spun LMPET/HMPET C/S bicomponent fibres have been utilised as reinforcement in polyester (PET) composites. Nanomaterials such as carbon nanotubes (CNTs), nanoclay, silver nanoparticles, etc. can be incorporated into the core or shell of nanocomposite fibres, while the fibres themselves are created through spinning. Bicomponent fibres with a magnetic or conductive nanomaterial in the core section may acquire new characteristics that make them suitable for use in electronic or smart apparel products. Certain sophisticated functional fibres have the potential to be employed in synthetic organs, such as vessels or muscles. Bicomponent

fibres with antibacterial properties are also widely used in medicine. Biodegradable polymers can give C/S fibres additional biological and cell proliferation properties during the fibre spinning process. The range of applications for bicomponent fibre spinning and treatment technologies will continue to expand in the future due to their steady advancement.

## CONCLUSIONS

The significance of bi-conjugation in synthetic fibres is emphasised in this article. Consequently, the traditional method of producing C/S fibres, known as bicomponent melt spinning, can be developed. Through the use of complementary materials (polymers and liquids) and a variety of fillers, C/S bicomponent fibres have recently found extensive applications in nonwoven, biotechnological, electronic, and sport flooring applications. The importance of these materials and products for various applications in the future will increase with the development of new materials and the establishment of novel methods. One of the most important raw materials used in the technical textiles sector for applications in the home, clothes, healthcare, automotive, and industrial sectors is bi-component fibre. Bi-component fibres are currently imported because there are no manufacturing facilities for them in India, despite the high demand for them on the international market. The Indian textile industry may be served by an in-house, cutting-edge melt spinning facility that produces bi-component products. These days, our country needs to create its own equipment using homegrown technology in order to become self-sufficient in this area as well.

## ACKNOWLEDGMENTS

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231_IEC78856

# Border Security Lighting: Comparison and Implementation of Different Types of Photometric Distribution

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***Abstract :*** *Border security lighting is a new age security lighting where object should be visible from 140M distance. To cover this high distance becomes very challenging. Earlier day's combination of two optical distribution luminaires were used to achieve that criteria. But now a days, due to rapid growth of LED, any type of distribution can be done by using different structure of lens. Here in this paper, different types of lens photometric distribution is simulated based on the criteria of CPWD Border Fencing Security criteria and after that the combination satisfied the criteria is tested in practical field.*

***Keywords:*** *Security Lighting; Border; Light Emitting Diode(LED); Vertical Illuminance; Uniformity*

## INTRODUCTION

Border security lighting is an emerging new chapter in security lighting. Earlier in days security lighting [1] was achieved by using normal market oriented Streetlight or Floodlight. Now in the world of 21st century, labors are replaced by artificial intelligence. Same in case of security lighting, the role of cameras is becoming more and more important than human eyes. [1] Cameras with sensor can trigger the notification of intruders. Being a sensitive region, in international border areas the authority now a days uses high frequency infrared cameras along with security personnel. To detect the intruders from the other side of the border, vertical illuminance plays a pivotal role than horizontal illuminance. [2] Also lighting should be like minimum back throw achievable so that the intruder cannot able to see the security personnel standing behind the pole position. Here we will discuss about how to achieve the required vertical illuminance by simulating with different market available lens.

## SCOPE OF STANDARDS

In border lighting, here we are going to follow the tender document of CPWD Border Fencing Circle [3] where different vertical illuminance at different distance is recommended. The values are fixed in different tenders. The wattages of the luminaires are changing based on requirement but the main criteria is to meet the vertical illuminance[3].

The luminaries field performance for each of the observer position (namely, at the Pole and at 50 Mtrs. from the Pole), as per following will be checked: [3]

(i) The point wise lux levels achieved in Grid size of 10mtr (Horizontal) x 10 mtr (Vertical) (at a height of 1.5 mts above ground level). [3]
(ii) The back throw light at 1.5 mtrs, 3 mtrs and 4.5 mtrs. behind the BFL Poles. [3]

The following minimum vertical illumination in lux (at a height of 1.5 mts above ground level) and Uniformity ratios are intended to be achieved taking into consideration a maintenance factor of 0.80 in the designing with the proposed configuration of LED Flood Light Fittings[3]

The back throw of light towards the observer should be less than 0.5 lux (with uniformity greater than 0.4)[3].

**Table 1** Vertical Illuminanance requirement at Border Security Lighting

| S. No. | Description of item and Periphery of the boundary where min. illumination is desired | Min. Illumination and Uniformity ratios (Min/Avg) |
|---|---|---|
| (i) | At a distance of 140 Mtrs from the BFL Poles (towards international border) | Min. 2.0 lux with UR > 0.5 |
| (ii) | At a distance of 100 Mtrs from the BFL Poles (towards international border) | Min. 2.5 lux with UR > 0.5 |
| (iii) | At a distance of 60 Mtrs from the BFL Poles (towards international border) | Min. 4.5 lux with UR > 0.5 |
| (iv) | At a distance of 30 Mtrs from the BFL Poles (towards international border) | Min. 6.0 lux with UR > 0.4 |

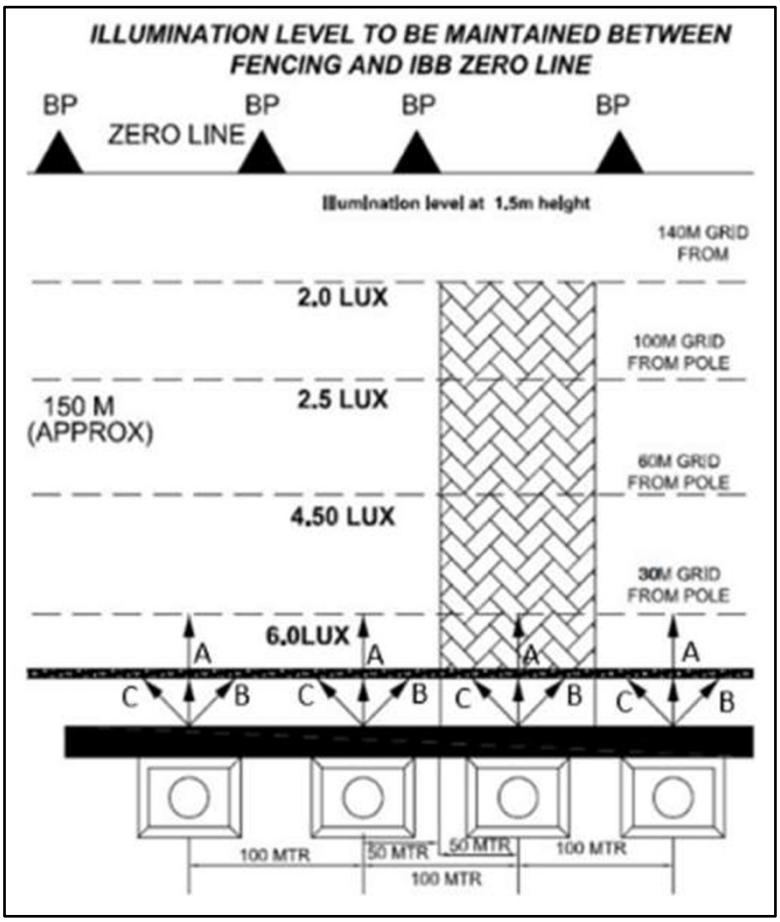
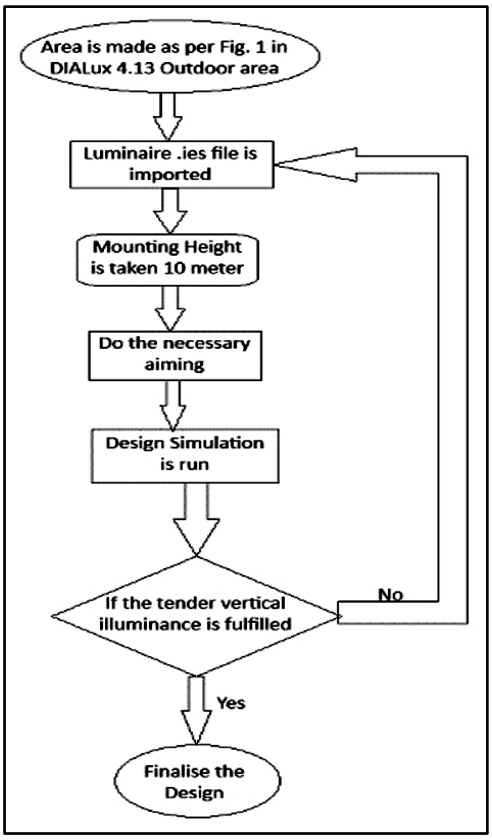



**Figure 1** Schematic sketch for lighting simulation area

**Figure 1** shows the schematic sketch for the area consideration while designing. In this figure each pole consists of three nos. luminaires which are denoted by A, B and C. Here 1.5M measurement height is taken considering the average human height of 1.5M from ground so that camera can detect the human face.

## DESIGN METHODOLOGY

Here we have used Conventional Luminaires which were used in earlier border fencing security lighting and 130W LED Luminaires of 120 Lumen/Watt system luminous efficacy of different photometric distributions.




## LUMINAIRES AND PHOTOMETRIC DISTRIBUTION

**Table No. 2** shows different Luminaires and their photometric distribution that is used in this design simulations. The Luminaires combinations in each pole is varied based on A, B and C (**Figure 1**) with specific legends that are described in **Table No. 3.**

**Table 2** Luminaires and their photometric distribution

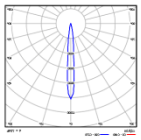
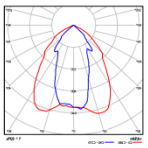
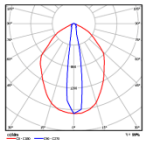
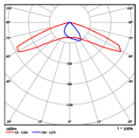
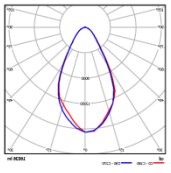
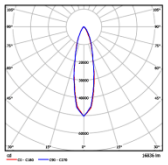
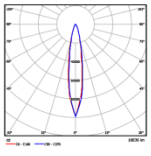
| Luminaire | Photometric Distribution | Luminaire | Photometric Distribution | Luminaire | Photometric Distribution |
|---|---|---|---|---|---|
| 250W HPSV Luminaire |  | 2X400W HPSV Luminaire |  | 130W LED Asymmetrical Luminaire |  |
| 130W LED Batwinged shaped distribution Luminaire |  | 130W LED Floodlight 60Degree Beam Angle Luminaire |  | 130W LED Floodlight 30Degree Beam Angle Luminaire |  |
| 130W LED Floodlight 15Degree Beam Angle Luminaire |  | | | | |

**Table 3** Luminaires combination used in design simulation

| Sl. No. | Legend | Luminaire A | Luminaire B | Luminaire C |
|---|---|---|---|---|
| 1. | CB1 | 250W HPSV Luminaire | 2X400W HPSV Luminaire | 2X400W HPSV Luminaire |
| 2. | CB2 | 130W LED Asymmetrical Luminaire | 130W LED Asymmetrical Luminaire | 130W LED Asymmetrical Luminaire |
| 3. | CB3 | 130W LED Batwinged shaped distribution Luminaire | 130W LED Batwinged shaped distribution Luminaire | 130W LED Batwinged shaped distribution Luminaire |
| 4. | CB4 | 130W LED Floodlight 60Degree Beam Angle Luminaire | 130W LED Floodlight 60Degree Beam Angle Luminaire | 130W LED Floodlight 60Degree Beam Angle Luminaire |
| 5. | CB5 | 130W LED Floodlight 30Degree Beam Angle Luminaire | 130W LED Floodlight 60Degree Beam Angle Luminaire | 130W LED Floodlight 60Degree Beam Angle Luminaire |
| 6. | CB6 | 130W LED Floodlight 15Degree Beam Angle Luminaire | 130W LED Floodlight 60Degree Beam Angle Luminaire | 130W LED Floodlight 60Degree Beam Angle Luminaire |
| 7. | CB7 | 130W LED Floodlight 30Degree Beam Angle Luminaire | 130W LED Floodlight 30Degree Beam Angle Luminaire | 130W LED Floodlight 30Degree Beam Angle Luminaire |
| 8. | CB8 | 130W LED Floodlight 15Degree Beam Angle Luminaire | 130W LED Floodlight 15Degree Beam Angle Luminaire | 130W LED Floodlight 15Degree Beam Angle Luminaire |

## RESULT ANALYSIS

After simulating the different combinations in DIALux 4.13, the results are represented in graphical format with comparison with tender standards values.

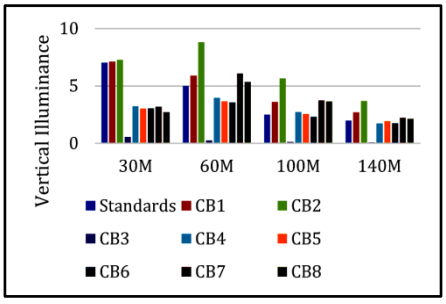



**Figure 3** The Vertical illuminance comparison for different combinations towards border area

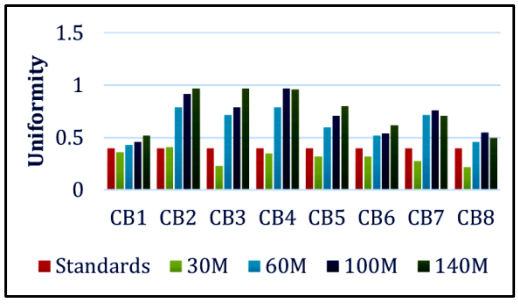



**Figure 4** The Uniformity comparison for different combinations towards Border Area

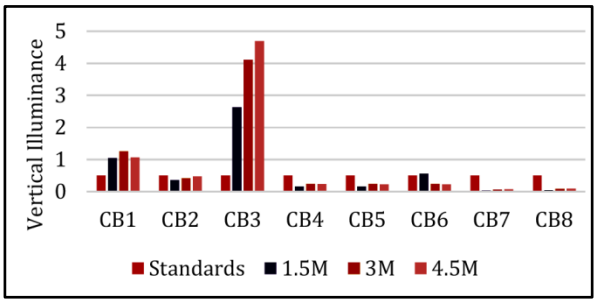



**Figure 5** The Back-throw comparison for different combinations

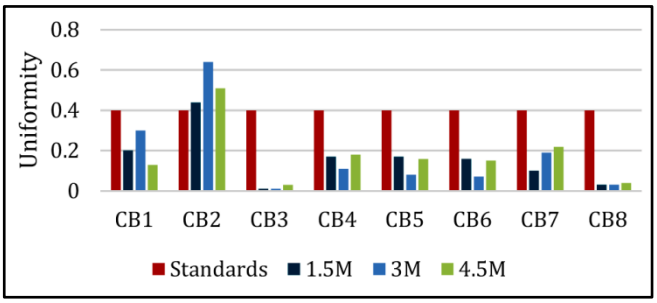



**Figure 6** The Back-throw Uniformity comparison for different combinations

From the **Figure 3**, only CB1 and CB2 satisfies the criteria of illuminance, but from **Figure 4**, only CB2 satisfies the uniformity criteria. In case of back-throw illuminance and uniformity, only CB2 satisfies the criteria. The combination CB2 is installed in site and checked the values.

## ON-SITE MEASUREMENTS

The on-site measurement is done by mounting the 130W LED Asymmetrical Luminaire in three poles at Indo-Bangladesh Border on January, 2023. The weather conditions were Dusty foggy weather.

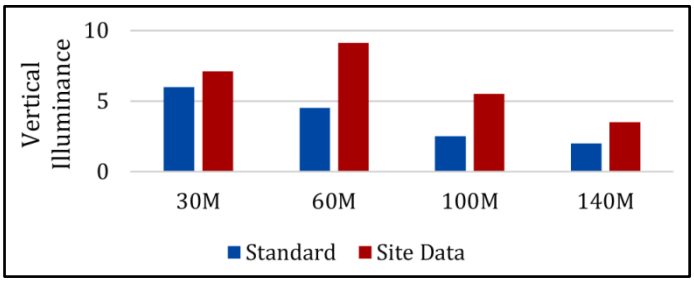



**Figure 6** Comparison between Site measurement data and standard data

## CONCLUSION

Due to heavy fog conditions, the back-throw of luminaires become higher. If it was tested during clear weather, the light level at back-throw will be decreased and light level to the front is increased. From the above analysis and from site obtained data it is clear that the CB2 combination is suitable for border security lighting where one component of distribution throws the light to far and other component of distribution spreads the light.

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# Infrastructure

## Sustainable Material for Infrastructural Systems

46_IEC75597

# Investigation on Behavior of Concrete Modified with Water Hyacinth Fiber

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***Abstract:*** *As we know concrete is brittle in nature, and have low strength against tension, so it has significant negative impact on the environment, human health, or both. The object of this study is development of environmental friendly concrete by incorporating natural water hyacinth fibers into the mix. The hyacinth fibers of lengths of 10 cm, 15 cm and 20 cm, added to the concrete in varying amounts of 0%, 0.3%, 0.4%, 0.5% and 0.6% of the concrete's volume. Cubes of 15 cm × 15 cm × 15 cm standard size are tested for compressive strength after 7 days, 14 days and 28 days curing. The specimens were cured by being fully submerged in a water tank at ambient temperature until the designated test age. Comparison of strength achievement of concrete based on percentage of water hyacinth fibers and curing period were done properly. After careful observation some important remarks have been drawn, which can be used for future research work.*

***Keywords:*** *Fiber Reinforced Concrete; Geopolymer Concrete; Lignocellulosic Fibers; Natural Fiber; Sustainability; Water Hyacinth Fiber*

## INTRODUCTION

As we know concrete is brittle in nature, and have low strength against tension, so it shows significant negative impact on the environment, human health, or both. These materials can contribute to pollution, environmental degradation, and health hazards. They often have characteristics such as toxicity, non-biodegradability, or high carbon emissions, among others. We have to point it out and get solutions for the use of such materials through a sustainable way to maintain healthy ecosystems for living creatures of the universe [1].

Use of fiber reinforced concrete (FRC) may be the most effective way to overcome this trouble. FRC having carbon fiber and carbon nanotubes that have the ability to act as a sensor. This have potential to develop smart devices with structural healthcare capabilities. It is required investigate the feasibility of adding cellulose fibers as it is recyclable, biodegradable and sustainable [2]

Adding fibers to concrete with proper proportions give a resilient matrix which is more ductile and minimize the formation of cracks, than conventional one. And incorporation of natural fiber provides a sustainable approach to safer way to the development of infrastructure.

By precisely evaluating the relevant factors and conducting comprehensive testing and analysis, it can be determine, how feasible it is to incorporate natural fibers into traditional concrete or geopolymer concrete. If properly implemented, this could results a sustainable concrete solutions that offer improved mechanical properties while significantly minimizing negative environmental impact [3].

Cracks in concrete can spread rapidly if not controlled, leading to a loss of strength and eventual failure. To improve the crack resistance of concrete, adding fibers to the mix is an effective solution. These fibers help to prevent microcracks from forming and make the concrete more ductile. However, most of the fibers used today are made from synthetic materials like steel, glass, carbon, and polypropylene, which are not environmentally friendly, and enhances environmental threats further. For this emphasis on development of alternate materials is more which can be used as fibers for reinforcement. With due time natural fibers from coconut, banana, sisal leaves, jute and water hyacinth are being tried out by different researchers [4].

## LITERATURE REVIEW

Water hyacinth, scientifically labeled as Eichhornia crassipes, is a buoyant aquatic plant originating from South America. However, it has spread extensively across tropical and subtropical areas globally. It reproduces rapidly and forms dense mats on the surface of lakes, ponds, rivers, and canals. Despite its attractive purple flowers, water hyacinth poses significant challenges. Its rapid growth disrupts native ecosystems by blocking sunlight and depleting oxygen levels, harming aquatic life and biodiversity. Water hyacinth causes serious problems to fisheries, irrigation, drainage system and public health as it completely cut the sunlight and oxygen approach to the water body at extremely rapid rate and thus affect the economy of that area [5].

Water hyacinth, which is a big problem for aquatic environments, can be used in the production of geopolymer concrete, which is in other way cost effective also[6].

The water hyacinth fibre-reinforced polymer composites exhibit acceptable mechanical properties for concrete strengthening applications. Moreover, their use offers environmental advantages compared to conventional alternatives, making them a promising solution for sustainable construction practices. This provide a significant contribution to the growing trend of utilizing eco-friendly materials and recycling technologies in the construction industry, addressing both environmental challenges and economic considerations [7].

Considering material costs and sustainability, addition of natural fiber is one of the best way to enhance the mechanical properties of concrete, which reduce the chance of hairline cracks as well.

## RESEARCH GAP

The use of water hyacinth is new in concrete technology, large scale research work is required to achieve a proper environmental friendly use. Water hyacinth may be used in different forms. It may be of ash form to substitute the cementitious material, of pulverized form to substitute the fine aggregate percentage. Water hyacinth extract can be used as super plasticizers. The fiber extracted from water hyacinth is our subject of discussion. The object of our study is to find the usefulness of water hyacinth fiber in concrete composite in a sustainable manner.

## PHYSICAL AND CHEMICAL PROPERTIES OF WATER HYACINTH FIBER

According to the research work of Ajithram Arivendan et al (2023) the density of the fiber is 1.33 g/cc and chemical properties of the fiber are cellulose 65.4 (wt %), hemicellulose-12.8 (wt %), lignin 7.2 (wt %), wax 0.24 (wt %) moisture 3.2 (wt %) ash 6.53 (wt %). The comparatively lower density is suitable to produce lightweight fiber reinforced composite material. The mechanical strength of fibers, particularly tensile strength and modulus, is influenced by the cellulose content present. In the case of water hyacinth fibers, they boast a high cellulose content which contributes significantly to their mechanical strength. Additionally, these fibers have minimal wax content, which enhances their bonding properties when incorporated as reinforcement [8].

## EXTRACTION OF FIBER

There are various methods to extract water hyacinth fibers. The methods are mechanical extraction, alkali treatment, aerobic and anaerobic retting etc. For a good quality and quantity of fiber, mechanical extraction method is better to have individual strands than any other methods. After about five days of anaerobic retting, it is easy to extract fiber with better strength. Another method which gives fiber with better tensile strength and individual strand is alkali treatment method but the diameter is reduced in this process. The clean surface of the fiber thus produced has better adhesion quality suitable for use in composite material. Moreover unlike cotton and other natural fibers, water hyacinth fibers possess a channel-like surface structure which enhances the suitability of water hyacinth fibers for composite materials where surface morphology significantly influences adhesion and mechanical properties [9].

## METHODOLOGY

Experimental studies on M25 grade concrete specimens, prepared by incorporating water hyacinth fibers, offer

insights into the potential improvements in concrete properties achieved through varying fiber proportions. These studies are crucial for understanding how the addition of natural fibers can enhance concrete performance, providing a sustainable solution that meets the evolving demands of the industry.

**Figure 1** Water hyacinth fiber and concrete mix

To prepare test specimens PCC cement [as per JSW cement manufacturing company, conforming to IS 16415], natural river sand and coarse aggregate with, maximum size of 20 mm were used. The mix designed to achieve a cube strength of 25 MPa after 28 days curing. Cube specimen size for compressive strength were 150 × 150 ×150 mm.

**Table 1** Concrete Matrix with fiber added by percentage of total concrete volume

| Total concrete volume | Water hyacinth fiber percentage | Water hyacinth fiber weight (kg) | Cement (Kg) | Water (Kg) or (Liter) | Fine Aggregate (Kg) | Coarse Aggregate (Kg) |
|---|---|---|---|---|---|---|
| 1 $m^3$ | 0% | 0 | 391.00 | 191.59 | 673.142 | 1145.28 |
| | 0.3% | 3.99 | 389.83 | 191.00 | 671.12 | 1141.80 |
| | 0.4% | 5.32 | 389.44 | 190.80 | 670.45 | 1140.70 |
| | 0.5% | 6.65 | 389.05 | 190.60 | 669.78 | 1139.50 |
| | 0.6% | 7.98 | 388.65 | 190.40 | 669.10 | 1138.40 |

Considering the Specific gravity of composite cement PCC = 2.88 [10], Coarse aggregate [at saturated surface dry (SSD) Condition] = 2.74 [IS-10262], Fine aggregate [at saturated surface dry (SSD) Condition] = 2.65 [IS-10262], Water hyacinth fiber = 1.33 [8]

## TESTS ON CONCRETE CUBES AND RESULTS

The test was carried out according to IS 516-1959 standards. Concrete was mixed with 0%, 0.3%, 0.4%, 0.5%, and 0.60% of water hyacinth fibers having different length of 10 mm to 20 mm, by concrete volume fractions were casted for 7th day, 14 day and 28th day to explore the result of added fiber on properties of concrete. All specimens were prepared in university laboratory. The coarse aggregate was mixed first, followed by the cement, sand, water hyacinth fibers, and water. After 24 hours, the molds were removed, and the specimens were cured in a moist environment for 28 days. Before testing, the specimens were thoroughly dried. The compression test, commonly performed on hardened concrete, is widely used because it is simple and because many of concrete's key properties are directly related to its compressive strength.

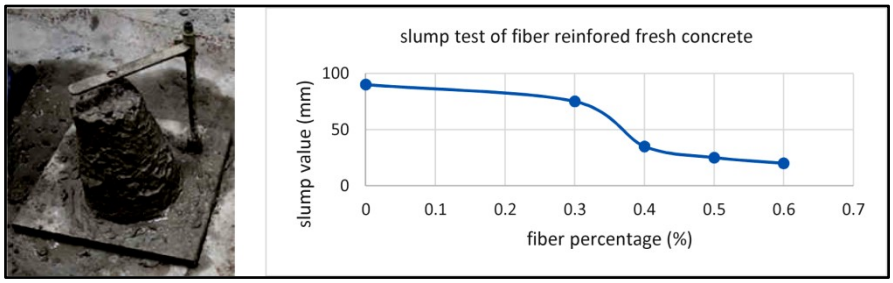


**Figure 2** Slump Test of fresh concrete

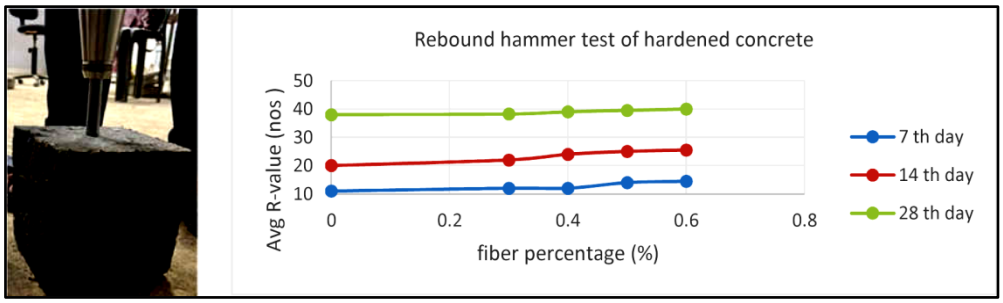


**Figure 3** Rebound Hammer Test (NDT) results after curing of 7th, 14th and 28th Days

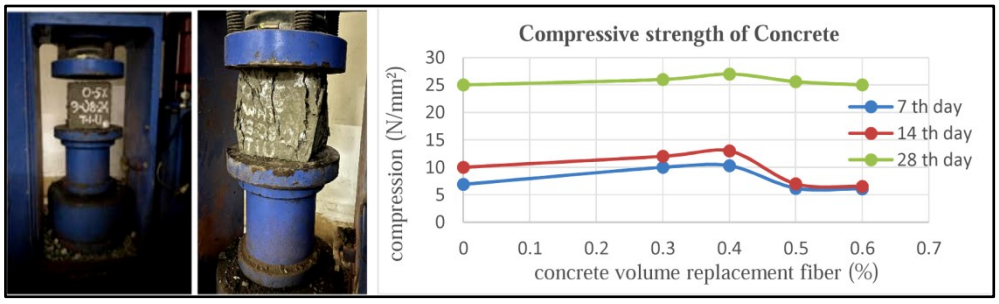


**Figure 4** Compressive Strength Test Results after curing of 7th, 14th and 28th Days

## CONCLUSIONS

- Examination findings demonstrate that concrete cubes with a 0.5% substitution of water hyacinth fiber (WHF) for total concrete volume fraction exhibit relatively high compressive and tensile strength.
- The workability inversely proportionate to the amount of fiber addition i.e. with the increase in fiber addition observed decrease in concrete workability.
- Development of light weight concrete is possible using WHF which is ideal for construction industry.
- The lower cost of natural fibers can make natural fiber-reinforced composites an attractive option, especially in applications where cost-efficiency is a priority. However, this advantage must be compared with the other factors such as strength, durability, and performance requirements in specific applications.
- More research should be focused on the durability aspects of water hyacinth fibers so that they can be effectively utilized.

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84_IEC8644

# Measuring Bitumen Consistency: A Journey through Penetration, Viscosity and Performance Grades

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***Abstract**: The consistency and performance of bituminous materials are pivotal in ensuring the durability and efficiency of road pavements. This study delves into the evolution of grading methodologies for bitumen, spanning from the rudimentary penetration and viscosity grades to the more comprehensive performance grading system. Historical practices, such as the penetration test introduced in the early 20th century, provided foundational insights but were limited by their empirical nature, failing to capture the rheological complexities of bitumen across varying temperatures. The transition to viscosity grading addressed some limitations by incorporating temperature susceptibility; however, challenges in managing intermediate and low-temperature behaviours persisted. Performance grading, a paradigm shift driven by the Strategic Highway Research Program (SHRP), evaluates bitumen under diverse stress and climatic conditions, aligning binder properties with real-world performance metrics like rutting, fatigue, and low-temperature cracking. This paper critically examines the limitations of the current grading systems, especially in the Indian context, where diverse climatic and traffic conditions demand a more tailored approach. It underscores the need for systematic data collection on ambient and pavement temperatures and proposes a robust framework for selecting binders based on rheological performance. By highlighting the shortcomings of existing standards and suggesting refinements, the study aims to advance bitumen grading practices, ensuring enhanced roadway durability and resilience.*

***Keywords:** Bituminous Material; Road Pavement; Consistency Test; Temperature; Traffic Load*

## BACKGROUND AND STUDY MOTIVES

The consistency of bitumen is primarily measured to differentiate among the various bitumen samples sourced from different crude origins. The grading system allows for the appropriate selection of bitumen for construction purposes based on its physical and rheological properties. Historically, before modern refining processes were developed, natural bitumen was widely used in construction, with notable sources such as Trinidad Lake bitumen. In the early 20th Century, methods like the chewing test were used by asphalt specialists to assess the consistency of bitumen. This was done by chewing the material to gauge the amount of pressure needed. Other basic methods, such as visually inspecting the bitumen sample and testing its solubility in carbon disulphide, were initially used for quality control. This was particularly important since natural bitumen often contained high levels of mineral impurities.

The binders were classified into grades based on measurable parameters correlated with field performance. The penetration grading system, developed in the early 1900s, utilized the penetration value at 25°C to specify parameters. However, this empirical method measured 'consistency' at a specific temperature without detailing the rheological behaviour of bitumen. To address these limitations, viscosity grading was introduced by ASTM D3381 in the early 1960s, grading bitumen based on viscosity at 60°C and 135°C to reflect maximum pavement temperature and mixing temperatures, respectively. This approach considers parameters such as softening point and ductility. Despite these advancements, variations in real-world pavement temperatures necessitated a grading system that ensures consistent performance across a range of temperatures, leading to the development of the performance grading system, grading bitumen based on rutting, fatigue, and low-temperature cracking parameters.

The primary objective of this study is to present a comprehensive review of the limitations in the current viscosity grading system, with a specific focus on the method outlined in IS 73:2013, as it applies to Indian roads. Given the specific climatic conditions and practical challenges in pavement performance, it is imperative to assess whether these grading systems adequately address the requirements for consistent performance under the varying temperature conditions as witnessed across the country. In this context, the current investigation offers a detailed analysis emphasizing the need for systematic collection of ambient and pavement temperature data over extended periods. This would help develop a comprehensive temperature database, guiding the conversion of air temperature to

pavement temperature and enabling a more accurate selection of bitumen in accordance with the performance grading system.

## EVOLVING CONCEPTUAL FRAMEWORK - A JOURNEY THROUGH PENETRATION, VISCOSITY, AND PERFORMANCE GRADES

Penetration testing of bitumen underwent significant evolution since its invention by HC Bowen in 1888, originally named the Bowen penetration machine. Over the years, ASTM and the Federal Highway Administration modified it into the modern penetrometer. The first specification for the consistency check of bitumen was established by the Bureau of Public Roads in 1918, focusing on penetration at 25°C (considering the average service temperature of pavements in the United States). This specification was formally published by AASHO in 1931. While penetration testing equipment is simple, cost-effective, and portable, it is empirical, testing bitumen consistency at a specific temperature without capturing fundamental properties. The test subject's bitumen to high and non-uniform shear rates, potentially misrepresenting bitumen behaviour across varied temperatures. For example, different bitumen samples may exhibit the same penetration value at 25°C but differ significantly in behaviour across other temperature ranges, highlighting the limitations of penetration grading in accounting for temperature susceptibility.

Figure 1 highlights the limitations of penetration testing in accurately capturing variations in bitumen consistency from different sources. The figure demonstrates this through an example where bitumen from three distinct sources shows identical penetration values at a specific temperature yet exhibits significantly different characteristics and behaviours across a broader temperature range. This highlights that the temperature susceptibility of bitumen can vary significantly between different sources over a range of temperatures. Assessing consistency solely at 25°C may lead to all bitumen samples being classified similarly, which may not be accurate. The figure clearly shows how the consistency of bitumen from sources A and C differs from that of source B, though they may converge at a specific temperature, $t_0$. This illustrates a limitation of the penetration testing method. Studies suggest that the primary flaw of the penetration test lies in its empirical nature, as it only provides index properties and lacks control over temperature sensitivity related to pavement conditions.

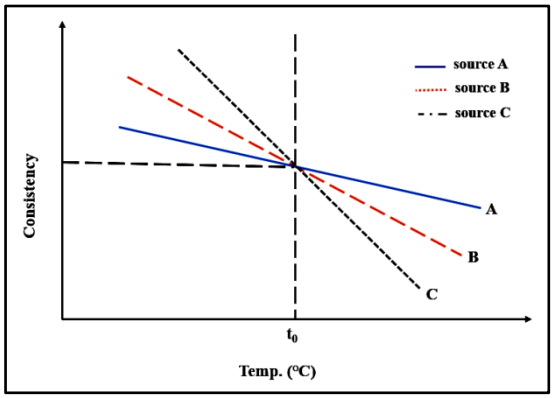


**Figure 1** Limitations of penetration testing in capturing variations in consistency of bitumen from different sources.

## METHODOLOGICAL EVOLUTION

The methodological evolution in bitumen grading began with the introduction of the penetration grading system. In the 1960s, the California Department of Highways developed the aged residue (AR) viscosity grading system to address tender mix issues experienced during construction. This system required tests for penetration at 25°C, viscosity at 60°C and 135°C, and ductility on aged binders. Recognizing that viscosity is a fundamental property of bitumen, this system provided better control over temperature susceptibility and rutting resistance in temperature extremities [1, 2]. The first edition of IS 73 was published in 1950, primarily for asphaltic bitumen and fluxed mastic asphalt used in road construction. The first revision, solely focused on paving grade bitumen, was released in 1961 and included various test methods. Subsequent revisions incorporated evolving standards and introduced waxy and non-waxy bitumen classifications based on differing behaviours at extreme temperatures [3,4]. By 1992, the

specification for penetration grading was aligned with the then-global standards. A significant shift came with the third revision in 2006, transitioning to the viscosity grading system [5]. Viscosity grading in India was denoted as VGX (VG representing viscosity grade and X signifying the viscosity number at 60°C). The specification was refined in 2013, which included provisions based on the seven-day average maximum air temperature at the construction location [6]. This ensured appropriate binder selection to meet specific climatic conditions, which brought in a range-based absolute viscosity requirement and refined penetration value criteria.

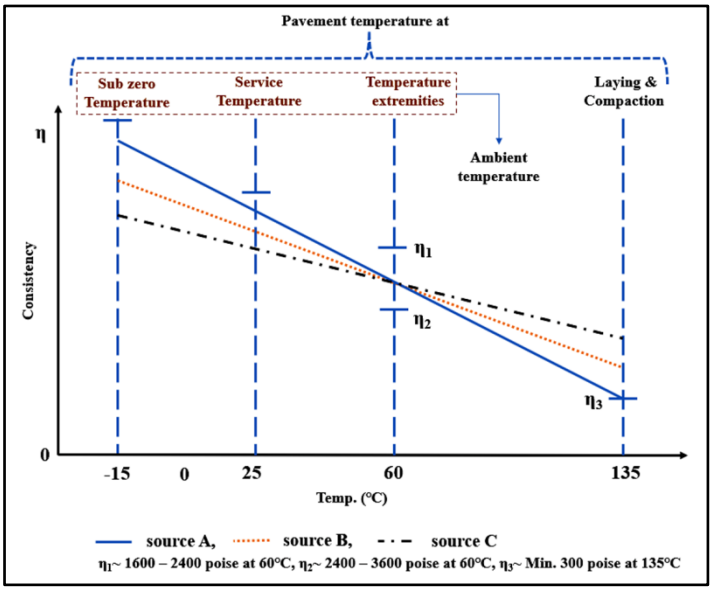


**Figure 2** Variations in viscosity across different temperature thresholds

**Figure 2** illustrates the variations in viscosity of different sources of bitumen across various temperature thresholds. This figure highlights how key temperature thresholds, such as ambient temperatures and laying and compaction temperatures, are managed during viscosity grading. Bitumen samples from sources A, B, and C fall within specified viscosity ranges, indicating that these samples can be classified as the same grade in the context of viscosity grading. This demonstrates how viscosity grading effectively controls a temperature range, in contrast to the singular temperature measurement associated with penetration grading. To address the limitations of both penetration and viscosity grading systems, performance grading (PG) was introduced. Performance grading evaluates bitumen's behaviour under various stress conditions, including rutting, fatigue, and low-temperature cracking, ensuring consistent performance across different climatic conditions. This holistic approach defines bitumen grades based on their real-world performance rather than empirical measurements, thereby aligning bitumen's properties more closely with field performance requirements.

## HOW EFFECTIVE IS THE PERFORMANCE GRADE SYSTEM?

The Superpave grading system utilizes rheological parameters rather than traditional physical properties, such as penetration and viscosity, to classify or grade bitumen samples [7,8]. Developed as part of the Strategic Highway Research Program (SHRP), a five-year initiative launched in 1987, this effort aimed to establish performance-based specifications for asphalt binders and mixtures [9,10]. This initiative resulted in the creation of the Superpave mix design criteria, with "Superpave" standing for Superior Performing Asphalt Pavements. It also led to the development of the Performance-Graded (PG) asphalt binder grading system in the mid-1990s [10,11]. The impetus for Superpave

arose from the empirical nature of existing specifications, which relied heavily on consistency tests to classify bitumen, often ignoring the broad spectrum of temperature conditions across different geographic locations [11]. For example, extreme northern regions in India can experience summer temperatures around 50°C, whereas northeastern or Himalayan regions have extremely low temperatures[12]. Given bitumen's viscoelastic nature, its response to loading is highly influenced by both temperature and load conditions. Therefore, classifying bitumen based on a

single test temperature was deemed irrational [13,14]. Additionally, previous grading systems focused primarily on short-term ageing to assess binder durability, neglecting the impact of long-term ageing when the binder is exposed to varying temperatures throughout its service life [15]. It was also observed that binders exhibited different temperature susceptibilities and performances within the same viscosity grading system, further complicating accurate assessments. Furthermore, these specifications were often unsuitable for modified binders, such as polymer-modified bitumen, which could clog capillary tubes during testing.

In performance grade specifications, the criteria remain constant, while the temperatures at which these criteria must be met vary for different grades. This system measures physical properties directly related to field performance, with test temperatures mirroring those encountered in practice. Performance grading assesses binders based on critical distresses like rutting, fatigue cracking, and low-temperature cracking. For instance, a binder graded as PG 52-10 indicates that the binder can perform satisfactorily at a seven-day average maximum pavement temperature of 52°C and a minimum temperature of -10°C. This approach ensures that the chosen binder is suitable for the specific climatic conditions at the construction site [16]. **Table 1** presents the various methods and apparatuses used for measuring the consistency of bitumen summarising the comprehensive progression from the penetration grading method to the performance grading method, including the intermediary viscosity grading method. The table outlines the objectives associated with each grading method, providing clarity on what each method aims to achieve in the context of bitumen performance evaluation. In addition to objectives, the measured parameters for each method are detailed. These parameters are vital as they influence the suitability of bitumen for specific applications within road construction. Furthermore, the limitations of all the methods employed are enlisted.

**Table 1** Methods and apparatus for measuring consistency of bitumen

| Method of grading | Objective (s) | Measuring apparatus | Measured parameter | Limitations |
|---|---|---|---|---|
| Penetration | Consistency of bitumen captured at 25°C temp. | Penetrometer \| Bowen penetration machine [IS 1203] | Penetration of 0.1 mm Dia needle through bitumen (in terms of mm). | Empirical test, performed at specified temperature. |
| Viscosity | Absolute and kinematic viscosity at 60°C and 135°C temp. Allied tests: Penetration, flash point, softening point, and ductility | Viscometer \| Cannon Manning Vacuums viscometers [IS 1206 (Part 2 &3)] | Viscosity at critical pavement and mixing temperature (in terms of poises and centistokes). | Unable to capture consistency at intermediate and low temperature. |
| Performance | Grading of bitumen based on the temperature range at which parameters (referred in col. 4) do not exceed the desirable values. | Dynamic shear rheometer [ASTM D 7175], Bending beam rheometer & Direct tension tester [ASTM D 6648; ASTM D 6723] | Complex shear modulus (G*), Phase angle (δ), Creep stiffness (S), and failure strain caused by application of direct tension (in terms of percentage). | No comprehensive performance data is available in context to Indian roads. |

## CHALLENGES, CONCLUSIONS AND FUTURE STEPS IN REFINING THE METHOD

The paper offers insights into methods for measuring bitumen consistency and traces the evolution of techniques from penetration and viscosity to performance grades. A critical review of the latest standards and guidelines, aimed at suggesting specifications for bitumen in India, highlights several important concerns.

- The test temperature considered is 60°C irrespective of the project location.
- Only short-term ageing is considered, even though it's clear that durability also depends on the long-term behaviour of the binders.

- The loading time on pavement is crucial; damage caused by high-speed vehicles is generally less compared to that from slow-moving vehicles at the same temperature. Therefore, vehicle speed specific to each location is essential for determining the right binder specification.
- There is no existing database on how binder variability is affected by the refinery process and the characteristics of the mixed crude.

The paper lays the groundwork for future research focused on creating an advanced framework for binder selection based on their rheological performance. The transition from penetration grade to performance grade bitumen marks a major advancement in pavement engineering. This shift addresses the need for more reliable and precise grading systems, aiming to enhance the durability and performance of roadways by considering their specific usage conditions.

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90_IEC38416

# Advancements in Sustainable Concrete Technologies and the Role of Graphene Oxide in Self-Compacting Concrete

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***Abstract:*** *The construction industry is evolving to incorporate advanced materials to improve the mechanical and durability properties of concrete. This study explores the integration of Graphene Oxide (GO) into M40-grade Self-Compacting Concrete (SCC) and its impact on workability and mechanical properties. GO, known for its high surface area and exceptional mechanical strength, was used at a 0.1% dosage. Experimental results revealed that while GO reduced the workability of SCC due to its water absorption characteristics but improved with addition of superplastierzer to achieve required followability and workability, it significantly enhanced both compressive and split tensile strengths. Compressive strength improvements of up to 34.29% and split tensile strength enhancements of 22.65% were observed after 28 days. Microstructural analyses using Field Emission Scanning Electron Microscopy (FESEM) and Energy Dispersive Spectroscopy (EDS) indicated reduced porosity and refined hydration products, contributing to superior mechanical performance. The research underscores the potential of GO-modified SCC as a sustainable and durable construction material, with the inclusion of superplasticizers to balance workability challenges.*

***Keywords:*** *Self-Compacting Concrete (SCC); Graphene Oxide (GO); Workability; Compressive Strength; Split Tensile Strength; Field Emission Scanning Electron Microscopy (FESEM); Energy Dispersive Spectroscopy (EDS)*

## INTRODUCTION

In recent years, the construction industry has seen a growing interest in improving the performance of concrete, especially with the development of high-performance materials like self-compacting concrete (SCC). SCC is widely known for its ability to flow under its own weight and fill formwork without the need for mechanical compaction, making it ideal for complex structures. However, ensuring the balance between workability and mechanical properties in SCC remains a challenge, particularly in applications that require high strength and durability.

One of the emerging areas of research focuses on the incorporation of nanomaterials like Graphene Oxide (GO) to enhance the properties of traditional concrete. GO, due to its exceptional mechanical strength, high surface area, and hydrophilic nature, has been studied for its potential to improve concrete's mechanical properties, durability, and resistance to cracking. The use of GO in concrete has shown promising results in improving strength and durability while potentially addressing limitations associated with traditional concrete mixes.

This study investigates the effect of GO on the workability and mechanical properties of M40 grade self-compacting concrete (SCC). Specifically, it evaluates SCC mixes with and without the addition of 0.1% GO in terms of slump flow, compressive strength, and split tensile strength. A brief review of literature suggests that while GO can improve the strength and durability of concrete, its influence on workability due to its water absorption characteristics has not been fully explored.

The experimental results show that the addition of GO significantly impacts both the workability and mechanical performance of SCC. Although the inclusion of GO reduced the workability of the concrete due to its water-absorbing properties, it enhanced both compressive and tensile strengths. FESEM analysis further revealed that GO not only filled nano-scale pores but also regulated the growth of crystal structures, contributing to the improvement of mechanical properties. Notably, the compressive strength increased by 34.29% after 28 days, and the split tensile strength improved by 22.65%.

These findings underscore the potential of GO as an additive in high-strength SCC applications, providing improved

mechanical properties at the cost of reduced workability. However, the reduction in workability highlights the need for the incorporation of superplasticizers to maintain proper flowability in concrete mixes.

## RESEARCH METHODOLOGY

This study investigates the impact of graphene oxide on the properties of M40-grade SCC, particularly focusing on compressive strength, split tensile strength, and durability. The experimental program involved:

### Materials

Ordinary Portland Cement (OPC) 53 Grade, manufactured sand (M-sand), crushed granite aggregate, Class F fly ash, water, superplasticizer SAN CHEM 1292, and graphene oxide.

### Mix Design

Following IS 10262:2019 guidelines, trial mixes were prepared with varying GO content to determine the optimal proportions for achieving the desired mechanical properties and workability.

### Tests on Fresh and Hardened Concrete

The slump flow, V-funnel, and L-box tests assessed the workability of SCC mixes, while compressive and split tensile strength tests (IS 516:1959) evaluated the mechanical performance of the concrete.

## EXPERIMENTAL RESULTS

The addition of graphene oxide to SCC resulted in notable improvements in both fresh and hardened properties. However, the high surface area of GO reduced the workability of the mix, which was addressed by adjusting the dosage of superplasticizers.

The main results of this study focus on the workability, compressive strength, and split tensile strength of M40 grade self-compacting concrete (SCC) mixed with varying doses of graphene oxide (GO). Two concrete mixes, SCC400 without GO and SCC401 with 0.1% GO, were used to evaluate the effects of graphene oxide on the concrete's mechanical properties. The nomenclature and testing process for compressive strength and split tensile strength involved the casting and testing of cubes and cylinders, with three samples tested at 3, 7, and 28 days for both types of strength.

### FESEM and EDS Analysis

Graphene oxide was analysed (**Figure 1.1** and **1.2**) using Field Emission Scanning Electron Microscopy (FESEM) and Energy Dispersive Spectroscopy (EDS). The analysis showed that GO not only filled nano-scale pores but also controlled the formation and growth of flower-like crystals, improving the concrete's mechanical properties.

### Workability Results

The slump flow test (**Table 1**) revealed a decrease in flowability with the addition of GO. SCC400 (without GO) had a slump flow of 640 mm, while SCC401 (with 0.1% GO) recorded a flow of 620 mm, indicating that GO, due to its high surface area, absorbed more water, reducing workability. However, the use of superplasticizers helped restore workability.

### Compressive Strength Results

The compressive strength results (**Figure 2**) showed that the addition of 0.1% GO significantly increased the strength of the concrete. SCC400 achieved compressive strengths of 21.49 MPa, 33.36 MPa, and 40.65 MPa at 3, 7, and 28 days, respectively, while SCC401 (with 0.1% GO) reached strengths of 25.49 MPa, 40.69 MPa, and 54.59 MPa. This represents an increase in compressive strength by 18.61%, 21.97%, and 34.29% at the respective intervals.

**Split Tensile Strength Results**

Similarly, the split tensile strength of SCC401 was superior to that of SCC400 (**Figure 3**). SCC400 achieved tensile strengths of 2.35 MPa, 2.79 MPa, and 3.93 MPa at 3, 7, and 28 days, respectively, while SCC401 with 0.1% GO recorded values of 2.88 MPa, 3.38 MPa, and 4.82 MPa. This equates to an increase of 22.55%, 21.15%, and 22.65% at 3, 7, and 28 days, respectively.

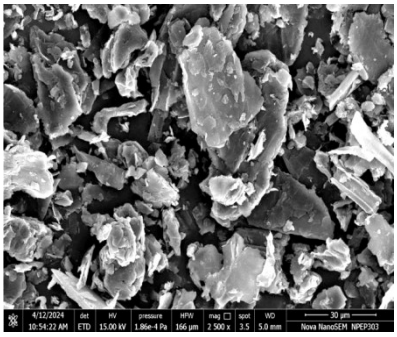

**Figure 1.1** FESEM_GO

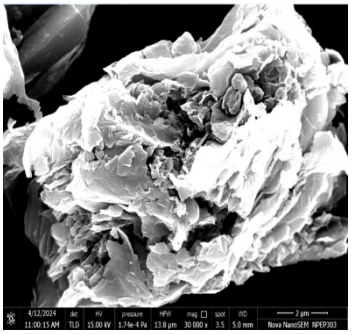

**Figure 1.2** FESEM_GO

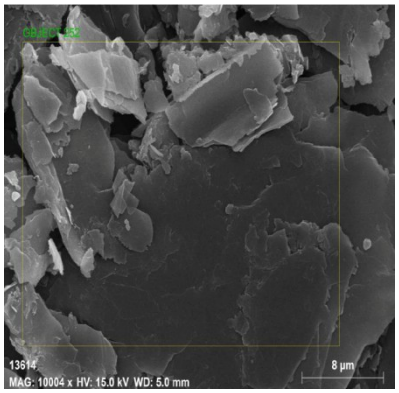


**Figure 1.1** EDS _GO

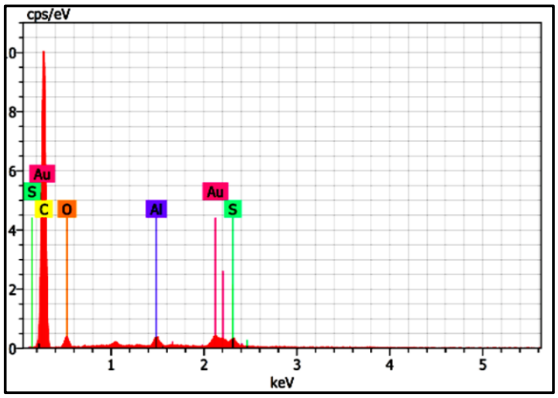


**Figure 1.1** EDS _GO

**Table 1** Results of Slump flow values in mm

| Sr. No. | Concrete Sample | Dose of admixture | Slump flow |
|---|---|---|---|
| 1 | M40 (SCC400) without GO | 1.0% | 640 mm |
| 2 | M40 (SCC401) with 0.1% GO | 1.1% | 620 mm |

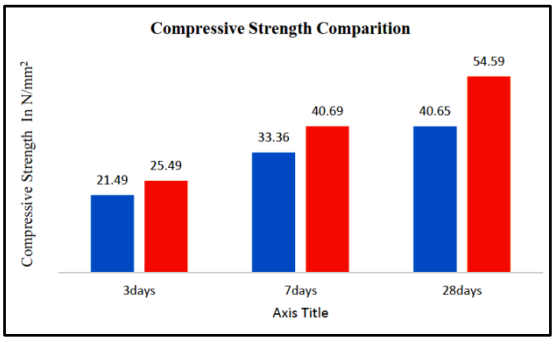


**Figure 2** Comparative graph of Compressive Strength test

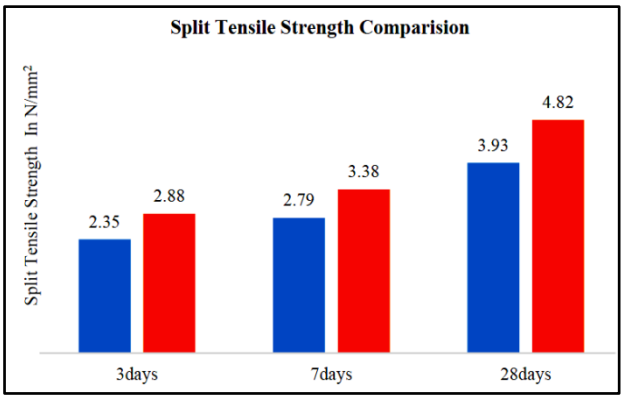


**Figure 3** Split tensile strength

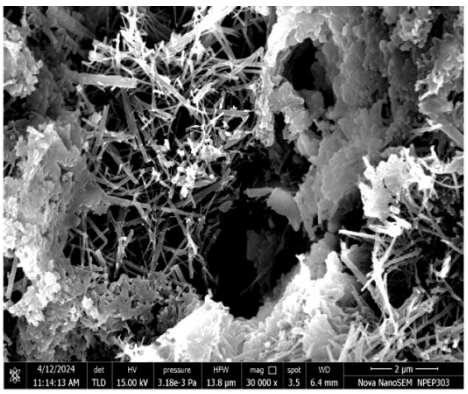

**Figure 2.1** FESEM_ SCC401

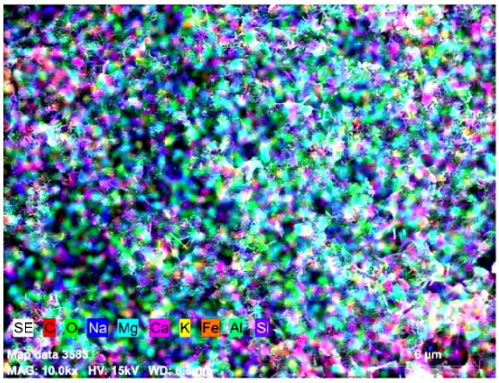


**Figure 2.2** EDS _ SCC401

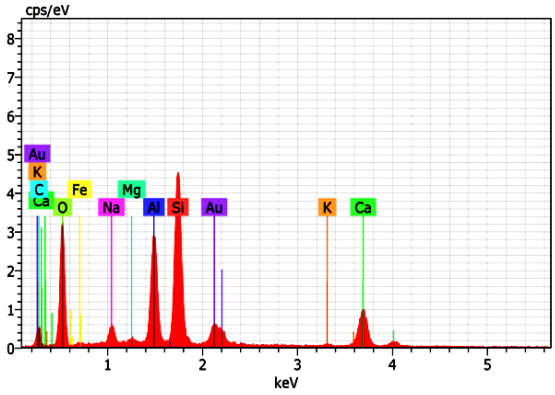


**Figure 2.3** EDS _ SCC401

Spectrum: OBJECT 253

| El | AN | Series | unn. C [wt.%] | norm. C [wt.%] | Atom. C [at.%] | Error (1 Sigma) [wt.%] |
|---|---|---|---|---|---|---|
| O | 8 | K-series | 29.16 | 41.26 | 51.28 | 4.40 |
| Si | 14 | K-series | 14.02 | 19.83 | 14.04 | 0.63 |
| Ca | 20 | K-series | 9.03 | 12.78 | 6.34 | 0.34 |
| Al | 13 | K-series | 7.59 | 10.74 | 7.92 | 0.40 |
| C | 6 | K-series | 7.39 | 10.46 | 17.31 | 1.91 |
| Na | 11 | K-series | 1.53 | 2.17 | 1.88 | 0.15 |
| Fe | 26 | K-series | 1.31 | 1.85 | 0.66 | 0.13 |
| K | 19 | K-series | 0.39 | 0.55 | 0.28 | 0.06 |
| Mg | 12 | K-series | 0.25 | 0.36 | 0.30 | 0.05 |
| Au | 79 | M-series | 0.00 | 0.00 | 0.00 | 0.00 |
| | | Total: | 70.67 | 100.00 | 100.00 | |

**Figure 2.4** EDS _ SCC401

## DISCUSSION

### Microstructural Analysis

FESEM (Field Emission Scanning Electron Microscopy) and XRD (X-ray Diffraction) analyses of the GO-infused SCC revealed a more refined microstructure with reduced porosity and fewer micro cracks. GO acted as a nano-filler, occupying voids and regulating the formation of hydration products in the cement matrix. This improved packing density and reduced pore sizes contributed to the observed increases in mechanical strength and durability.

**Microstructural Analysis and Its Role in Mechanical Properties**

The microstructural properties of GO were analyzed using Field Emission Scanning Electron Microscopy (FESEM) and Energy Dispersive Spectroscopy (EDS). These analyses demonstrated that GO particles not only filled nano-scale voids but also regulated the formation and growth of flower-like crystals in the concrete matrix. This microstructural modification likely contributes to the improvement of concrete's mechanical properties by reducing the porosity and refining the crystalline structure. The enhanced packing density due to GO resulted in better load transfer within the matrix, justifying the observed improvements in compressive and tensile strengths.

**Impact of GO on Workability**

Workability is a critical parameter for SCC as it directly influences the ease of placement and the homogeneity of the concrete mix. In this study, the slump flow test results indicated that the introduction of 0.1% GO into the mix led to a reduction in flowability, with SCC400 (without GO) showing a slump flow of 640 mm, while SCC401 (with 0.1% GO) recorded 620 mm. This reduction can be attributed to the high surface area of GO, which absorbs water, thereby decreasing the effective water content available for workability. However, the use of superplasticizers mitigated this issue, restoring workability to acceptable levels. Despite this, it is important to carefully control the dosage of GO to avoid excessive water absorption, which could negatively impact the placement and performance of the concrete.

**Correlation between Workability and Compressive Strength**

While GO reduced workability due to increased water absorption, its presence led to a significant improvement in compressive strength. The correlation between workability and compressive strength is evident from the results. As the workability slightly decreased with GO addition, the compressive strength increased markedly, suggesting that the reduction in workability is a trade-off for the improved strength characteristics. SCC400 (without GO) recorded compressive strengths of 21.49 MPa, 33.36 MPa, and 40.65 MPa at 3, 7, and 28 days, respectively, whereas SCC401 (with 0.1% GO) exhibited compressive strengths of 25.49 MPa, 40.69 MPa, and 54.59 MPa at the same intervals. This improvement can be linked to the refined microstructure of the concrete due to GO, which resulted in better packing density and fewer voids, thereby enhancing the load-bearing capacity of the material.

**Correlation between Compressive Strength and Split Tensile Strength**

A clear correlation between the compressive strength and split tensile strength of the concrete was also observed. As GO improved the compressive strength, it similarly enhanced the split tensile strength. SCC400 exhibited split tensile strengths of 2.35 MPa, 2.79 MPa, and 3.93 MPa at 3, 7, and 28 days, respectively, while SCC401 (with 0.1% GO) reached values of 2.88 MPa, 3.38 MPa, and 4.82 MPa at the same intervals. The increase in split tensile strength is consistent with the improvement in compressive strength, confirming that GO has a positive influence on the overall mechanical performance of the concrete. The enhancements in both compressive and tensile strengths are attributed to the improved interfacial bonding between the GO-modified cement matrix and the aggregates, as well as the reduction in porosity and micro cracking within the matrix.

**CONCLUSION**

- The experimental results confirm that the addition of GO enhances the mechanical performance of SCC. The reduction in workability, while a potential concern, can be mitigated with the use of suitable superplasticizers, making GO-modified SCC a viable option for modern construction applications. Furthermore, the microstructural changes induced by GO reduce the permeability of the concrete, improving its resistance to environmental aggressors such as chloride ions, sulfates, and freeze-thaw cycles.
- This research highlights the potential of integrating graphene oxide into Self-Compacting Concrete to achieve enhanced strength, durability, and sustainability. With the construction industry increasingly focused on reducing its environmental impact, GO-modified SCC presents a promising solution for improving both the performance and eco-friendliness of concrete structures.
- By incorporating green concrete practices and advanced materials like GO, the construction sector can reduce

its carbon footprint while maintaining the mechanical performance required for durable, long-lasting infrastructure.

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101_IEC82835

# Review of Nanomaterials in the Civil Engineering Infrastructures

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***Abstract:*** *Nanocarbon tubes and nanomaterials are poised to revolutionize the civil engineering industry shortly by offering environmentally friendly and sustainable design options to minimize carbon emissions from coal burning in cement production. Their potential applications extend beyond civil engineering to include industries such as automotive, transmissions, solar energy, wind energy, lightweight armour for military tanks, shipbuilding, medicine, mechanical and electrical engineering, and more. Nanomaterials offer the added benefit of being lightweight, which can reduce foundation loads, bridge superstructure weight, cable diameter in cable-stayed bridges, ground improvement techniques, leak prevention, crack prevention, corrosion prevention in reinforced concrete elements, and materials for repairs and renovations. This paper compiles research and studies conducted worldwide on the sustainable and optimal use of nanomaterials, specifically nanocarbon tubes, nanocarbon powder, nanocarbon materials, nanofibers, nano silica, and titanium dioxide, which enhance concrete and cement paste strength while minimizing crack development and preventing rebar corrosion. It aims to provide future researchers with the most recent advancements in nanotechnology across the globe.*

***Keywords:*** *Nanocarbon Tubes; Nanomaterials; Titanium Dioxide*

## INTRODUCTION

Nanotechnology deals with materials on a very small scale, specifically at the nanometer level, and materials with dimensions in the nanometer range are known as nanomaterials. This article investigates the potential uses of carbon nanotubes (CNT). Given the nature of civil engineering and public exposure projects, it is necessary to use environmentally friendly nanomaterials, as there are various forms and types of nanotechnology, some of which may be harmful to the environment, social issues, or human health upon exposure. By utilizing such materials, it is possible to enhance their strength and durability and alter their engineering properties.

To address the challenges faced by twenty-first-century civil engineering, this paper explores advanced technologies. Nanotechnology is a fundamental technology that tackles some of the issues related to sustainable infrastructure. The article emphasizes the development of sustainable infrastructure and presents potential avenues for further research.

## NANOTECHNOLOGY USED IN CIVIL ENGINEERING

CNT is presently utilized for producing strong composites with enhanced bonding material properties, minimal maintenance, and improved sound insulation, heat insulation, and water-repellent surfaces. Additionally, it also enhances glass reflectivity to prevent fogging, provides UV protection, and is used in solar cells for structural health monitoring. The extensive use of nanomaterials in civil engineering includes the following:-

- Carbon-Based Nano Materials
  - Carbon Nanotubes
- Improves flexural and compressive strength.
- Possesses self-cleaning and self-sensing properties.
- Improves thermal properties.
- Improves mechanical properties.
- Reduces shrinkage.
- Improves antibacterial properties.
- Metal-based nanomaterials.
  - Calcium Carbon
- Increases setting time and compressive strength and increase in the rate of hydration.

- Di-Oxide categories – Titanium Dioxide and Silicon Dioxide
- Improves durability, reduces porosity, and improves mechanical performance.
- Antibacterial, Self-cleaning, fire resistant, scratch resistant, corrosion resistant.
- Better insulating properties, photocatalyst, and anti-fogging properties.
- Oxide categories – Copper oxide, Ferric oxide, Aluminum oxide, Chromium Oxide, Silver oxide, Zirconium oxide and Zinc oxide
- Improves durability, compressive strength, flexural strength, self-cleaning, and fire resistance.
- Light weight improves mechanical performance and heat performance.
- Reduction in porosity, compact, strong, and durable.
- Antifogging, Photocatalyst and Foaling resistant.
- Bacterial protection, Fungus, and microviral protection

## LITERATURE REVIEW

This section focuses on research and the implementation of nanotechnology in the following branches of civil engineering.

- Designs – Durability, Porosity, Flexural and compressive strength, lightweight, fire resistance, scratch resistance, Mechanical properties, Sound absorption.
- Construction Application – Eco-friendly and sustainable
- Highway & Transportation – Reduction in overall cost and economic
- Buildings – Improves life span, lightweight and highly durable compared to present materials.
- Concrete Technology – Reduction in sizes of the structural elements and more durable and robust.
- Self-consolidating Concrete – Very useful for the production of high-performance concrete.
- Geotechnical Engineering – Ground improvement with economic solutions
- Materials – Improvement in properties of materials, Stronger and more durable materials, lightweight.
- Highway Materials – Smart materials, enhanced bituminous materials, joint materials, Dry Lean Concrete and Performance Quality Concrete.

## NANOMATERIALS

### Carbon Nano Tubes (CNTs)

CNTs are considered a crucial research area in nanotechnology due to their ability to enhance the technical properties of construction materials and their environmental sustainability. Their exceptional mechanical properties, such as high strength, elasticity, and electrical and thermal conductivity, make them highly suitable for reinforcing concrete. CNTs are composed of tiny molecules held together by a very strong bond. With diameters ranging from 20 to 40 nm and a typical strength 100 times that of steel, CNTs, with a carbon purity exceeding 90%, have the potential to reduce or eliminate the need for steel reinforcement in concrete mixes. Incorporating CNTs into concrete acts as a filler, preventing early-age cracking and accelerating the final setting time of concrete through cement-to-cement bonding interactions and fillings.

### Carbon Nano Fibers (CNFs)

Carbon nanofiber CNFs are composed of grapheme (the thinnest and strongest building material ever invented, consisting of only one layer of carbon atoms). Although both CNTs and CNFs serve the same function in most civil engineering buildings, CNFs are still considered the best option before CNTs because the stacked edge structure can create a large area, can be easily manufactured, and has a comparable lower cost for CNT. (Coleman, et. al., 2006)

### Silicon Dioxide ($SiO_2$) Nanoparticles

In applications of civil engineering, nano-silica is a type of nanomaterial that can substitute for silica fume and micro-silica. When cement undergoes hydration, nano-silica reacts with lime to form a gel, which possesses properties that

enhance the strength and durability of concrete. The presence of well-dispersed nano-silica in cement-based products can lead to quicker hydration of cement paste, resulting in a more compact microstructure. Conversely, an excessive number of nanoparticles may aggregate due to their high surface energy, leading to uneven dispersion. Figure 1 illustrates the scale ranges of various materials utilized in concrete manufacturing.

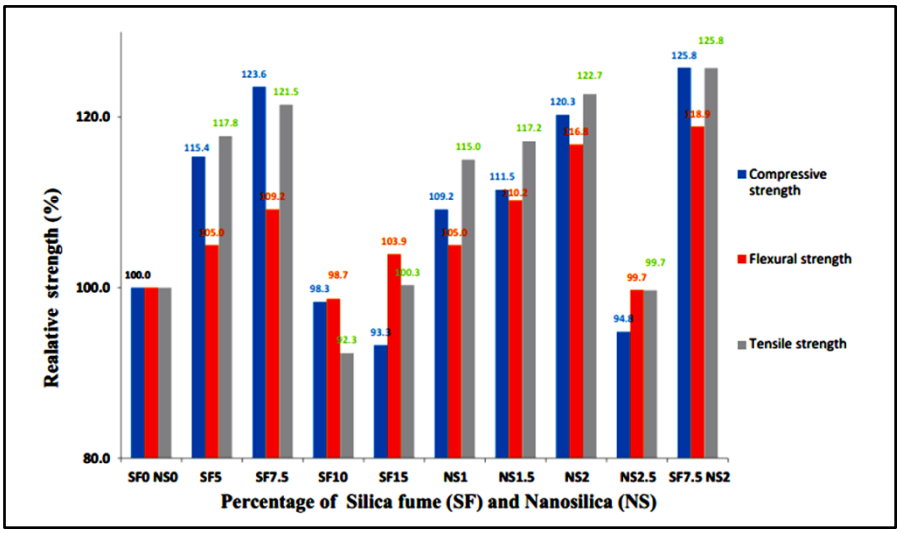


**Figure 1** Mechanical Strength of Concrete [1]

**Titanium Dioxide ($TiO_2$)**

Titanium dioxide ($TiO_2$) nanoparticles are a popular nanotechnology-based material utilized in concrete, particularly for concrete pavements in parking lots, roadway decks, airport runways, and road surfaces. $TiO_2$ nanoparticles are tiny particles with a density of less than 0.13 g/cm3, a high purity of 99.9%, and an average size of 15 nm. The use of nano-$TiO_2$ accelerates the early-age hydration of ordinary Portland cement (OPC), leading to increased flexural strengths, compressive strengths, and improved abrasion resistance of concrete, making it well-suited for concrete pavements.

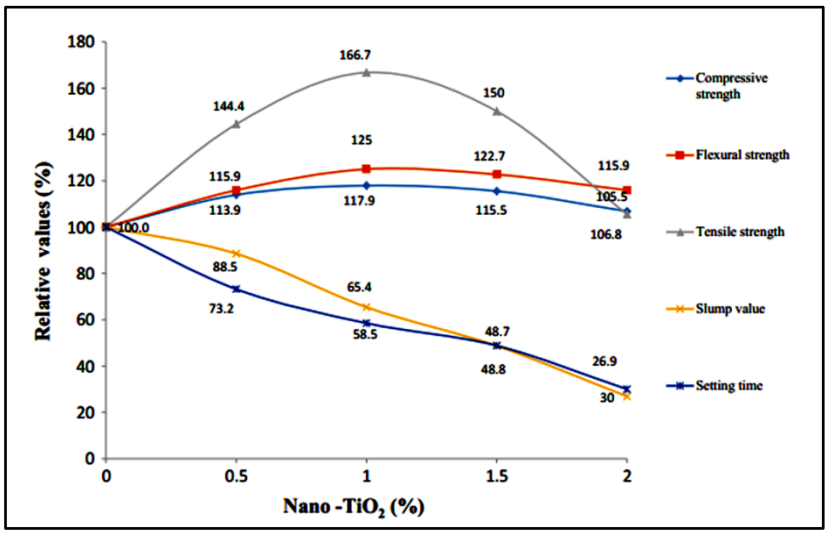


**Figure 2** Properties TiO2 [1].

**Ferric Oxide ($Fe_2O_3$) Nanoparticles**

The incorporation of nanoparticles into cement mixes shows potential for improving mechanical properties.

Researchers noticed that nano-$Fe_2O_3$-infused concrete can self-detect stress and enhance its compressive and flexural strengths. This distinctive characteristic enables real-time monitoring of structural properties without the reliance on embedded sensors, opening up possibilities for the development of intelligent and environmentally friendly structures.

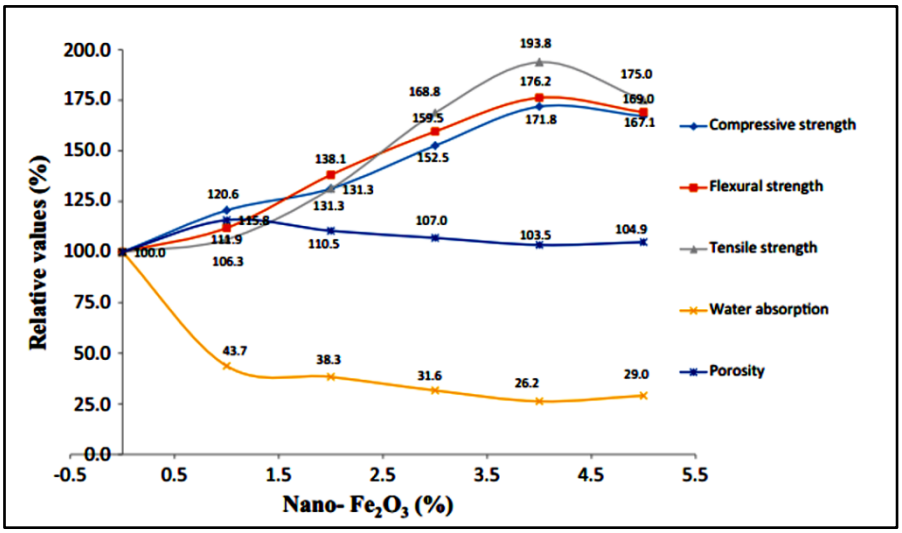


**Figure 3** Properties of $Fe_2O_3$ [1]

**Copper Oxide (Cu O) Nanoparticles**

After the inclusion of Cu O nanoparticles in self-compacting concrete, various characteristics of the samples were evaluated. The results indicate that Cu O nanoparticles can mitigate the adverse effects of superplasticizers on the compressive strength of the samples and self-compacting concrete. By substituting cement with Cu O nanoparticles up to 4% by weight, there was an accelerated formation of C-S-H gel. This was attributed to the increased crystalline Ca $(OH)_2$ content during hydration. However, exceeding a weight percentage of 4 for Cu O nanoparticles led to a reduction in compressive strength, as the nanoparticles were not effectively distributed throughout the concrete matrix.

**Aluminum Oxide ($Al_2O_3$) Nanoparticles**

Substituting some of the cement in concrete with nano alumina is an additional method to reduce the greenhouse effect associated with cement usage. Calcium aluminium-silicate gel is formed in concrete when calcium hydroxide resulting from the hydration of calcium aluminates reacts with nano alumina. The rate of this reaction is directly impacted by the available surface area. Therefore, the addition of nano-alumina is aimed at enhancing the concrete properties.

**Zirconium Oxide ($ZrO_2$) Nanoparticles**

Substituting some of the cement in concrete with nano alumina is an additional method to reduce the greenhouse effect associated with cement use. The combination of calcium hydroxide with nano alumina results in the formation of Calcium aluminium-silicate gel in concrete. The rate of this reaction is influenced by the surface area that is accessible. Therefore, incorporating fine-value nano-alumina can enhance the characteristics of concrete.

**Zinc Oxide (Zn O) Nanoparticles**

The study demonstrated that incorporating ZnO nanoparticles into concrete at a maximum replacement rate of 1.5% leads to increased concrete strength. Nano ZnO at levels of 0%, 0.5%, 1%, and 1.5% by weight of cement was utilized to partially substitute the cement. As per the findings of the experimental investigation, the addition of a superplasticizer is essential because the incorporation of nano zinc oxide particles into the binding material reduces

the workability of concrete and prolongs the setting time.

**Calcium Carbonate Nanoparticles**

Researchers have conducted experiments involving the incorporation of $CaCO_3$ nanoparticles into cement and concrete to enhance their characteristics. The results indicate that the inclusion of $CaCO_3$ in foamed concrete led to enhancements in its mechanical and durability properties, with the most significant improvement observed at a 4% $CaCO_3$ addition. The addition of $CaCO_3$ improved both the porosity and water absorption of the foamed concrete. However, it also caused a decrease in the workability of the mixtures.

## RISK TO ENVIRONMENT

The release of nanomaterials into the atmosphere as dust could lead to potential environmental issues. Nanomaterials might leach into groundwater, and exposure during building and maintenance activities could also be a concern. Carbon nanotubes (SWNT and MWNT) have the potential to be hazardous because of their antibacterial capabilities and their ability to cause lung damage, respiratory function slowdown, and other impacts. These nanotubes can injure DNA and cause cytotoxicity and inflammation in mammals by producing reactive oxygen species. Similarly, SiO2 nanoparticles have been found to have carcinogenic properties, damage bacteria by producing reactive oxygen species, and be harmful to marine algae and other organisms. When exposed to copper oxide or copper nanoparticles, cells of humans, algae, bacteria, and yeast are exposed to oxidative stress and DNA damage. Therefore, using nanomaterials in the building or civil engineering sectors has drawbacks, and additional research and carefully designed projects are essential to ensure sustainable building projects.

## CONCLUSIONS

The fundamental characteristics of materials at the nanoscale level result in significant changes in their mechanical, physical, and thermal properties. The main objectives of nanomaterials research and applications include understanding material nanostructure, modifying it, creating smart structures, and assessing the impact of nanomaterials on the environment and human health. Nanomaterials such as those based on metal or carbon, semiconductors, dendrites, nanocomposites, and nanohybrids can all be utilized in structural engineering to enhance and broaden the capabilities of building materials. The benefits of nanoparticles for materials like steel, glass, coatings, concrete, and cement have already been discussed. All nanomaterials have the potential to enhance the hydration, microstructure, and porosity of cementitious composites, thereby affecting their mechanical and transport-related properties. Current research in nanomaterial applications focuses on cement composites and structural health monitoring, but challenges related to toxicity and industrial use still exist. Future research may also concentrate on reducing the high energy consumption of buildings and other structures. A more holistic perspective should be adopted when assessing the potential of nanomaterials to enhance sustainability. Prioritizing the improvement of material properties, reduction of toxicity, and decreased energy consumption is crucial for future research. This work provides an overview of achievements in structural engineering, emphasizing attributes and applications, and underscores the need for further study and research to ensure the sustainable implementation of nanotechnology in civil engineering.

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117_IEC30711

# Ground Improvement by Admixture using Banana Fiber: Experimental Study

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***Abstract:*** *Construction of a transport infrastructure such as highways and railways is often challenging when the natural soil subgrade is weak, with low strength and compressibility. In order to ensure long-term sustainability of the transport corridors, such weak soil needs to be sufficiently improved prior to commencement of construction. Several methods are available for ground improvement for transport infrastructure including dynamic compaction, preloading with consolidation and chemical stabilization. Among these techniques, using admixtures in virgin soil has been observed to enhance the strength, stiffness and penetration characteristics of soft ground. This paper presents an innovative technique of ground improvement by using natural banana fiber which is derived by splitting stems of banana trees and slicing them to desired shape and size. The primary advantage of this material is its wide availability, less expensive and eco-friendly. Soft soil is collected from a local site and banana fibers with desired specification and proportion is intimately mixed with it. The soil mixtures have been tested in laboratory to determine its compaction and penetration characteristics. It is observed that using this specific admixture enhance the soil properties significantly. From the entire study, a set of important conclusions are drawn.*

***Keywords:*** *Optimum Moisture Content; Maximum Dry Density; California Bearing Ratio; Ground Improvement*

## INTRODUCTION

Buildings and other civil engineering constructions could be quite problematic on poor soil. Numerous ground enhancement techniques can be used to improve the desirable properties of soil, such as permeability, shear strength, and bearing capacity [1]. The development of soft ground for transportation infrastructure has been a national priority in numerous countries. Various techniques available for soil improvement includes compaction, consolidation with preloading, chemical stabilization and using mechanical admixtures. In case of compaction, external compacting energy is applied to the soil, static or dynamic. In case of consolidation with preloading, vertical drains are bored through the soft soil deposit, either partially or fully penetrated, and filled either with jute drains (called as prefabricated vertical drains), sand (called sand compaction piles) or angular coarse aggregates (called stone columns), while sustained vertical dead load is imparted to the ground surface to allow consolidation. The other important technique is chemical stabilization wherein a set of chemical compounds are injected to the soft ground to improve its characteristics. Using mechanical admixture is comparatively a new technique in which a specific admixture is mixed to the virgin soil which acts as a foreign material to mechanically enhance the subsoil properties[2, 3].

In mechanical soil stabilization, numerous natural fibers are globally used, including flax, bamboo, coconut coir, jute, sisal, palm, barely straw, as well as cane fibers [4]. Researchers and scientists are increasingly interested in natural fibers as alternatives to Fiber Reinforced Soils (FRS) as well as Fiber Reinforced Composites (FRC), including jute, sisal, coir, flax, kenaf fibers and palm fiber. The South Carolina Highways Department acknowledged the usage of natural fibers in the building of roads for the first time in engineering history in 1926 [5]. Researchers have also used bagasse ashes and stone dusts as mechanical stabilizers for soft ground improvement with cost effectiveness [6].

In India, banana trees are available in enormous quantities. Extracted from the stalks of banana plants, banana fiber is a sustainable, biodegradable, and natural substance. The natural incidence that shows interactions between roots of plants and the adjoining superficial area soil of natural slope could guard the slope against rain wash is the source of inspiration for the ancient technique of randomly distributing different fibers combined into a soil matrix for

strengthening of the soft ground [7]. The naturally extracted bamboo fibers behaves as a reinforcing material to soft soil and in addition, enhance its ductility and CBR value [8].

The Proctor and California Bearing Ratio (CBR) tests are crucial for assessing the compaction and penetration characteristics of soft soil in the laboratory, respectively. The critical values relevant to these parameters can be utilized to effectively quantify the suitability of the improved soil subgrade to support the pavement and traffic loads and accordingly the design and construction should be conducted [9]. In case of cellulose-based fiber used as admixtures, optimization of physical and strength performance can be obtained through rigorous laboratory experimentations [10]. A comparison of various ground improvement techniques from the view point of safety and serviceability of supporting structures was summarized by Basack et al [11].

The main goal of the project is to study the use of natural banana fibers as a mechanical stabilizer to enhance the compaction and penetration characteristics of soft compressible soil, via a series of laboratory experimentations and derive conclusions there from.

## MATERIALS AND METHODOLOGY

First of all, disturbed soil samples in bulk quantity was collected from a selected site in the Nadia District of West Bengal, India, at a depth of 2 meters beneath the surface of the ground. The soil samples were transferred to the geotechnical lab and subjected to an initial period of air drying for 30 days, followed by drying in an oven for a duration of 24 hours. The dried samples were grounded by hand and routine tests were conducted to determine its engineering properties. Banana fibers were also separately collected from nearby areas and split to desired specifications. They were intimately mixed with dried soil samples and tested in the geotechnical laboratory to study the alteration in the soil properties.

The geotechnical attributes of disturbed soil samples obtained from laboratory tests are displayed in **Table 1**. Based on the laboratory's outcomes, the soil is classified as ML [12].

**Table 1** Geotechnical properties of disturbed soil samples

| Soil Properties | | | Values |
|---|---|---|---|
| Specific gravity of solid particles | | | 2.46 |
| Atterberg Limits | Liquid Limit (%) | | 26 |
| | Plastic Limit (%) | | 21.79 |
| | Plasticity Index (%) | | 4.21 |
| Particle Size Distribution | Clay (%) | | 33.8 |
| | Silt (%) | | 44.2 |
| | Sand | Fine (%) | 19.0 |
| | | Medium (%) | 3.0 |
| | | Coarse (%) | 0.0 |
| | Uniformity Coefficient ($C_u$) | | 24.29 |
| | Coefficient of Curvature ($C_c$) | | 0.44 |
| Standard Proctor Compaction Test | Optimum Moisture Content, $w_o$ (%) | | 12.5 |
| | Maximum Dry Density, $\gamma_d^{max}$ (kN/m$^3$) | | 17.44 |
| Unsoaked CBR at $w_o$ | | | 8.14 |

In close proximity to the site, bushes with banana and other trees were found to be located. Large banana fibers were extracted from the stems of the banana trees. The fibers so collected were transported to the geotechnical laboratory. They were initially air dried for 30 days and the dried were cut into small pieces of thickness 2 mm and varying lengths of measuring 10 mm, 20 mm and 30 mm. A photography view of the fibers is presented in **Figure 1**.

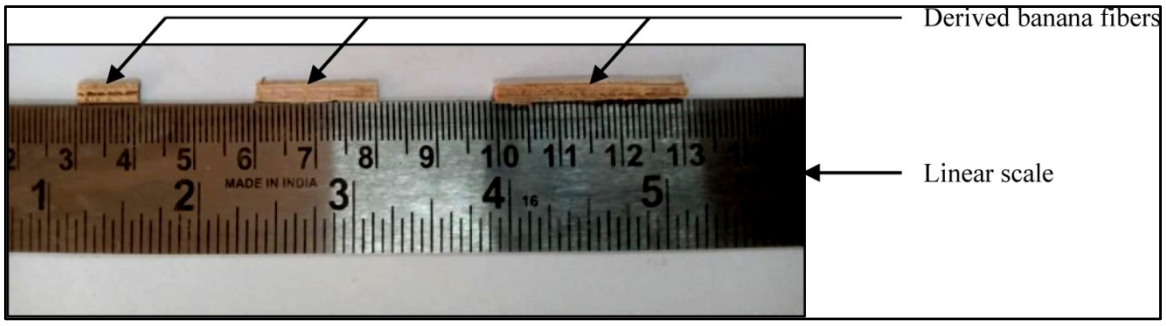


**Figure 1** Photographic view of the derived banana fibers

## RESULTS AND DISCUSSION

The derived banana fibers at selected lengths were intimately mixed with soil sample at different proportions of 0.5%, 1%, 1.5%, and 2% by weight of dry soil. For each of the soil-fiber composite samples, the standard Proctor compaction and Unsoaked CBR tests were performed. The test results are presented in **Table 2**. The experimental goal is to determine the ideal banana fiber length and percentage which would yield the optimum compaction and CBR values.

The variations of dry density of soil-fiber mixtures with the moisture content are presented in **Figure 2**. The variations of $w_0$ and $\gamma_d^{max}$ with different fiber-contents are portrayed in **Figures 3** and **4**, respectively. The variation of unsoaked CBR with various fiber-contents is shown in **Figure 4**. Analysis and interpretations from the laboratory test results are also given.

From **Figure 3(a)**, it is observed that the parameter $w_0$ of soil-fiber composite increases following a curvilinear pattern with ascending fibre content. Similarly, from **Figure 3(b)**, the parameter $\gamma_d^{max}$ decreases nonlinearly with increasing fiber-content.

From CBR tests, it is observed that the values of unsoaked CBR varies curvilinearly with fiber-content. Initially, the CBR increases up to a peak value and thereafter decreases, as may be visualized from **Figure 4**. The peak CBR was found to be attained at a fiber-content of 1%.

**Table 2** Geotechnical properties of fiber-soil composite samples

| Length of Fiber (mm) | Percentage of Fibre by Weight of Dry Soil (%) | Proctor Compaction Test | | CBR |
|---|---|---|---|---|
| | | $w_0$ (%) | $\gamma_d^{max}$(kN/m$^3$) | |
| 10 | 0.5 | 13.20 | 16.562 | 9.69 |
| | 1.0 | 14.10 | 16.072 | 9.97 |
| | 1.5 | 16.40 | 15.386 | 9.36 |
| | 2.0 | 17.90 | 14.896 | 9.4 |
| 20 | 0.5 | 13.50 | 16.366 | 9.45 |
| | 1.0 | 14.40 | 15.778 | 10.01 |
| | 1.5 | 16.90 | 15.092 | 9.53 |
| | 2.0 | 18.50 | 14.602 | 8.95 |
| 30 | 0.5 | 14.30 | 16.17 | 9.65 |
| | 1.0 | 15.10 | 15.484 | 9.9 |
| | 1.5 | 17.60 | 14.896 | 9.45 |
| | 2.0 | 19.40 | 14.406 | 9 |

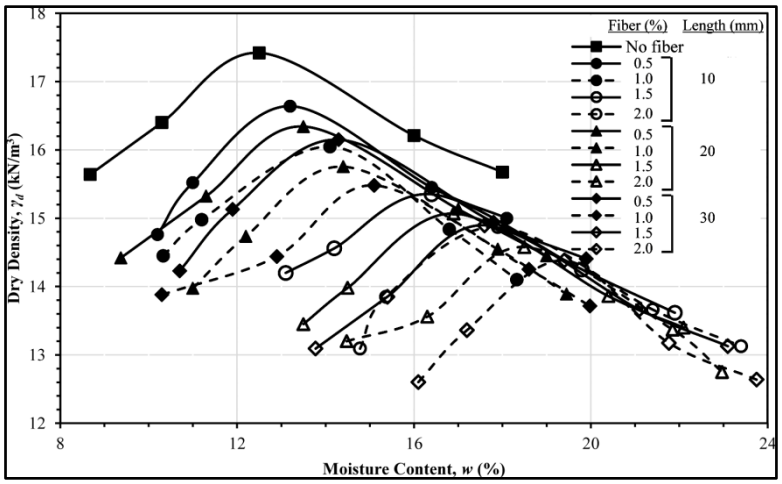


**Figure 2** Variation of $w_0$ and $\gamma_d^{max}$ for different soil-fiber composites

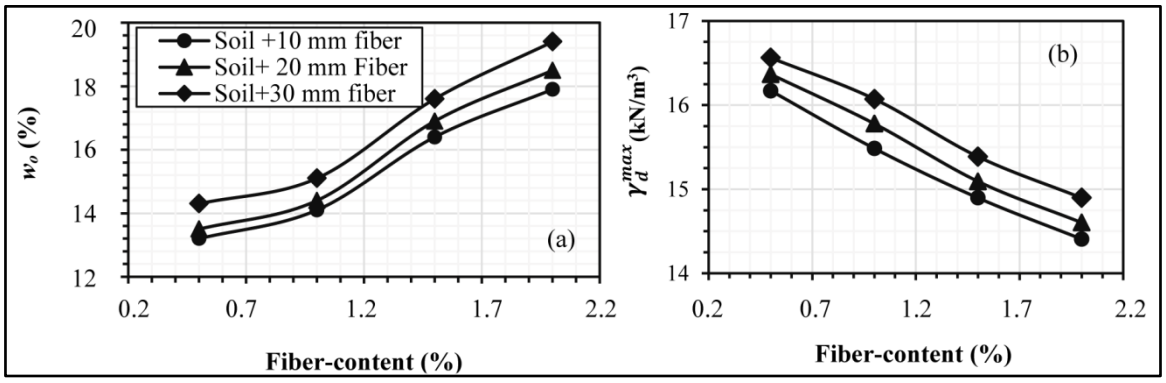


**Figure 3** Influence of fiber-content on: (a) optimum moisture content, and (b) maximum dry density

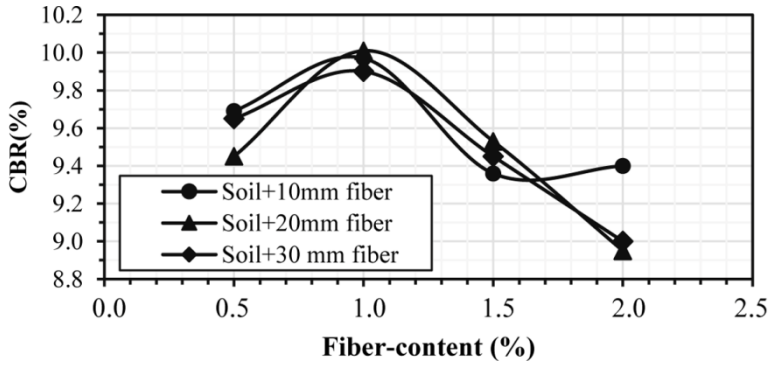


**Figure 4** Variation of CBR with fiber-content

## CONCLUSION

The experimental study indicates that using banana fibers as mechanical admixtures influences both the compaction and the penetration characteristics of soft soil. With ascending fiber-content, the optimum moisture content increases while the maximum dry density decreases in a nonlinear pattern. In case of CBR test, the CBR value varied curvilinearly. Initially, the CBR value increases, attains peak value at fiber-content of 1% and thereafter decreases.

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141_IEC47603

# A Review on Seismic Performance of Smart Structures and Bridges with Shape Memory Alloy Reinforcements

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***Abstract:*** *Bridge columns are most vulnerable to earthquake forces and the damages can be of high intensity, leading to affect the safety and serviceability of the structure. Hence protecting them against damages due to severe earthquakes is at most priority. This paved the way for introducing smart infrastructure and smart materials for construction. Shape memory alloy (SMA) is one of the smart materials which has the potential to control damages due to seismic forces and reduce deformations. This alloy finds its application in structures in the form of bars, wires, dampers and many more. SMAs in the form of reinforcement bars along with conventional bars can be deployed in critical regions in bridge piers and beam columns for better performance and controlling deformations. To clearly understand the performance of shape memory alloys in seismic resistance of structures, various experimental and analytical studies were conducted by many researchers across the globe. A detailed review of literature is utmost necessary to understand the potential performance of various types of SMAs and efficacy of these unique smart material in the field of earthquake engineering. This paper critically reviews the application of shape memory alloys reinforcements in structures in mitigating the earthquake forces and performance of piers.*

***Keywords:*** *Shape Memory Alloy; Bridge Piers; Seismic Resistance; Smart Alloys*

## INTRODUCTION

Bridges being considered as the arteries of the infrastructure network, are often subjected to excessive damages due to aging, extreme loading conditions and mainly seismic forces. Any catastrophic effect on the structure shall attract heavy maintenances or sometimes demolishing the structure as a whole. A huge expenditure is being devoted in repairing the structure and hence structural safety against natural disasters like earthquake is of at most priority. Shape memory alloys are the smart materials which is gaining attraction since a decade in the area of earthquake engineering and can create a breakthrough in the infrastructure sector by enhancing the performance of bridges and structures. They are one of the potential candidates for better energy dissipation and controlling larger deformations in structures.

## OVERVIEW OF LITERATURE

### Shape Memory Alloys in Construction

Shape memory alloys are unique materials that can undergo large deformations and regain its original undeformed shape upon unloading and stress reversal. Refer [1]The SMA possesses two properties namely Shape memory effect (SME) which is temperature induced phenomena and Pseudoelasticity or Super elasticity (SE) which is stress based phenomena. A typical shape memory alloy possesses four different temperature states called as the high temperature state, termed as Austinite start and finish and the low temperature state named as Martensite start and finish. These transformation temperatures are different for different shape memory alloys families and composition and this property is deployed in various civil engineering applications till date. Among the many types Copper based, Nitinol (Ni-Ti) based and Ferrous based are the main commercially available SMA category which got its attention and major application in civil engineering field. Vast research is been carried out in the application of Ni-Ti alloys and found successful and it was considered as one of the best suited SMA for civil and structural applications. But Niti alloys are meant for its high cost and difficulty in manufacturing, there raised a growing demand for an alternative to Ni-Ti alloy.

**Development of Iron based SMA**

Ni-Ti due to its high cost and difficult manufacturing process, there is a need for developing an alternate SMA material. Thus, iron based SMA are one of the best alternatives for Ni-Ti alloys due to its reduced cost, better corrosion resistance and easy manufacturing process. Ferrous based alloys were considered to be one of the best alternatives for Ni-Ti and recent researches have proved its significant applications in repair and rehabilitation of heritage structures, strengthening of existing structures, SMA dampers and many more to add. Most widely used Fe-SMA are Fe-Mn-Si, Fe-Mn-Si-Cr and Fe-Mn-Si-Cr-Ni. Refer [2]A novel iron-based shape memory alloy (Fe-SMA) Fe-17Mn-5Si-10Cr-4Ni-1(V,C) (ma.-%) refer [3] has been developed and patented at Empa in Switzerland. (2009). Features of Fe-SMA are High tensile strength, Excellent shape recovery stress (i.e. prestress), high elastic stiffness, desirable prestressing capability, excellent low-cycle fatigue (LCF) resistance

**METHODOLOGY**

Normally, in ductile moment resisting frames, the plastic hinge regions are formed between strong column-week beam joints. The reinforcement detailing of these hinge regions are done in such a way that the longitudinal rebars dissipates the earthquake energy. Usage of SMA at these locations will enhance the dissipating capacity and also helps to restore the original shape after the earthquake. Hence this SMA rebar could be effectively used in piers especially at plastic hinge regions. Due to high cost of SMA Ni-Ti bars are used in combination with conventional bars. As an alternative Fe-based SMAs considered to be one of the cost-effective alloys, these can be combined with conventional bars and shall be proposed to be used in critical zone of bridge piers. This will enable the structure to undergo little damages and minimize the joint repairs post-earthquake. SMAs can prove as a suitable alternate to conventional steel to enhance the functionality of major structures like RC bridges.

Billah and Alam (2016) [4]developed a performance-based design approach for RC bridge piers with SMA reinforcements, with displacement-based approach. The target parameters were maximum drift and residual drift. A specific damping ductility relationship is also developed for SMA RC piers which is essential for calculating design base shear and thus by ensuring the residual drifts are within limits. A detailed design is demonstrated for a NI-TI based SMA RC bridge pier. The validation is executed by NLTHA considering 10 ground motion records and the results obtained were able to match the target values of performance.

Kabir, et.al, refer [5]conducted a study of seismic performance of exterior beam column joints of an eight storey RC building. The test specimens were reinforced with 5 different types of SMA viz Ni-Ti based, Copper based and Ferrous based at plastic hinge locations to form a steel-SMA hybrid connection. The specimen was subjected to reverse cyclic loading. The results showed that the BCJ with SMA s are able to withstand higher amount of load when compared to conventional steel specimen at 4% storey drift. Also, FE simulation of the same was done using Seismostruct to predict the behaviour of Beam column joints (BCJ) and predictions were in compliance with the experimental results.

Billah and Alam (2018) Refer [6] conducted research and presented Probabilistic seismic demand models for bridge piers with five different SMAs. The engineering demand parameter considered were maximum and residual drift and they developed fragility cures and seismic hazard curves to predict the different damage states if bridges. The results showed that the RC bridge piers with SMA showed less probability of collapse for the considered level of earthquake. Also, among the five different types of SMAs Ni-Ti, ferrous and Cu based, FeNCTAB alloy showed better performance when compared to other types.

(Wang 2004) Refer [7] designed and constructed and tested 2 spiral RC columns representing bridge piers and tested using shake .RC columns were reinforced with shape memory alloy reinforcements at plastic hinge locations in and coupled with conventional rebars by using with mechanical anchors. The result showed that the RC columns with SMA bars showed better performance limiting the residual displacement and also the column tip displacement when compared to conventional RC columns. It was also observed that these SMA RC column withstood larger amplitude of seismic forces.

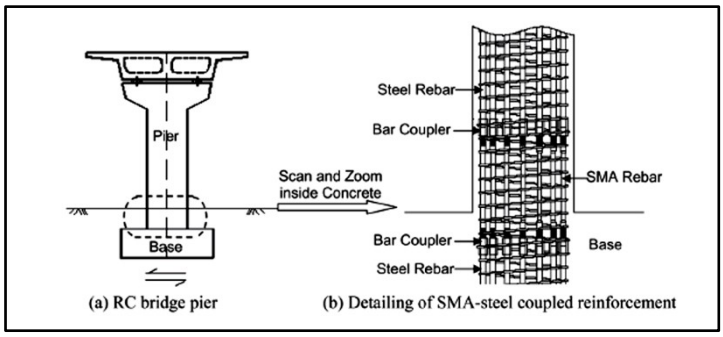


**Figure 1** RC bridge pier reinforced with coupled SMA-steel rebar (Source: Wang 2004)

## RESULTS AND CONCLUSION

This paper intends to critically review the potential application of shape memory alloys for seismic resistance of structures, especially SMA reinforcements in critical locations of piers and beam column joints. The findings of the literature studies are summarised as follows.

- SMA rebars in plastic hinge location of bridge pier can be effective in reducing the residual deformation and showed better performance of structure against earthquakes
- The performance-based design approach of Ni-Ti based SMA RC bridge piers using Nitinol SMA with a target residual drift of 0.6% and a maximum drift of 4.92%. The validation of this using NLTHA showed that the bridge pier that was designed could match with the expected performance with almost 15% of target values of maximum and residual drift.
- Shape memory alloys deployed in plastic hinge location of beam column joint, under seismic forces showed better performance of joints with adequate energy dissipation and minimal residual drift. Among the five different types of SMAs considered, Ferrous based SMA FeNCTAB showed better performance when compared to other alloys, thus making a cost-effective alternative to Ni-Ti SMA.
- In general, SMA-RC bridge piers are very much effective in minimising the vulnerability and can exhibit low probability of collapse up to less than 1% of maximum drift

From the above literature and conclusions, it is clear that SMAs are the most promising alloy in near future for seismic resistance. The future scope of the research may be extended to not only in bridges piers, but also apply this material in substructure, other building and bridge components, Research in this area can be extended to develop a new alloy with suitable composition of Fe-based for enhanced performance and cost reduction. Hence this smart alloy can be incorporated in varieties of civil engineering structures like bridges, beam columns, retrofitting and in steel structures without any hesitation in near future.

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307_IEC43265

# Overview of using Construction & Demolition Waste in Hot Mix Asphalt

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***Abstract:*** *The escalating production of Construction and Demolition waste (C&DW) resulting from fast urbanization has prompted apprehensions about its disposal and environmental repercussions. Additionally, overexploitation of virgin aggregate to meet the requirements of roadway construction creates resource depletion and promotes the use of alternate materials in a sustainable way. This review paper discusses the utilization of C&DW as an alternative to virgin aggregate in Hot Mix Asphalt (HMA). The paper also tries to describe different characterizations of recycled aggregate (RA) and their benefits and drawbacks on the performance of RA-modified HMA mixes in terms of Strength, moisture durability, stiffness of asphalt mixes, and rutting and fatigue resistance. Based on the available literature the C&DW offers sustainable, eco-friendly, and cost-effective advantages over natural resources, since it reduces waste to landfills, conserves virgin resources, and reduces emissions. However, it is quite challenging to establish a strong correlation between the performances of HMA mixes with RA content.*

***Keywords:*** *C&DW; Recycled Aggregate; Hot Mix Asphalt; Marshall Stability; TSR*

## INTRODUCTION

Rapid urbanization and infrastructure development expansion have resulted in a massive generation of Construction and Demolition waste (C&DW), causing serious environmental challenges. In India, roughly 430 million tons of C&DW are generated [1], but only 1 % of the waste is processed for its utility [2] due to the lack of guidelines, resulting in serious disposal issues such as landfilling, environmental degradation, and resource depletion. Simultaneously, growing pavement building puts pressure on traditional aggregate. However, the increasing scarcity of natural resources and environmental concerns have encouraged studies into integrating C&DW into hot mix asphalt (HMA) as a method of cutting material prices, minimizing waste, and promoting sustainability.

This paper looks into the viability of employing C&DW as a substitute for natural aggregates in HMA, focussing on how it affects the performance, durability, and environmental impact of asphalt mixes.

## CHARACTERIZATION OF C&DW

The physical properties of recycled aggregate (RA) obtained from C&DW are highly affected by the adhered mortar on its surface. According to Prasad et al. [3], apart from adherence of cement mortar, strained aggregate is yet another factor that influences the physical properties of RA. In this regard, different laboratory tests were conducted by different researchers as shown in **Figure 1**. It is very conspicuous from the result that RA has shown less specific gravity, more water absorption, and higher impact and crushing resistance than the virgin aggregate. According to Lee et al. [4], RA has a rough, porous, flat, and even morphology compared with VA. Moreover, the chemical composition of RA must be quantified so that the affinity of bitumen towards RA is established. **Figure 2** indicates the chemical composition of the RA presented by various studies. Ma et al. [5] noted an elevated $SiO_2$ concentration and a diminished CaO content in comparison to limestone while Yang and Lim [6] noted that the composition rate of CaO in recycled aggregate (RA) was significantly greater than that in virgin aggregate (VA) due to the residual mortar adhered to the RA. Additionally, a study by Nwakaire et al. [7] found that the chemical characteristics of RA is intermediate between that of VA and cement.

## PERFORMANCE CHARACTERISTICS OF HMA MIX WITH C&DW

Incorporating RA in the HMA mix significantly impacted its performance characteristics. Some investigations found an enhancement in Marshall Stability in HMA mixtures containing RA [7-10]. On the other hand, some researchers

found the opposite to be true [4,11,12]. A study by Nwakaire et al. [7] found that cement on the surface of RA increases internal cohesion and improves the stability value. Furthermore, some authors also claim that moisture susceptibility characteristics are enhanced with the addition of RA, as it initiates self-cementing characteristics and enhances the adherence of RA to asphalt mix [8,11-13]. Contrary to that, some researchers found that the TSR value reduced with the incorporation of RA [7,14,15]. Various studies have been conducted to estimate the effect of the addition of RA on bituminous mixture stiffness in terms of resilient modulus and dynamics modulus. Some of the researchers [10,14,15] found that improvement in the resilient modulus of the bituminous mix containing RA, whereas [9,16] reported the opposite result. Additionally, a study by Nwakaire et al. [7] observed that fine RA exhibits the most significant deformation overall cycle duration while coarse RA experienced greater deformations during the beginning cycles but surpassed the control by the end of the testing. The summary of the findings of various investigators regarding the performance of the RA-modified HMA mix is presented in **Table 1**.

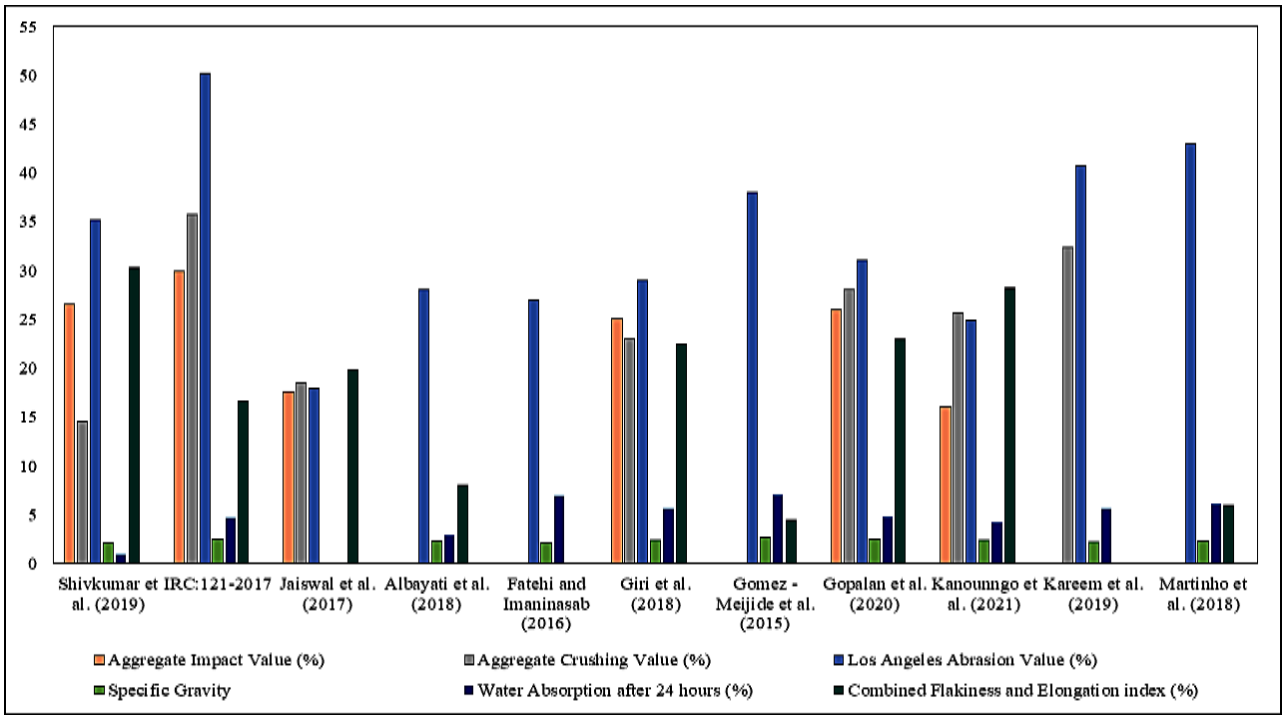


**Figure 1** Physical characterization of C&DW

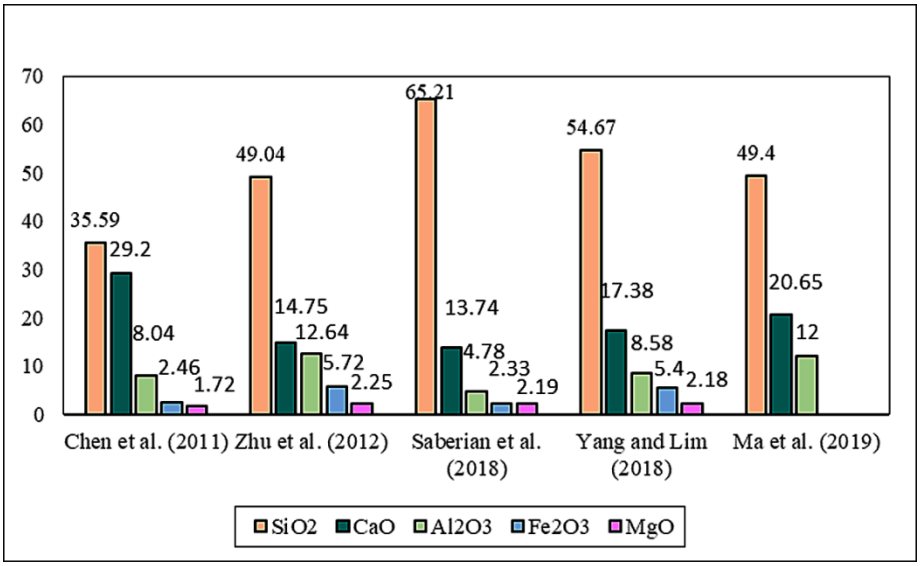

**Figure 2** Chemical characterization of C&DW

**Table 1** Performance characteristics of RA-modified HMA mix

| RA (%) | Fraction | Impact on the HMA mixes | | | | | | | | | References |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | MS | ITS | TSR | Rutting | PD | RM | DM | FL | LTC | |
| 0, 15, 30 and 45 | Coarse | | ↓ | ↓ | → | | ↑ | | | | [14] |
| 0, 15, 30 and 45 | Fine, coarse, and both | ↑ | | | | → | | ↓ | ↑ | ↓ | [9, 16] |
| 0, 20, 40, 60, 80, 100 | Coarse | ↑ | ↓ | ↑↓ | | ↑↓ | ↑↓ | | ↑ | | [7] |
| 0, 20, 40 and 60 surface treatment | Coarse | | | | | ↑ | | → | ↑ | | [17] |
| 0, 5, 10, 20 and 30 | Coarse | ↑ | ↑ | ↑ | ↑ | ↑ | | | | | [8] |
| 0, 35, 42 | Fine-coarse | | | ↑ | | | | | ↑ | | [13] |
| 10, 20, 30, and 40 | Coarse | ↑ | ↓ | ↑ | ↑ | | ↑ | | | | [15] |
| 0, 6, 41, 53 and 100 | coarse | ↑ | | | ↑ | ↑ | ↑ | | ↑ | | [10] |

MS: Marshall Stability, ITS: Indirect tensile strength, TSR: Tensile strength ratio, PD: Permanent deformation, RM: Resilient modulus, DM: Dynamic modulus, FL: Fatigue life, LTC: Low-temperature cracking.

↑ Increases ↓ Decrease ↑↓ Increase then decrease → remain unchanged

## TREATMENT OF RECYCLED AGGREGATE FOR HMA MIX

From the above discussion, the higher porous nature and lower strength of the RA significantly affect the HMA performance. To overcome this issue, various researchers adopted different treatment techniques to improve the mechanical characteristics. Studies adopted by Kareem et al. [18,19] utilize double coating with cement slag paste and Sikka Tite BE leads to water absorption reduction and improvement in stiffness and moisture resistance of the mix. On the other hand, silicon resin-treated RA in the HMA mix observed a marked improvement in permanent deformation and water-induced damage [20]. Furthermore, a study conducted by Pasandín and P´erez [21] utilized thermal treatment for the loose RA-modified HMA mix in the oven at 170°C resulting in an improved coating of aggregate by bitumen with a marked reduction in porosity. Another study conducted by Giri et al. [22], utilized waste polythene for RA coating, resulting in improved cohesion between RA and bitumen and enhancement in water-induced illness.

## ENVIRONMENTAL & COST ANALYSIS OF HMA MIX WITH C&DW

C&DW management is a severe challenge due to its non-putrescible and non-combustible nature. This section will be intended to the energy consumption and emissions issues connected with the use of RA versus natural aggregates. Generally, Life cycle assessment (LCA) methods as proposed by Thives and Ghisi [23] are applied to evaluate the impacts of natural aggregate production from raw materials and RA production from C&D waste. Research conducted by Hossain et al. [24], reveals the environmental effect regarding climatic change, human health, ecosystem quality, and resources is decreased by nearly 49–51%. This will further save non-renewable energy use 185 MJ and will reduce 14 kg $CO_2$ equivalent. The expected environmental consequence of manufacturing 1 ton of fine and coarse aggregate is estimated and the result shows that to produce 1 ton of fine aggregates, it requires about 518 MJ of non-renewable energy with process emission 33 kg $CO_2$ equivalent GHGs. In contrast, the LCA outcomes show that approximately 12 kg $CO_2$ eq/tons (GHGs) is emitted to produce 1 ton of recycled fine aggregate. Similarly, for the coarse aggregate, approximately 32 kg of $CO_2$ eq GHGs/tons are released, whereas to generate recycled coarse

aggregate, around 11 kg of $CO_2$ eq/tons (GHGs) are released [24]. Furthermore, the HMA blend with approximately 20 and 30% RA content exhibits reduced direct costs of $0.4 and $0.7 per tonne compared to similar asphalt mixes produced with traditional virgin aggregates [25, 26].

## CONCLUSION

Based on the extensive literature study on the incorporation of recycled aggregate from C&D waste in HMA mixtures, the following points can be concluded:

- Recycled aggregate can be a sustainable and eco-friendly solution for the shortage of virgin aggregate and can be effectively utilized in low-volume roads, but the use of RA in India is quite limited due to the lack of specifications.
- Due to the heterogeneity of RA, it is very difficult to establish the correlation between the performance characteristics of HMA mixes and RA content.
- The presence of mortar on the RA surface increases the porosity and rise the bitumen and water absorption. To mitigate these issues, various pre-treatment techniques have been conducted by different investigators to improve the physical characteristics of RA.
- Based on the outcomes of various literature, studies can be conducted on the effect of surface texture and internal friction of RA on the performance of mixes. The use of C&DW as a mineral filler and bituminous mastic is also not well-explored.

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# Infrastructure

## Transportation Infrastructure

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# Traffic Signal Optimization and Synchronization using PTV Vissim

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***Abstract:*** *Traffic congestion is one of the major problems in the metropolitan city. The rise in traffic is mainly due to increase in population and vehicle volume day by day, it leads to increase in queue lengths and delay time during peak hours. There are two methods to counteract this problem; the first one is by modifying the geometry of the road like widening of the roads and the second one is by optimizing the various facilities which are available on the roads. Nowadays due to the advancement of technology, it is easy to simulate the traffic simulation at various junctions which are available on the roads with a simulation tool. One such a simulation tool is Vissim. PTV Vissim is a micro simulation software which has been widely used to evaluate different traffic management scenarios to choose the best alternative and optimization measures before implementation of traffic. The aim of optimizing of the traffic signal is to provide smooth flow of traffic along streets and highways to reduce travel time, stops and delay. The output values obtained in Vissim were compared to the corresponding values before coordination.*

***Keywords*:**

## INTRODUCTION

The rapid migration of people from rural areas to cities has led to a surge in population growth, resulting in overcrowding on roads, particularly at junctions. The increasing use of motor vehicles has exacerbated the issue, causing congestion on roads. India's heterogeneous traffic conditions, characterized by a lack of lane discipline, further compound the problem. However, current technology offers solutions to mitigate traffic congestion. One such solution is the use of microsimulation software.

Traffic congestion is a major challenge facing metropolitan cities, including Vijayawada. In this study, we conducted a case study on the corridor from Tadigadapa junction to Poranki, where we performed traffic volume and speed studies. To optimize signal cycle length, we calibrated the VISSIM simulation software model by selecting suitable parameters to replicate real-world conditions. Our goal is to develop a systematic approach to reduce traffic congestion using technology. By calibrating the model, we can simulate various scenarios to identify the most effective solutions to alleviate traffic congestion.

Simulating real-time traffic operations has become essential for traffic engineers and transport planners to ensure smooth traffic flow, minimize congestion and delays, and optimize traffic flows for both public and private transportation. Traffic modeling can be logically categorized into three approaches: macroscopic models, which focus on larger-scale traffic flow, measuring roadway capacity, average travel time, and average speed; microscopic models, which concentrate on individual vehicles and their flow characteristics; and mesoscopic models, which bridge the gap between macro and micro models. Microscopic simulation is a powerful tool, offering a fast, inexpensive, and risk-free environment for testing traffic scenarios, and software such as VISSIM has gained prominence in recent years, enabling traffic engineers and planners to model dynamic traffic systems, make informed decisions, and optimize traffic flow.

### Literature Review

Christopher M. Day and Darcy M. Bullock's et al. [2] 2018 paper presents a detailed study on signal operation, examining the progression of cyclic flow profiles and predicting changes to the traffic stream under trial offset adjustments. The researchers utilized the cyclic flow profile and the link pivot algorithm to analyze the impact of offset adjustments on traffic flow. Their findings suggest that link pivot offset optimization relies on a prediction

methodology that accurately forecasts vehicle arrivals at coordinated signals. This method has been successfully integrated into open-source software for automated traffic signal performance. The study demonstrates the effectiveness of static analysis in improving traffic flow by adjusting anticipated values, highlighting the potential for optimized signal timing to enhance traffic efficiency.

Gokce et al. [3] optimized traffic signal timings at a major roundabout in Izmir, Turkey, using Particle Swarm Optimization (PSO) to reduce wait times. They simulated the intersection using VISSIM and implemented PSO in MATLAB, considering 12 out of 28 traffic signals. The optimization resulted in a 55.9% decrease in average delay (from 36.98 seconds to 16.23 seconds) and a 9.3% increase in vehicles passing through the roundabout. By varying the cycle time from 149s to 5s, they found the optimal signal cycle time, significantly improving traffic flow and reducing congestion.

Zhang et al. [4] developed a multi-objective optimization model for metropolitan traffic signal timing, considering traffic volume, latency, and emissions. They used the genetic algorithm NSGAIII to solve the model and introduced a hybrid binding strategy (HCNSGAIII) to improve signal timing schemes. Simulation experiments showed that HCNSGAIII outperformed existing methods, with significant advantages in reducing traffic volume, latency, and emissions. The results demonstrated the effectiveness of the proposed approach in optimizing traffic signal timing for real-world applications.

Alvaro J. Calle-Laguna's et al. [5] 2019 study applied Webster plan techniques to optimize cycle length at intersections, reducing delay, fuel consumption, and air pollution. Simulation results showed that optimized cycle lengths decreased congestion, improved traffic flow, and provided an effective approach to mitigating environmental impacts at intersections.

Mathew and Radhakrishnan et al. [6] mention that macroscopic modelling of traffic in Asian cities has resulted in big errors and proposed micro-simulation models as better suited alternatives to account for the high degree of heterogeneity in terms of vehicle characteristics and lane behavior in Asian traffic. They also checked the effectiveness of VISSIM (2011) to model heterogeneous conditions and found satisfactory results. Heterogeneous conditions were simulated by permitting overtaking from both left and right sides and by allowing diamond-shaped queuing in VISSIM.

Sariri et al. [6] used VISSIM to simulate traffic at a 3-way intersection in Makassar City. They optimized signals by increasing cycle time from 105 to 120 seconds, reducing average queue length by half (233.93m to 122.26m). Optimizing cycle times improved traffic performance at the intersections.

**Objectives**

- To study performance of existing signal.
- Optimization of existing signal.
- Synchronization of traffic signal.

**METHODOLOGY**

- Selection of study area.
- Performing traffic studies.
- Calculation of optimum cycle length of existing traffic signal.
- Inputting data into Vissim.
- Generation of model in Vissim.
- Simulation of signal and analyzing the results.

## RESULTS

### Volume Data Collection

Strech: Tadigadapa to Poranki on which volume studies are performed.

Time: Time collection of traffic volume data is 1hr at each junction for 3 peak periods of a day.

Observations: Classified volume count

Method: Direct manual method

### Traffic Signal Design

Traffic volume is taken at morning, afternoon, and evening for carrying these studies we have selected a stretch from Tadigadapa junction to Poranki Junction in Vijayawada, Andhra Pradesh. We stand beside the road and different vehicles were counted manually. We take average of 3 peak hours. The PCU values are calculated by multiplying obtained volume with corresponding PCU values. By using webster method we calculated green time for each lane. while designing, U-turn volume for Vijayada is not considered because there is divider for Vijayawada Uturn volume.

**Table 1** Green time for each lane in Tadigadapa junction

| From | To | Total PCU | Green time for each direction |
|---|---|---|---|
| 100 feet road | Tadigadapa | 487 | 6 |
| Vijayawada | Tadigadapa | 1221 | 24 |
| Tadigadapa | Tadigadapa | 233 | 4 |
| Poranki | Tadigadapa | 1362 | 27 |
| U-turn to Poranki | Tadigadapa | 181 | 3 |
| U-turn to Vijayawda | Tadigadapa | 535 | 7 |

**Table 2** Green time for each lane in Poranki junction

| From | To | Total PCU | Green time for each direction |
|---|---|---|---|
| Penemaluru | Poranki | 233 | 4 |
| Vignan Bharathi road | Poranki | 733 | 14 |
| Poranki | Poranki | 192 | 3 |
| Gosala | Poranki | 1298 | 24 |
| U-turn to Penemluru | Poranki | 403 | 5 |

### Vissim Modelling

- Background and scaling
- Links and connectors
- Vehicle types and classes
- Vehicle volume input
- Routes generation
- Signal program
- Data collection points
- Evaluation
- Simulation parameters
- Simulation run

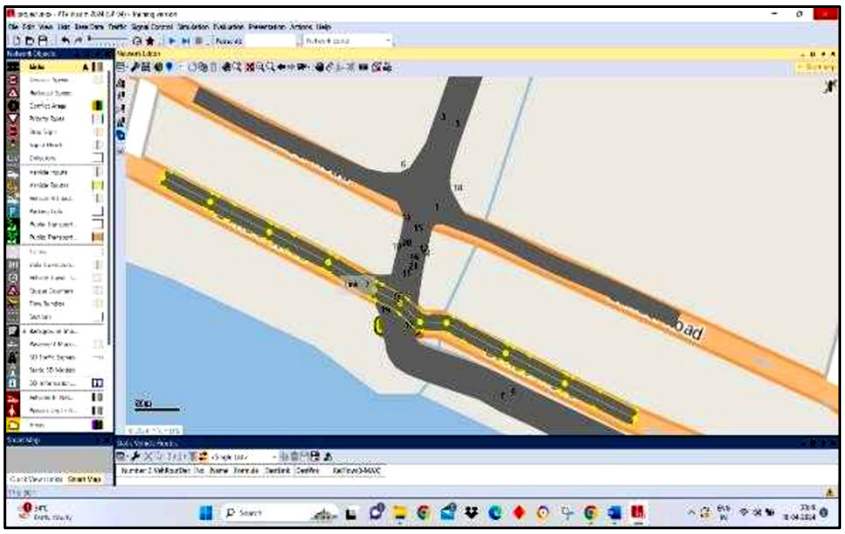

**Figure 1** Lane creation and route generation

We completed our model up to route generation; we are unable to present more information regarding this due to limitations.

## FUTURE SCOPE OF PROJECT

In our project we only designed the traffic signal using Webster's approach method. We do not generate real time simulation using optimum cycle length, which is calculated through the webster's method and whole operation will perform with PTV Vissim.

## CONCLUSION

The improvement of town traffic condition is largely dependent on the modern ways of traffic management and control. Advanced traffic signal controllers and control system contribute to the improvement of the urban traffic problem. The intelligent of traffic signal controller that is introduced in this project with the help of a Webster's approach method. In our study we performed traffic volume study at different junctions in the corridor from Tadigadapa junction to Poranki junction. From our study we conclude that traffic signal is the most economical, effective, and suitable for that area.

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49_IEC71570

# The Scenario of Advanced Aviation Manufacturing and Maintenance in India for Deployment throughout the subcontinent: Opportunities, Threats and Strategic Outlook

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***Abstract:*** *The extremely opportune geological position of India, its favorable demographics, its technological superiority and its diplomatic allegiance with neighboring countries ensures a thriving market for small and medium range aircrafts for servicing civil as well as freight aviation channels in and around the subcontinent. Given her unchallenged superiority in space exploration and an enthusiastic but small domestic aeronautics production capabilities, the next two decades of growth and rise in demand shall produce unprecedented prospects in the aviation services sector. The impetus provided by the Make-in-India movement shall help usher in a new era of advancements in production practices by the infusion of investments both from within and abroad. The following article provides a speculative analysis of the benefits and challenges involved in such a venture while providing special care to building strategic ties with important global partners. Finally, a case is presented for the incorporation of advanced sustainable materials and zero-carbon product life-cycle techniques that will cement India's position as a tactical global leader in the aviation sector.*

***Keywords:*** *Aviation; Infrastructure; Manufacture; Maintenance; Civil; Military*

## INTRODUCTION

India has proclaimed its air superiority boldly with the help of ISRO and stands second to none in the space exploration sector. ISRO has left its mark in the Global space exploration sector and has proven the excellence of our scientist beyond the shadow of a doubt. ISRO was able to achieve this with a very modest budget and healthy dose of skepticism from other space organizations throughout the world.

Despite this, ISRO has also established itself as a global communications leader in satellite deployment service for various countries and a knowledge base for gathering meteorological data. Just as we have successfully exploited our geological proximity to the equator (specifically Satish Dhawan Space Center, Sriharikota) with strategic help from European friends like France we should also be able to achieve this in the aviation sector with transcontinental allies like Brazil.

Another Jewel in India's Aeronautical superiority crown is Hindustan Aeronautics Limited (HAL). Closely resembling ISRO successes HAL was also able to establish itself as a global aeronautics leader with help of allies like Russia and the USA. In addition to strategic partnerships and knowledge exchange programs, HAL has been able to develop its own indigenous aircrafts like the Tejas light combat aircraft (LCA) and has also established itself as a major maintenance hub for global aviation systems from various manufacturers. The benefits however are not limited to technology exchange alone as it also provides a great deal of foreign exchange funds to the GDP. Defense exports have also helped us to strain in our eyes with Argentina, Nigeria, Egypt and the Philippines.

## MOTIVATION

There is legitimate cause for excitement in the consumer aviation space in India and around the subcontinent owing to the changing market landscape. For example, in 2023 alone India has registered around 23% growth in the domestic space alone while serving an aggregate of 152 million consumers[1]. Now take into account that this constitutes only 69% of the subcontinental market and we begin to perceive a sector teeming with opportunity when supported by timely investment and technological inputs. But exactly how large is this growth being estimated at? International

passenger traffic which is a premium and lucrative market has served 68 million passengers in 2023 and is projected to serve beyond 225 million individuals in 2024 (surpassing Great Britain). By 2030, this growth is projected to be 300 million even by modest estimates owing to rising incomes for both the middle and upper middle classes. In addition to this, the government of India (GoI) has pledged to increase the number of airports from 150 to around 220 facilities by 2025.

Taking into consideration the size of the expanding market, and the fact that India is not even top 10 by revenue in the global aviation manufacturing and assembly industry, the huge lacuna within the domestic production sector needs to be targeted in order to meet increasing demand in and around the sub-continental region[2].

## METHODOLOGY

Indian automotive sector can be used as an example to assess the trends in consumer behavior and benefits derived from the implementation of sustainable goals within every step of the product life cycle[3]. The electric vehicles market in India led by two-wheelers is set to grow by a multiple of 3 within the next three years, taking gross revenue in this sector from US$2bn to above US$7bn by the end of 2025. In this scenario, it should also be noted that the GoI has taken an active interest in this sector by implementing policies such as EV30@30 which aims to capture 30% of total vehicle sales in pure electric vehicles(EVs). The GoI can provide similar policy benefits, such as production linked incentives (PLIs), to the aerospace sector to provide impetus and fast development of manufacturing hubs across the country.

Similarly, to follow the trends in vehicle exports, one has to pay close attention to the two wheeler exports from India to countries such as ASEAN nations and Nigeria. India has achieved global dominance in this space with the help of Japanese technology. This success can be replicated by accepting Boeing and Airbus as technology partners for the production of light and medium passenger aircrafts for inter-city usage with a maximum flight distance of 3000 miles and an operating roof of 15000 feet. A precedence has already been set in this space by collaborating with Embraer (Brazil) E175, EJ145 and similar smaller aircrafts.

Having established the arguments for benefits within the civil aviation space, similar focus can be applied to the defense aviation space where India has to maintain its air superiority among its neighbors to maintain strategic military advantages. Embraer has also collaborated with our military for the production and maintenance of C-390 aircraft[4]. It provides a positive outlook for collaborating with high-tech partners such as Dassault, Boeing, Lockheed Martin and the Russian aerospace players. India has yet to develop a strategic light combat aircraft (LCA) which is capable of delivering large payloads over multiple missions. This specific class of combat aircrafts should be targeted to enhance our defense capabilities in the near future.

The long term future (spanning the next 50 years) of aviation depends heavily on the development full electric of hybrid-electric powertrains for both propeller-driven and jet-engine airliners. Honda is hard at work developing these prototypes[5] and special mention must be made of their eVTOL (electric hybrid Vertical Take-off and Landing) tech display platform which is a light passenger aircraft having a hybrid-electric propeller driven twin tail short wingspan design that the best of buzzwords in the highlights today and is aimed squarely at the Japanese domestic aviation market where flight distances are short and the same vehicle can be operated for several shuttle trips[6] rendering it as a perfect option as an air taxi. Although, the Indian passenger could not pay such high prices individually per flight, we could still have feasible taxi services within closely spaced cities with high commercial activity. Mumbai-Ahmedabad, Delhi-Mumbai and Pune-Nagpur are certain feasible pairs for air taxi operation within reasonable distances. Similar services could be rendered from Bangladesh to Myanmar for the international audience. The pathway to industrial development in the aerospace sector then becomes clear.

## ECONOMIC FEASIBILITY

Excitement in the market may not always translate to large economic benefits and this is especially true for technology and resource intensive manufacturing. However, a deep examination of the present market circumstances should lead us into the next logical stage, which is to perform a “MAKE/BUY” investigation. This will ensure a

concrete base to found future business decisions as to the benefits of manufacturing avionics domestically, rather than importing. The key elements influencing this critical decision are:

A. Make cost vs buy cost: this is self-explanatory and requires a detailed analysis of all the expenditure involved in domestic production as opposed to outsourcing the project.

B. Quality control: when the manufacturer is the consumer, maintaining the highest standards becomes necessary and prime motive of operations.

C. Capacity and expertise: these are key features for the development of sophisticated industries

D. Supplier reliability: this becomes an important factor when we consider important mutable factors like foreign relations and regional stability.

E. Flexibility and adaptability: having self-governed industries increases autonomy and enables all involved stakeholders to move quickly with the ebb and flow of changing markets.

Other indices prompting the commencement of fabrication include

I. Risk Adjusted Return on Capital (RAROC):

$$\text{RAROC} = \frac{\{Revenue - Cost - (Probability\ of\ Default * Loss\ given\ Default)\}}{Invested\ Capital} \qquad \text{Eq 1}$$

II. Markov Chain Monte Carlo Stochastic Volatility (MC2SV): It takes into account the time-variance of asset return volatility.

$$\gamma_t = \sigma_t + \epsilon_t \qquad \text{Eq 2a}$$

$$\text{Log } \sigma^2_t = \phi \log \sigma^2_{t-1} + \eta_t \qquad \text{Eq 2b}$$

Where, $\gamma_t$ are the asset returns, $\sigma_t$ is the time-varying volatility, $\phi$ is latent volatility and $\epsilon_t$ and $\eta_t$ are Gaussian errors

On a different note, some airliners can be developed for micro-consumption serving ten passengers and small freight load at a time. These operators could function on a scale similar to call cabs.

**SUSTAINABILITY**

Owing to the provisions of climate action included within sustainable development goals (UN-SDGs) which dictates that industries must align themselves to objectives like zero waste and zero carbon discharge, India would do well to develop its aeronautical industry indigenously in order to cope with the changes introduced by these rules rather than having to depend on technology partners for knowledge transfer.

The following focus areas need to be operated upon in order to align industry goals with UN-SDGs and minimize the ambition gap (gap between industrial growth expectations and its negative climatic impacts based on conventional planned pathways)

- Development of sustainable biodegradable composites for aircraft internal structures
  - Biodegradable polymers obtained from plant fibers and recycled carbon fibers have been developed specifically for use in 3D printing with appropriate strength and other mechanical characteristics[2] so that they can be used in aircraft internal structures such as cladding for the inner cabin where it can be used to replace a slew of conventional plastics and polymers such as has been demonstrated by the Eco-compass project already.

- These advanced materials pose benefits even during regular operation of the product by enhancement of resource consumption and reduction in weight thereby significantly enhancing the cause for sustainability.

- Development of low-carbon manufacturing infrastructure and techniques

  - Life cycle assessment (LCA) of the entire service life of an aircraft has to be taken into account which includes monitoring of wastes, reduction of pollutants, collaborating with suppliers for consolidating low carbon plans and finally, completely embracing sustainable aviation fuels (SAFs) from the design inception stage[7].

  - Similar approach can be taken in the passenger and freight service industry by reduction of printed documents for tracking, energy consumption improvements in maintenance of the aircraft and reduction in the emission of greenhouse gases during operation.

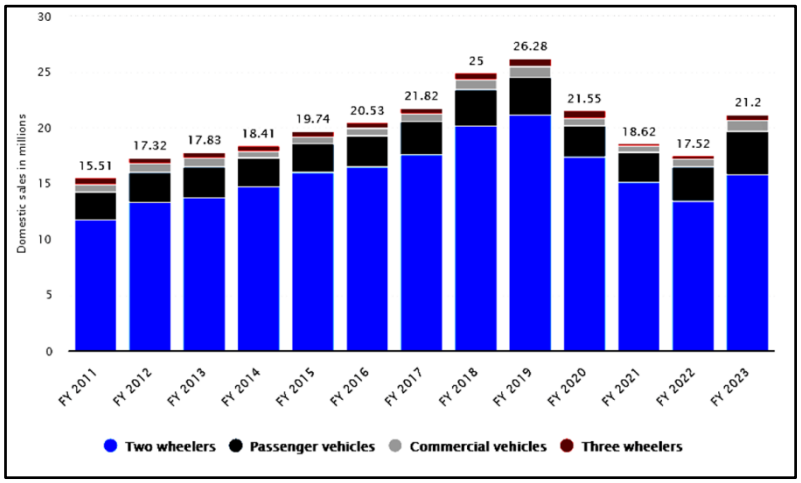


**Figure 1** total vehicle sales in India 2011-23

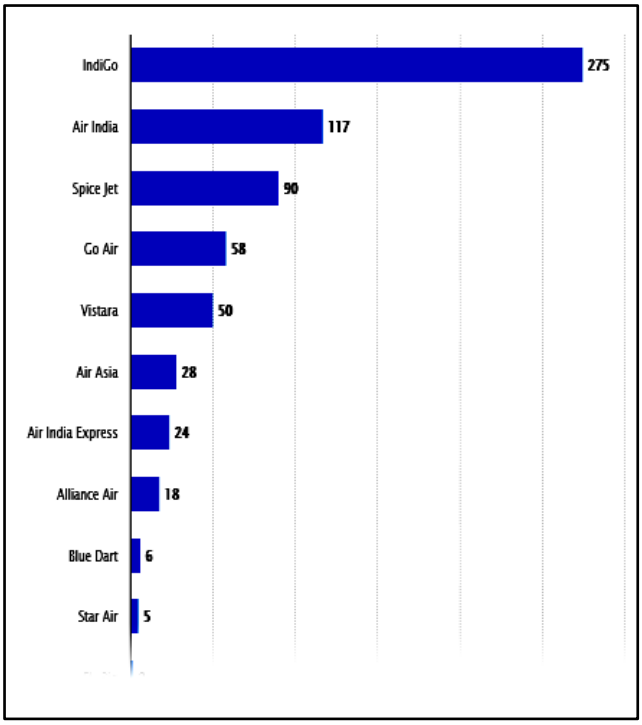


**Figure 2** numbers of aircraft in service by individual carrier FY2022

**Figure 3** techno-artistic rendition of futuristic (left) passenger aircraft and military reconnaissance helicopter (right) with conventional attack helicopter in background, generated by AI

## CONCLUSION

This study aims to promulgate the importance of the development of strategic civil and military aircraft manufacture as well as maintenance indigenously and the benefits derived thereof. The sub-continental aviation market is poised to achieve unprecedented progress in the coming decade and India is perfectly positioned to take advantage of this growth owing to the existence of a sophisticated engineering talent pool and the willingness of private and public sector, both domestic and foreign, to invest necessary fiscal support within the window of opportunity. This opportunity when exploited properly shall well and truly push indigenous manufacturing into the realms of "Irresistible India".

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96_IEC25991

# Can Indigenous Driving Simulators Surpass the Limits of Automated Simulation Trials?

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***Abstract:*** *This study explores the capabilities of indigenous driving simulators to address the shortcomings of automated trials that utilise off-the-shelf simulation tools. Driving simulators have become crucial instruments for examining driver behaviour and road safety in controlled environments, enabling the replication of various road and environmental conditions. Nonetheless, commercial simulation software frequently fails to adequately represent the intricacies of real-world situations, particularly those shaped by specific geographic and cultural factors. This paper examines the potential of indigenous simulators to enhance flexibility and realism through the customisation of road environments and the incorporation of human factors like visual acuity, age, and cognitive variability into experimental designs. A series of controlled trials were carried out utilising automated scripts within commercial simulation software, investigating drivers' perception-reaction times (PRTs) under diverse visibility and weather conditions, such as clear weather, fog, and rain at various times of day. The findings indicated a consistent yet unrealistic set of PRT values across different scenarios, underscoring major limitations in the ability of commercial programs to effectively consider human behavioural variability and environmental subtleties. Indigenous simulators provide the capability to fine-tune scenarios with local field data, accurately reflecting native driving conditions and tackling the shortcomings in realism and validity seen in commercial tools. Through the incorporation of various driver characteristics and authentic road settings, these simulators facilitate more dependable evaluations of cognitive and behavioural reactions. This study highlights the importance of native approaches to enhance road safety research, setting the stage for developments in simulation technologies and their role in analysing driver behaviour.*

***Keywords:*** *Road Safety; Vehicle Simulation; Experimental Trial Performance*

## INTRODUCTION

Alarming life losses caused by road traffic injuries [1] has led global and local organisations to make conscious efforts to curb road traffic crashes. Research has shown that the likelihood of traffic accidents is greatly influenced by the interactions between drivers, their vehicles, and the roadway; over 90% of accidents are caused by driver-related factors [2,3]. To enhance road safety, a full comprehension of these relationships is necessary. Driving requires drivers to navigate while engaging with other road users since it requires them to perceive distances and integrate visual inputs from the surroundings [4]. Around 90% of information pertaining to driving is visual [5]; therefore, processing complex visual sceneries requires the brain's processing speed, which can occasionally cause confusion and contribute to risky driving [6]. Adverse weather conditions like rain, fog, dim lighting, etc., make driving strenuous and raise the possibility of accidents [7]. These elements emphasize how crucial it is to comprehend how visual perception affects driving behaviour and traffic safety. Drivers' visual abilities affect the sequential phases of detecting the road environment, which includes sensing, processing, and application [8].

Experiences shed light on the fact that conducting behavioural studies of drivers in a real-world scenario is crucial [9, 10]. Earlier investigations also highlighted traffic sign occlusions increase driver perplexity [11]. The dynamic and unpredictable nature of road environments makes it hard to control for variables such as traffic density, weather conditions, and driver intent, all of which can significantly influence driving behaviours. Data collection in real-time, fast-moving situations also requires sophisticated equipment and precise synchronization between vehicles, which can be logistically challenging and costly. Additionally, researchers must address ethical concerns related to privacy, as capturing data on public roads might inadvertently involve individuals who have not consented to participate in the study. Furthermore, the presence of an observer may lead to reactivity, where drivers alter their behaviours simply because they know they are being watched [12], which can skew the data. The investigations require that similar studies be repeated in various geographic or cultural contexts. Because field trials are unable to capture all potential

impacts and implications in the real world [13], conducting controlled tests with a simulator in a virtual reality (VR) platform is preferable. These VR platforms, like driving simulators, range in fidelity from low to high, and the choice of one would rely on the goals and designs of the experiments. A simulator with high realism may not always imply high validity since the relationship between fidelity and validity of simulators is not simple [14]. Using a low-fidelity simulator with a systematic experimental strategy offers a cost-effective way to ensure high validity in testing safety performance.

The primary objective of this study is to examine drivers' perception reaction time (PRT), a critical factor influencing road safety and driving performance. To achieve this goal, the research employs a series of experimental trials designed to investigate how PRT varies under different environmental conditions. Specifically, the trials were conducted in three distinct weather scenarios: (a) clear weather to assess baseline perception reaction times under optimal driving conditions (b) rainy conditions to evaluate how precipitation affects drivers' ability to perceive and react to stimuli and (c) foggy weather to investigate the impact of reduced visibility on reaction times. Also, these trials were made during various times of day, which include daylight to understand reaction times during fully visible scenarios, twilight to analyse the transitional period when visibility decreases, and night-time to examine the effects of darkness on drivers' perception and response. While performing experiments, the study developed roadside environments using out-of-the-box elements. These environments are designed to simulate real-world conditions and include built-in analytic tools for precise measurement.

## METHODOLOGY

The goal of the experimental design was to investigate how a driver would interpret and respond to different visibility situations in comparable traffic scenarios. In light of this, a methodical procedure was employed (see Figure 1) to examine in detail the situations in which the drivers engage with various on-road entities. Initially, the study created scenarios using a commercial simulation application [15]. The resulting scenario was a 100-meter straight trial road stretch with two lanes and bituminous surface, a raised kerb, and a paved sidewalk. Next, the section was assigned desired road logic, in this case, it was made bi-directional with a designated vehicle spawn point. Lastly, a rural roadside setting was added to the scene by using a variety of out-of-the-box agents.

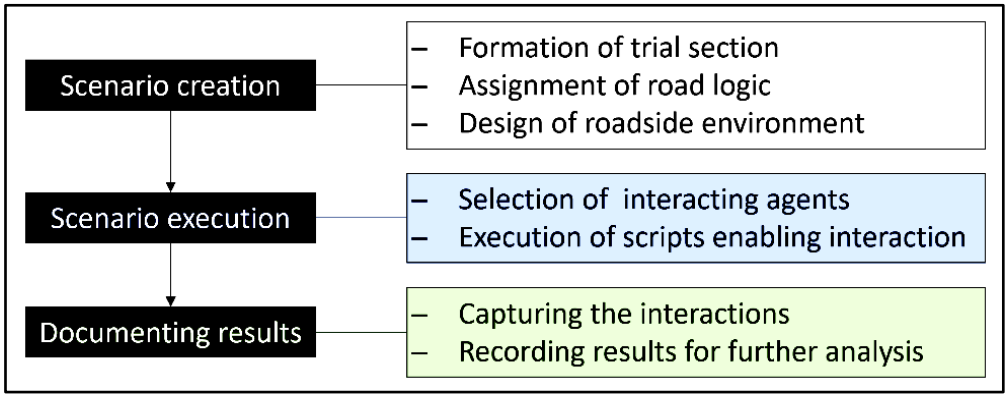


**Figure 1** Sequential steps followed in off-the-shelf simulation program for experimental trials.

Subsequently, the entire scene was executed by using script automation bundled with the software package, wherein the interaction points were defined for different on-road agents. Repeated trial runs attempted to measure driver's PRT at various visibility conditions viz. clear weather at daylight, twilight and night and at daylight in foggy and rainy weather conditions. Ultimately, every interaction was captured and monitored and were documented for in-depth analysis. The software offers the freedom to modify the environment's visibility circumstances while the scenario is running (see **Figure 2**). One can produce scenarios with permutation and combination of six different environmental variables which are time of day, rain intensity, wind speed, fog intensity, snowfall intensity and ambient humidity. This study has shortlisted variables based on the prevalent local conditions. The chosen variables are (a) time of day: daylight, twilight and night; (b) rain: at intensities 0, 25, 50, 75; (c) fog: at intensities 0, 25, 50,75.


**Figure 2** Experimental trials at different visibility: (a-b) with third person perspective at daylight and twilight in clear weather and (c-d) with first person perspective at daylight during foggy and rainy conditions.

By default, the scripts designate a driver to operate the given car under different circumstances; nevertheless, the driver's characteristics don't alter while the script is running. The scripts continuously monitor the positions of different mobile entities present in the scenario. It keeps track of the vehicle's position by recording its coordinates along with its speed. Various activities taking place in a scenario, viz. change in vehicle position, pedestrian movement, etc., can be validated by changing the camera perspectives, namely first and third-person perspective (see **Figure 2**). Another crucial role which the automated scripts play is in defining the time and position at which the interaction between various agents will trigger. In this particular scenario, the interaction took place between a passenger car and a pedestrian. The pedestrian was spawned on the sidewalk, and whenever the car crossed the halfway mark on the trial section, the pedestrian entity started to cross the road, which in turn triggered the application of brakes. All of these activities were coded in the script and repeatedly performed in all the scenarios.

## RESULT ANALYSIS

As mentioned in the previous section, the automated scripts employed in this study facilitate the comprehensive documentation of a variety of variables. Among these variables, vehicle speed and simulation time, defined as the total runtime of the simulation, are particularly crucial for analysing drivers' perception reaction time (PRT). The total duration of the simulation was set to 18 s. During this period, the speed of the vehicle was recorded at regular intervals of 0.1 s. Subsequently, the collected data was plotted for further analysis (see **Figure 3**). The scatter plot depicts the relationship between vehicle speed and simulation time. This visual representation clearly illustrates distinct zones of acceleration and deceleration, providing valuable insights into the dynamics of driver behaviour during the simulation.

The analysis follows the textbook definition of perception reaction time which is the time it takes for a driver to identify a hazard and take action. In this study, all the scenarios consist of the same hazard (termed as interaction), which is – a pedestrian suddenly attempts to cross the road in front of the car, and the action taken is the application of brakes. Examination of Figure 3 reveals that at point A, the driver and the pedestrian start interacting as the pedestrian starts walking towards the road; the driver perceives this information, identifies the hazard and then takes action by applying the brake, denoted by point B, in order to avoid a collision. Eventually, the vehicle stopped and remained stationary (point C) till the pedestrian cleared the front of the vehicle. At point D the vehicle restarts and

accelerates till the simulation ends (point E). The crucial points to interpret driver's PRT are points A and B. The gap between these two points represents the required PRT of the driver, which is calculated to be 0.09 s. This value seems implausible when considered in the context of realistic driving reactions. Additionally, it is noteworthy that the automated scripts yielded identical PRT results across all visibility scenarios tested. This consistency raises concerns about the validity of the findings, suggesting the need for further investigation into the accuracy of the simulation parameters and the reliability of the automated measurement process.

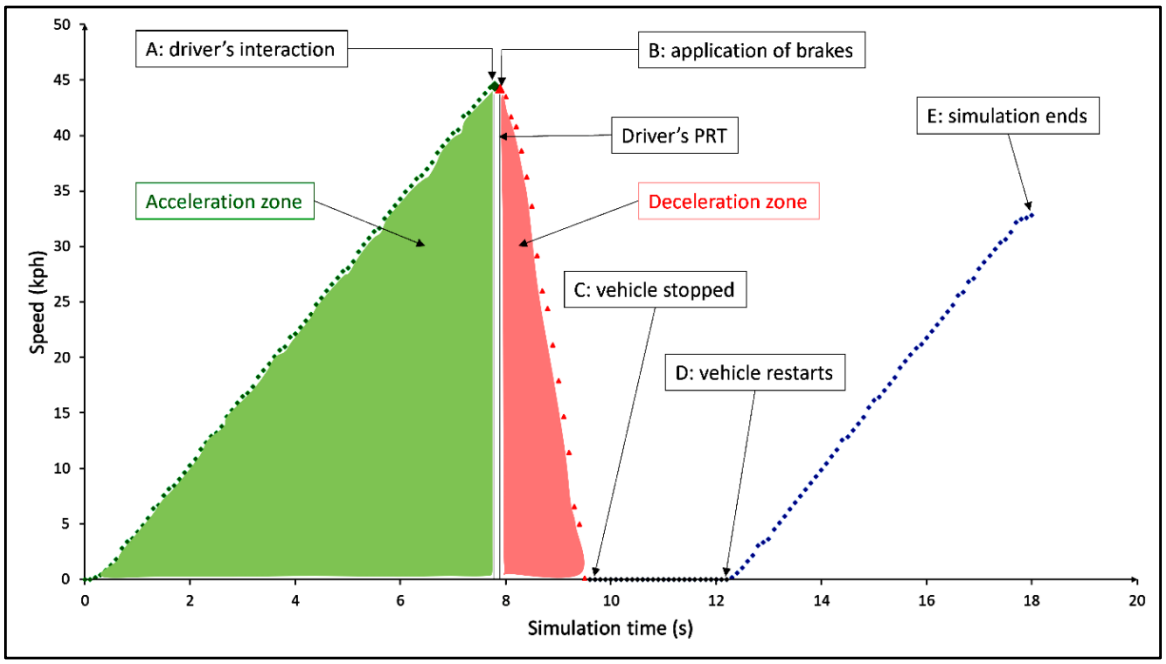


**Figure 3** Examining driver's perception-reaction time (PRT) based on repeated simulation trials at defined visibility.

## CONCLUSION AND NEED FOR FUTURE RESEARCH

The purpose of this study was to examine drivers' PRT in different weather and lighting scenarios using an off-the-shelf simulation software with automation scripts. The precise PRT acquisition in every scenario was made possible by these scripts. The approach used here shows the benefits of automation and scenario customisation, particularly when it comes to simulating intricate traffic scenarios without sacrificing ethical or safety considerations. The automated scripts in the simulated environment enabled a simplified evaluation of the driver's PRT to an unexpected pedestrian crossing the road, or sudden road hazard. This was achieved by using repeated trials with different permutations and combinations of various weather conditions, including daylight, twilight, night, rain, and fog.

Albeit, the results show a perception reaction time of 0.09s across all scenarios, which is acceptable but too good to be true even in ideal visibility conditions and simply unrealistic in every other scenario. Moreover, a keen look at the deceleration slope shows that the rate of deceleration is very high; in real-life conditions, a driver would not decelerate at such a high rate as it induces jerk, causing discomfort along with the risks of skidding and overturning. These anomalies arise due to the implementation of automation scripts. As for a script, the interaction remains a piece of code with a bunch of instructions, which will invariably take place in a sequential manner irrespective of varied visibility conditions. Moreover, the automated entities don't have a personality and diverse physical attributes like age, gender, visual acuity etc. These attributes are an integral part of road contingencies that heavily influence driving behaviour and are crucial for cognitive behaviour studies.

There is no second thought on the ability of simulators to control variables like weather, lighting, and road user interactions in a controlled environment, which makes it an efficient tool for understanding the cognitive and behavioural responses of drivers in real-world conditions. However, despite the advances in simulation technologies, challenges remain, particularly in replicating real-world complexities and accounting for the unpredictable nature of

human behaviour. Automation in simulation experiments would only simplify the precise capture of data but it won't account for the dynamic nature of humans.

Driving behaviour is influenced by the surrounding landscapes [16], highlighting the need for future studies to replicate native road environments for investigations. Creating such simulated environments necessitates a rigorous calibration and validation process for simulators, utilizing field data to ensure accuracy. Integrating indigenous driving simulations with actual human drivers will allow researchers to bypass the limitations associated with the standard scenarios provided by commercial simulation software packages. This approach establishes a foundational framework for future initiatives aimed at conducting experiments using a platform for virtual reality-controlled experiments that accurately reflects indigenous driving conditions.

## ACKNOWLEDGEMENT

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138_IEC31743

# Erection of Two Stage Cantilever Concourse and Platform Pier Arm for Elevated Metro Stations

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***Abstract:*** *Increasing traffic volumes and a deteriorating transportation infrastructure have stimulated the development of new systems and methods to accelerate the construction. Precast & prestress pier arms components offer a potential alternative to conventional reinforced, cast-in-place concrete components. The use of precast components has the potential to minimize traffic disruptions, improve work zone safety, reduce environmental impacts, improve constructability, increase quality, and lower life-cycle costs. As per above introduction to the topic "Erection of Two Stage Cantilever Concourse and Platform Pier Arm for Metro Stations". The technical presentation put up for discussion, is a structure at station piers location, which is to support the station girders and slabs. The structure is completed and handed over to Station Civil Contractors to finally establish station buildings. The structure casted in stages with accuracy and with zero tolerance of errors in design, methodology and sequence of casting. The structure is a precast structure and executed in 2 levels with 3+6 complex stages.*

***Keywords:*** *Pier Arms; Concourse Level; Track Level; Platform Level; Match Casting; Precast Concrete; Rapid Construction; Segment; Formwork*

## METHODOLOGY

Metro Station is divided into 3 levels mainly ground level, concourse level and platform level. Ground floor consist of various utilities like access to Entry and Exit of station, pumps houses, earth pits, parking etc.

Concourse level usually location at minimum 5.5 m from ground level at elevated stations or as per the alignment height of the metro corridor. It consists of various technical and commercial rooms, public utilities and act as the floor to access the platform level usually for MRTS the length of concourse is 140 m and width is 21 m. Platform level is level where passage can board the metro rail usually for MRTS the length of concourse is 140 m and width is 21 m with up and down line track in middle. The type structure of this arrangement is foundation with pier with cantilever arms (Concourse and platform) over will different I/T type of RCC or prestressed girders will be placed followed by deck slab and flooring. Usually Elevated metro stations are in densely populated area with high density of traffic movement on road hence obtaining a cast in situ model is risky, time consuming and increase traffic jams in area. Hence precast model is preferable.

Time Cycle of erection of Arms after casting of piers up to concourse level

- Erection of middle segment at concourse level - 1 day
- Stitch concrete at Concourse level – 2 days
- Casting of Pier with corbel- 7 days
- Erection of Middle segment at Platform level – 1 day.
- Stitch concrete at Platform level – 2 days
- Erection of Cribs for end segment erection at Concourse level – 2 days
- Erection of segment A1 at concourse level- 1 day
- Erection of segment A2 at concourse level – 1 day
- 1st stage stressing and grouting at concourse level – 2 days
- Erection of Cribs for end segment erection at platform level – 1 day.
- Erection of segment A1 at platform level- 1 day
- Erection of segment A2 at platform level – 1 day
- 1st stage stressing and grouting at platform level – 2 days

- Dismantling of cribs – 2 days

Total 26 days

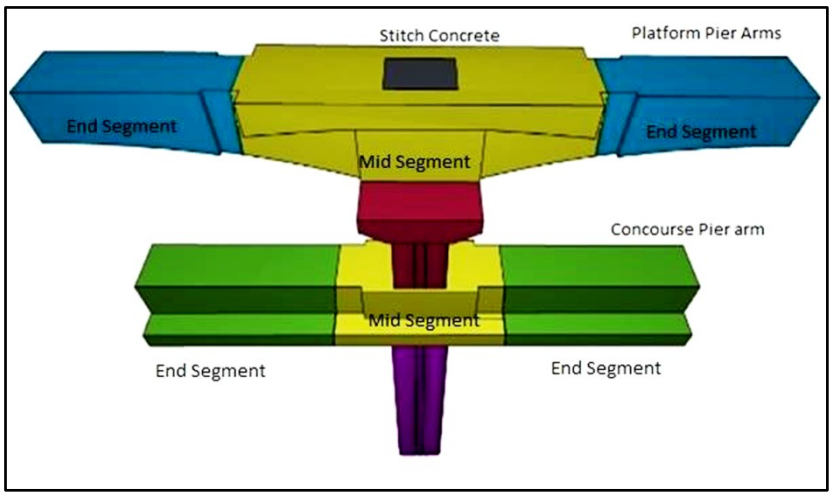



**Figure 1**

**Erection of Concourse Pier Arms**

The sequence of work involved in the erection of Concourse Pier arm at Concourse level and Platform Pier arm at Track Level. The Pier lift to be cast at desired concourse level along with dowels for the construction of pier above concourse level. The Erection of cribs of size 600x600 mm is to do with proper tying with pier ensure firm support.

**Erection of Mid Element (Segment B)**

After achieving desired strength as per design, necessary visual check is to do, and component is dispatched from casting yard. After receiving the pier arm segment from casting yard, the component is to be erected on the cribs with help of crane of suitable capacity (250 MT & 400 MT) with proper position on the constructed pier. Care should be taken while adjusting the pier steel side of HDPE Ducts. Due care to be taken related to survey and alignment of mid segment to avoid any error. After erection of mid segment Pier is to be cast from Concourse level to Corbel level.

**Erection of Mid Segment at Platform Level**

After achieving desired strength as per design, necessary visual check is to be done and component is dispatched from casting yard. After receiving the pier arm segment from casting yard, it is to be lifted using crane of desired capacity (250 MT & 400 MT). Crane must be positioned in the direction and in sequence of Pier arm Erection stage. The middle segment is be placed at proper position on the constructed pier and levelled by using mechanical jacks/ hydraulic jack as per the requirement. The HDPE Ducts should be adjusted carefully. Due care is to be taken related to survey and alignment to avoid any error.

**Erection of End segments at Concourse level**

End pier arm segments to be placed at each level only after 3 days of casting of hollow portion (Stitch concrete) (Connection between pier and arm). The cribs is to be erected as per drawing for placement of end pier arm segments. After erection of cribs and proper levelling the other two end pier arm segments to be lifted one by one. The segments are be erected at proper positions. Trolley, Jack arrangement is kept, above which end pier arm segment is to be placed one by one. For fine tuning of levels and position, trolley and mechanical jack are used, if required hydraulic jack can be used.

Approved segmental bonding agent (Glue) is to be used for bonding of end pier arm segments with middle segment.

Temporary pre-stressing is to be done with the sleeve arrangements provided in precast units with the help of mac alloy bar and jacking frame as per approved drawing. Before commissioning of temporary stressing, all the fabricated units used for temporary pre-stressing shall be tested under load (10 % Extra) before putting in regular use. After completion of above activities stage wise stressing and grouting to be done.

**Erection of Cribs for Platform/ Track level Pier arm.**

End pier arm segments is to place at each level only after 14 days of casting of stitch concrete (Connection between pier and arm). The cribs to be erected as per drawing for placement of end pier arm segments. After erection of cribs and proper levelling the other two end pier arm segments to be lifted one by one. The segments are to be erected at proper positions. Trolley, Jack arrangement is kept, above which end pier arm segment is to be placed one by one. For fine tuning of levels and position, trolley and mechanical jack are used, if required hydraulic jack can be used.

Approved segmental bonding agent (Glue) is used for bonding of end pier arm segments with middle segment. Temporary pre-stressing to be done with the sleeve arrangements provided in precast units with the help of mac alloy bar and jacking frame as per approved drawing. Before commissioning of temporary stressing, all the fabricated units used for temporary pre-stressing shall be tested under load (10 % Extra) before putting in regular use.

After completion of above activities stage wise stressing and grouting to be done.

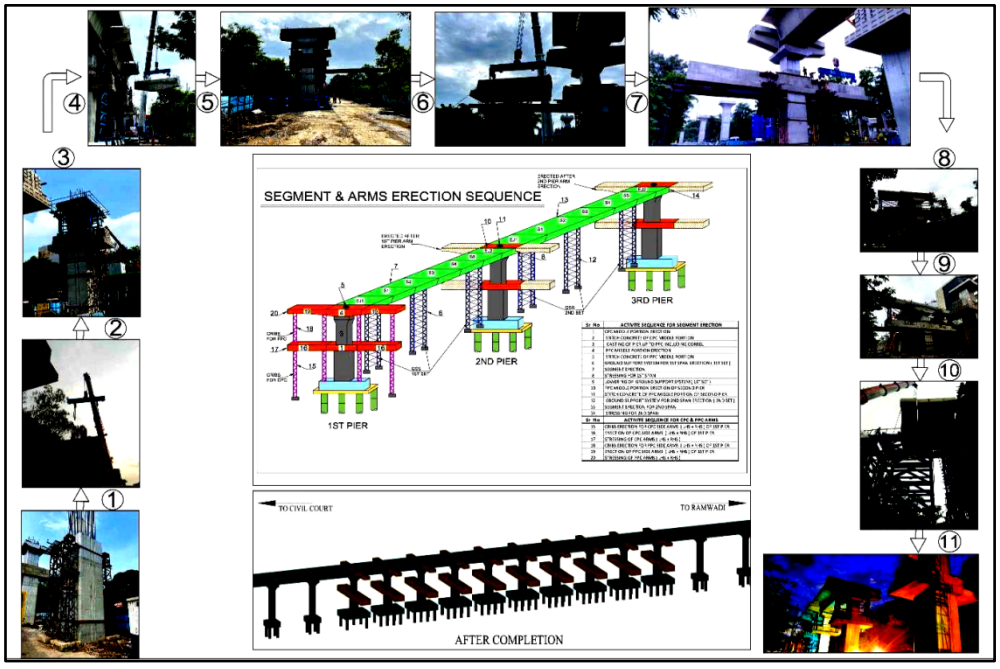
**Stage of Stressing**

The stressing of pier is in divided into following 3 stages:

1. 1st stage stressing after erection of arms at concourse level and platform level.
2. 2nd stage stressing after erection of casting of station girder and deck slab at concourse level and platform level.
3. 3rd stage stressing after application of super imposed dead load.

**Grouting Work after Stressing**

Once the stressing is completed; the load of joints and complete arms are taken by stressed strand and temporary load bearing cribs can be removed. Grouting with approved materials and mix design will be done as per codal provision. The grouting can be done before erection of cribs even after removal of cribs.



## RESULTS

Enhance safety at site as time cycle of erection of arm is very less in comparison of cast-in-situ component. As casting of arms done at casting yard, so quality of component and appearance of component is very good. It maintains cash flow to the contractor as he is getting the part payment of segments in the casting yard itself. This method is time and cost effective if quantum of work is vast. However, there are some constraints also like Heavy cranes and lifting equipment's are required. Specific skilled manpower is required. Trained and skilled riggers are required. Higher level of accuracy is required.

## CONCLUSION

Development of a new propriety precast pier arms at concourse and platform level has been described. As the casting work of precast arm can be done parallel with the casting of pier at station area, it stands as a cost effective, time effective and safety enhance method which cut down the completion time of project and reduce the complex structure cast-in-situ casting above moving traffic. The successful applications in recent projects have further endorsed this cost-effective option. Further research will be focused on the development of structural framing, jointing system, moulding, erection method and standardization to further simplify the casting and erection.

175_IEC1445

# Evaluation of Dowel Joints using Ground Penetrating Rader — A Case Study on a Highway Stretch

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***Abstract:*** *This study investigates the use of Ground Penetrating Radar (GPR) for evaluating the condition of dowel joints in a specific stretch of a national highway. Dowel joints are essential for load transfer between concrete slabs in highway pavements, and their proper functioning is critical for long-term pavement performance. Issues like dowel misalignment, corrosion, or voids can lead to early deterioration and costly repairs. The present research utilizes GPR, a non-destructive testing method, to identify subsurface anomalies in dowel joint placement and surrounding concrete. GPR's ability to generate high-resolution images of the pavement subsurface makes it ideal for detecting defects such as improper dowel positioning, misalignment, and voids that could compromise pavement integrity. The study focuses on a case stretch of a national highway, where GPR scans were conducted to assess the dowel joints' condition. The findings demonstrate GPR's efficiency in detecting dowel positions, providing a quick and accurate alternative to more invasive testing techniques.*

***Keywords:*** *Nondestructive Tests; Ground Penetrating Rader; Concrete Pavement; Dowel Joints*

## INTRODUCTION

Highway pavements are critical infrastructural elements that facilitate transportation, economic development, and mobility. The structural integrity and longevity of pavements are of paramount importance, as they directly impact the safety and performance of road networks. In rigid pavements, particularly concrete highways, dowel joints play an essential role in distributing traffic loads across adjacent concrete slabs. These dowel bars, typically made of steel, are placed across transverse joints to allow for effective load transfer and to prevent slab displacement, cracking, and faulting. The durability of dowel joints significantly influences the overall performance and service life of concrete pavements. However, over time, various issues such as misalignment during installation, and voids around the dowel bars can compromise their functionality. Misaligned or damaged dowel joints can result in uneven load transfer between slabs, leading to increased stresses, joint deterioration, and ultimately, pavement failure. Addressing these issues early is crucial for preventing costly repairs and reducing the disruption caused by pavement maintenance.

In recent years, Ground Penetrating Radar (GPR) has emerged as a powerful non-destructive testing (NDT) technology for pavement evaluation. Saarenketo et al. (2000)[1] gave an overview of the applications of Ground Penetrating Radar (GPR) for evaluating road structures, including subgrade conditions, pavement thickness, and detecting defects, with a focus on its implementation in Scandinavia and the USA. Ground Penetrating Radar (GPR) operates based on the scattering of electromagnetic waves to detect underground objects. It works by emitting an electromagnetic wave from a transmitting antenna, which moves through the material at a speed mainly influenced by the material's permittivity. As the wave propagates downward, it encounters objects with differing electrical characteristics from the surrounding material, causing the wave to scatter. This scattered signal is then captured by a receiving antenna for analysis. GPR's ability to detect subsurface anomalies, such as dowel bar placement, voids, and misalignments, makes it an attractive option for assessing dowel joints in highway pavements. Unlike traditional methods, GPR offers the advantage of rapid data collection, allowing for real-time evaluations of large pavement areas with minimal traffic disruption.

The primary goal of this research is to evaluate the performance and condition of dowel joints on a national highway stretch using Ground Penetrating Radar. This case study aims to explore the practical application of GPR in identifying dowel-related issues, mainly its vertical and horizontal placement at the joint. Key research objectives

include assessing the dowel bar placement and defects around dowel joints. Dowel bars, when properly aligned and placed within the pavement, become effective in load transferring. Misaligned dowel bars can lead to uneven stress distribution and joint failures.GPR allows for the detection of these subsurface defects. While GPR provides a non-destructive way of evaluating dowel joints, its accuracy and reliability need to be validated by comparing the results with visual inspection. Stryk et al. (2013)[2] discusses the effective use of Ground Penetrating Radar (GPR) for non-destructive testing to measure and assess the placement of dowels and tie bars in concrete pavements during road construction. Amer-Yahia et al.(2014) [3] proposes an approach using Ground Penetrating Radar (GPR) to detect and quantify dowel and tie bar misalignment in concrete pavements, assessing its impact on pavement performance. Lai et al.(2017)[4] reviews 30 years of advancements in Ground Penetrating Radar (GPR) technology, focusing on its applications in civil engineering for infrastructure assessment, from locating objects to providing detailed imaging and diagnostics. Alsharqawi et al.(2022) [5]presents a comprehensive approach to condition assessment of concrete-made structures using Ground Penetrating Radar (GPR), focusing on defect detection, data interpretation, and advanced processing techniques for civil engineering applications.

## METHODOLOGY

A section of a national highway has been selected for joint condition evaluation using Ground Penetrating Radar (GPR). This highway is a four-lane divided carriageway, with each lane being 3,500 mm wide (two lanes in each direction), separated by a median that is 9,000 mm wide. Each two-lane carriageway is accompanied by a 1,500 mm wide paved (concrete) shoulder. Transverse (contraction) joints, spaced 4,500 mm apart, are used to manage the contraction and expansion of the concrete slabs. Additionally, longitudinal joints exist between the traffic lanes and between the lanes and the shoulders. The pavement structure consists of a 300 mm thick concrete slab, which rests on a 150 mm thick layer of dry lean concrete (DLC) as a base. Below the DLC is a 150 mm thick granular subbase (GSB), which is made from wet mix macadam (WMM). The pavement also has a compacted subgrade layer that is 500 mm thick, providing support to the subbase. A 125-micron thick impermeable polythene sheet is used as a separation membrane between the concrete slab and the DLC to prevent moisture infiltration. Mild steel round dowel bars, 32 mm in diameter and 600 mm in length, are placed at 400 mm intervals at the mid-depth of the concrete slab across the transverse joints to facilitate load transfer.

GPR is used to assess the condition of various joints along different sections (chainages) of this stretch. Various joints along the stretch of the national highway have been chosen for analyzing the condition and placement of dowel bars. These dowel bars are designed to be positioned at the mid-depth of the concrete slab and should be aligned parallel to the direction of traffic for effective load transfer.

For the evaluation, a Ground Penetrating Radar (GPR) device is moved laterally across the pavement, starting from the shoulder and extending to the lane's edge, continuing up to the median (Refer **Figure 1**). This scanning process enables the GPR to capture detailed data about the subsurface features of the pavement. By analyzing this data, the positions of the dowel bars at different joints are observed, helping to identify any issues such as misalignment or incorrect placement. This method provides an accurate, non-destructive way to assess the structural integrity of dowel joints along the highway.

**Figure 1** GPR Scan being conducted on the study stretch

## RESULT

Based on the data collected using GPR instrument, different joints are evaluated. Some of these joints are explained below. **Figure 2** shows a typical scanned picture obtained from the field test using GPR along a joint (Joint 1) with embedded dowel bars. The vertical scale on the left indicates depth in meters from the surface of the pavement. The top horizontal scalemarks distance along the transverse joint in meters. The dark and light bands represent different materials or interfaces. Top dark parabolic shapes indicate the presence of dowel bars at a particular position. In this joint, it's observed that most dowel bars are at a depth of approximately 150 mm from top, but some are at a slightly shallower depth at around 146-148 mm.

**Figure 3** is another scanned image of a joint (Joint 2), and the annotations give further details on dowel bar alignment within the slab. The dowel bars are supposed to be placed at a depth of 150 mm from the top surface of the concrete pavement (marked by the yellow dashed line).The figure indicates that some dowel bars are not positioned at the intended depth. These dowel bars are found at a depth of 170 mm, which is 20 mm deeper than expected, indicating misalignment. Some dowel bars are found at depths of 146-148 mm. The rectangular yellow box highlights a section where dowel bars are incorrectly placed at 170 mm depth instead of 150 mm. The improper placement of dowels could potentially result into in adequate load transfer across the joint. This can lead to formation of cracks or joint failure due to stress concentration at improper locations. These misalignments could be due to construction errors, improper dowel bar placement, or movement during concrete pouring.

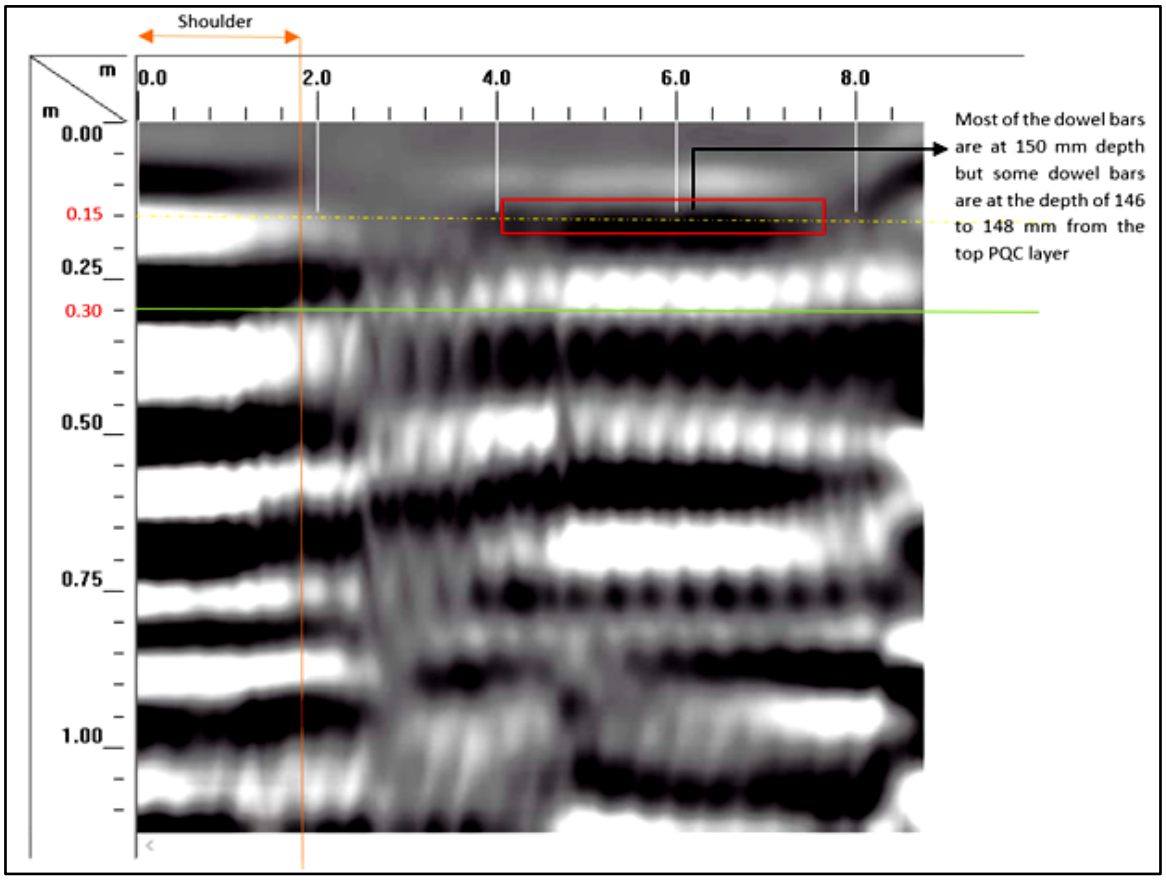


**Figure 2** GPR Scanned Picture of Joint 1

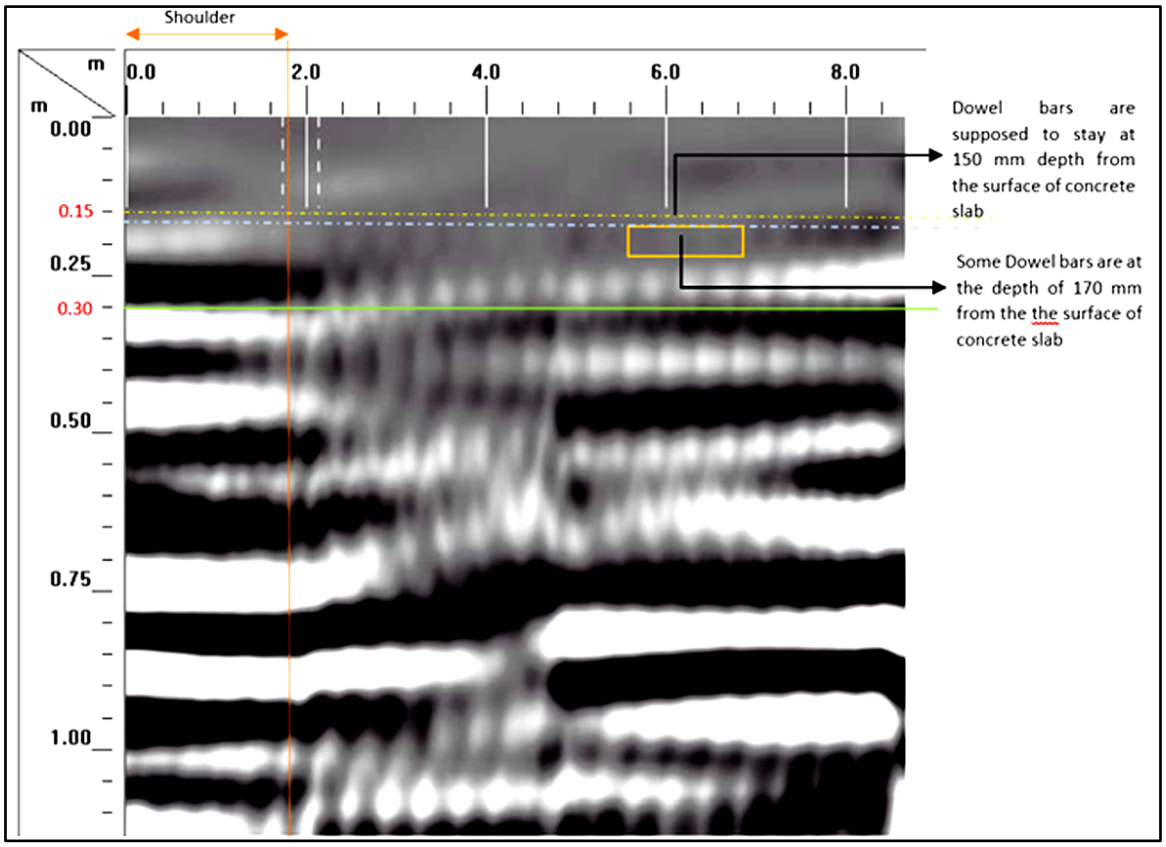


**Figure 3** GPR Scanned Picture of Joint 2

## CONCLUSION

The present study throws lights about the effectiveness of GPR in identifying pavement internal characteristics. A highway stretch with dowel joints have been evaluated using GPR to recognize the dowel bars and their positions. In concrete pavement, proper placement of dowel bars is essential for the joints to transfer the applied wheel load from one panel to another. Analysis of the GPR scanned image son several dowel joints in the concrete pavement reveals that some of the dowel bars are misaligned. This may lead to poor load transfer efficiency, faulting of joints and other distresses. Further works may be carried out to explore the efficacy of GPR in identifying other details of the pavement.

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314_IEC1506

# Evaluating the Performance of Cell-Filled Concrete Pavement using Non-Destructive Testing Techniques

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***Abstract:*** *Cell-filled Concrete Pavement (CFCP) technology represents an innovative and sustainable solution for low-volume roads, leveraging the structural benefits of polyethene cells filled with concrete. This study evaluates the performance of CFCP using non-destructive testing (NDT) techniques across twelve road sections in the Jhargram district of West Bengal. Tests, including rebound hammer and Ultrasonic Pulse Velocity (UPV), were conducted to assess the compressive strength, homogeneity, and overall structural integrity of the pavement. Results revealed that most UPV values exceeded the 3.650 km/s threshold for M-40 grade concrete, affirming the material's quality. Compressive strength measurements were consistent across test sections, varying within a ± ten percent range of the mean, further highlighting the homogeneity of the paving concrete. However, two sections exhibited discrepancies due to surface conditions impacting measurement accuracy. This study underscores the durability and cost-effectiveness of CFCP for rural infrastructure, showcasing its ability to withstand repeated loading while maintaining structural integrity. By employing NDT techniques, this research provides a reliable framework for evaluating CFCP performance, offering critical insights for policymakers and engineers to optimize material use and enhance rural road durability. These findings establish CFCP as a viable alternative to traditional pavement systems, contributing to sustainable infrastructure development.*

***Keywords:*** *Cell-Filled Concrete Pavement; Performance; Non-Destructive Testing*

## INTRODUCTION

The development of cell-filled concrete pavement (CFCP) technology has gained momentum in the international arena over the past few decades [1-4]. This innovative pavement structure is composed of polyethenecells, which come in various thicknesses ranging from 50 -150 mm. These cells are filled with concrete and compacted, resting on a granular sub-base or a stabilized layer above the subgrade. When cast using plastic cell formwork, these concrete blocks exhibit an elastic modulus equivalent to that of traditional concrete [1]. This characteristic makes cell-filled pavements particularly suitable for low-volume roads, where they can provide effective support and durability while optimizing material use [3].

Experiments have demonstrated that CFCP functions similarly to a flexible layer [2]. In one study, researchers constructed a test section to investigate the behaviour of cell-filled pavement under load. They observed that after 1,500 repetitions of 141 kN loaded trucks, the rut depth remained less than 2 mm [4]. These results indicate that CFCP can effectively withstand repeated loading without showing any signs of distress or failure.Furthermore, the authors of the study highlighted that CFCP is a cost-effective alternative when compared to traditional flexible and rigid pavements. Another investigation focused on evaluating the structural integrity of cell-filled pavements through a finite element model. This analysis assessed critical structural performance metrics, including surface deflections and vertical subgrade strains [4].

A comprehensive study was conducted on CFCP specifically for low-volume rural roads. This research encompassed a series of tests aimed at evaluating both pavement distress and economic viability through the establishment of a dedicated test section [5]. Furthermore, another investigation assessed the performance of CFCP and established that distress evaluation can be effectively performed using the Pavement Condition Index (PCI). The results indicated favourable ratings consistent with PCI assessment criteria [6]. Additionally, a recent study explored in-situ concrete block pavements by measuring the vertical stresses induced by mobile and impact loads across two test sections. This research investigated various load levels to analyze their effects on the underlying granular base [7].

The aim of the current study is to evaluate the performance of CFCP using non-destructive testing techniques. This

evaluation is conducted through a field study on roads with CFCP sections in the state of West Bengal. The paper is organized into three main sections: methodology, result analysis, and conclusion. The methodology section provides insights into the test procedures, specific locations, and relevant characteristics of the test sites. Following this, a comprehensive analysis is conducted to interpret the results and draw meaningful conclusions.

## METHODOLOGY

Based on a comprehensive review of the current state of the art in the subject area, an assessment framework was developed to guide the methodology. In collaboration with the relevant authorities, twelve test sections were strategically selected; located in the Jhargram district of West Bengal. **Table 1** provides a categorized list of the roads selected for the evaluation. It is important to note that the ages of the test sections vary; mostly ranging from 1 to 4 years. Since the CFCPs were constructed on an experimental basis, the lengths of these sections typically range from 200 to 700 meters on those roads. A reconnaissance survey was conducted on the selected roads. The performance evaluation of these selected test sections is carried out using non-destructive testing techniques.

**Table 1** Details of study section: road name, length and age

| Sl. No | Road Name | Length [km] | Age [y] | Sl. No | Road Name | Length [km] | Age [y] |
|---|---|---|---|---|---|---|---|
| 1 | L038-Banspahari to Deshmul | 5.65 | 1 | 7 | L062-Krishnapur to Ghagra | 3.75 | 1 |
| 2 | L041-Jyotsna to Kendbani | 6.35 | 2 | 8 | L052-Porsona to Simulia | 6.80 | 2 |
| 3 | L043-Rajpara to Pathra-II | 9.02 | 2 | 9 | L026-Pamchami to Dudhiasole | 6.09 | 3 |
| 4 | L048-Jaynagar to Chandanpur | 3.25 | 0.5 | 10 | L044-Marapada to Harimari | 3.84 | 4 |
| 5 | L053-Chakadoba to Khandarbhula | 8.95 | 2 | 11 | L046-Dihikhelar to Ramchandrapur | 6.06 | 4 |
| 6 | L060-Chhurimara to Telighana | 5.60 | 2 | 12 | L023-Radhapara to Joykhunta | 2.35 | 4 |

As part of the comprehensive non-destructive testing (NDT) approach for this study, several critical tests were planned to evaluate the performance of the selected pavement sections. Firstly, a rebound hammer test was conducted at various random locations within each test section. This test is essential for estimating the compressive strength of the concrete, providing valuable insights into the material's durability and structural integrity. Secondly, an Ultrasonic Pulse Velocity (UPV) test was employed to assess the homogeneity of the paving concrete. This technique uses high-frequency sound waves to identify internal flaws and variations in density. Lastly, a thorough pavement condition assessment was carried out by videotaping the road surface. This method enables detailed visual documentation of the pavement's condition, helping identify distresses such as cracking, and surface wear. Collectively, these non-destructive testing techniques helped carry out a comprehensive evaluation of the cell-filled concrete pavement's performance and overall condition.

## RESULT ANALYSIS

UPV test was performed since pulse velocity is directly proportional to the compressive strength of concrete (see **Figure 2a**). The study used indirect transmission, i.e. surface probing, to assess the quality of surface concrete. A diagnostic assessment of quality and strength indicates that UPV is generally above the tentative threshold of 3.650 km/s as applicable for concrete grade M-40 or more, signifying that the quality is good except in a few cases where it drops down. UPV measurements taken at different points on a pavement vary insignificantly in a way that generally it is within ±10 percent from the mean for all study sections, signifying the homogeneity of the paving concrete. To evaluate the paving concrete's uniformity, the study assessed the compressive strength on-site by striking the pavement surface with a rebound hammer (see **Figure 2b**).

Like UPV measurements, compressive strength taken at different points on pavement also varies within a range of ±10 percent from the mean for all study sections, thereby further establishing the paving concrete's homogeneity. Evaluation of rebound readings and compressive strength based on the calibrated chart as applicable for the case when the hammer plunger is kept vertically downward on horizontal surfaces reveals that the current condition of

concrete in the pavement layer is good. By and large, UPV measurements and compressive strengths across study sections are comparable except for two sections, namely L053 and L060,wherein the study noted uncorrelated and incomparable values (see **Figure 3**). This may bedue to pavement surface conditions that have affected the accuracy of UPV measurements.

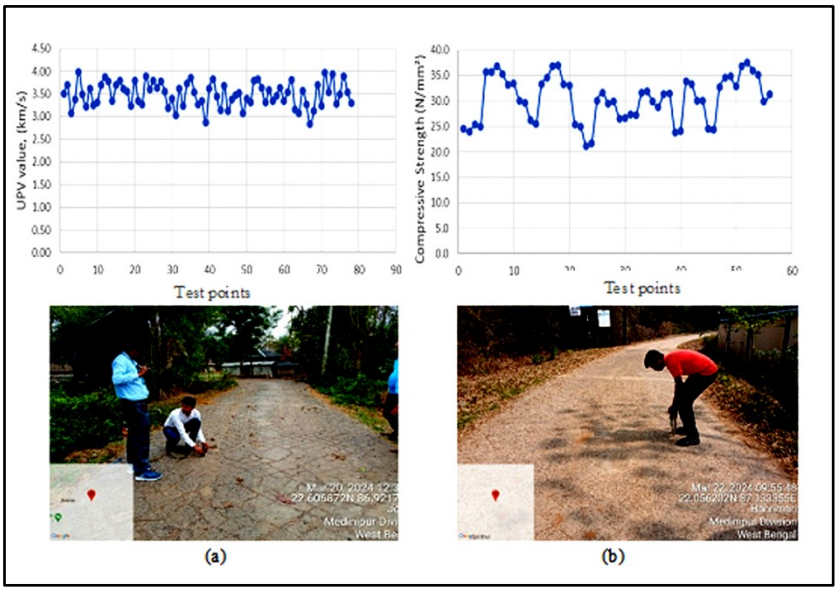


**Figure 2** A glimpse of UPV and compressive strength measurements: (a) L041 - Jyotsna to Kendbani Road and (b) L044 - Marapada to Harimari

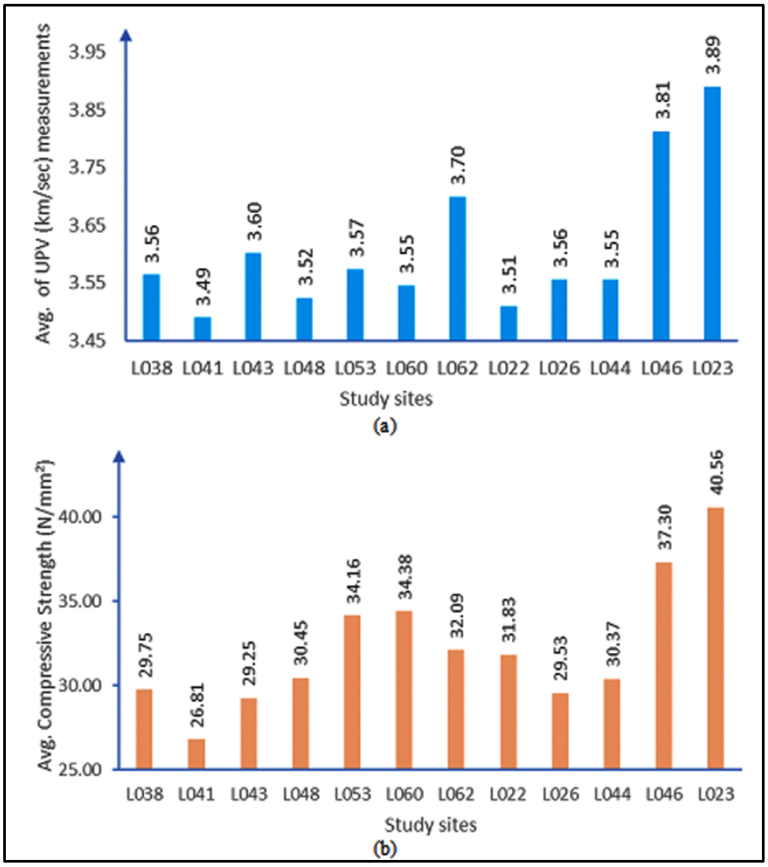


**Figure 3** Details of field measurements at the study sections: (a) UPV and (b) compressive strength

## CONCLUSION

The experimental results, combined with field reconnaissance, indicate that CFCP has performed satisfactorily in most instances over the years.The pulse velocity exhibits a direct correlation with the compressive strength of concrete. The study applied the indirect transmission method, i.e. surface probing, to assess the quality of paving concrete. The diagnostic assessment indicated that the UPV values generally exceed or are very close to the tentative threshold of 3.650 km/s, signifying good quality across most samples, with some exceptions of around twenty-five percent, where readings fell below this benchmark by about four percent. Measurements of UPV at various points along the pavement demonstrated consistent results, typically varying within the working hypothesis of ten percent of the mean across all study sections, which underscores the homogeneity of the paving concrete. To further evaluate the uniformity of the material, the study also conducted on-site assessments of compressive strength using a rebound hammer, which similarly yielded results that varied within ten percent from the mean across the study sections. This consistency further validates our findings regarding the overall uniformity of the concrete strength.Largely, the UPV measurements and compressive strength results from the different study sections were closely aligned, except for two sections that presented uncorrelated and inconsistent values. This discrepancy is likely due to specific pavement surface conditions that may have affected the accuracy of the UPV measurements.

## ACKNOWLEDGEMENT

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349_IEC98772

# Construction of Whitetopping and its Performance in Early Years — a Case Study in India

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***Abstract:*** *India predominantly employs bituminous pavements for road construction due to their ease-of-construction and lower initial cost. However, these pavements often exhibit distresses, e.g., rutting and cracking, leading to frequent maintenance and reduced service life. While rehabilitating these pavements with bituminous overlays is common, it does not address the persistent issue of recurring maintenance. Despite their widespread use, there is a notable research gap in exploring durable and more efficient alternatives tailored for Indian climatic and traffic conditions. The present study attempts to bridge-up this gap by investigating Whitetopping also commonly known as Concrete Overlay as a potential solution, emphasizing its construction and performance reported from a pilot project in Eastern India. The results of pavement's performance at its initial years in terms of surface condition, surface roughness and quality of concrete overlay using non-destructive testing techniques revealed the promise of Whitetopping as a sustainable measure to revolutionize road rehabilitation practices in India.*

***Keywords:*** *Whitetopping; Bituminous Pavement; Rehabilitation; Construction; Performance Evaluation*

## INTRODUCTION

In India, most roads have been constructed as bituminous pavements because of their lower initial cost and ease of construction [1]. However, bituminous pavements undergo several distresses like rutting, cracking, potholes, etc., due to their susceptibility to moisture and temperature, resulting in lesser service lives [2]. These pavements, thus, require frequent repair, maintenance and also rehabilitation when the condition is significantly deteriorated, which involves traffic disruption, user inconvenience, drainage problems, environmental pollution as well as cost. Rehabilitation of these pavements with bituminous overlay however, does not solve the problem of frequent maintenance. Concrete overlay, on the other hand, offers an attractive alternative for strengthening deteriorated bituminous pavements and thereby improving their functionality and extending the service life [3]. Concrete overlay also popularly termed as Whitetopping is more sustainable as it provides good riding quality with fewer maintenance requirements, reduces the delay and traffic disruption thus lowers the user cost and thereby has lesser life cycle cost as compared to bituminous overlay [4]. Whitetopping also provides environmental benefit due to less pollution on site during construction process and results in reduction of urban heat island effect due to its higher albedo range in comparison to bituminous pavement owing to its light color[5].

As a result, Whitetopping has started being considered by the Transport Departments of various States in India with an aim to adopt this technology for wider applications. In few cities in western and southern parts of the country such as, Mumbai, Pune, Nagpur, Hyderabad, Bangaluru etc., the construction of Whitetopping is increasing overlaying several kilometres of the traditional bituminous surfacing [6]. However, as the technology is comparatively new in India, the experience of construction of Whitetopping is less. In many cases, distresses may appear even on the newly constructed pavements causing a hindrance for its widespread adoption by the Transport agencies. More number of constructions is therefore, essential to have experience and also to gain confidence about this technology in the country.

The present paper demonstrates a case study of the construction of a Whitetopping stretch as a rehabilitation measure for a distressed bituminous road, which is the first major work on Whitetopping in Eastern India. The details of the existing pavement, construction stages of the Whitetopping stretch, and the performance evaluation at its initial years are discussed in the subsequent sections of the manuscript.

## CONSTRUCTION OF WHITETOPPING ON KHARAGPUR BYEPASS

The construction of Whitetopping involves several stages. The details of the existing pavement, tests carried out on it before concreting, surface preparation and the various steps of construction are discussed in the following subsections.

### Details of the Existing Pavement

In this study, a 1.0 km stretch of a 7.0 m wide road within the Midnapur District in the State of West Bengal, India was selected for the construction of Whitetopping as a rehabilitation measure. The selected stretch, from Chainage +8.000 km to +9.000 km, was part of a total 16 km long stretch of Kharagpur Byepass, a Major District Road.

### Field Tests on Existing Pavement

The existing road condition was evaluated with several field tests. Trial pits were dug and samples were collected to determine the soil properties at the laboratory. The pavement had bituminous layers of varying thicknesses from 155 to 180 mm over a Water Bound Macadam (WBM) layer of thicknesses ranging from 120 to 150 mm. Below the WBM, layers of laterite materials consolidated with moorum of thicknesses 225 to 350 mm were also present. The soaked CBR of the soil was obtained as 4.0%. Benkelman Beam Deflection (BBD) test was carried out [7] on the selected road to determine the strength of the existing pavement. Twenty-four-hour axle load survey and classified traffic volume count survey were conducted on both sides of the road. The number of commercial vehicles per day (CVPD) was estimated as 936 from the traffic surveys.

### Design of Whitetopping

Based on the existing pavement strength, subgrade characteristics and traffic condition, Whitetopping was designed as per Indian Roads Congress Guidelines IRC: SP: 76 – 2015 [5]. The design of Whitetopping was carried out considering critical stress criterion and fatigue criterion. The designed panel size was obtained as 1.0 m × 1.0 m with a thickness of 200 mm. Flexural stresses were estimated for each single axle and tandem axle load class [5]. The maximum flexural stress for single axle load class was estimated as 2.46 MPa and that for tandem axle load was 2.13 MPa. The maximum stresses were found to be well below the flexural strength of concrete of 4.5 MPa, thus can be considered as safe.

### Surface Preparation

The surface condition of the existing road was poor with a number of cracks and potholes. Before concreting, the existing bituminous layer was chiselled and milled up to a depth of 25 to 50 mm to have a uniform surface. The existing road had 1.5 m wide shoulders on both sides. For widening the existing road to 10.0 m with 1.5 m wide hard shoulder on both sides, subgrade and subbase were prepared. Initially 500 mm sand filling was done, which was followed by placing a 300 mm thick GSB and a 250 mm thick WMM layer along with a prime coat at the top. The layers were compacted with roller. The pavement quality concrete (PQC) mix design was carried out as per Indian guidelines [5,8], for a characteristic compressive strength of 40 MPa. Ordinary Portland Cement (OPC) of grade 43 [8], sand confirming to grading zone II with maximum size of 4.75 mm and coarse aggregate with maximum nominal size of 20.0 mm were considered.

### Concreting

Concreting was done for the carriageway portions, over the culvert portion and also at the two transition zones, which are the junctions of concrete overlay and the bituminous pavement of the remaining road. For the 10.0 m wide road, concreting was carried out in three stages based on the paver dimension. In the first two stages, 4.0 m width on either side of the road was casted by fixed form paver. In the third stage, concreting was done at the middle 2.0 m portion manually. A picture of the construction process of the Whitetopping is shown in **Figure 1**. Concrete mix was obtained from a batching plant and was carried to the site by a Transit Mixer. Two nozzle vibrator were used in addition to the in-built vibrators of the paver for compaction of the concrete mix. After placing of concrete, surface

finishing was done using a 1.0 m wide bullfloater followed by texturing using a 1.0 m wide tine grooving rake. A wax-based curing compound was sprayed for curing. After about 8 to 10 hours of concreting, saw cutting was done on the concrete up to 1/3rd the slab depth to form transverse and longitudinal contraction joints using a saw-cutting machine. Once the cutting was over, the surface of the concrete slab was covered by wet hessian bags and watering was done regularly. Concrete cubes were prepared at the site for strength testing. The average 28-day cube compressive strength was obtained as 47 MPa, which was considered as satisfactory.

**Figure 1** Construction process of Whitetopping

**Completion and Opening of Road**

The construction was completed including curing in the month of April, 2020 and the road was open to traffic thereafter. The finished road is now fully operational. A photograph of the Whitetopping road is shown in **Figure 2**.

**Figure 2** Constructed Whitetopping road in operation

## PERFORMANCE IN INNITIAL YEARS

The performance of the Whitetopping pavement was evaluated at its initial years after construction. Functional evaluation was carried out to assess the surface condition in terms of Pavement Condition Index (PCI) and riding quality in terms of International Roughness Index (IRI). Structural evaluation was carried out using nondestructive tests (NDT) Ultrasonic Pulse Velocity test to determine the strength and quality of concrete respectively.

Surface Condition - Pavement Condition Index (PCI) In the present work, the pavement surface condition was evaluated in terms of Pavement Condition Index (PCI), by visual inspection survey. It is a comprehensive method of evaluating the functional performance of pavement based on observed surface distresses, which is also an indirect and qualitative measure of physical integrity for the operating conditions of existing pavement. An average PCI value for the Whitetopping stretch was obtained as 85.2. As per code [9], a PCI value more than 85 is considered as good, which indicates that the Whitetopping pavement has a good surface condition and is performing well. A photograph of the surface condition of the Whitetopping pavement taken during the field testing for PCI data collection is shown as **Figure 2**.

### Surface Roughness - International Roughness Index (IRI)

Road surface roughness is important for measuring its functional performance. It is the measure of the longitudinal profile of a road. In the present study, an accelerometer-based device, known as IRIMETER-2, is used for measuring the longitudinal profile or roughness of the Whitetopping road in terms of International Roughness Index (IRI). IRI is a widely accepted unit for expressing road roughness. A typical one-quarter of a car was taken and IRIMETER-2, the vehicle-mounted road roughness measuring device was utilized to determine the roughness in IRI. The measured (average) IRI value for the study stretch was obtained as 3.12 mm/m. This can be considered as good, as per the recommendations for cement concrete MDR in India [10].

### Quality of Concrete - Ultrasonic Pulse Velocity Test

The non-destructive Ultrasonic Pulse Velocity (UPV) test provides an assessment of the quality of concrete within the structure. In the present work, Pundit UPV test set up was used to carry out the tests on the pavement as per [11]. Tests were carried out at regular intervals along the entire length of the Whitetopping stretch. From the test results, it is found that all the UPV values are much higher than 4000 m/sec, indicating the quality of concrete in Whitetopping is good to excellent, as can be observed in **Figure 3**.

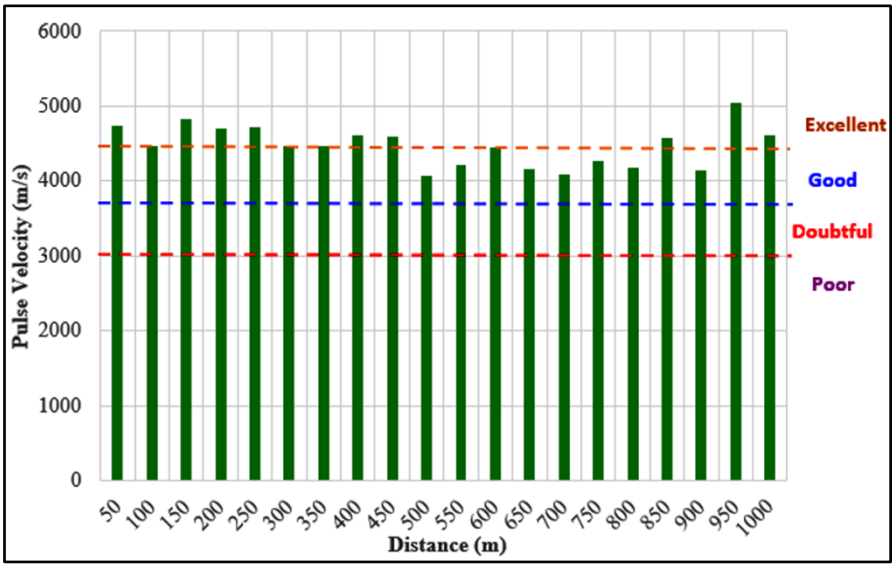


**Figure 3** Ultrasonic Pulse Velocity of the Whitetopping Stretch

## CONCLUSION

The present paper reports the details of construction and early performance evaluation of a Whitetopping road developed in India. The construction details of the pavement have been outlined, covering, field tests of the existing pavement, traffic survey, design method, surface preparation, and steps for concreting and finishing. After construction, the pavement was evaluated for its functional and structural evaluation in its early years, which were found to be good to excellent in terms of surface condition, riding quality and quality of concrete. In summary, this case study demonstrates the potential of Whitetopping as a viable rehabilitation option for distressed bituminous pavements in India. The initial performance evaluations, both functional and structural, give confidence in adopting this technology for its widespread application in the country.

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362_IEC63043

# Autonomous Vehicle in India: Navigating Technological Potential and Regulatory Hurdles

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***Abstract:*** *Recent years have witnessed revolutionary advancement in AI, leading to the introduction of Autonomous Vehicle (AV) in the transport sector. Through the advancement in the technological ecosystem involving machine learning algorithms, high-tech sensors, and robotic control, the technology of AV has established surreal capabilities of perceiving and interpreting the surroundings including, independent driving decisions without direct human intervention.As per the 2024 report of the AV Industry Association, over 90% of motor vehicle crashes are caused by human errors. AV lacks basic human trails that contribute to such errors, establishing the possibility of AV offering safer mode of transportation. Moreover, AV increases mobility access for those unable to drive, primarily children, elderly people and individuals with a disability.*

*Although, the idea of driverless vehicle have been around for decades and the development and deployment of AV has become a reality today in some parts of the world, the primary challenges in the introduction of AV in India, however apart from technological aspects, include the absence of a strategic regulatory framework that will improve the scope of structured testing and implementing AV, in India. Critical challenges around liability, data privacy, and decision making in critical situation also raises ethical and regulatory questions that is needed to be addressed. To propose an effective solution to the development and deployment of AV, the research demands both analytical and logical approach. Comprehensive analysis will be done over the existing legal frameworks of leading countries that have achieved significant advancement in AV technology. The findings shall elaborate on the gaps and grey areas that have hindered the progress of AV in India. The research expects that by addressing the grey areas in the existing legislation, scope of enactment of a new legislation may be introduced.*

***Keywords:*** *Artificial Intelligence (AI), Autonomous Vehicle, Machine Learning, Transportation, Infrastructure*

## INTRODUCTION

Recent years have witnessed revolutionary advancements in AI, leading to the introduction of Autonomous Vehicle (AV) in the transport sector. Through the advancement in the technological ecosystem involving machine learning algorithms, high-tech sensors, and robotic control, the technology of AV has established surreal capabilities of perceiving and interpreting the surroundings including, independent driving decisions without direct human intervention.[1] As per the 2024 report of the AV Industry Association, over 90% of motor vehicle crashes are caused by human errors. AV lacks basic human trails that contribute to such errors, establishing the possibility of AV offering safer mode of transportation. [2] Moreover, AV increases mobility access for those unable to drive, primarily children, elderly people and individuals with a disability. In an emergency also, when no human driver is available, AV will be of great assistance. AV will be devoid of rash driving or over speeding, leading to a safer social system[3].

Although, the idea of driverless vehicles have been around for decades, the development and deployment of AV has become a reality today in some parts of the world. The primary challenges however apart from technological aspects, include the absence of a strategic regulatory framework that will facilitate the introduction of AV, improving the scope of structured testing and implementing AV, in India. Without a clear regulatory framework, AV deployment in India's complex road system poses significant challenges. AV navigation requires complex, dynamic, and efficient system with advance prediction ability. Critical challenges around liability, data privacy, and decision making in critical situation also raise ethical and regulatory questions that need to be addressed. Other factors such as addressing infrastructure limitations, heterogenous population, road condition and traffic congestion can significantly contribute in combating the delay in the development and deployment of AV in India. [4]

Amidst a plethora of changes, the laws shall require a considerable role to play. A promising approach to evolve the landscape of transportation can be by redefining the definition of 'driver' in the Motor Vehicle Act, 1988 and taking into account the possibility of including AV to start with. This will benefit in having a clear perspective over the liability, insurance and operational standard while establishing a regulatory framework.[5] The cybersecurity regulation also needs to be reevaluated due to the reliance of AV on V2X communication system which allows them to avail information regarding traffic conditions, obstacle and other important information. The dependence on V2X makes AV more vulnerable to cyberattacks, as hackers could potentially manipulate the data that is crucial for AV regulation. [6]

## METHODOLOGY

To propose an effective solution to the development and deployment of AV, the research demands both analytical and logical approach. It begins with exploring and examining the existing legal frameworks of leading countries that have achieved significant advancement in AV technology, while assessing their effectiveness in light of growing complications posed by AV. It also includes comprehensive analysis of secondary sources to evaluate an insight into a comprehensive perspective over AV. The findings shall elaborate on the gaps and grey areas that have hindered the progress of AV in India, resulting in a weak position of AV implementation, globally. This research also compares the ecosystem of AV, used in some countries and their legal framework that supports its successful and progressive implementation. The author aims to identify the grey areas in the legal and policy landscape and tries to provide adequate recommendations for a successful launch of AV in India.

## RESULTS

There is ample opportunity for AI-driven AV to be introduced as a revolutionary mode of transportation. These vehicle holds the potential to operate without human intervention by using machine learning algorithms, high tech sensors, and robotic control. By analysing the surroundings through V2X communication system, AVs can enhance the efficiency and safety of transportation. However, despite the potential AV holds, the current legal framework does not recognize AV in the transportation sector. Successful introduction of AV as mainstream transportation requires overcoming legal, ethical, technological, economic and social challenges. The absence of regulatory framework for AV has resulted into becoming a barrier for the development of AV. The existing gaps and grey areas in the development and deployment of AV need to be addressed for the successful development of AV leading to efficient integration into the transportation sector.

## CONCLUSION

The evolutionary potential of AV in transportation is undeniable, presenting an opportunity to enhance road safety, increase accessibility, and reduce human error. While AV technology offers promising future, the current regulatory regimes struggle to keep pace with technology advancement, resulting into creating a significant barrier to the development of AV and clearly indicating the distance between innovation and regulation. The current scenario of India shows that AV development is primarily at Level 1 and Level 2, focused on driver assistance technology. To advance the transportation sector and unlock full potential of AV, it is essential to establish ground rules on infrastructure development as well as a regulator regime for the smooth development of AV is required. For instance, beginning with reestablishing an appropriate definition of 'driver' in the Motor Vehicle Act, 1988 that will cover both technological innovation and regulatory framework could play an effective role over AVs infrastructure operation and planning. The need for a proper cybersecurity regime also holds an integral part, failure to address potential cybersecurity attacks could disrupt the whole vehicle network, endangering road safety and passenger lives. These adequate measures need to be taken into account to ensure the safe integration of AV into mainstream transportation.

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# Metals & Minerals

# Automation in Mining Operation

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# Evaluation of Social Hazard, Psychological Conditions, and Innovation in Automated Mining Operations

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***Abstract:*** *Automation's quick adoption in mining activities has changed environmental impact, safety and production. These developments pose difficult social and psychological problems for employees, causing worries about psychological issue, social risks that could impair productivity and employee well-being. The social risks associated with automated mining are examined in this essay, including role ambiguity, job displacement, the changing dynamic between automated systems and workers. Pressure, job insecurity, and low job satisfaction are examples of psychological variables that are evaluated for their effects on employees' mental health and productivity. We quantify the psychological effects on workers using qualitative as well as quantitative methods, and we use an organized structure to assess social hazards in automated environments. To find treatment strategies that can reduce social hazards and promote a positive work environment by looking into these factors. We investigate cutting edge technologies that can lessen psychological stress and enhance human-machine cooperation, such as adaptive training programs and real-time monitoring systems. In order to ensure an equal dedication to security, effectiveness, and workers happiness in the mining industry, the findings add to a thorough understanding of how modern technology as well as beneficial workplace systems can enhance mental wellness and productivity gains in automated mining.*

***Keywords:*** *Environmental Impact; Safety-Production; Social Risks; Cutting-Edge Technologies*

## INTRODUCTION

An industry that was formerly mostly dependent on manual labor is being revolutionized by the rising automation of mining operations. Automation increases productivity, safety, and cost-effectiveness, but it also presents new issues that need careful consideration, particularly in relation to social risks and psychological effects on employees. The mining industry is dealing with complicated social dynamics as it moves into high-tech settings, including the loss of traditional occupations, changes in the skills needed, and possible disturbances to community life. Assessing these social hazards is essential because they affect community connections, industry sustainability, and employee mental health and well-being.

Furthermore, special concern must be given to the psychological well-being of employees in automated mining environments. Instead of contact directly with the actual mining environment, job duties increasingly demand interaction with advanced technologies, which can cause stress, worry, and a sense of detachment from traditional labor. Building resilient, driven teams that can adjust to the industry's technical advancements requires an understanding of and ability to manage these psychological elements. Innovation in automated mining must therefore integrate robust systems for assessing both social hazards and psychological conditions, ensuring a balanced approach to technological progress. This article explores the critical aspects of evaluating these impacts and discusses how mining companies can foster an environment that supports workers' mental health while leveraging the full potential of automation. According to these authors, technology by itself can never transform an industry or offer a company a competitive advantage. History has demonstrated, however, that technology used in conjunction with sound planning and strategy may have a big impact. The mining business has never needed a step change or faced such formidable obstacles. The use of autonomous systems in the mining sector has been growing over time. The minerals mining value chain has evolved from discovery to extraction, processing, and refining due to automation technology [1]. Using primarily Australian examples, this article reviews the state of robotics in the mining sector today and suggests possible paths for the technology's development. For ages, automation has existed in a variety of forms. However, the 20th century saw a strong adoption of automation in the industrial sector. a number of the innovations and practices

established by factories are being adopted by the mining industry as the fourth industrial century approaches. The cooperation between industry and academia has significantly aided in the deployment of automation [2]. As our society becomes more technologically sophisticated, the number of motor vehicle accidents is rising. A great deal of traffic accidents are the result of driver mistake, despite the use of mobile devices, in-car entertainment systems, increased traffic, and better road infrastructure. Road safety would benefit from technologies that may reduce human-caused accidents. The implementation of autonomous vehicles could lead to a rise in road safety. To accomplish this, everyone in the automobile is working very hard. Completely autonomous vehicles are being researched and developed by Volvo, Audi, BMW, Ford, Google, General Motors, Tesla, and Volkswagen. Google's "Waymo" product is well-known [3]. The quick development and use of automation technology is causing a radical change in the mining sector. This study offers a thorough analysis of the condition of robotics in mining today, looking at new developments in technology, their uses, and the future of automated in this vital sector. This paper's main focus is on how automation affects mining operations' productivity and safety. Demonstrating how Automatic Haul Truck Systems have been successfully used in surface mining. The evolution of mechanization in underground mining is also examined in this research, along with its difficulties, especially communication and localization constraints that impede the creation and implementation of completely autonomous systems [4].

## REVIEW ON AUTOMATION MINING OPERATION

Automation will continue to permeate more procedures and the overall architecture of the system in the future. It is helpful to examine and assess the existing level of automation in minerals development in order to gain a better understanding of the near-future potential of automation. The current status of automation research is reviewed. Three key areas will be examined in this review: automation technology, automation-related system engineering and management procedures, and the function of the field of human factors in controlled and semi-automated systems. A examination of the political and social concerns of automation in relation to sustainable development and shared value concludes the review [1]. By analysing the starting and ending points on Google Maps, the current study can ascertain the route. Convertcsv.com can extract the longitude and latitude coordinates from the KML route. After a component of the coordinates was input into the Arduino Uno's code. The automobile's latitude and longitude coordinates, as well as its movement in real time, are tracked using an Arduino Uno and AGPS sensors. The data is then uploaded to the Things Peak Cloud. The cell phones of today require AGPS sensors. The esp8266 Wi-Fi module allows the Arduino Uno to connect to the Issues peak cloud. After retrieving the most recent data, it uses the latitudes to determine the direction and angle that our driverless car should travel [3]. It will be essential to look ahead to future developments in enabling technologies in order to advance mining automation. Intelligent automation will depend more and more on machine learning and artificial intelligence (AI), which will allow autonomous systems to adjust to changing conditions, streamline operations, and make wise choices. The potential benefits of mining collaboration between humans and robots are examined in this research. In order to promote working together as the sector moves toward further automation, it is crucial to take into account the changing roles of human workers. For a smooth transition to a more automated future, this entails putting human safety first, offering sufficient training, and resolving worries about job loss [4].

Field research on automation in Ontario Division Inco mines served as the foundation for this thesis. It takes into account the development of technology and methods for automating underground hardrock mining, with a focus on the evolution and automation of the load-haul-dump machine. It makes an effort to outline the specifications for upcoming mining operations, such as the possibility of prolonged teleoperation and machine autonomy from secure locations. Effective subterranean communications, automation-friendly machinery, and process and workspace compatibility are among the design challenges that are thoroughly examined before being linked to design and implementation solutions. Discussions and suggestions for future autonomous haulage solutions for extremely long distance scenarios round out this thesis [5]. The findings indicate that the operational, fiscal, enterprise, safety, and environmental goals of the subterranean Smart Mine are in line with those of academics and mining practitioners. Infrastructure at the time, the internet, people, culture, operating procedures, and equipment are all part of the multitude of suggested solutions to create a Smart Mine. While culture and individuals are undervalued, mining practitioners and scholars alike concentrate on technology and machinery projects. These solutions cover a range of company management procedures, but practitioners place more of an emphasis on information and data management

as well as environmental, social, and governance (ESG) issues. Nonetheless, there is a dearth of scholarly research on business management procedures, with the majority of it concentrating on automation management, ESG management, and education and training. It is necessary to advance the management of assets, handling changes, & risk and safety management [6]. Examples of modern digital technologies used in mining operations are found in this literature study, along with information on their purported advantages. Despite the fact that a number of advantages were mentioned, mining corporations often prioritize cost, productivity, and safety. Although they have the potential to reduce the mining carbon footprint, resource and emissions reductions are frequently disregarded. The business case for increasing the adoption of digital technologies and assisting the mining industry in achieving decarbonisation objectives might be strengthened by measuring the savings in energy consumption and emission reductions in greenhouse gases attained through their application [7].

Access to a platform that contains technology-related information is essential for organizations and individual operations to think about for future research and development. To this end, a Mining Cycle platform was developed that includes all of the mining phases, including exploration, evaluation, design, operations, closure, and post-closure. After that, each phase's constituent value drivers were examined and added. These addressed the several areas of emphasis within the mining cycle, including the relevant sub-phases, systems, activities, processes, or particular difficulties that affect a mine's functioning. A Technology Map was then created by integrating digital and physical technologies that could benefit these priority areas into the platform [8]. Due to the aging workforce and decades of cost reduction, mining corporations have little room to adapt. These days, a quickly developing collection of new technologies known as the "Digital Transformation" offer new opportunities to enhance operational efficiency, create more precise, and more. All of these must be carefully examined in order to spur growth and boost efficiency. Mining firms must comprehend the digital transition and the risks and opportunities it brings. An operation that is more information-based and networked will keep pushing the boundaries of what requires human contact. The next wave of industrial differentiation will be shaped by the potential for novel business models and higher degrees of optimization [9]. Reaching the

proper level of maturity for Industry 4.0 in the mining sector is fraught with difficulties. Challenges associated with digitalization include the development of online data hubs, storage via the cloud, intelligent data architecture, and data collection technologies. Furthermore, for computerization, prediction, and optimization, sophisticated analytics models that utilize machine learning and AI models are crucial. For mine managers to create smarter mines and make better decisions, they require an intelligent mining virtual assistant [11]. Industry 4.0 is bringing forth new conditions for mining, which is causing a technological transition in the mining sector. A common term for this is Mining 4.0. The industry must effectively manage a number of issues in order to survive the technological shift, including how to use the new digital technology to support environmentally friendly workplaces, how to attract qualified personnel, and how to handle organizational issues brought on by the change. A wide range of literature on how Mining 4.0 may impact the mining sector in areas like work environment, competencies, organization and society, and what can be done to advance sustainability in the future is examined in this scoping literature study [12]. By its very nature, the mining industry is a hard and difficult one. In addition to mineral extraction, mining operations also include management, processing, and transportation. Mining activities are capital-intensive and have significant effects on the environment and society. They are frequently found in isolated and distant locations. In terms of innovation, the industry is seen as mature and conservative. However, because of its multifaceted character, diminishing ore grades, and the growing demand for limited resources, innovation and the adoption of new technologies are necessary. The framework for integrating technologies like the Internet of Things (IoT), automated drones, 3D printing, robots, sensors, data analytics for monitoring, and performance evaluation in the mining industry is known as Mining 4.0, which is in line with Industry 4.0. Adoption of novel ideas in the mining industry is frequently hampered by laws, regulations, and governance structures [13]. However, mining is the human activity that has had the most negative environmental effects and is associated with significant socioeconomic implications and inequality. However, mining has a significant impact on our future. From uranium to phosphate, a number of mining industries are examined, and their present effects and difficulties are talked about. Environmental health and sustainable development are examined in relation to the mining legacy and environmental clean-up, current mining and its issues, and mining and society in the future. It is determined that in order to be environmentally acceptable and in line with sustainable development goals, current mining techniques must be modified to support more equitable community development

and to safeguard superior natural resources and ecosystems[14]. Additionally, mining 4.0 is a reaction to the technology shocks brought on by the manufacturing and infrastructure sectors' rapid digital upgrading. In order to illustrate the core and frontiers of Mining 4.0 expansion, as well as the opportunities and threats of substituting cyber-physical systems for physical systems and humans in mining, this article aims to provide a multilateral overview of the mining industry's transformation as a result of the spread of Industry 4.0 technologies. Additionally, the risks of complete digitization are associated with the technological, economic, and social horizons of the shift from Mining 4.0 to Mining 5.0 [15].

## RESULT AND DISCUSSION ON THE EVALUATION PROCESS

Substantial insights into the advantages and difficulties of mechanization in high-risk industries can be gained from the assessment of community hazards, psychological circumstances, and innovation in mechanized mining operations. Results show that by reducing the requirement need human presence in hazardous mining situations, automation can significantly lower social hazards. This change reduces direct physical risk exposure, which has previously resulted in high injury and death rates. But when physical hazards decline, psychological problems—like stress, loneliness, and the need to adjust to new technology—become more significant among employees. Employees transitioning from traditional mining tasks to managing automated systems were most likely to experience these psychological variables, highlighting the significance of good change management and mental health support. Automated mining innovation also had conflicting effects on worker happiness and operational efficiency. Automation increased productivity, but it also reduced the workforce, raising social issues about job security. Effective retraining programs, however, can lessen certain psychological and social effects since workers who have acquired new skills adjust more favourably, according to the study. These findings highlight the necessity for enterprises to give equal weight to technology innovation and psychological support systems. Employee resilience and acceptance of automation can be increased by implementing routine psychological testing and cultivating a culture that prioritizes employee well-being. By examining long-term psychological changes and the effect of developing technology on employee morale in automated industries, future study could build on these findings

## CONCLUSION

The mining industry's future depends on assessing psychological conditions, social dangers, and encouraging development in automated mining processes. Understanding the connection between social dangers and workers' emotional health is crucial as mining automation advances. By recognizing social hazards, such as social isolation, communication breakdowns, and job displacement, supportive systems that safeguard mental health and foster a more positive work environment can be established. In addition to increasing employee satisfaction, this awareness fortifies the industry's resilience and sustainability. Innovative automated mining techniques necessitate constant evaluation and improvement of both technology and human factors. Businesses can reduce possible dangers by emphasizing a comprehensive system that prioritizes both technology improvements and the psychological well-being of its employees. By fostering a balanced interaction between automated and human components and increasing operational efficiency, this proactive approach fosters an inclusive and flexible work environment.

## ACKNOWLEDGMENT

Do not use the name of any persons in the Acknowledgment.

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# Metals & Minerals

# High Performance Structural Materials for Mobility Applications

35_IEC14509

# An Efficient Method to Enhance the Life of "Sprocket (Ground Engaging Tools)" in Hydraulic Excavators by Adding "Boron" as a Micro-alloying Element

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***Abstract:*** *Excavators are being used for various industrial, mining, agricultural and material handling applications. The market has been segmented by type, end-use industry, and geography. Based on the application, the global Excavator's market is segmented into construction, forestry, and agriculture, mining, and others. Now a day due to demand of low cost & high efficiency production rates in field of building construction, road construction, agricultural application, mineral excavation, ship & ports management, military applications, industrial applications, etc excavators are treated as first line of machinery. In spite of wide use of Excavators in Mining, Construction, irrigation, roads & other segments, the major challenge in at present is "Wear & Tear "of abrasion parts like Ground engaging tools & Track parts. The present invention generally relates to hydraulic excavators. This invention relates to enhancement of Wear & Tear life of 20T Class Sprocket which is one of the most selling excavators of THCM. We had field complain regarding less life of Sprocket in 20T Class domestic machines from customers.*

***Keywords:*** *THCM; Ground Engaging Tools; Boron Steel; Induction Hardening; Hardness; Microstructure; Tensile; Case Depth; Wear Tear*

**Figure 1** Excavator Image


**Figure 2** & **3** Worn-out Sprocket

## UNDERSTANDING WEAR PHENOMENA

Every Mechanical part of a machine or Tool , that is undergoing some rolling or sliding contact, is subject to wear. Mechanical moving parts is having a common failure in terms of wear. The life ,performance and the replacement cost for a machine with moving parts , like the excavators , is greatly affected by wear. Abrasive wear is the most serious problem for moving parts and machinery. It alone stands for almost 50% of the total wear loss of developed countries. The process starts when hard, mostly mineral parts gets in contact with the working surface part of the machinery. We can increase the life of service parts by using abrasion resistant materials or treating surface layers to create a abrasion resistant surface on the specific part of the machine or tool.

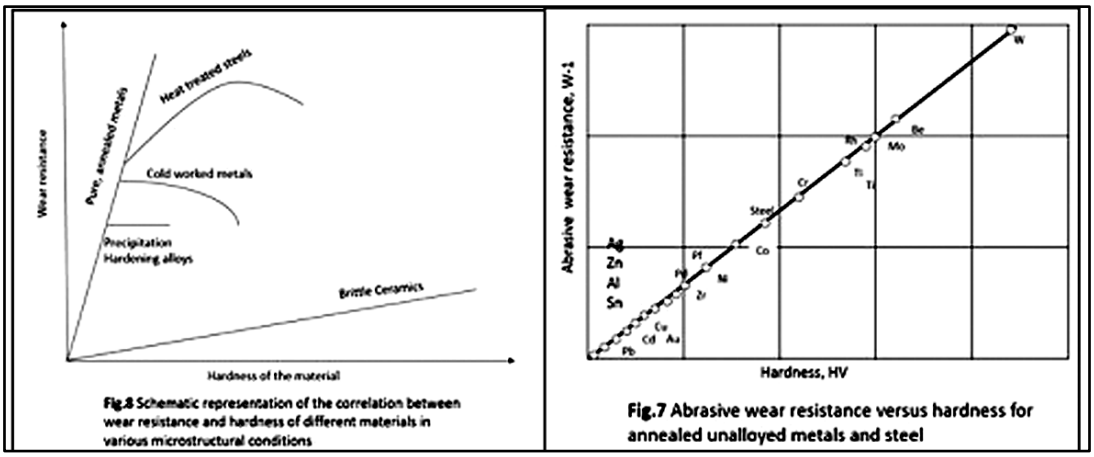



Fig.8 Schematic representation of the correlation between wear resistance and hardness of different materials in various microstructural conditions

Fig.7 Abrasive wear resistance versus hardness for annealed unalloyed metals and steel

Ref. Metals Handbook, Service characteristics of carbon and alloy steels , p 277-279

## INTRODUCTION

### Field of Invention

The present invention generally relates to hydraulic excavators. This invention relates to enhancement of Wear & Tear life of 20T Class Sprocket which is one of the most selling excavators of THCM.We had field complain regarding less life of Sprocket in 20T Class domestic machines from customers. As per the field data sprocket average life should be

- In THCM machine – 2500~2600 HMR
- In Competitors machine – 3000~3500 HMR

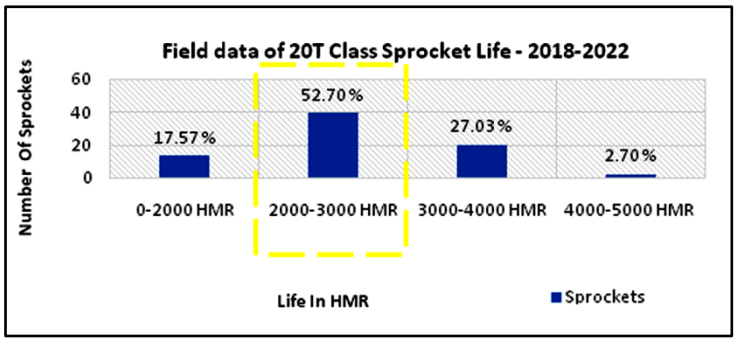



**Figure 3** Trend of Failure (Worn-out) of Sprocket in Field

## METHODOLOGY

Excavators are digging and dumping machines with specialized attachments for handling specialized jobs such as digging, levelling, loading, pipe laying, rock breaking etc. Field applications in Excavators involve wear mechanisms like abrasion, corrosion, impact, frictional wear, erosion, humidity, particle shape etc. all significantly contribute to the deterioration of the component. However, Abrasion has been found to be the most critical wear mechanism with Ground engaging parts. At present, the life of 20T Class Sprockets are being reduced subsequently in field & Worn-out with early hours.

To address the concerns mentioned above, we have 3 options to overcome these issues

- Developing forged Sprocket in India
- By Importing Forged Sprockets

- Use improved material grade (casting) with higher hardenability & depth of hardness

**Objective**

We opted with "Improved material grade with high Hardenability & Depth of Hardness"

- Material with higher alloying element like Chromium, Molybdenum etc. can improve the hardenability, surface hardness with carbide formation and improve wear resistance but cost associated is high. Hence, considering the cost constraint, we focussed on "Boron"addition for following reasons:
- No major cost escalation (Boron in very small amount increases hardenability
- Ease of implementation in the current process

**Summary**

Why we selected Boron?

Even in the small quantity of the degree of size up to 0.0030 % i.e., 30 ppm, boron gives the same effect of the hardenability enhancement as other more expensive elements which must be added in much bigger quantity. For example, the addition of Boron in SAE replaces elements like.

| Addition | Elements replaced (approximately) by Boron |
|---|---|
| 0.0030 % Boron (30 ppm) | 1.00 % Nickle |
| | 0.12 % Vanadium |
| | 0.30 % Molybdenum |
| | 0.40 % Chromium |

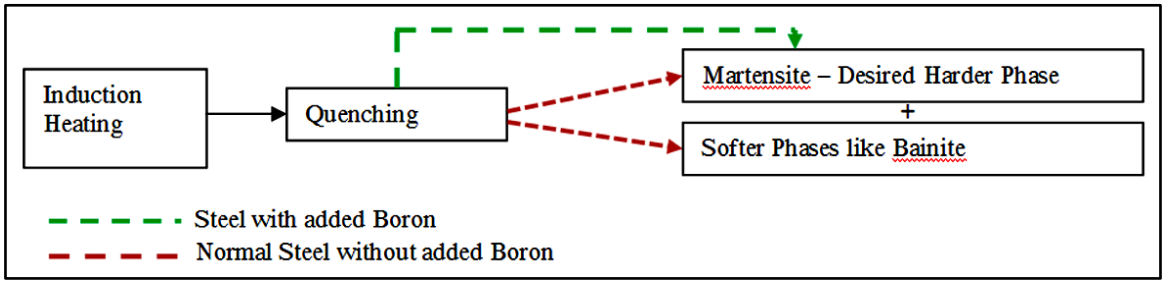
- Brief Description of Testing Methodologies

  The details analysis reports are enclosed below

  1. Metallurgical & Mechanical comparison study
  2. Wear Characteristics (Sand-Abrasion test)
  3. Microstructure & Case Depth Hardness Pattern

- Effect of Boron on Steel – Boron in Steel - Boron is added in very small amount (0.003%) to unalloyed and low alloyed steels to enhance the hardness level through enhancement of depth hardenability. How?

By delaying the transformation of Softer Phase i.e., bainite, ferrite and pearlite structures, which are softer than martensite during Heat treatment (Hardening & Induction Hardening).



## RESULTS

### Comparison Test results of Born & Non-Born Material Grade

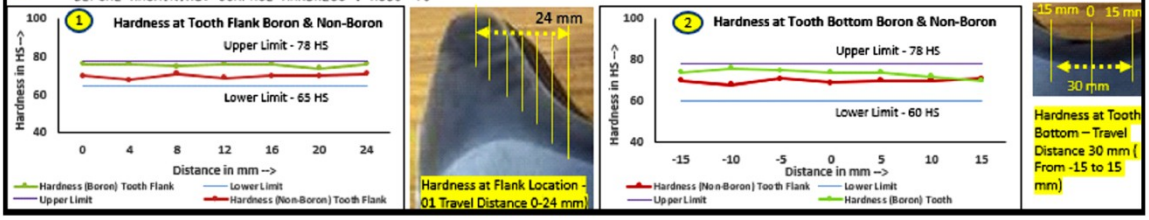
| Properties | | Specification | Actual Test Results – Non-Boron P&H 11 | Actual Test Results – Boron added P&H 11 | Remarks | Equipment's used |
|---|---|---|---|---|---|---|
| **Chemical Property** | % C | 0.35-0.42 | 0.36 | 0.41 | Boron Added – 15 ppm ** As per the requirement Boron can be added up to 0.0030 % i.e., up to 30 ppm maximum. | Spectro-machine |
| | % Si | 0.30-0.60 | 0.52 | 0.43 | | |
| | % Mn | 1.10-1.50 | 1.22 | 1.15 | | |
| | % P max. | 0.035 | 0.018 | 0.011 | | |
| | % S max. | 0.035 | 0.008 | 0.009 | | |
| | % Cr max. | 0.25 | 0.066 | 0.089 | | |
| | % Mo | 0.15-0.30 | 0.23 | 0.16 | | |
| | % Ni max. | 0.4 | 0.022 | 0.042 | | |
| | % V max. | 0.05 | 0.008 | 0.003 | | |
| | **% B** | **Nil.** | **Nil.** | **0.0015 **** | | |
| **Mechanical Property (Normalised Condition)** | Tensile Strength mix. | 630 MPa | 756 | **786** | 4 % more TS | Universal Testing Machine |
| | Yield Strength mix. | 420 MPa | 468 | **556** | 19 % more YS | |
| | Elongation min. | 15% | 18.50% | 17.11% | | |
| **Abrasion Test (After Induction Hardening)** | Sand Abrasion Test | ---- | 0.332 gm weight loss | **0.316 gm weight loss** | **Less wear loss in boron steel** | Sand Abrasion Tester |

### Metallurgical Inspection after Post Induction Hardening Process

Surface hardness (equipment's used – hardness tester with hs scale)

| Parameters | Specification | Actual (Without Boron) | Actual (With Boron) | Remarks |
|---|---|---|---|---|
| Surface Hardness (After Induction Hardening) ① | **Tooth Flank** -- 65-78 HS (490-650 HV) | **Tooth Flank** – Within the specification | **Tooth Flank** – Within the specification (Mentioned in the graph below) | Hardness at Tooth Flank & Tooth Bottom are within the specification Judgement - PASS |
| ② | **Tooth Bottom** -- 60-78 HS (450-650 HV) | **Tooth Bottom** -- Within the specification | **Tooth Bottom** -- Within the specification (Mentioned in the graph below) | |

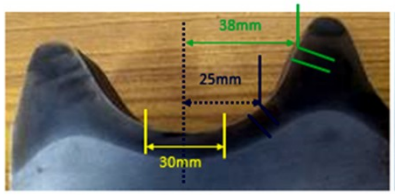
① NOTE FOR MACHINING
1. MUST BE PERFORMED SPIN INDUCTION HARDENING TO HATCHED PART (TOOTH FLANK, TOOTH BOTTOM) ← Drawing location 1-D
BEFORE MACHINING. SURFACE HARDNESS : HS65~78



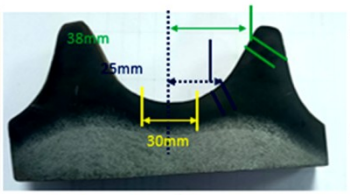
**Induction Hardened Case Depth from Surface to Core**

Equipment's used – micro-Vicker hardness tester

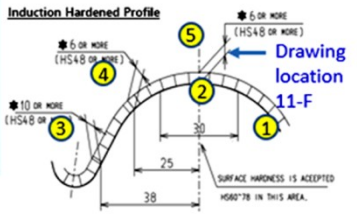
| Parameters | Specification | Actual (Without Boron) | Actual (With Boron) | Remarks |
|---|---|---|---|---|
| Case Depth | At 38mm location - ≥10mm @48 HS (350HV) | At 38mm location - Within the specification (mentioned in the graph) | At 38mm location - Within the specification (mentioned in the graph) | Case Depth (Boron & without Boron) at 38 mm - NO Cut-off value (350HV) observed since the Tooth Surface get fully hardened |
| | At 25mm location - ≥6mm @48 HS (350HV) | At 25mm location – Within the specification (mentioned in the graph) | At 25mm location – Within the specification (mentioned in the graph) | |
| | At 30mm location (Tooth Bottom) - ≥6mm @48 HS (350HV) | At 30mm location (Tooth Bottom) – Within the specification (mentioned in the graph) | At 30mm location (Tooth Bottom) – Within the specification (mentioned in the graph) | Judgement - PASS |

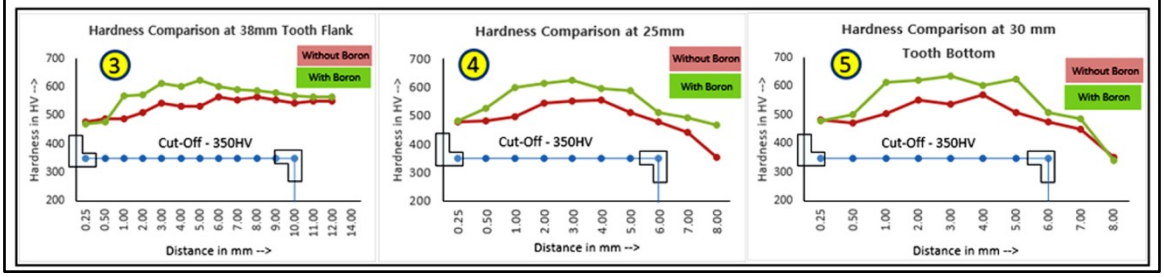



Hardness Profile Non-Boron Sprocket




Hardness Profile Boron Added Sprocket




**Metallography (Microstructure at Case at Magnification 100X)**

Measuring method – optical microscope

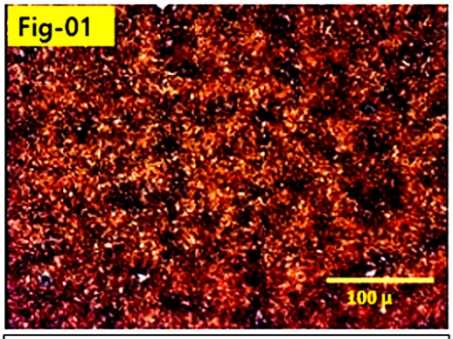



Fig-01 Microstructure Analysis of Non-Boron Sprocket (Case) – Fine Tempered Martensite

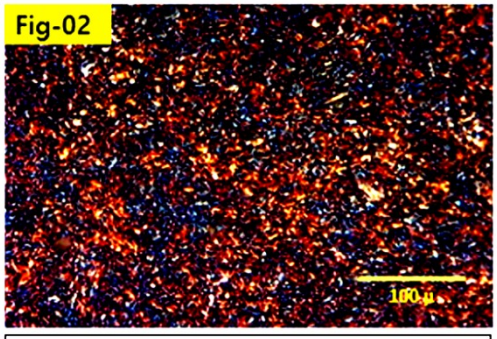
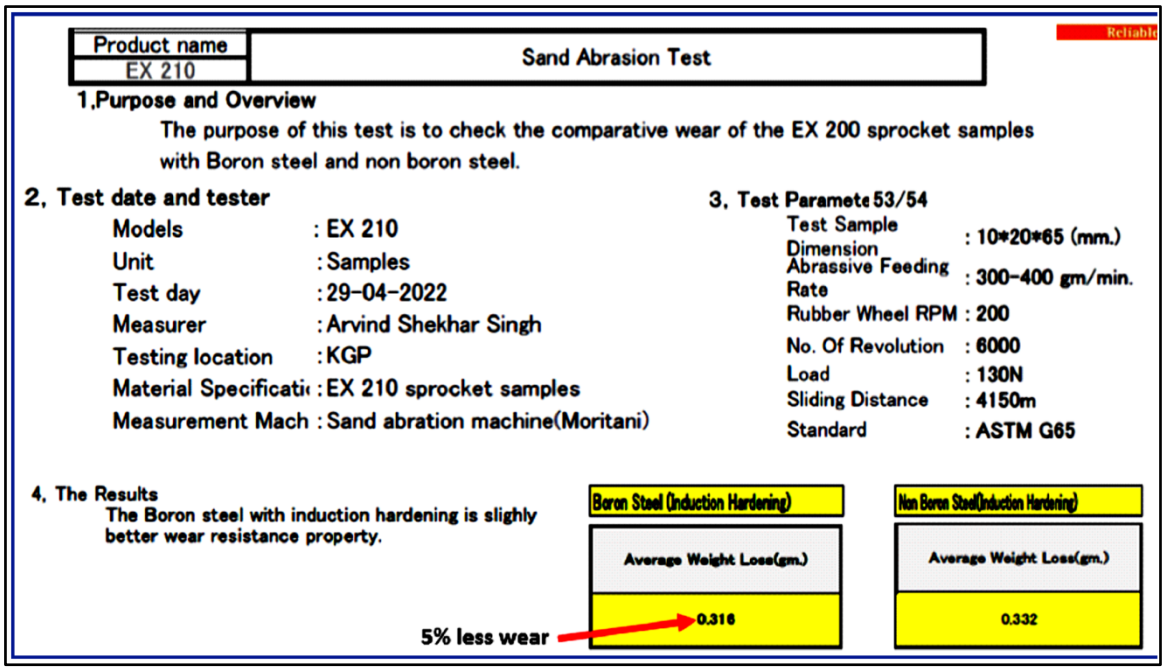



Fig-02 Microstructure Analysis of Boron added Sprocket (Case) – Fine Tempered Martensite

**Sand Abrasion Test - Equipment's Used – Sand Abrasion Tester**




Born Steel Sprocket having better Wear Resistance properties In-place of Non-Born Steel

## CONCLUSION AND FUTURE SCOPE

- Warranty Cost Saving 1182677 INR
- Enhance the life of Sprocket >3500 HMR (9 machines running >5000 HMR till now)
- Reduce customer compliant & Gaining the customer satisfaction
- Innovative Cost-effective improvement for enhancing the life of sprocket
- Future opportunity for import substitution & cost saving
- No effect of currency fluctuation on our cost
- Promote "Make in India" concept
- Chance of Horizontal deployment in other models

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68_IEC82798

# Mitigating Failures in 309S Stainless Steel Furnace Component: Causes and Solutions

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***Abstract:*** *The failure mechanisms and the prevention methods for 309S stainless steel inner covers used in Batch Annealing Furnace in Cold Rolling Mill are presented in this paper. In this work, the studies included characterization of material and microstructures analysis with Optical Microscope and Scanning Electron Microscope (SEM) coupled with Energy Dispersive Spectrometer (EDS). Microstructures examination and EDS analysis indicate the formation of carbide and precipitations of sigma phase in the matrix. Formation of carbides and sigma phases associated with depletion of alloying elements from the matrix deteriorates the mechanical properties and sensitizes the steel to corrosion attack because of reduction of chromium from the matrix of the inner cover material making it prone to bulging and cracking. To mitigate these issues, a mechanized cleaning system was developed and implemented to periodically clean the inner covers. It was also recommended to adjust the alloy composition and reduce the exposure time to high temperatures of the inner covers, where the formation of sigma phase can help minimize its presence. The introduction of this cleaning system significantly decreased the downtime associated with these failures, effectively enhancing operational efficiency.*

***Keywords:*** *Inner Cover; Batch Annealing Furnace; Sigma Phases; Cracking & Bulging*

281_IEC69270

# Modeling and Simulation Studies on TIG Welding of Gas Turbine Combustion Liner Sub-Assemblies

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***Abstract:*** *In aero gas turbines engines, combustor liner is one of the major sub-assembly. The sub-assembly is to be realized through TIG welding(17 welds) with a weld joint thickness of 1.2mm. The present study explores a methodology to minimize the distortion of assembly combustor liner by numerical welding simulation of combustion liner sub-assemblies. Simulation of TIG welding is associated with thermal, metallurgical, and mechanical analysis. It involves the non-uniform heating and cooling of the material, which leads to changes in phases and material properties with variations in temperatures [1]. The non-uniform heating and cooling also causes uneven thermal expansion and contraction around the weld zone, which results in the formation of transient stresses and plastic deformation. As a result, the residual stresses and weld distortions are produced in the welded part. In this study, a sequentially coupled thermo-mechanical analysis was performed to calculate the weld thermal profile and deformation. The weld sequence and fixturing conditions was optimized by developing the temperature dependent material database of nickel based C263 alloy which was the input data for the numerical welding simulation. The simulation was implemented in Finite Element Analysis (FEA) software, Sysweld 17.0 [2]. Two different welding techniques such as progressive and segmental methods were used in the welding of combustion liner sub-assemblies to minimize the distortion. The total length of the weld was divided into 8 quadrants (45 $^{0}$ each). In the progressive method, continuous welding is carried out throughout the first two quadrants of the parts, followed by welding on the next two quadrants. However, in the segmental method, the welding is carried out initially in one of the diagonal quadrants of the part, then it is carried out in the next diagonal quadrant. By varying the weld sequence and clamping conditions, the optimal weld parameters for minimum distortion of the assembly were determined.*

*Keywords: Combustor Liner; Modelling and Simulation; TIG Welding; Distortion*

## INTRODUCTION

In aero gas turbines engines, combustor liner is one of the major components. The combustor liner is shown in Figure 1 (d) consists of 3 major sub-assemblies the front part Figure 1(a), inner part Figure 1(b) and the rear part Figure 1(c). The assembly is to be realized through TIG welding of cooling rings with a weld joint thickness of 1.2 mm. The present study explores a methodology to minimize the distortion of assembly combustor liner by numerical welding simulation of combustion liner subassemblies. Simulation of TIG welding is associated with thermal, metallurgical, and mechanical analysis. It involves the nonuniform heating and cooling of the material, which leads to changes in phases and material properties with variations in temperatures [1]. The non-uniform heating and cooling also causes uneven thermal expansion and contraction around the weld zone, which results in the formation of transient stresses and plastic deformation. As a result, the residual stresses and weld distortions are produced in the welded part. In this study, a sequentially coupled thermo-mechanical analysis was performed to calculate the weld thermal profile and deformation. The weld sequence and fixturing conditions was optimized by developing the temperature dependent material database of nickel based C263 alloy which was the input data for the numerical welding simulation. The simulation was implemented in Finite Element Analysis (FEA) software, Sysweld 17.0[2]. Two different welding techniques such as progressive and segmental methods were used in the welding of combustion liner sub-assemblies to minimize the distortion. The total length of the weld was divided into 8 quadrants (45° each). In the progressive method, continuous welding is carried out throughout the first two quadrants of the cooling rings, followed by welding on the next two quadrants. However, in the segmental method, the welding is carried out initially in one of the diagonal quadrants of the rings then it is carried out in the next diagonal quadrant. By varying the weld sequence and clamping conditions, the optimal weld parameters for minimum distortion of the assembly were determined.

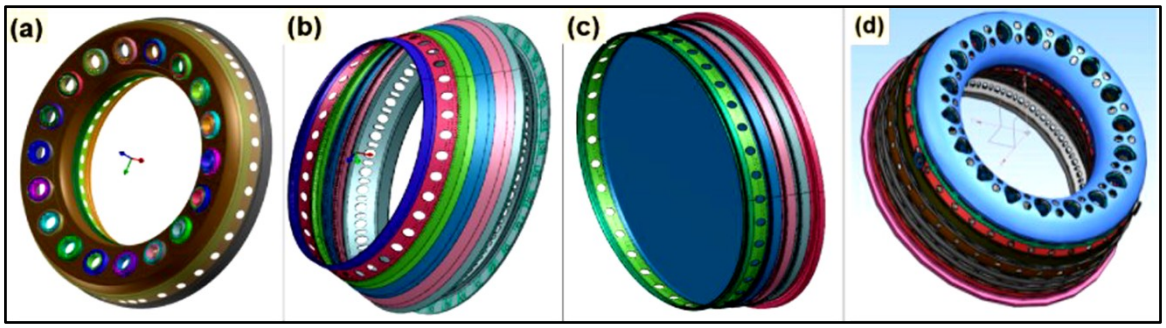


**Figure 1** 3D model of the liner sub-assemblies (a) Front part; (b) Inner part; (c) Rear part; (d) Liner Assembly

## METHODOLOGY

**Figure 2** shows the overall methodology adopted for numerical welding simulation of combustion liner sub-assemblies. The 3D CAD model of the combustion liner sub-assemblies is converted into a shell model to reduce the computational time and improve the accuracy of the results. Based on the initial weld trials, the weld bead geometry and trajectories were predicted and used for numerical simulation. For numerical simulation, Goldak Double Ellipsoidal Heat Source Model (DEHSM) was used to predict thermal and stress fields. Numerical simulation has two kinds of analysis: one is thermal and another is mechanical. In thermal analysis, the non-linear transient, moving heat source model solves the heat transfer equation and determines the temperature field across the weldment. The thermal analysis was performed from the validated heat source model for the Gas Tungsten Arc Welding (GTAW) of C263 alloy. **Table 1** shows the welding parameters used for the butt joint. The temperature-dependent physical properties of Alloy C263, such as density, thermal conductivity, and specific heat capacity were considered for the thermal analysis. In mechanical analysis, it uses the thermo-elasto-plastic models to determine weld deformation of the welded component. Based on the results the distortion induced in the weldments were determined. This formed the input for the designer and the manufacturing application engineer.

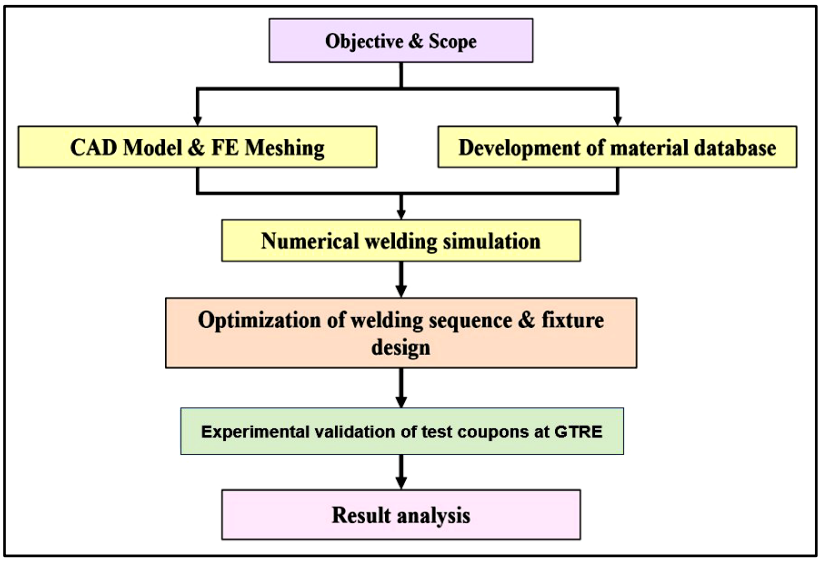


**Figure 2** Proposed methodology of numerical welding simulation of combustion liner

**Table 1** GTAW parameters

| | |
|---|---|
| Current | 33 A |
| Voltage | 6-10 V |
| Travel Speed | 60 mm/min |

## RESULTS

The welding is carried out between the two cooling rings in a circumferential direction. As a result, eight passes of welding are required to join the single pair of cooling rings. The dwell time between each weld pass is 200 secs for both the methods. The component was clamped in a condition such that the restraints were in the X, Y and Z directions. The combustor liner has 17 welded joints (the front part has 6 welds, 4 welds in the inner part and 5 welds on the rear part and the final assembly has 2 welds) with a joining thickness of 1.20mm and for each joint progressive method and segmental method simulation was carried out, it was observed that high distortion is induced by the progressive method for all the welds.

**Figure 3a** shows the distortion profile of the front part of the combustion liner sub-assembly (SB-I) determined using the progressive method. The welded component experiences maximum distortion of about +12.21 mm from the datum plane. In this method, continuous welding is carried out throughout the first two quadrants and then another two quadrants, so the weld length covers the complete distance on one half of the component which induces more circumferential deformation in the other half of the component. Then, if the welding is carried out on the other two quadrants it again induces more distortion on the component.

**Figure 3b** shows the distortion profile of the front part of the combustion liner sub-assembly (SB-I) determined using the segmental method. In this method, the welding is carried out in an opposite quadrant-wise and the component experiences maximum distortion of about +2.12 mm from the datum plane. It is identified that maximum level of the weld deformation is reduced in segmental method when compared to the progressive method. The distortion values of SB-I for both the methods are given in **Table 2**. Similar results were seen in all the other sub-assemblies.

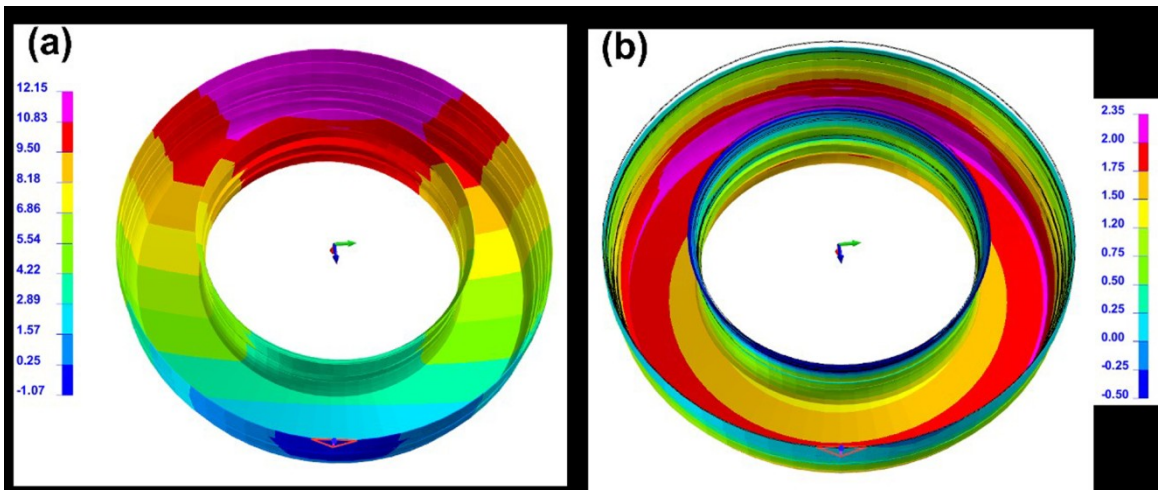


**Figure 3** Distortion profile of front part (SB-I) (a) Progressive method: (b) Segmental method

**Table 2** Summary of weld distortion for front part (SB-I)

| Cooling rings in Front Part | Circumferential Deformation (mm) | |
|---|---|---|
| | Progressive method | Segmental Method |
| CR-1 | 12.21 | 0.35 |
| CR-2 | 11.58 | 1.74 |
| CR-3 | 9.89 | 2.00 |
| CR-4 | 7.71 | 1.093 |
| CR-5 | 10.85 | 0.008 |
| CR-6 | 10.93 | 0.01 |
| CP-1 | 11.65 | 2.12 |

## CONCLUSION

Based on the simulated results, the following conclusion are drawn.

- The temperature-dependent material database of Alloy C263 is developed and the MAT file for the numerical simulation has been generated.
- The welding distortion analysis of combustion liner sub-assemblies SB-I, SB-II, and SB-III has been completed by optimizing the welding sequence using progressive and segmental methods.
- The segmental method displays reduced distortion in all the combustion liner sub-assemblies (SB-I, SB-II and SB-II) compared to the progressive method.
- Based on the above study the segmental method of welding is proposed to be taken up for the actual component welding.

## ACKNOWLEDGMENT

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299_IEC82979

# Case Study of FEM Analysis of Spreader Beam (Lifting of Beam)

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***Abstract:*** *Spreader beam is used in various industries such as Steel plant, power plant, construction, shipping, or manufacturing for lifitng heavy equipment, spreader beams are essential tools used for distributing the load evenly across lifting points. This reduces the risk of damage to the load and increases safety during the lifting process. Let's break down the impact and benefits of using a spreader beam for lifting heavy beams: The lifting of heavy beams, particularly using a spreader beam, presents complex engineering challenges that necessitate a detailed understanding of load distribution, structural stability, and equipment interaction. This study employs Finite Element Method (FEM) analysis to evaluate the performance of a spreader beam system in lifting operations. The objective is to assess the structural integrity and dynamic behavior of the spreader beam under various loading conditions and to optimize its design for enhanced safety and efficiency*

*In this study, a Finite Element Method (FEM) analysis was conducted on a spreader beam used for lifting heavy beams in industrial applications. The primary objective was to evaluate the structural integrity, load distribution, and performance of the spreader beam under various loading conditions. The spreader beam, which plays a crucial role in distributing load evenly across multiple lifting points, was analyzed for its ability to minimize bending moments, shear forces, and stress concentrations that typically arise in heavy lifting scenarios.*

*The FEM analysis simulated different loading configurations, including uniform and eccentric loads, to determine the optimal design parameters of the spreader beam. Key parameters such as material selection, beam dimensions, and sling angles were incorporated into the model to assess their impact on stress distribution and deformation. The results of the analysis were validated against standard safety factors and industry regulations to ensure the reliability of the spreader beam under real-world conditions.*

*Findings from the FEM analysis revealed that the spreader beam significantly reduces stress concentration on the lifted load, thus enhancing overall lifting safety and reducing the risk of beam failure. The results also identified critical stress points on the spreader beam, guiding future design optimizations. This case study provides insights into the use of FEM in optimizing lifting equipment design and highlights the importance of precision in load distribution for safer lifting operations in the construction and heavy manufacturing industries.*

***Keywords:*** *Finite Element Method (FEM); Industrial Design; Spreader Beam; Load Distribution; Heavy Lifting; Structural Integrity; Stress Analysis*

372_IEC81891

# Prediction of Lankford Constant from the Composition and Processing Parameters of High-Strength DP Steel using Machine Learning

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***Abstract:*** *Enhancing fuel efficiency in automotive applications involves minimizing vehicle weight by integrating lightweight metal alloys such as dual-phase (DP) steel. The unique microstructure of DP steel characterized by martensitic regions dispersed within a ferritic matrix imparts a favourable strength-to-weight ratio, a low yield-to-tensile strength ratio, substantial work hardening capacity, and superior formability[1][2]. A critical parameter influencing formability is the Lankford coefficient, or r-value, which quantifies plastic anisotropy[3]. It is the ratio of the plastic strain in the width direction to that in the thickness direction. Accurate r-value determination is, therefore, essential for formability assessments in engineering applications.*

*Traditionally, the r-value was determined through uniaxial tensile testing. However, this experimental approach is resource intensive, requiring a large volume of samples and considerable time investment. The advent of Digital Image Correlation (DIC) technology has revolutionized strain field measurement, enabling precise strain mapping via sophisticated image processing techniques[4]. Concurrently, advances in computational modelling, such as Hill's 1948 yield criterion within finite element analysis frameworks, have bolstered predictive capabilities[5]. However, these finite element models demand high computational resources[6].*

*Machine learning (ML) offers a solution to these constraints by leveraging experimental data to establish predictive relationships between compositional and process variables and mechanical outcomes. This approach mitigates the reliance on extensive experimental and computational resources[7]. While ML models have been successfully applied to predict traditional mechanical properties of DP steel such as ultimate tensile strength (UTS), yield strength (YS), and elongation percentage[8], predicting the Lankford coefficient remains underexplored. Addressing this gap represents an opportunity to extend ML applications to encompass plastic anisotropy predictions.*

*This study aims to employ supervised ML models to predict the Lankford constant for DP steel, utilizing compositional attributes and annealing temperature as primary inputs.*

***Keywords:*** *Lankford Constant; Carbon Equivalent; Gradient Boosting Regressor; Metric Scores*

## METHODOLOGY

### Data Collection

A dataset comprising 356 experimental observations of high-strength dual-phase (DP) steel was sourced from a Chinese patent, detailing critical mechanical properties such as the Lankford constant, ultimate tensile strength (UTS), yield strength (YS), and elongation percentage, each corresponding to distinct compositional variants and annealing temperatures.

### Feature Selection

Pearson's correlation coefficients were calculated and visualized in a heat map to evaluate the relationships between input features. This analysis identified specific alloying elements namely nitrogen (N2), chromium (Cr), molybdenum (Mo), copper (Cu), and nickel (Ni) as exhibiting low or redundant correlations with the r-value, suggesting limited predictive utility.

Further dimensionality reduction via analysis of variance corroborated these findings; features such as carbon (C), silicon (Si), manganese (Mn), phosphorus (P), and the Lankford constant (r) exhibited significant retained variance, indicating their essential role in capturing the dataset's underlying patterns. In contrast, Ni, Cu, Cr, Mo, and N2 were

found to contribute negligible or zero retained variance, indicating a lack of unique information contribution within the reduced feature space (**Figure 1**). Consequently, these five elements were omitted from further analysis.

To substantiate this exclusion, an evaluation of differences in carbon equivalency was conducted, revealing that the removal of these elements resulted in negligible changes in carbon equivalency values, which were considered inconsequential. This refined dataset, therefore, focuses on the most impactful input parameters for modelling the Lankford constant of DP steel.

## TRAINING MODEL

Following the analysis of feature relevance and interrelationships, the input parameters were finalized. The selected variables included the compositions of essential alloying elements—carbon (C), silicon (Si), manganese (Mn), phosphorus (P), sulphur (S), aluminium (Al), vanadium (V), niobium (Nb), and titanium (Ti) along with processing parameter annealing temperature. The Lankford constant was chosen as the output variable, aligning with this study's objective of developing a robust model to predict formability characteristics.

The dataset comprised labelled observations, where each set of input features corresponded to a measured Lankford constant value. This facilitated the use of supervised learning techniques. To ensure the model's generalizability, the dataset was partitioned into training and testing subsets. Several regression algorithms were evaluated for predicting the Lankford constant, aiming to capture both linear and non-linear patterns in the data. Linear regression was initially applied as a baseline model which evaluates the predictive power of a straightforward linear association between input features and the target variable. Subsequently, a random forest regressor, composed of multiple decision trees, was implemented to capture complex, non-linear interactions among variables, which is particularly effective in managing high-dimensional data and mitigating overfitting[7]. Decision tree regressor was also explored, which evaluates specific feature splits that contribute directly to reducing prediction error. Although simpler than the random forest, this model offered an interpretable framework for understanding feature importance. A gradient-boosting regressor was also tested, combining sequential weak learners to improve accuracy by incrementally correcting residuals from previous iterations. To account for potentially intricate feature interactions, a support vector regressor (SVR) was employed to construct an optimal hyperplane, capturing nuanced relationships in the data[10]. The k-nearest neighbours (kNN) regressor was applied which investigate local data patterns, predicting the Lankford constant based on the average outcome of proximate data points within the feature space.

Each model's efficacy was assessed using metrics such as mean squared error (MSE) and R-squared ($R^2$) to evaluate predictive accuracy and model fit. The highest-performing model underwent extensive hyperparameter tuning by adjusting factors. Through this rigorous process of model comparison and optimization, a finely-tuned model for predicting the Lankford constant was developed.

## RESULTS AND DISCUSSIONS

The evaluation metrics for the five regression models employed are detailed in **Table 1**. Notably, the gradient boosting regressor demonstrated the highest $R^2$ score (0.860954) and overall predictive accuracy (86.0954%).

The graph in **Figure 2** shows the distribution of residuals for this Gradient Boosting Regressor. Residuals, which represent the differences between actual and predicted values. Most residuals are close to zero, indicating that the model's predictions are generally accurate. The smooth line overlaid on the histogram, called a Kernel Density Estimate (KDE) curve, provides a continuous estimate of the probability density of the residuals. The KDE peaks around zero, which supports the histogram's indication that the model's errors are generally small and balanced around the true values. Also, this residual distribution approximates a normal shape, with a symmetrical, belllike curve centred near zero. This symmetry suggests that errors are spread randomly, without systematic over- or under-predictions. Such a balanced, random distribution is desirable because it shows the model is likely capturing the real pattern in the data rather than introducing biased predictions. Additionally, the residuals are contained within a narrow range, mostly between -0.3 and 0.3. This limited spread shows a low variance in prediction errors, which indicates the consistency of the model. The narrow distribution further supports that the Gradient Boosting Regressor

is effectively modelling the relationship between inputs and the Lankford constant.

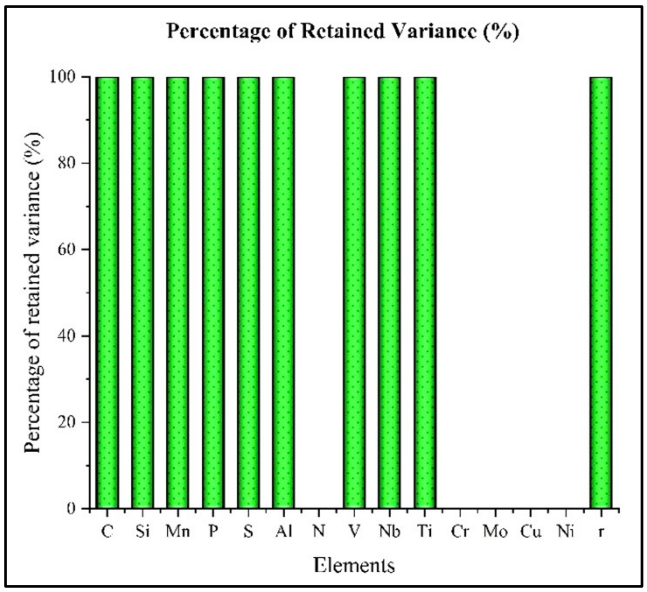


**Figure 1** Percentage of retained variance of the elements of DP steel

**Table 1** Evaluation metrics of the regression models

| Model | MSE | $R^2$ Score | Accuracy (%) |
|---|---|---|---|
| Linear Regression | 0.245227 | -1.473311 | -147.331052 |
| Decision Tree Regressor | 0.060417 | 0.390650 | 39.064962 |
| Random Forest Regressor | 0.016592 | 0.832656 | 83.265642 |
| Gradient Boosting Regressor | 0.013108 | 0.860954 | 86.0954 |
| Support Vector Regressor | 0.075496 | 0.238565 | 23.856547 |
| kNN Regressor | 0.062572 | 0.368909 | 36.890912 |

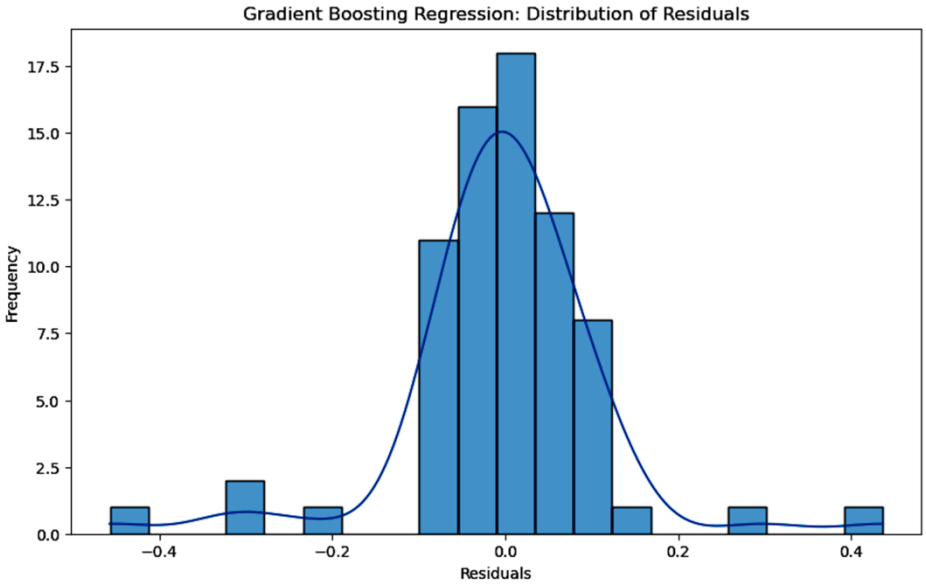


**Figure 2** Distribution of residuals for Gadient Boosting Regressor

## CONCLUSION

The results of this study significantly advance our comprehension of the relationship between compositional variables and the Lankford constant of dual-phase (DP) steel, establishing a reliable framework for future investigations focused on optimizing material properties for advanced engineering applications without necessitating extensive experimental trials or substantial computational resources. This research is particularly advantageous for the automobile industry, where precise predictions of mechanical properties are essential for the design and production of lightweight, high-strength materials.

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373_IEC45597

# Structure-Property Correlation of a Novel Quenched and Partitioned (Q&P) Steel

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***Abstract:*** *The weight reduction of automobiles and improvement of safety have recently garnered interest for the development of advanced high-strength Q&P steels, comprising martensite (M) and retained austenite (RA). In this research, two high carbon Nb microalloyed hot rolled steel plates were processed, one in as rolled condition (HRAC) and the other subjected to one-step Q&P treatment at 200°C for 30 min, were selected to correlate the microstructure and mechanical properties. The characterisations were carried out by optical microscopy, SEM, EBSD, hardness and tensile testing. The UTS and TEL% for the HRAC and Q&P samples were 2010 MPa, 12% and 1897 MPa, 19%, respectively. Image Quality maps revealed the area (%) of RA is more in the Q&P sample (2.10%) than in HRAC (1.51%). From the orientation distribution function (ODF) it was found that higher volume % of the rotated cube ({001}<110>) component in the HRAC sample (14.52) than the Q&P sample (7.54) leads to higher UTS.*

***Keywords:*** *High Carbon Steel; Quenching and Partitioning; Microstructure; Texture; Mechanical Properties*

## INTRODUCTION

The worldwide urge to develop the 3rd generation of advanced high-strength steels (AHSS) to manufacture lightweight car-body retaining crashworthiness has brought attention to adopt quenching and partitioning (Q&P), a novel multi-step processing route, developed by Speer et al. [1] which includes multiphase microstructures comprising martensite (M) and/or bainite (B) and considerable amount of retained austenite (RA). The Q&P process begins with partial or full austenitization, and thereafter, quenched to a predetermined temperature (QT) within martensite start (Ms) and finish (Mf) temperatures forming controlled volume fractions of M and untransformed austenite (γ). Subsequently, a partitioning step at the same QT (one-step) or above QT (two-step) is introduced to make carbon (C) diffuse from supersaturated M to the neighbouring γ. Finally, the material is quenched to room temperature (RT), during which the C-enriched γ becomes stable at RT and the rest transforms to fresh M. The M laths provide ultrahigh strength whereas, C enriched RA enhances the elongation and toughness due to the TRIP (transformation-induced plasticity) assisted behaviour of RA during deformation, leading to significant strain hardening. The resultant microstructure after Q&P depends on partitioning temperature (PT), partitioning time (Pt), cooling rates (CRs) and chemical compositions. Carbide precipitation in M is often witnessed during partitioning, for both low and high carbon steels (HCS), [2-4, 5] although the steels contain high Si [6]. If carbide precipitation occurs, some C is already consumed, thereby reducing the remaining C in M that

can be enriched in γ during the partitioning step. The C concentration in γ after partitioning is supposed to be lower than that expected under the constrained carbon equilibrium condition (CCE) excluding carbide precipitation [5]. The selection of proper alloying elements is crucial for desired M+RA microstructures after Q&P. C and Mn are γ stabilizers whereas, Si retards the undesirable carbide formations. Nb, a microalloying element can combine with C to form fine carbide precipitates, leading to precipitation strengthening. The presence of these elements results in the formation of pancaked γ grains during HR, which increases the volume fractions of RA, M, B etc. leading to more uneven and refined microstructures [7].

Kernel Average Misorientation (KAM), and Image Quality (IQ) are some significant parameters for Electron Back Scattered Diffraction (EBSD) analysis for studying the microstructure and morphology of phases present in a sample. KAM is the average misorientation between a kernel point with its neighbours' measuring deformation and strain, whereas, IQ displays the clarity of diffraction patterns. Texture, i.e., preferred crystallographic orientation is useful

for studying the mechanical properties. Orientations of texture components can be expressed by Miller indices {hkl} <uvw> and Euler angles ( Φ1, Φ, Φ2): the {hkl} indicates the crystallographic plane parallel to the rolling plane, while <uvw> shows the crystal direction parallel to rolling direction (RD) [8]. As BCC steels tend to develop the characteristics of fibre textures, the Orientation Distribution Function (ODF) is represented as iso-intensity lines in Euler space.

Although there is plenty of literature available on Q&P for low and medium C steels, however, the microstructure-mechanical property correlations after Q&P treatment for microalloyed (HCS) are limited to date [7, 9, 10]. Therefore, in this research, the microstructure evolution during Q&P processing of an Nb microalloyed hot rolled HCS has been analysed by optical microscope (OM), scanning electron microscope (SEM) and EBSD.

## METHODOLOGY

In this study, forged bars (30 mm thick) of 0.68C-1.72Mn-2.2Si-0.036Nb (wt.%) steel, were initially heated at 1200°C for 1h for complete homogenization and subsequently hot rolled (~75% deformation) with a finish rolling temperature (FRT) of 1000°C and subsequently underwent air cooling (AC) to RT. These hot-rolled air-cooled (HRAC) plates were then austenitized at 900°C for 45 mins and then subjected to one-step Q&P at 200°C for 30 mins followed by AC to RT. Liu's formula [11] was used to estimate the Ms≈ 215°C. A standard metallographic sample preparation technique was applied for observing the microstructure using an OM (Carl Zeiss, Axiovert 40 Mat) and SEM (Hitachi, S-3400N). Bruker Advance D8 machine was used to carry out X-ray diffraction (XRD) studies. The RA volume fractions were estimated by using DIFFRAC.TOPAS software. Zeiss Supra 55 FESEM was used for EBSD imaging (step size 0.225 μm) and the analysis was accomplished by ATEX software. The Vickers hardness values (HV) were recorded at 30 kg load and 20 s dwelling time. Tensile tests were performed on specimens (gauge length 25 mm), prepared by the ASTM E8M-2016 standard in a uniaxial universal tensile testing machine (Instron 5900R) at the fixed strain rate of 3.33×10-4 s-1 using an extensometer.

## RESULTS AND DISCUSSION

**Figure 1**(a, b) display optical and SEM microstructures respectively, of the HRAC sample (S1-AC), which reveal mixed phase microstructures comprising M, pearlite (P) and a small amount of RA. As shown in **Figure 1**(c, d), Q&P (sample S2-200-30) results in a multiphase system of preformed or tempered martensite (PTM), high‑C untempered fresh martensite (FM) and RA. The Vickers hardness values for S1-AC and S1-200-30 mins are 865 and 804 HV, respectively. It is found that though the QT < $M_s$, B exists in the microstructure in **Figure 1 (c, d)**, which is in correlation with forming ultrafine B and fine interlath RA [6]. Bs has no strict lower limit, as shown by Bhadeshia upon observation on $M_s$ and $B_s$ with varying wt.% of C (0.2-1.4 %) in Fe-3Mn-2Si-C steel [12]. On the other hand, the B formation rate slows down significantly with lower transformation temperature. As observed by L. Quain, FM and RA were formed from remaining austenite which was not transformed to B after Q&P treatment, upon cooling to RT transforms partially to FM owing to low thermal stability. Conversely, PTM originated from supercooled γ, thereby, tempered while partitioning below Ms. PT of 30 mins suffices the partitioning of C from supersaturated M to C depleted γ, ensuring the stabilisation of a considerable amount of γ at RT which lowers the possibility of forming more LB from unstable γ as clearly shown in **Figure 1(b)**. It is noteworthy that despite high Si content (2.2 wt.%) and low QT, carbide precipitation cannot be averted due to high C content (0.68%) [13].

**Figure 1(e, f)** for S1-200-30 and S1-AC samples, RA accounts for 2.10 and 1.51 vol. %, respectively. Vol % of RA detected by EBSD is less than that measured (~10 %) by XRD, as the large step size is unable to detect the majority of a thin film of γ and some RA can transform to M during sample preparation. The dark regions in IQ maps are considered unindexed and fresh martensite. In KAM maps different colours (blue, green, yellow, orange, red) are assigned to indicate misorientation of different angles. The S1-AC sample shows blue spots (~0°) which signify the lowest stress concentration accumulated at some places but in S2-200-30, the blue spots seem evenly scattered all over the space indicating homogenization of stress distribution after Q&P. The M phase possesses a higher dislocation density (~4×1015 $m^{-2}$) and the associating KAM map shows yellow/red regions, whereas, F is signified by the blue regions in the KAM map owing to low dislocation density (~1014 $m^{-2}$) [14]. In general, the highest KAM

values were significantly found at or near the grain boundaries as dislocations tend to accumulate there. In the S1-AC sample as shown in **Figure 1(g)** blue regions are quite visible indicating F, along with, there is M (in yellow (~3°) and red (5°)) also as expected [15]. In the S2-200-30 sample (**Figure 1(h)**), F is very low in amount and there is less red colour M. The KAM value is calculated to be 0.784 and 0.695 for the S1-AC and S2-200-30 samples, respectively; the decrease is assigned to the heat treatment which brings about homogeneity in grains' orientation evident from the histograms.

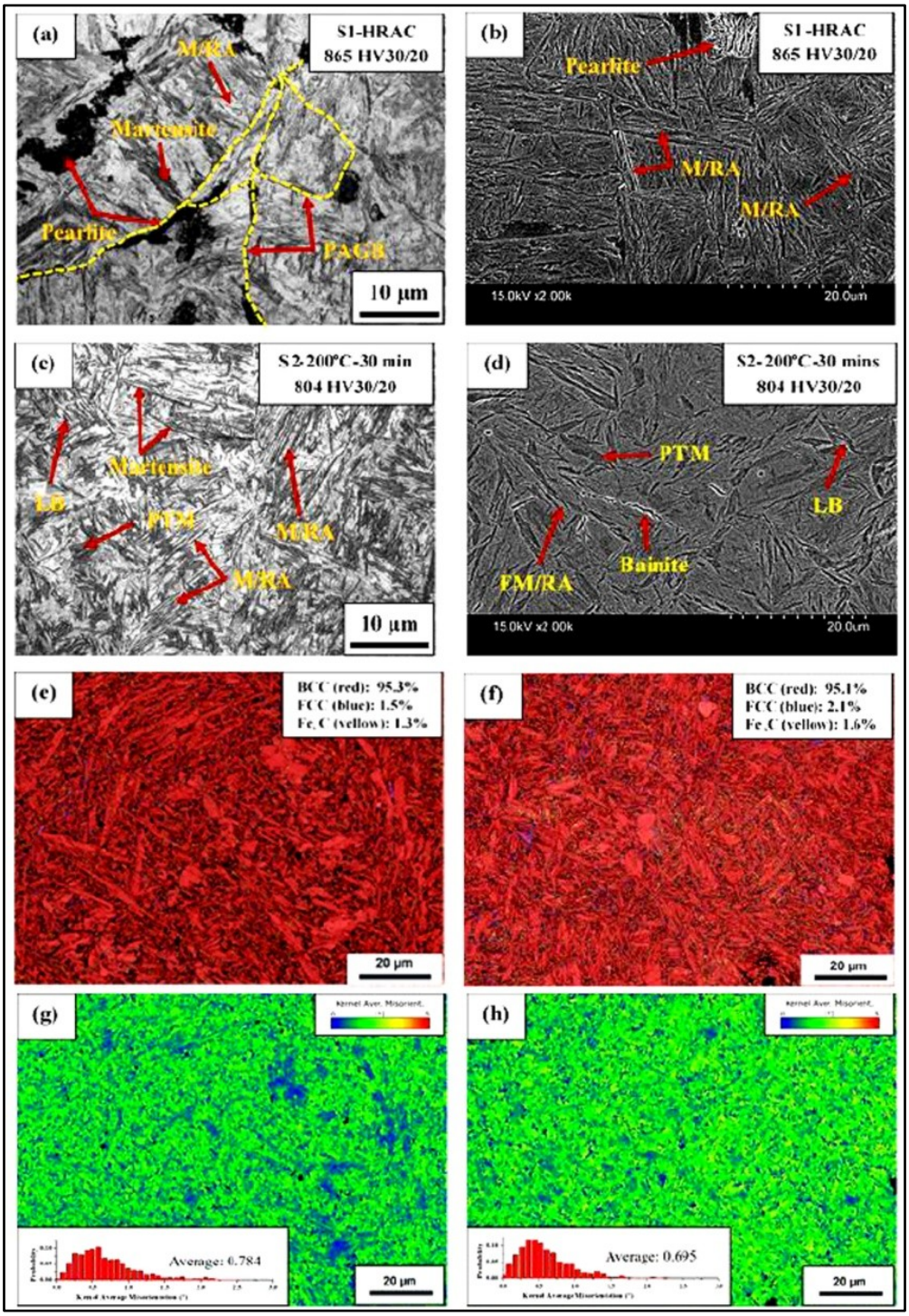


**Figure 1** Optical and SEM micrographs of (a) & (b) S1-AC, and (c) & (d) S2-200-30 samples. (e, f) IQ-map, (g, h) KAM of S1-AC (e, g) and S2-200-30 (f, h).

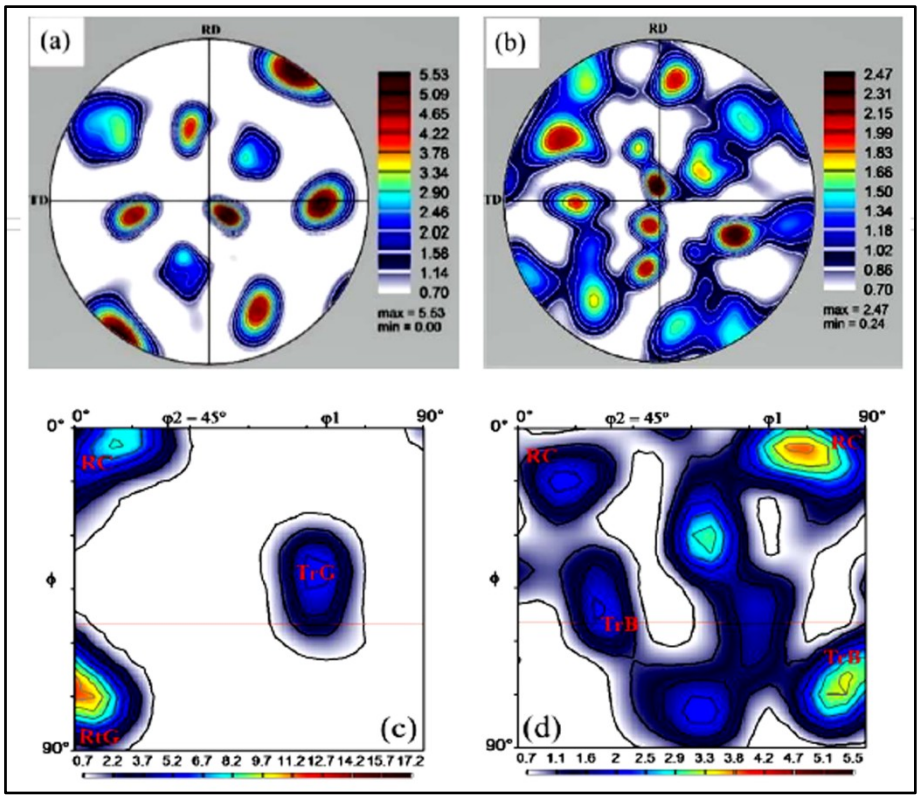


**Figure 2** Pole figure diagrams (a,b) and ODF maps (c,d) of S1-AC (a,c) and S1-200-30 (b,d), RD- Rolling Direction, TD-Transverse Direction

For quantification of the texture intensity due to heat treatment, the texture index (TI) {TI=$\int(f(g))^2\,dg$), where f, g and f (g) are the distribution of texture orientation, the coordinate system in Euler space and the ODF, respectively} is calculated [16]. In **Figure 2 (a, b)**, the pole figure maps of S1-AC (maximal TI= 5.53) and S2-200-30 (maximal TI = 2.47) samples show a clear difference in the effect of Q&P as the poles in S1-HRAC sample shows distinct poles but in S2-200-30 poles look overlapped, elongated and interconnected because it shows isotropy as result of further heat treatment. In the ODF maps as shown in **Figure 2(c)**, the major texture components evident in S1-AC are Rotated Cube (RC,{001}<110>), Rotated Goss (RtG,{110}□ 110□ ) and Transformed Goss (TrG,{111}<110>) with volume (%) as 14.52, 10.53 and 22.93, respectively; whereas, in sample S1-200-30 (**Figure 2(d)**), the major texture components, as shown in **Figure 2(d)**, are RC, TrG, Transformed Brass (TrB, {111}<112>) with volume (%) as 7.54, 7.44, 8.48, respectively. The maximum intensity of ODF decreases from 17.2 to 5.54 after Q&P treatment as shown in **Figure 2 (c, d)** which is usually expected and agrees with the earlier research [15,17-21]. The low transformation stability of the rotated cube (RC {001}⟨110⟩) texture component indicates that the RA grains possessing this crystallographic configuration are considerably stable which means that there remain more austenite grains which will transform at higher deformation resulting in further strain hardening which can be noticed in the high UTS value (1897 MPa) as shown in **Table 1**. The combination of the texture components in γ fibre (<111>||ND): TrG and TrB are responsible for higher ductility in Q&P samples [22]. The absence of the TrB component in S1-AC leads to lower total elongation (~12%).

**Table 1** Summarised tensile results for HRAC and Q&P samples

| Sample Code | YS (MPa) | UTS (MPa) | UEL (%) | TEL (%) | UTS×TEL (GPa%) |
|---|---|---|---|---|---|
| **S1-AC** | 1790 | 2010 | 6.26 | 12 | 24.12 |
| **S2-200-30** | 1513 | 1897 | 9.87 | 19 | 36.04 |

## CONCLUSION

A high carbon (0.68 wt.%) Nb-microalloyed steel manufactured through Q&P treatment is subjected to various structural and mechanical characterization and compared to a steel air-cooled (AC) with similar chemical composition. Micrographs show that the AC sample comprises M, P and some amount of RA whereas the Q&P sample contains a mixed-phase microstructure of PTM, high‑carbon FM and RA. The EBSD IQ map reveals a

higher amount of RA in the Q&P sample (2.10 vol.%) than in the AC (1.51 vol.%) which accounts for higher TEL (~19%) in Q&P samples. KAM maps show that the stress distribution becomes uniform after Q&P. The maximal texture index is higher in HRAC (5.53) than in Q&P (2.47). From the ODF map, it is clear that the Q&P treatment significantly alters the fibre texture components e.g., Rotated Cube ({001}<110>), Transformed Brass ({111} <112>) and Transformed Goss ({111}<110>) which in turn affects the tensile properties; which do not depend on a single texture component but on the combination of effects of more than one component. The AC sample shows maximum UTS (2010 MPa) whereas the S1-200-30 sample after Q&P shows maximum UTS × TEL product (~36 GPa%).

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# Metals & Minerals

# Integrated Computational Materials Engineering (ICME)

363_IEC27948

# Molecular Dynamics Study on Bending Creep Characteristics of $BaPd_2$ Crystal using Developed Embedded-Atom Method Potential of Palladium-Barium Alloy

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***Abstract:*** *Molecular dynamics (MD) simulation has been performed to study the bending creep characteristics of $BaPd_2$ crystal (C15 laves phase compound) using our developed embedded-atom method (EAM) potential for Palladium-Barium alloy. The force-matching method has been implemented to develop the EAM potential first, and then optimization to converged density-functional theory (DFT) data sets has been done to generate the accurate and reliable potential for the Pd-Ba alloy system. Density, elastic properties, and thermal expansion coefficient have been calculated using MD simulation and validated these properties with the help of DFT analysis to examine the performance of the potential. Then, using a force of around 2 pN applied in the Y direction with both ends held stationary, bending creep simulations have been carried out on $BaPd_2$ crystal at 100 K, 490 K, 600 K, and 900 K. Tertiary region has been observed above 490 K. Creep rate increases with increase in temperature.*

***Keywords:*** *Embedded-Atom Method; Bending Creep; Density-Functional Theory; Pd-Ba Alloy*

## INTRODUCTION

Palladium-Barium (Pd-Ba) alloys have been successfully used as cathodes in pulsed magnetrons [1,2]. Stability and longer service life are two main aspects to look after while creating cathodes for magnetrons under the condition of ion and electron impact [3]. This impact creates various problems such as overheating of the cathode, fluctuation in the output frequency, reduction in the magnetron work stability, decrement in the service life, etc. These requirements are mostly carried out by different metal-alloy cathodes [3]. They have some important properties such as emission resistance to ion and electron impact, smoothness of surface, high electrical conductivity, etc. which help them to work well in breakdown conditions [3]. Pd-Ba alloys among them are the most significant because of their good resistance ability to ion impact [3]. Such cathodes make yield of magnetrons is around 75-80% [1]. Their service life is also not less than 5000 hours [1].

Experimental work on this alloy system is very less. Different metallurgical aspects like nanoindentation, tensile deformation, creep deformation, surface property analysis etc. are not studied till now for this alloy system, which indicates the research gap in this sector. Our aim is to forward the research on MD simulation of the Pd-Ba alloy system by developing an appropriate EAM potential [4]. Here, we have studied bending creep [5] characteristics of C15 laves phase compound (cubic crystal structure) BaPd2 at 100 K, 490 K, 600 K, and 900 K using a force of around 2 pN applied in the Y direction with both ends held stationary. Tertiary region has been observed for higher temperatures like 490 K and 900 K. Primary region cannot clearly be distinguished for all the mentioned cases.

## METHODOLOGY

Force-matching method by ERCOLESSI and ADAMS [6], have been used to generate EAM potential. The Perdew-Burke-Ernzerhof (PBE) functional [7] and the projector augmented-wave (PAW) pseudopotentials [8] generated by CORSO [9] have been used to perform DFT calculations using the plane-wave self-consistent field (PWscf) package in QUANTUM ESPRESSO [10]. In self-consistent field calculation, 4×4×4 k-point mesh, kinetic energy cutoff of about 612.26 eV for plane-wave function, kinetic energy cutoff of about 3265.37 eV for charge density, and ordinary Gaussian spreading of about 0.14 eV have been used to satisfy the convergence criteria. POTFIT [11] package has been used to generate an EAM potential for the Pd-Ba system using DFT datasets.

MD simulation has been carried out with 216000 atoms using LAMMPS [12]. The ends of the specimen are fixed and a load of around 2 pN is applied along Y direction. Non-periodic and shrink-wrapped boundary conditions have been used to simulate the bending creep deformation process. The simulation has been carried out using our EAM potential [4] at constant volume. Energy minimization or relaxation of the specimen has been performed by using conjugate gradient method [13], which is robust and effective. The bending creep deformation is performed at constant temperatures taking NVT ensemble and the temperature is controlled by using Nosé-Hoover thermostat [14].

## RESULTS

EAM potential validation has been carried out as mentioned in the literature [4]. Good agreement between MD and DFT results has been observed while calculating different properties such as density, elastic constants, and thermal conductivity. Here, the thermal expansion coefficient of BaPd2 has been calculated using MD and DFT simulations, which are also in the same order of magnitude. From bending creep characteristics, it is clear that the creep rate increases with an increase in temperature. The tertiary region has been observed for higher temperatures like 490 K and 900 K. The primary region cannot be clearly visible for all the mentioned temperatures. This behavior is attributed to the developed EAM potential.

## CONCLUSIONS

BaPd2 is an anisotropic crystal, as concluded from elastic property analysis. A low thermal expansion coefficient indicates that these types of C15 compounds expand very little when exposed to temperature changes. It is evident from bending creep characteristics that as temperature rises, so does the creep rate. At higher temperatures, such as 490 K and 900 K, the tertiary area has been seen. Low-temperature creep deformation occurs by a climb of grain boundary dislocations through jog formation. Diffusion causes creep deformation at high temperatures. The primary region is not readily visible for all of the temperatures stated. This may be due to the inadequacies of the developed EAM potential.

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# Metals & Minerals

## Materials for Energy, Sensors and other Electronics Applications

17_IEC14477

# Synthesis and Characterization of Delafossite $CuAlO_2$ by Sol-Gel Process

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***Abstract:*** *Delafossite copper aluminate ($CuAlO_2$) was synthesized by sol-gel process using Analytical Research (AR) grade precursors. Precursors were used in required molar ratio along with citric acid in deionized water after proper mixing. Jellification was obtained after drying the net resultant solution followed by annealing at about 1200°C for 4 hours. Phase analysis after annealing was carried by XRD followed by crystallite size estimated to be about 35.5 nm. Bonding analysis was carried by FTIR spectroscopy to observe M-O co-ordinations followed by morphological feature studies by SEM. SEM analysis reveals agglomeration tendency while individual particulates to be polygonal in shape with few interconnected porosity. EDX analysis reveals presence of required elements only responsible for formation of $CuAlO_2$ delafossite. Luminscence of the sample is obtained after having excitation at 280 nm wavelength leading to high intensity emission centred at about 557 nm. XRD, FTIR and EDX results were noted to be in close relation with each other.*

***Keywords:*** *Delafossite; Phase Analysis; Bonding Analysis; Microstructure; PL Analysis*

## INTRODUCTION

Transparent conducting oxides (TCO) are getting attention due to its application as optoelectronic materials. They have several applications encompassing various devices like solar cells, touch panels of mobile phones, flat panel displays, UV detectors, invisible security circuits and others. Generally electron doped ZnO, $In_2O_3$, $SnO_2$, CdO are widely used for such applications including organic optoelectronic devices. Thus, n type transparent conducting oxides are more widely found which have the main fundamental characteristics of having wider direct band gap (3.1eV). Depending on the composition TCOs, can be both n-type and p-type one. Perovskite based materials having general formula ABO3 is noted to have extensive influence towards application for transparent conducting oxides (TCO) as well as superconductors like La doped $BaSnO_3$, $SrVO_3$ and others. [1-2]P-type conductivity is found to be observed Kawazoe and co-authors during their experiment with transparent p-type $CuAlO_{2+x}$ thin film thus opening new window for transparent electronics. There is possibility of combining 2 types of TCOs leading to formation of p-n junction with possible application towards functional window. It actually transmits visible portion of solar light but generates electricity only by absorbing UV component of wavelength. [2-3] There is a difficulty in producing ptype $CuAlO_2$ based thin films mainly for strong localization of holes within the binary metal oxides for the electronegative behaviour of oxygen ions. The delafossite based material shows the interest due to its p-type mobility resistance towards corrosion under oxidation, catalysis, thermal and magnetic properties. [2] It is noted from research that delafossite structure $CuAlO_2$ is a p-type semiconductor having band gap around 3.5eV while the transmission of the film deposited is noted to be about 80%. Such optical nature makes the material as a suitable candidate for TCOs. [3-4] Materials with wider band gaps and high transparency are used as widow layers for solar cell. Metal s-orbital formed conduction band while oxygen 2p-orbital forms valence band in case of metal oxides. $CuBO_2$ based delafossite structure have p-typeconductivity due to Cu vacancies as the holes are strongly localized and have less mobility in the upper valence band (O-2p states) as oxygen ions apply extensive Coulomb forces on holes. Covalent bond addition in metal oxides reduces the high coulombic interactions generated by oxygen atoms. It is due to mixing of Cu-3d states into the valence band because of highly energetic d10 states of Cu atoms that lead to a smaller ionization energy and allow hole mobility. [5-7]

In the present research sol-gel process is carried to synthesize delafossite copper aluminate ($CualO_2$) followed by its characterization. The concerned material is fit for transparent conducting oxides, thermoelectric, semiconducting and even photocatalytic applications. Researchers are working on this domain to generate new fascinating applications based on noble properties and microstructural evolutions.

## EXPERIMENTAL

AR Grades of Copper nitrate, Al-Nitrate, Citric acid is taken for the synthesis. They are weighed in 1:1 molar ratio with precision up to 3 digits and made to dissolve in de-ionized water. Both nitrate precursors (10mM) are mixed under stirring action in 200mL DI water at proper stoichiometric ratio. After proper stirring, 10mM of Citric acid is added to the resultant solution followed by stirring for 1 hour. Then the resultant solution is stirred for 70°C for 3 hours to obtain jellification. The gel is then made to undergo heat treatment at 1200°C for 4 hours. Annealed powder is made to undergo phase analysis by XRD (Rigaku, Ultima III) with a scan rate of 5 degree/min with step size 0.04 degree. Crystallite size is measured using scherrer's formula along with planes of indexation. Bonding analysis of the synthesized samples is carried to obtain information on M-O co-ordinations (Shimadzu IR Prestige-21). KBr is added to the sample to make pellets under hydraulic press. Morphological and microstructural features were obtained from the synthesized sample using electron microscopy. Elemental analysis is also carried to find the elements and the findings were noted to be in correlation with phase analysis. Luminescence behaviour of the material is noted with excitation wavelength of 280 nm using Xe laser source. (Model-RF 6000, Shimadzu).

## RESULTS & DISCUSSION

**Figure** 1 indicates phase analysis of the synthesized compound after air annealing at different conditions. No major amorphous zone is noted even at lower temperature of annealing but crystalline nature of the peak is more prominent at higher soaking temperature and duration. Phase analysis revealed the peaks got indexed as per JCPDS data and corresponds to delafossite $CuAlO_2$ in majority. JCPDS data for delafossite are having PDF card number #752360, 762398, #781605. Crystallite size are estimated using Debye Scherer's formula

$$t = \frac{0.9\lambda}{\beta Cos\theta}$$

where "t" is the crystallite size, β is the full width at half maximum in radian, λ is the wavelength in nm. Sol -Gel process using citric acid executes much better phase evolution of delafossite without any formation of other phases. The above data is indexed with PDF card number #762398, #752360 which clearly indicates the system to be hexagonal with rhombohedral lattice. Crystallite size is estimated to be about 35.747 nm for sol-gel using citric acid as one of the precursors for reaction.

**Figure 2** represents FTIR spectra of the synthesized samples. Majority of the M-O co-ordinations are noted within 1000$cm^{-1}$. KBr is used as reference material to make pellet under hydraulic press for the following characterization. FTIR scan is carried in the scan range of 450-4500 $cm^{-1}$ where M-O co-ordinations are noted. For sol-gel process main spectra's are about 556 $cm^{-1}$, 780 $cm^{-1}$, 941 $cm^{-1}$ corresponding to Cu-O stretching (Cu-O linear co-ordinate) and Al-O stretching vibration in distorted $AlO_6$ octahedra. Broad band is noted at about 3440cm-1 due to O-H stretching vibration along with bending vibration at about 1570 $cm^{-1}$ for physi-sorbed water. [8]

Microstructural analysis is carried by Scanning electron microscope using powder sample. Conducting tape is used to adhere the sample since it is non conducting in nature. It is observed that sample has agglomeration tendency one having chunk shape whereas individual particulates are polygonal shapes with hexagonal in appearance. Intermediate porosity among connected particulates is also noted in some region. EDX analysis executes presence of required elements only which confirms successful generation of delafossite.

The PL spectra is shown after preparing the sample in solution in DI water. The sample is sonicated for 1 hour for proper dispersion followed by excitation using Xe Laser at 280nm wavelength. A prominent spectra is noted wigh intensity at above 107 cps with main peak indexed at about 557nm. It corresponds to band gap close to about 2.23eV. The prominent luminenscence behaviour is the visible spectrum range thus provide a proof of the sample being luminescent in nature. The range is pertinent with excitation using predominantly green light (495-570 nm) within the visible spectrum.

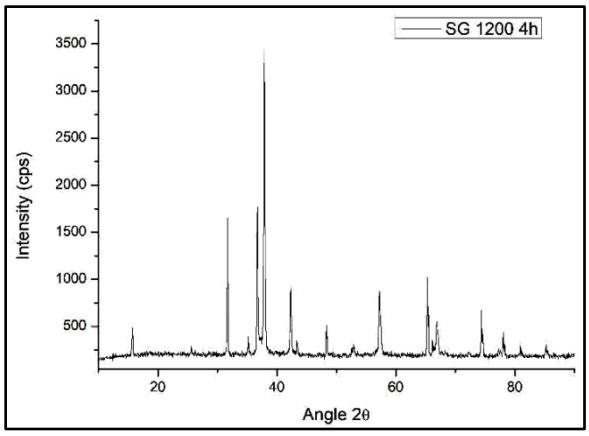


**Figure** 1 XRD plot of Samples after heat treatment at 1200 for 4 hours by Sol-Gel process

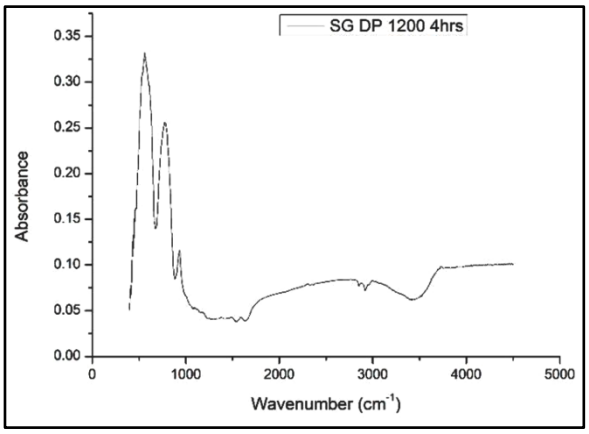


**Figure** 2 FTIR spectra of $CuAlO_2$ after heat treatment at 1200 for 4 hours by Sol-Gel process

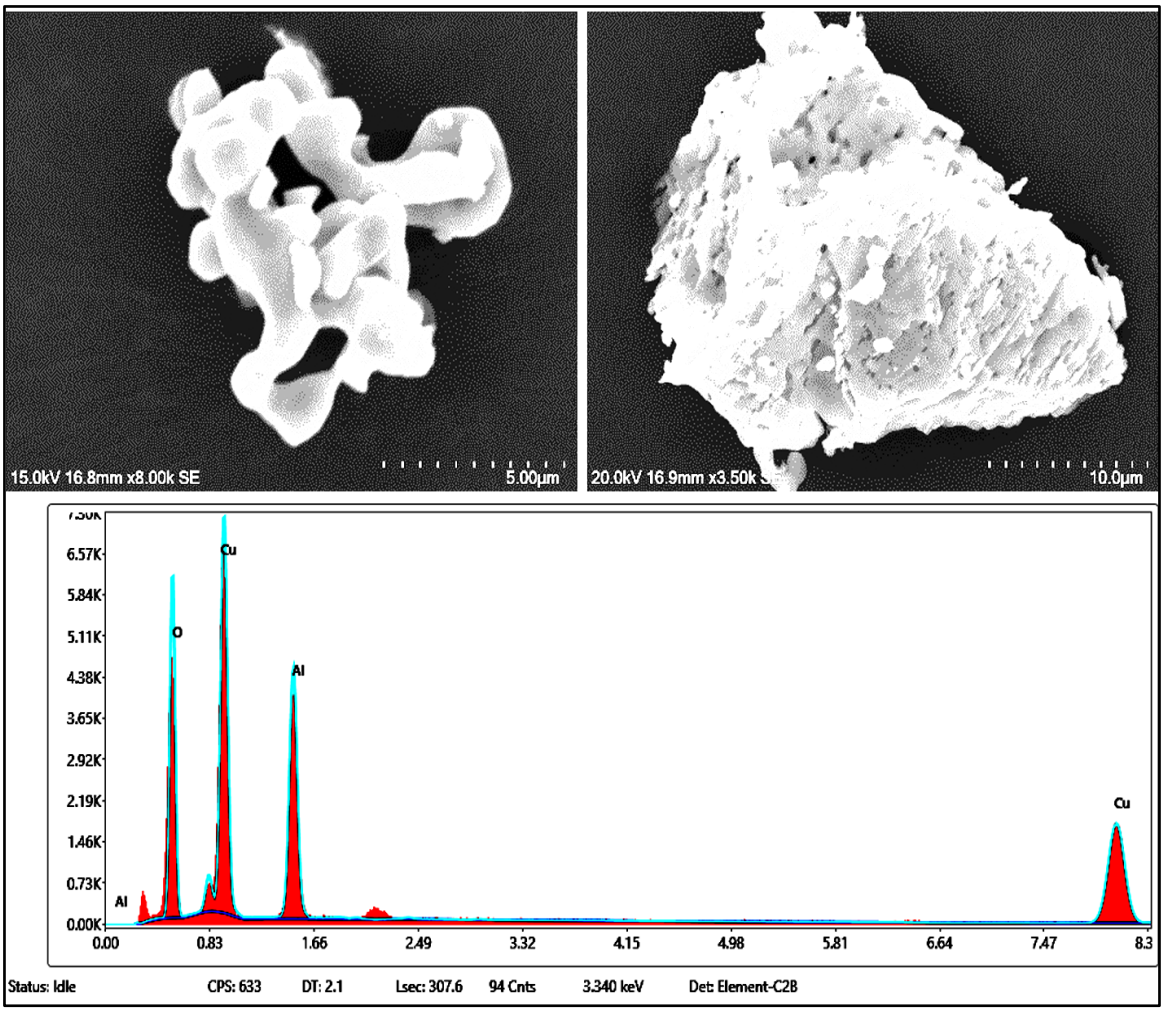


**Figure** 3 SEM microstructure of delafossite $CuAlO_2$ at 1200C for 4 hours soaking period by Sol-Gel process followed by EDX spectrum

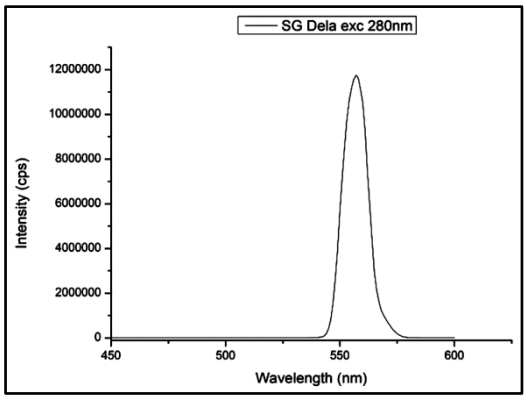


**Figure 4** PL spectra of delafossite $CuAlO_2$ at 1200°C for 4 hours soaking period by Sol-Gel process

## CONCLUSIONS

1. Sol-gel process was carried to synthesize delafossite Copper Aluminate. using citric acid and nitrate precursors.
2. Phase analysis was carried to study development of phases. It exhibits better evolution of phase using sol-gel process with citric acid as one of the prominent precursors. Crystallite size are estimated using Debye scherrer's formula to be about 35.5nm.
3. Bonding analysis was carried by FTIR to find M-O coordinations.
4. Micro-structural analyses exhibits agglomeration while particulates are polygonal shape. EDX confirms presence of required elements.
5. PL spectra analysis exhibits luminescent behavior of the material in visible spectrum close to green light region.

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150_IEC57684

# Phase Analysis, Dielectric, PL and Microhardness of $CuAlO_2$ by Ball Milling Process

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***Abstract:*** *In the present article a ball milling assisted solid state process was undergone to synthesize delafossite having composition based on Cu-Al-O. Mecahnochemical activation by Ball milling was carried in air atmosphere keeping ball:sample ratio fixed at 10:1 having 370 rpm for 100 hours duration in acetone medium followed by air drying for 24 hours to recover the activated powder sample. Based on thermal analysis, annealing was carried at 1200°C for 6 hours duration for phase development. Crystallite was estimated using both Scherrer's formula and William-Son Hall equation along with micro-strain. Dielectric property was evaluated using LCR meter while mechanical integrity of the sample was done using microhardness and noted to be about 2.84 Gpa. Luminescene behaviour of the sample was noted in the lower visible spectrum (violet-blue) with maxima peak centred at about 433 nm wavelength.*

***Keywords:*** *Delafossite; Phase Analysis; Ball Milling; Microhardness; PL Analysis*

## INTRODUCTION

In recent times, copper-alumina phase diagram got importance for its possible applications in microelectronics, optics, electronics, oxygen production, magnetic devices and even as catalyst. Many studies on copper aluminate ($CuAl_2O_4$) have proven its role as catalyst. From calculation carried by Density Function theory, based on binding energy, it is revealed that the interaction of active metal with copper aluminates constitute an important parameter for its stability as a catalyst. On the other hand $CuAlO_2$ is also a material of study with interesting properties like p-type conductivity and optical transparency in the visible spectrum. [1] Moreover, optoelectronic materials are getting attention in the form Transparent conducting oxides (TCO) which have several applications encompassing various devices like solar cells, touch panels of mobile phones, flat panel displays, UV detectors, invisible security circuits and others. Generally electron doped ZnO, $In_2O_3$, $SnO_2$, CdO (n type TCO) are widely used for such applications including organic optoelectronic devices which have the main fundamental characteristics of having wider direct band gap (3.1eV). Depending on the composition TCOs, can be both n-type and p-type one. Perovskite based materials having general formula ABO3 is noted to have extensive influence towards application for transparent conducting oxides (TCO) as well as superconductors like La doped $BaSnO_3$, $SrVO_3$ and others. [2-3] Kawazoe and co-authors during their experiment with transparent p-type $CuAlO_{2+x}$ thin film observed P-type conductivity, thus opening new window for transparent electronics. There is possibility of combining 2 types of TCOs leading to formation of p-n junction with possible application towards functional window. It actually transmits visible portion of solar light but generates electricity only by absorbing UV component of wavelength. [3-4] Thin films based on p-type $CuAlO_2$ is difficult to produce for strong localization of holes within the binary metal oxides for the electronegative behaviour of oxygen ions. The delafossite based material shows the interest due to its p-type mobility resistance towards corrosion under oxidation, catalysis, thermal and magnetic properties. [3] It is noted from research that delafossite structure $CuAlO_2$ is a p-type semiconductor having band gap around 3.5eV while the transmission of the film deposited is noted to be about 80%. Such optical nature makes the material as a suitable candidate for TCOs. [4-5] Materials with wider band gaps and high transparency are used as widow layers for solar cell. Metal s-orbital formed conduction band while oxygen 2p-orbital forms valence band in case of metal oxides. $CuBO_2$ based delafossite structure have p-type conductivity due to Cu vacancies as the holes are strongly localized and have less mobility in the upper valence band (O-2p states) as oxygen ions apply extensive Coulomb forces on holes. Covalent bond addition in metal oxides reduces the high coulombic interactions generated by oxygen atoms. It is due to mixing of Cu-3d states into the valence band because of highly energetic d10 states of Cu atoms that lead to a smaller

ionization energy and allow hole mobility[6-8].

In the present article, ball milling assisted solid-state process is carried to synthesize delafossite copper aluminate ($CualO_2$) followed by its characterization. The material is fit for transparent conducting oxides, thermoelectric, semiconductors, photocatalytic applications depending on micro-structural evolution, noble property estimation by process modifications.

## EXPERIMENTAL

AR Grades of Copper Oxide, Alumina (Loba Chemie, India) is taken for the synthesis after proper weighing in 1:1 molar ratio with precision up to 3 digits. Ball milling is carried in wet condition using acetone as the medium. WC balls are mainly used for milling assisted mechanochemical activation using ball:sample ratio 10:1 for 100 hours. After milling, sample is dried and put to Alumina tray for annealing in tubular furnace for proper phase development. Heating is carried at 1200°C for 6 hours in normal atmosphere. Annealed powder is made to undergo phase analysis by Cu Kα radiation 1.54Å (Pan Analytical, Voltage 40KV, current 40 mA) with a scan rate of 5 degree/min with step size 0.04 degree. Crystallite size is measured using scherrer's formula along with planes of indexation. Dielectric behaviour is obtained followed by value of dielectric at about 200 using LCR meter (Agilent 4294A Precision Impedance Analyzer, Agilent Technologies, Inc. USA) while mechanical property of sample is determined by Microhardness analysis (MHT-Smart, Metatech Industries). Both dielectric and Microhardness is carried in pellet form. Luminescence behaviour of the material is noted with excitation wavelength of 280 nm using Xe laser source. (Horiba FluoroMax 4 Spectrofluorometer).

## RESULTS & DISCUSSION

XRD from **Figure 1** indicates phase analysis of the synthesized compound after air annealing at 1200°C for 6 hours duration followed by mechanochemical activation for 100 hours. No major amorphous zone is noted with peak split in the graph. Moreover, intermediate phases are also not observed. Phase analysis revealed the peaks got indexed as per JCPDS data and corresponds to delafossite $CuAlO_2$ in majority. JCPDS data for delafossite are having PDF card number #04-700-5080, 762398, #781605.

$$t = \frac{0.9\lambda}{\beta \mathrm{Cos}\theta}$$

where "t" is the crystallite size, β is the full width at half maximum in radian, λ is the wavelength in nm. Some minor Alumina phase is noted along with spinel Copper aluminate ($CuAl_2O_4$) phase. Crystallite size is estimated to be about 70 nm for ball milling assisted solid state process using oxide precursors for reaction. Micro-strain calculation from Williamson Hall equation is done and estimated to be about $1.15*10^{-3}$.

**Figure 2** represents dielectric behaviour of the synthesized sample in pellet form. Au paste is given on 2 surfaces for the test and carried in ambient temperature within the frequency range 106 Hz. Dielectric constant is noted to be about 200. Dielectric behaviour is found to be higher at lower frequency than at higher frequency. Such polarization effect arises due to space charge polarization following Maxwell- Wagner interface polarization effect.

Microhardness analysis is carried for the ball milled activated solid state process prepared sample. Pellet is prepared by hydraulic press having dia 10 mm, thickness 2 mm with proper surface finish by polishing. Vicker hardness with diamond indentator is used to create the impression. Duration for indentation is carried for 20 seconds to get proper impression leading to some microharness of the sample. The mechanical integrity of the sample is obtained from hardness value and estimated to be about 2.84 Gpa.

The PL spectra (**Figure 4**) is shown after preparing the sample in solution in DI water. The ball milled sample is sonicated for 1 hour for proper dispersion followed by excitation using Xe Laser at 250 nm wavelength. A prominent spectra is noted wigh intensity at above 107 cps with main peak indexed at about 435 nm having correspondance to band gap close to about 2.85eV. The luminescence behaviour is noted within the visible region 400-700 nm. Prominent luminescence behaviour is close to transition of violet-blue light emission region.

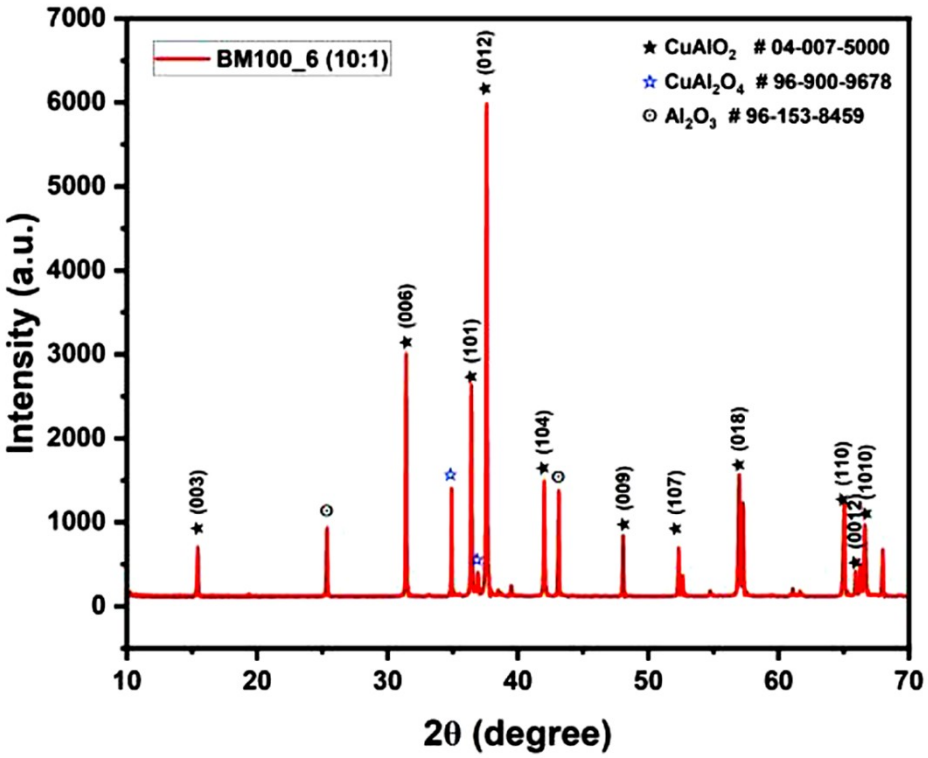


**Figure 1** XRD plot of Samples after heat treatment at 1200°C for 6 hours by Ball Milling activated Solid State process

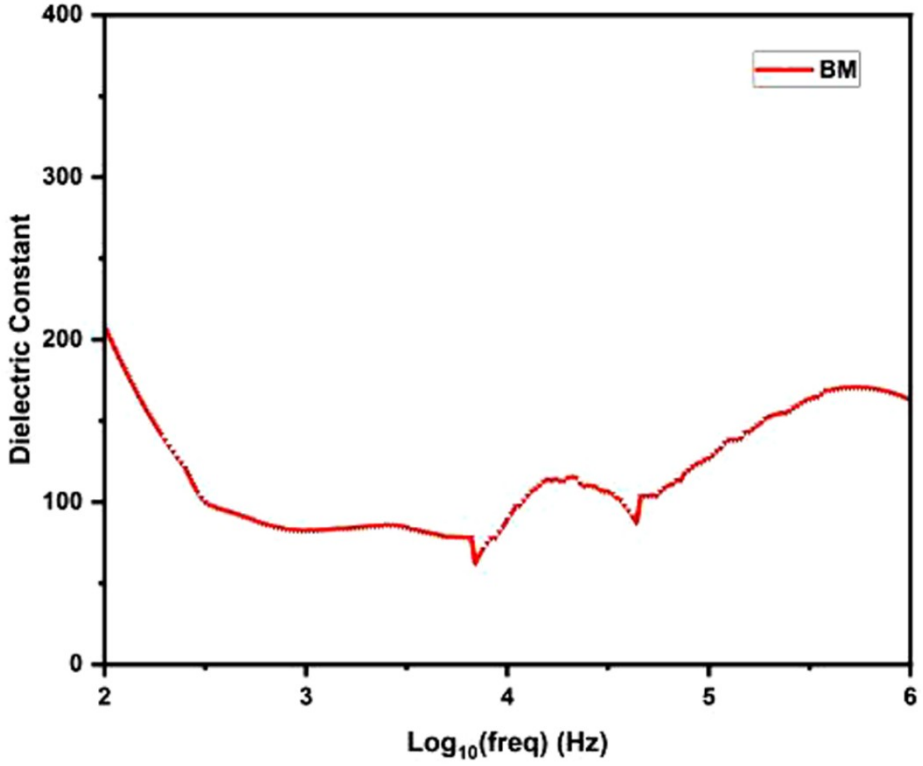


**Figure 2** Dielectric behaviour of $CuAlO_2$ after heat treatment at 1200 for 6 hours by Ball-Milling activated Solid State process

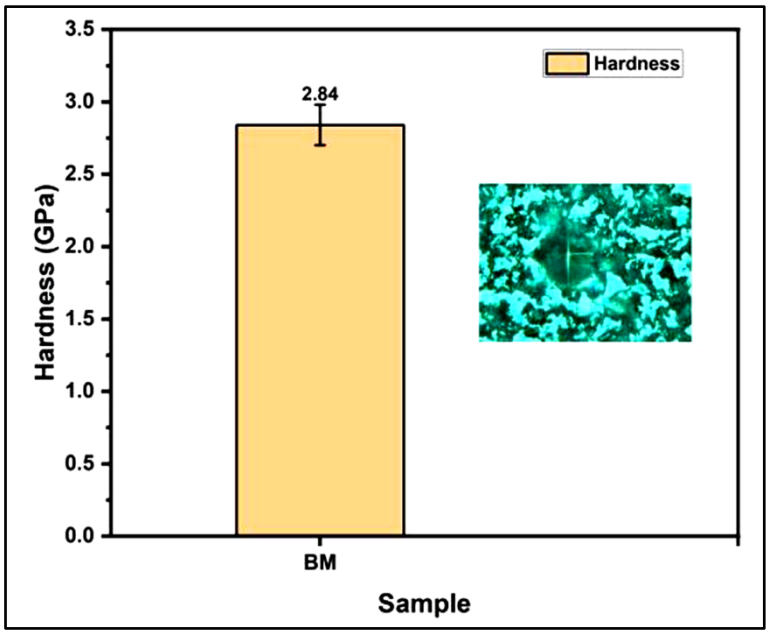


**Figure 3** PL spectra of delafossite $CuAlO_2$ at 1200°C for 6 hours soaking period by Ball Milling activated Solid State process

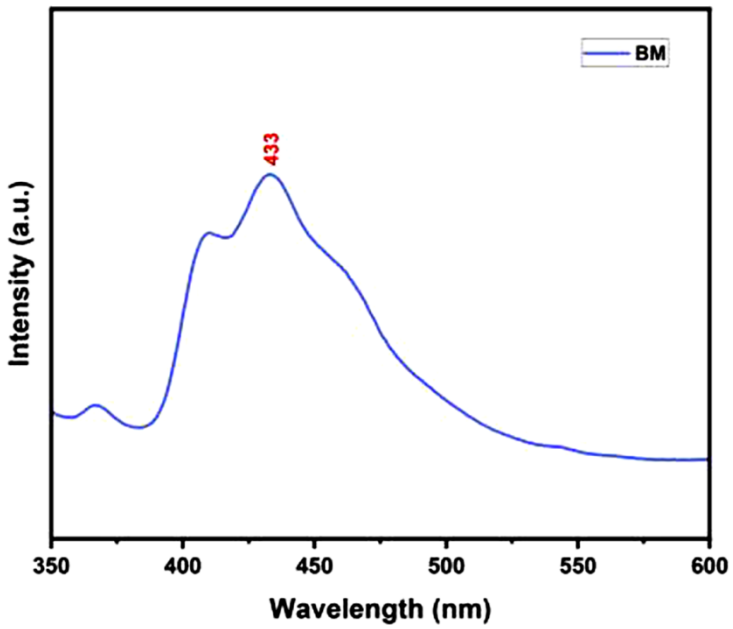


**Figure 4** PL spectra of delafossite $CuAlO_2$ at 1200°C for 6 hours soaking period by Ball Milling activated Solid State process

## CONCLUSIONS

1. Mechanochemical activation process is carried to synthesize delafossite Copper Aluminate. using oxide precursors in proper stoichometric ratio
2. Phase analysis is carried to study development of phases. Crystallite size is estimated using Debye scherrer's formula to be about 70nm while micro-strain from W-H plot to be about $1.15*10^{-3}$.
3. Microhardness analyses is done and estimated to be about 2.84Gpa.
4. Dielectric behavior is noted to be about 200 after annealing to obtain phase formation after ball milling.

5. PL spectra analysis exhibits luminescent behavior of the material centred at about 433nm in visible spectrum close to violetblue light region.

## ACKNOWLEDGMENT

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# Metals & Minerals

# Mineral Beneficiation and Waste Management

31_IEC13634

# A Brief Glimpse on the Development of Aluminium Matrix based Composites using Wastes by Powder Metallurgy Route

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***Abstract:*** *Aluminium based composites are in demand due to its low density, weight, high strength-weight ratio and others. This class of composites is generated by popular techniques like stir casting process, powder metallurgical routes, additive manufacturing and others. Composites are generated by adding different inorganic ingredients or by incorporating both industrial and agricultural wastes. Wastes (industrial & agricultural) have different oxide constituents which may aid in improving hardness, wear resistance, ultimate tensile strength and corrosion resistance of the composite in compare to virgin Al based material. The present article encompasses a brief insight into the world of composites based on light metal based matrix using agricultural wastes. Powder metallurgy-based metal matrix composites (MMCs) are widely chosen and used for the development of components in the fields spanning aerospace, automotive and even electronic components. Engineered MMCs are known to offer a high strength-to-weight (σ/ρ) ratio. Novel materials based on metal matrix based composites are capable of handling advanced technological needs.*

***Keywords:*** *Metal Matrix Composite; Powder Metallurgy; Compaction Load; Hardness*

## INTRODUCTION

The powder metallurgy (PM) method is very useful, economically cost-effective and feasible method for producing any dimension of required parts. In recent years, the PM technique has been proven to have an edge over casting processes to produce any metal matrix based composites (MMCs). It has been noted, that this Powder metallurgy-based metal matrix composites (MMCs) are being chosen and used for the development of automotive components, aerospace components due to its flexibility of operations. Presently, PM techniques have been adopted in conjunction with additive manufacturing process. Powder metallurgy (PM)-based composites have been noted in general with lower density, higher hardness with a higher porosity when compared with products obtained by stir casting-based methodology. Aluminum and its alloys are usually chosen as the matrix primarily because of its low density, high strength-to-weight (σ/ρ) ratio, excellent corrosion resistance, ductile matrix and economically viable cost. Silicon carbide, alumina ($Al_2O_3$) are the commonly chosen and used reinforcements for aluminum, other metal matrixes due to a combination of favorable properties of (i) a high service temperature; (ii) a high hot strength; (iii) a high elastic modulus and (iv) good thermal shock resistance. In addition, they have the tendency to form a strong interfacial bond with the aluminum metal matrix and have a high wear resistance. Zhang et al. (2020) studied the evolution of the microstructure of two varieties of hybrid composites. One of the most notable materials science breakthroughs was the development of Al based MMCs, which were created to improve the characteristics of aluminium alloys to meet modern technical standards. Al based MMCs have a wide range of applications, including bicycle frames, transportation equipment, pipelines, architectural uses, bridge railings, and welded constructions, including the automotive and aerospace industries, because they have higher strength, wear resistance, and elastic modulus than unreinforced aluminium alloys. The production of Al based MMCs was crafted out by reinforcing agricultural waste derivatives such as rice husk ash (RHA), coconut shell ash (CSA), palm oil fuel ash (POFA), bamboo leaf ash (BLA), bagasse ash (BA), corn cob ash (CCA) and other agricultural waste derivatives having a great interest in terms of property management. Due to low-cost, easy-to-access alternative reinforcing materials with physical and mechanical properties comparable to conventional particulates, agricultural wastes with a high oxide content can be used as a replacement material in metal matrix based composites (MMCs).

**Agro Waste**

Agricultural waste or agro-waste is a term for unwanted materials that result from agricultural operations like growing crops or raising animals. This can include waste from cultivating and processing agricultural products like fruits, vegetables, dairy, grains, meat, poultry and crops. It can also include chemicals, pesticides or fertilizers used during farming practices. Agro-wastes can be used to synthesize nanosilica, which has applications in biomedical, agricultural and environmental remediation.

**LITERATURE SURVEY**

Commercially available aluminum powder (Fe: 0.2%; Mn: 0.03%; Ti: 0.03%; Cu: 0.02%; Si: 0.4%; and balance Al) with a mean particle size of 48 μm was used for the preparation of the test specimens. In addition, laboratory-based non-metallic ceramic particles such as alumina (aluminum oxide ($Al_2O_3$)) and silicon carbide (SiC) were blended with the aluminium powder to make four varieties of composite materials, each containing a different volume fraction of the ceramic particle reinforcements.

Huang, Yue, et al. was found that to eliminate carbonaceous elements, Rice Husk was heated to 600°C over 12 hours. RH's color was once again converted from black to grayish white after this heat treatment. Burnt ash was considered a strengthening material for the production of composites because it has a significant amount of silica.

**Chemical Compositions of Different Agro-wastes [Ref 15 ]**

| Agro Waste | Chemical Composition(%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $Al2O_3$ | $Fe_2O_3$ | CaO | $K_2O$ | MgO | $SO_3$ | $Na_2O$ | $P_2O_5$ | MnO |
| RHA | 94.03 | 0.249 | 0.136 | 0.622 | 2.49 | 0.422 | - | 0.023 | - | - |
| BA | 73 | 6-7 | 6.3 | 2.8 | 2.4 | 3.2 | - | 1.1 | - | - |
| CSA | 45.05 | 15.6 | 12.4 | 0.57 | 0.52 | 16.2 | - | 0.45 | - | - |
| POFA | 52.35 | 6.27 | 13.36 | 11.72 | 15.52 | - | 1.5 | - | - | 0.11 |
| GSA | 51.54 | 22.45 | 2.4 | 15.63 | - | 1.2 | 0.94 | - | 0.6 | 0.05 |
| BLA | 75.9 | 4.13 | 1.22 | 7.47 | 5.62 | 1.85 | - | - | 3.22 | - |

High-strength, lightweight and energy-efficient materials receive a lot of attention in modern technology since environmental and energy issues are hot topics. Researchers are working to develop new and improved materials to meet this need. Many users in a variety of engineering as well as other industries have been motivated by this exceptional flexibility in design tailoring, as well as other qualities such as ease of fabrication, durability, corrosion resistance, and cost-effectiveness. Because of its low density as well as excellent mechanical qualities, Al based MMCs is a common material for making lightweight parts for a diverse range of market needs.[15]

**DISCUSSIONS**

As per researchers, using RHA filler reduces the rate of wear at any specified load. It is reported that increased hardness provides resistance to counter-face asperity cutting. According to Krishnarao et al., the subsurface of said composite is stronger as a result of those strain fields. The majority of RHA particles are spherical, which helps to reduce stress concentration as well as premature particle separation from the aluminium matrix while sliding. The addition of RHA via the PM route results a 15-40% improvement in wear behavior. It is found that RHA survives the applied force as well as lowers the real contact area of the worn sample with the counter disc. The worn surface of the aluminium matrix expresses a sense of plastic deformation. Frictional heat develops when the pin surface, as well as the counter surface comes into contact. This causes the sliding surface to flow plastically, resulting in this state. Adhesive wear has now been recognized as the wear model. The existence of RHA restricts plastic deformation, so as the RHA content increases, the plastic deformation of worn surfaces decreases. It has been discovered that under test conditions, parallel grooves pattern at greater volume fractions. The mode of wear shifts from adhesive to abrasive.

RHA nanoparticle reinforcement improves the ultimate tensile stress (UTS) as well as the micro hardness of

AlMMCs in a significant way. The micro hardness of AA6061/8 wt.% RHA AMC is 167.27 times higher and the UTS is 57.42 times higher than that of unreinforced aluminium alloy. Hardness improves by 24 percent and tensile strength increases from 4453 KPa to 6339 KPa when 2 wt.% RHA is added to AA6061 alloy. Dislocations strengthen when dislocation motion is slowed or delayed. Aluminium alloy and RHA particles have different coefficients of thermal expansion. During solidification, strain fields emerge around RHA particles when the coefficient of thermal expansion is changed. The UTS, YS, and percent E of Al-Mg (1.5 percent)–Cu-coated RHA ($SiO_2$) composites are 52, 32.95, and 15.83 percent higher, respectively than the composite reinforced with uncoated $SiO_2$ particles.

Effect of RHA on mechanical properties of AlMMCs

| Compositions | Mechanical Properties Improvements | | |
|---|---|---|---|
| | Hardness | TS (MPa) | CS (MPa) |
| | (BHN) | | |
| A-356.2 + 2 wt.% RHA | 77 | 175 | 233 |
| A-356.2 + 4 wt.% RHA | 83 | 239 | 261 |
| A-356.2 + 8 wt.% RHA | 84 | 278 | 268 |
| | (BHN) | | Elongation (%) |
| AA6061 | 152 | 6 | 2 |
| AA6061/2wt.% RHA | 170 | 6.03 | 2.4 |
| AA6061/4wt.% RHA | 175 | 6.13 | 2.5 |
| AA6061/6wt.% RHA | 178 | 6.23 | 2.7 |
| AA6061/8wt.% RHA | 188 | 6.34 | 2.9 |
| $SiO_2$ (RHA derived) | (HRA) | | E (GPa) |
| Al6063 | 62 | 110 | 15 |
| Al6063/2wt.% $SiO_2$ | 65 | 130 | 25 |
| Al6063/4wt.% $SiO_2$ | 67 | 150 | 37 |
| Al6063/6wt.% $SiO_2$ | 69 | 160 | 43 |
| Al6063/8wt.% $SiO_2$ | 72 | 200 | 50 |

As the density of the reinforcing SiCp and Al2O3p is inherently higher than that of aluminum, its presence in the material led to a higher density of the aluminum matrix composite (AMC), which could be analyzed using the rule of mixtures theory . We concluded that the density of the engineered aluminum composite varied between the density of the matrix and the density of the particulate reinforcement.

## FUTURE SCOPE OF WORK

The following future scopes are probable from the present brief glimpse on the topic.

1. Heat treatments can be used to make RHA reinforcements better in order to replace expensive materials like SiC, $Al_2O_3$, and others.
2. More research needs to be done on manufacturing processes that can help improve the bonding between the aluminium matrix and the RHA reinforcements despite the fact that there are some limits.
3. Process parameter optimization for the manufacture of RHA reinforced AlMMCs with optimal property achievement has not been investigated previously.
4. There have been no studies on the optimization of wear resistance qualities for RHA reinforced Al based MMCs at extreme temperatures.

## CONCLUSIONS

Based on the outcomes of several studies, the following conclusions have been drawn:

1. Rice husk ash particles are evenly distributed in the aluminium matrix, regardless of volume fraction. RHA particles did not clump together or segregate within the matrix alloy. Most of the particles are discovered within grain boundaries. RHA particles created places where grains started to form, which made it possible to refine the grains in the aluminium matrix.
2. The RHA-reinforced aluminium composite can also be successfully constructed through the powder metallurgy route. RHA lowers the density of the AlMMCs as RHA has a lower density than aluminium alloy. The addition of RHA (up to 10% wt.) boosts the hardness of developed Al based MMCs.

3. The wear resistance is improved when composites contain RHA particles and aluminium granules are unable to develop over the RHA particles. The overall amount of plastic deformation on the wear surface is reduced and the size of the surface erosion is caused due to its linkage to RHA. Greater hardness, the formation of strain fields, homogeneous distribution, RHA particles having a spherical shape and a reduction in the contact area were all credited with improved wear resistance. The wear model is drastically altered after RHA particles are added. It changed from sticky to abrasive.

## ACKNOWLEDGMENT

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# Dry Beneficiation of Coal by DE-XRT SBS Technology

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***Abstract**: Dry beneficiation of coal by Dual Energy X-Ray transmission sensor-based sorting technology does not need any water and occupies much less space compared to other beneficiation methods. The system works on the principles of Physics of Non-destructive evaluation. It employs X-ray technology, Machine learning and Cloud computing techniques. Crushed ROM coal is transported through chute, vibrating feeder and conveyor. Such transportation enables line camera system to have 360-degree view of each of the coal pieces. Intensities of incident and attenuated X-rays are measured. Particle shape, particle size, material thickness, and texture of the constituent elements in the pieces of feed material are fed into the computers.Based on acceptance criteria, computer algorithm decides acceptance and rejection of pieces of feed materials. Rejection is accomplished through an ejection mechanism. This technology does not degrade the environment, does not use water, has got the potential to segregate ROM coal in different grades thereby ensuring considerable yield of ROM Coal. Thus, it contributes in attainment of Sustainable Development Goal-2030.*

***Keywords:** Dry Beneficiation of Coal; Dual Energy X-Ray Transmission; Sensor Based Sorting*

## ABBREVIATION FULL MEANING

| | |
|---|---|
| CFPP | Coal Fired Power Plant (CFPP) |
| CPCB | Central Pollution Control Board |
| DE | Dual Energy |
| IGCC | Integrated Gasification Combined Cycle (IGCC) power plants: |
| KLD | kilo Litres per day |
| kVp | kilo Volts Peak |
| mAs | Milli-Ampere Second |
| MOC | Ministry of Coal |
| MOEF&CC | Ministry of Environment, Forest and Climate Change |
| PCC | Post-combustion $CO_2$ capture (PCC) system |
| PLC | Programmable Logic Controller |
| ROM | Run of Mine |
| SBS | Sensor Based Sorting |
| SDG | Sustainable Development Goal 2030 |
| SG | Specific Gravity |
| SID | Source to Image Distance |
| TPH | Tonnes per Hour |
| TPP | Thermal Power Plant |
| XRT | X-Ray Transmission |

## INTRODUCTION

In order to achieve Sustainable Development Goals, beneficiation of coal without any further burden on environment is obvious imperative. In FY2023 Power Sector and Steel & Washery Sector in India has consumed 787.65 MT and 8.58 MT coal[1]. Ash content in Indian coal is 25 to 45%. MOEF&CC stipulated <34% Ash content for TPPs. MOC stipulates <15% Ash content for Steel-I Grade of Coal having specific gravity of 1.42[2] CPCB stipulations restrict Emission Standards for all TPPs. Beneficiation of such a huge amount of high Ash content ROM coal necessitates a robust full proof technology. This paper outlines a theoretical multidisciplinary approach towards Dry beneficiation of Coal by DE-XRT technology involving the principles of Physics of Non-destructive Evaluation along with Computer Science & Engineering.

**FLOW-PATH FOR COAL BENEFICIATION BY DE-XRT SBS**

The flow path involves comminution, presentation, detection, processing and separation of impurities and coal.

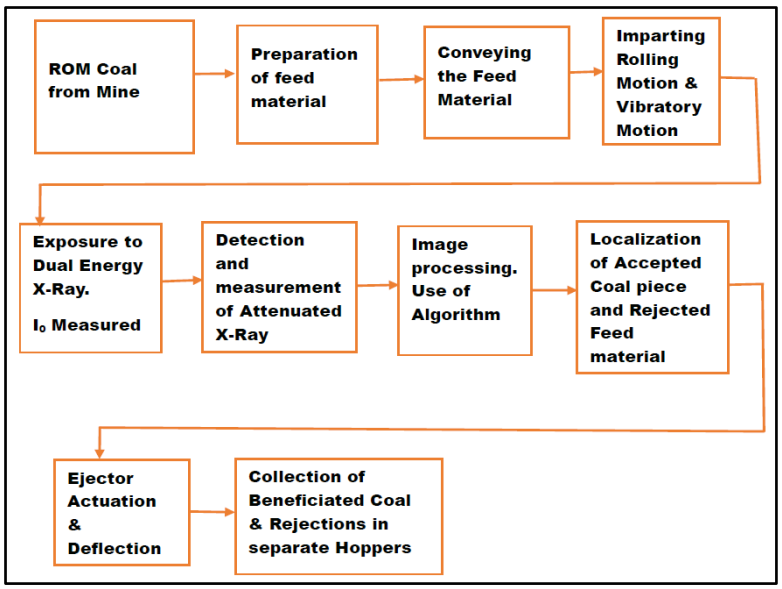


**Figure 1** Flow chart of dry beneficiation of coal by DE-XRT SBS technology

Preparation stage involves sizing which is accomplished in crushers. From crushers, the sized coal is fed onto the hoppers. The system provides both spatial and spectral resolution to know the position and material properties of each of the pieces of feed materials passing through the sensors. For this reason and also to impart kinetic energy to facilitate segregation by ejection at the end of the beneficiation process, the crushed coal is made to pass through a chute and vibrating feeder. DE-XRT Sensors are there in the path – it may be at chute-end or at a certain point on conveyor belt. The sensors read the particles passing through the passage, detects all its properties limited to the capability of the sensors and send information to the data-processing centre. Data-processing centre informs the system about the particles having impurities. Such detected impure particles are then rejected by any of the amplified processes involving mechanical (Mechanical Flaps) or hydraulic (Water Jets) or pneumatic (Air Compressor and Pneumatic Valves) equipment.

**DE-XRT SBS**

DE-XRT SBS stands for Dual Energy X-Ray Transmission enabled Sensor Based Sorting of minerals and gangue.

(a) DE-XRT: Medical application of X-ray is used here on industrial basis.

The voltage difference between the cathode and anode of the X-ray tube (kVp) controls the energy of the X-rays and also their penetrating power. Increasing kVp increases the number of photons produced. Dual Energy X-Ray (DE X-Ray), i.e., one Lower and one Higher energy X-Ray is thus produced by adjusting kVp. X-ray quantity (number of X-ray photons) is determined by mAs, kVp, SID, and filtration, while kVp and filtration determine X-ray quality (effective energy of X-ray photons). The incident X-ray beam contains photons of varying energy with a high proportion of low-energy photons, which have a negligible impact on image production as they cannot traverse the feed material to reach the detector and thereby only contribute to noise. Filters are used to absorb these low-energy photons, thereby reducing noise. Filtration decreases X-ray tube output but generates a more uniform beam with an overall increased average effective energy of X-ray photons.

This method measures the attenuation of individual objects of the feed material in two settings: Lower energy setting where the Photoelectric effect is dominant and Higher energy setting, where the Compton-scattering is dominant. However, Linear Attenuation Coefficient is determined by photoelectric effect, Compton scatter, and Rayleigh scatter

– all taken together.

(b) SBS: X-Ray Transmission (XRT) is used as scanner in Sensor Based Sorting (SBS) system.

XRT works on the basis of properties like X-Ray Attenuation Co-efficient and Atomic Number of different elements as given in Periodic Table. Sorting is done on the basis of image identification. For this, images need to appear in different shades of a given colour.

X-rays are types of electromagnetic radiation. The mass attenuation coefficient of a material is energy dependent; it decreases as the photon energy increases, except at K-edges. These two characteristics of interactions of X-Rays incident on matter gives Electromagnetic spectrum which is applied to get spectral resolution of the pieces of feed material.

Mass attenuation co-efficient derived from Beer-Lambert's law is given by

$$I = I_0 e^{-(\mu/\rho)\rho x} \qquad (1)$$

Where, I = intensity of X-ray coming out of a piece of material fed on the conveyor; $I_0$ = Initial intensity of X-ray incident of that piece of material; $\mu/\rho$ = mass attenuation (or absorptivity) coefficient ($cm^2/g$) of compositional element within that piece of material where $\mu$ = linear attenuation coefficient ($cm^{-1}$) of that element & $\rho$ = density ($g/cm^3$) of that element; $\rho x$ = mass thickness ($g/cm^2$) of that element where x = path length (cm) of the incident X-ray passing through the element.

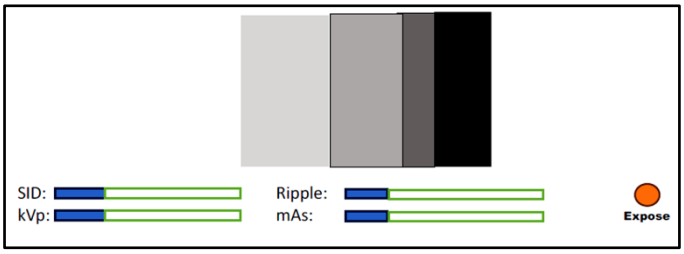


**Figure 2** Medical X-ray is automated in DE-XRT

From **Equation (1)**, shape, size and dimensions of the pieces give spatial resolution of the feed materials.

Final product size for of crushed and screened coal is determined as per Wire mesh sizing in accordance with ISO:2591 and ISO:3310. As per these standards, there can be no more than 95% probability of getting any particular size. Also, crushers give two dimensioned coals, which means that in two dimensions like breadth and width, a required size can be adhered to but not in length. Bigger the size, increased shall be the impurities and ash content. Gauging is essential.

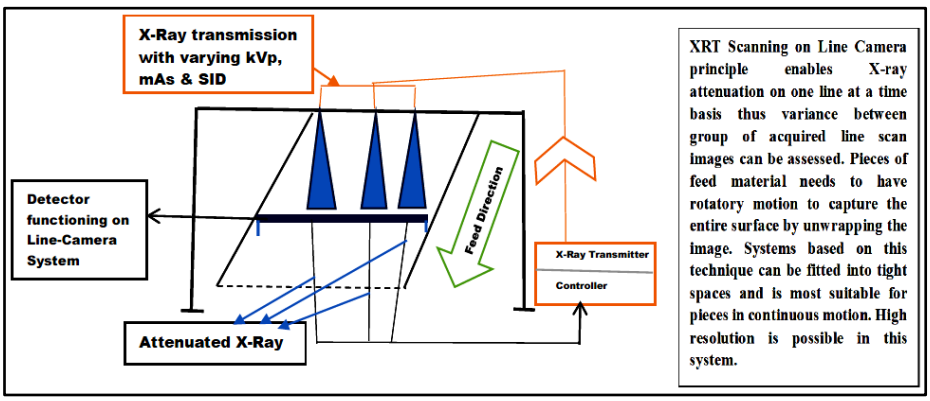


**Figure 3** X-Ray transmission & detection

Spectral and spatial resolutions of each of the pieces of the feed material are fed into the computing mechanism.

**HOW THE SYSTEM WORKS**

A schematic diagram showing flow of feed material and up to the point of final sorting is given in Figure:4. As the feed materials pass through X-Ray Transmitter, detectors record intensities of attenuated X-ray photons. Relationship between Atomic Number Density, Atomic Weight and Material Density is given by

$$N = n/V = (\rho N_A)/M \qquad (2)$$

Where, N – Atomic Number Density (atoms/cm$^3$), n – number of atoms per unit volume, V – volume (cm$^3$), ρ – material density (gm/cm$^3$), $N_A$ – Avogadro's number = $6.02214076 \times 10^{23}$ atoms or molecules per mole, M – Atomic or Molecular weight (grams/mol).

The Linear Attenuation Coefficient increases as the atomic number of the material increases and also increases with the increase in material density. As such, Linear Attenuation Coefficient varies with the Atomic Number Density. **Equation (1)** and **(2)** establishes a relationship between Linear Attenuation Coefficient, Atomic Number Density and material density. Interaction of incident X-Rays on elements of different atomic number densities are transformed into images of different spectral ranges, which make it possible to classify different colour pixels according to specific atomic number densities. Sensors used in SBS system are usually of high resolution. This enables evaluation of the particle shape, particle size, material thickness, and texture of the of the constituent elements in the pieces of feed material. From all these grey-scale images representing inclusions of material of various densities are produced.

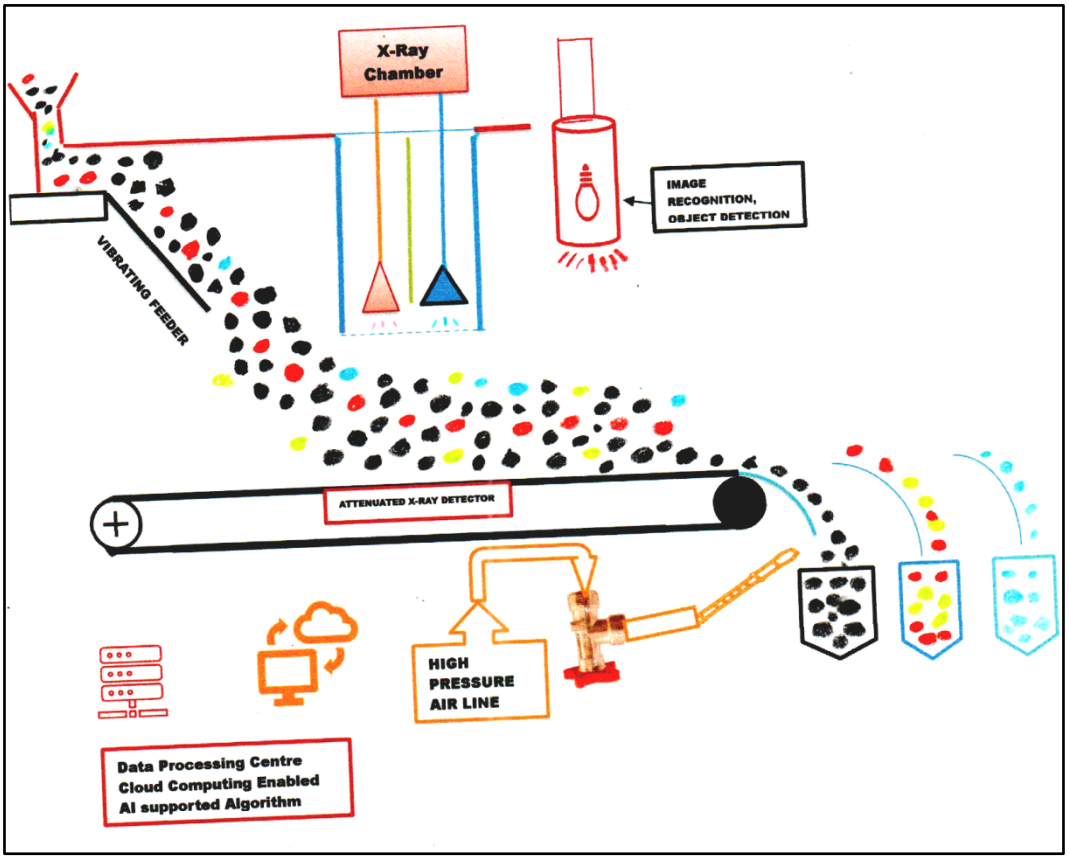


**Figure 4** Schematic diagram of dry beneficiation of coal by DE-XRT SBS technology

Grey-scale images are converted to simulated images in different colour scales. Generally, specific gravity is considered as the basis for sorting program. Indian coal is having 17 grades whose Specific Gravity ranges from 1.42 to 1.76. More the sorting program sets the cut-off point nearer to lowest SG, higher shall be the sensitivity, increased

shall be the rejection and improved shall be the separation efficiency. This may be a loss to nation. The cut-off point is to be decided, then the colour scale of images may be set as red, green, blue for lowest, medium and highest densities of feed material. Machine Learning based algorithm is used and by applying AI Image Recognition, sorting of coal is done in accepted, re-processing and reject category. A compressed air powered ejection system is activated through sensors and the sorted coal and gangue are diverted in their respective designated bin or conveyor belt.

Re-processing shall be necessary if SG cut-off point is kept too low. In that case, SBS needs to be carried out in second pass and may be in third pass also for full extraction of usable coal from ROM coal.

Indian coal contains Sulphur in the form of Sulphides. Lignite coal also contain Sulphur. It is essential to carry out thorough laboratory tests and build up a data base for coal, lignite of each seam or geological area. Based on these scanning parameters need to be decided, colour scales are to be attributed and cut-off points to be set for optimum separation efficiency. Setting cut-off point solely on the basis of SG is not suitable as minerals (impurities) present in ROM coal may have same or near-same SG as that of coal.

**DISCUSSION**

In the year 2022-23 production of washed coal was 16.24MT for non-coking and 5.31MT for coking coal. Only 1.951% of non-coking coal produced was washed[3]. Contrast to this, in the year 2007, it was stated that by calculating the power plants coal requirements on the basis of total energy units (BTU's or Kcal's) required to produce the projected quantity of electricity, (i.e. Heat Rate times Units Generated divided by Heat Content of Washed Coal), net quantity of washed coal (adjusted to include both the heat required for the original power generation and the additional capacity) was calculated. The then net quantity (by weight) of washed coal required was found to be 92.5% of the original ROM quantity[4]. Obviously, the task is huge.

It has been found that carbon dioxide emissions in the range of 1.11 kilogram per kW generated are reduced by 6.5% to 1.045 kilograms per kW when using 30% ash coal versus 42% ash.[5] Obviously, there is huge potential to reduce $CO_2$ Emission by using coal with lesser Ash content, than what is being presently done. Apart from this, transportation cost per tonne of enriched coal shall reduce.

Pre-feasibility report of February 2020 of Greenfield 0.99 Million Tons Per Annum throughput Capacity Coal Washery at Vill: Khargahani, Distt. Bilaspur, (Chhattisgarh-495112) prepared by M/s. Mahavir Coal Washeries Pvt. Ltd for their 500TPH capacity coal washery stated requirement of 1500KVA electric power, 250KLD (2,50,000 Litres per day) of water, 14.74 Acre of land for yield of 80% clean coal and 20% reject by installing a coal washery based on Heavy Media Cyclone process with PLC based control system, working 8 hours per day basis, giving output of clean coal with Ash 34%, GCV - 4350 Kcal / Kg from input of raw coal with Ash 45%[6].

Compared to this, an equipment working on DE-XRT SBS based technology, for an output of 240 to 300TPH shall occupy approximately 32 sq.m. area, requiring 40kw power and no water. Compared to huge land and water requirement, benefit of Dry Coal Beneficiation by DE-XRT SBS based technology is absolutely visible, particularly so, as this technology gives much superior quality of coal with minimal rejection.

**CONCLUSION**

Enormity of SDG task aimed to protect future generations, Dry Coal Beneficiation by DE-XRT SBS based technology is best suited for India. With the depletion of coal reserve on top seams and anthropocentric pressure on lands, it has become a compulsion to go for deep mining thereby increasing cost of coal production. Pressure on water resources is also building up. Expansion of water based washeries shall have adverse effect on agricultural land and yield. Once DE-XRT SBS becomes successful for coal, the same may be applied for enriching of other minerals, whose reserve is very scarce in India. Thermal efficiency can be greatly improved by reducing load on PCC system used in some present day CFPPs. This require providing coal with high carbon content. Not only reduced Ash content but also removal of toxic & GHG enhance-potential impurities from ROM coal is a definite task to be accomplished for the next-generation IGCC power plants.

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# Metals & Minerals

## Multifunctional Materials

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# Emerging New Technologies in Metal Forming of Aluminium Alloys

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**Abstract:** Performance of casting is dictated by many metallurgical features, such as, secondary dendrite arm spacing (SDAS), intermetallics, oxides/inclusions and porosity. Castings exhibit defects such as shrinkage and gas porosity, hot tears, inclusion and alloy segregation that generally result in lower and more variable mechanical properties than their wrought counterparts. The fatigue endurance of castings is very sensitive to the size of casting defects. On the other hand, solidification time as reflected by secondary dendrite arm spacing (SDAS) and size of Silicon particles also affect it to lesser extent. The complete elimination of gas and shrinkage porosity defects is not always possible without the application of external forces to close voids and porosity. It is also utmost important to get equi-axed / rounded and non-dendritic structure in place of columnar / dendritic structure. Many new technologies have emerged out in recent past to induce the required structure in order to get higher castability & mechanical properties specially fatigue strength. Some of the new technologies which have attracted the Defence, Aero space & automobile industries are Hot Isostatic Pressing (HIPing), Semi Solid Forming (SSF), Metal Spray Casting (MSC) and Electro Slag Refining (ESR) .

**Keywords:** Aluminium; Strength; Toughness; HIPing; SSF

## INTRODUCTION

The excellent properties of Aluminium alloys have revolutionized today's fast changing technology due to its excellent characteristics of very high strength to weight ratio, high resilience, corrosion resistance, good machinability, very good formability, conductivity and crashworthiness. It has got tremendous potential to replace fully the conventional High Strength Low Alloy (HSLA) Steels. Several cast alloys and casting processes have emerged in recent times. However, due to lack castability, wrought alloys are not considered for casting applications. Applications in Defence, Aerospace & automobile requiring high mechanical properties including resistance to fatigue failure and weight saving, look for aluminum castings. This is because of their excellent casting characteristics, corrosion resistance, near-net-shape capability and especially high strength to weight ratio.

Performance of casting is dictated by many metallurgical features, such as, secondary dendrite arm spacing (SDAS), intermetallics, oxides/inclusions and porosity. Castings exhibit defects such as shrinkage and gas porosity, hot tears, inclusion and alloy segregation that generally result in lower and more variable mechanical properties than their wrought counterparts. The fatigue endurance of castings is very sensitive to the size of casting defects. On the other hand, solidification time as reflected by secondary dendrite arm spacing (SDAS) and size of Silicon particles also affect it to lesser extent. The complete elimination of gas and shrinkage porosity defects is not always possible without the application of external forces to close voids and porosity. It is also utmost important to get equi-axed / rounded and non-dendritic structure in place of columnar / dendritic structure. Many new technologies have emerged out in recent past to induce the required structure in order to get higher castability & mechanical properties specially fatigue strength. Some of the new technologies which have attracted the Defence, Aero space & automobile industries are —

(a) Hot Isostatic Pressing (HIPing)
(b) Semi-Solid Forming

## HOT ISOSTATIC PRESSING (HIPING)

This is a very beneficial post casting process. In Hot Isostatic Pressings, the castings are placed in an autoclave chamber and slowly heated while the pressure of the surrounding inert gas is simultaneously increased. Castings/components are subjected to the simultaneous application of both heat and high pressure in an inert gas like Argon or Nitrogen atmosphere. The temperature varies from 480°C for Aluminium alloys to the tune of 1315° C for Nickel base super alloys. The pressure varies from 15,000 p.s.i.(103 MPa) to 30,000 p.s.i.(206 MPa). In quick HIP (Rapid Isostatic Pressing), the pressure goes up to 75,000 p.s.i.(517 MPa). An inert gas is used, so that the material does not chemically react. The chamber is heated, causing the pressure inside the chamber to increase. Due to the presence of the gas, pressure is applied to the material from all directions and justifies the term 'Isostatic'. This pressure, while acting on the casting isostatically, enables collapse of any internal porosity left in the castings. Later, the castings are cooled to the room temperature. The simultaneous application of heat and pressure converts the material into a plastic state leading to the longer creep life. The components are densified due to removal of cavities and porosities and consequently mechanical properties are improved enormously. This process is extensively used in UK USA & other European countries. In India, it is being developed and industrialized.

Augmentation and installation of this technique involves huge investment for costly machineries. But, providing HIPing service and subcontracting is less costly. Many service providing companies are available. Aerospace, energy, automobile, medical, Defence and tooling industries take benefits of this advance cost–effective technique of heat-treatment. In recent years, the lower cost HIPing processes such as LHIPing, Densal and Quick HIPing have emerged with their lower cost enabling them to be considered as a post–casting treatment option for Aluminium castings in highly stressed applications. LHIPing pressing uses a molten mixture of salts as liquid/ fluid instead of inert gas to apply the isostatic pressure on the cast components. A few minutes cycle time is sufficient to achieve the results of Isostatic Pressing equivalent to those obtained with the traditional gas HIPing with longer cycle time even up to ten hours. Densal process uses purpose built unit having a shorter cycle time and much lower acquisition and operating cost than a standard HIPing unit. It uses more cost effective Nickel–Chromium furnace instead of costly molybdenum furnace.The less expensive Nitrogen gas is used as a cover instead of costly Argon gas used in standard HIPing unit. Quick-HIPing (Rapid Hot Isostatic Pressing) uses very high pressure to the tune of 75,000 p.s.i. (517 MPa). It is equipped with modular furnace units which allow independent control of both temp. and pressure profiles during processing. The material can be densified at lower temperature and/or shorter time than with conventional HIPing process. It reduces thermal exposure and minimizes undesirable high temperature interactions such as grain coarsening and interfacial reactions. It also enables components to be processed at a potentially lower cost than by conventional HIPing. **Figure 1** illustrates schematically the Quick - HIPing (Rapid Hot Isostatic Pressing) process. **Figure 2** reveals the method of Semi Solid Forming (Electo Magnetic Stirring).

The HIPed Castings have the following edge over conventional castings —

1. An approximately 50% improvement in ductility
2. 3-10 times improvement in fatigue life
3. Definite improvement in ultimate tensile strength (UTS) and creep life
4. Reduction in porosity and thus minimizing the scatter in mechanical properties
5. Increase of yield due to Salvaging the scrapped castings
6. Can make any shape of complex geometry
7. Greater flexibility in design & hence dual alloy components can be made
8. Cladding (selective bonding of hard facing material on lower cost material is possible by HIPing to replace expensive wear resistant materials.

The **Table 1** compares the properties of conventional castings and HIPed castings.

## SEMI SOLID FORMING

Semi Solid Forming (SSF), an innovative method of getting high quality near net shaped castings, was developed during the 1970s by MIT, USA. In contrast to the conventional casting processes, SSF uses the physical state between

solidus and liquidus temperature. The processing of materials in the temperature range where both liquid and solid states co-exist (mushy – semi solid state), provides significant benefits in Production of continuous cast billets with non-dendritic globular micro structure with the help of Electro Magnetic Stirring(EMS). product quality and productivity. The substantial reduction of flow stresses allows production of complex cast structures with very low forming.

The following steps are involved in the Semi-Solid- Forming Process —

(a) Cutting of the non-dendritic (Semi-Solid) billets to the required dimension to form slugs for further processing.

(b) Heating of slugs to the semi solid state (550°C for Al- Si Alloy) and then using a machine such as a high pressure die caster to inject the high viscosity semi solid material into the die cavity and the part is then allowed to solidify fully. This results in the near net shape casting. The production of non dendritic billets is perhaps the most crucial step in SSF. It is well known that vigorous stirring can break the dendrites and create semi solid slurry.

(c) These are mainly two methods of stirring the melt in the stirring chamber.

  (a) Mechanical stirring &
  (b) Electro Magnetic Stirring. (EMS).

It has been now widely accepted that the EMS system is the most consistent and reliable method for obtaining non dendritic billets. This technology for casting of non dendritic bellete is available with only a selected few industries and R & D institutions across the world and at present not accessible to the Indian industries. SSF is widely used in USA and European countries. In India, it is being developed at IISc Bangalore, NMRL Ambarnath & IIT Kharagpur. At present EM stirrer is being imported from Switzerland. The EMS incorporates filtering and degassing of the metal. The metal near the freezing point in the mould is vigoursly stirred by a dynamic electro-magetic field creating shearing action. Due to the shearing action, nuclei formed during solidification can not grow in the form of dendrites. Nuclei partially remelt in contact with the hotter metal in the hot top before they are deposited in the solidification front. Finally the micro structure of the billet contains fine, homogenous, pores free, dense & globular grains. The schematic diagram of vertical EMS is shown in **Figure 3** and **Figure 4** depicts in the various steps in SSF. **Figure 5** reveals the typical micro structures of A357 alloy with or without SSF. **Table 2** & **Table 3** illustrate the improved properties of SSF as compared normal casting. Some of the parts / components made by SSF are shown in **Figure 6**.

**Table 1** Comparison of mechanical properties of typical Aluminium alloy castings without and with HIPing treatment

| Alloy | Condition | UTS MPa | YS MPa | Elongation% | Fatigue strength MPa |
|---|---|---|---|---|---|
| A356 | As-Cast | 169±10 | 132±5 | 3±1 | - - |
| A356 | Sand Cast, un chilled quenched directly after liquid HIPing and aged | 269-275 | 187-210 | 6.2-9.1 | - |
| A356 | Sand cast +T6<br>Sand cast+ LHIP + T6 | 230-250<br>300-320 | 190-210<br>230-250 | 1-2<br>4-6 | 80-100<br>120-180 |

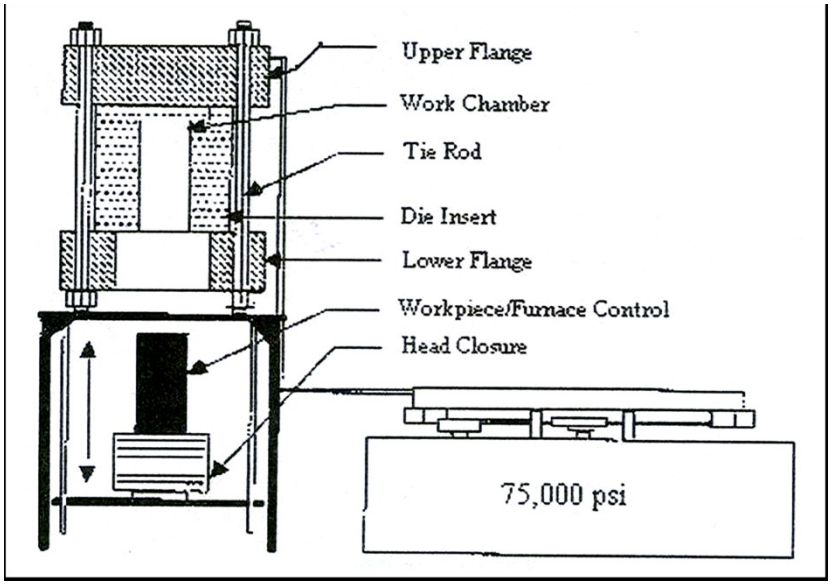


**Figure 1** Schematic Diagram of Rapid Isostatic Pressing (Quick HIP)

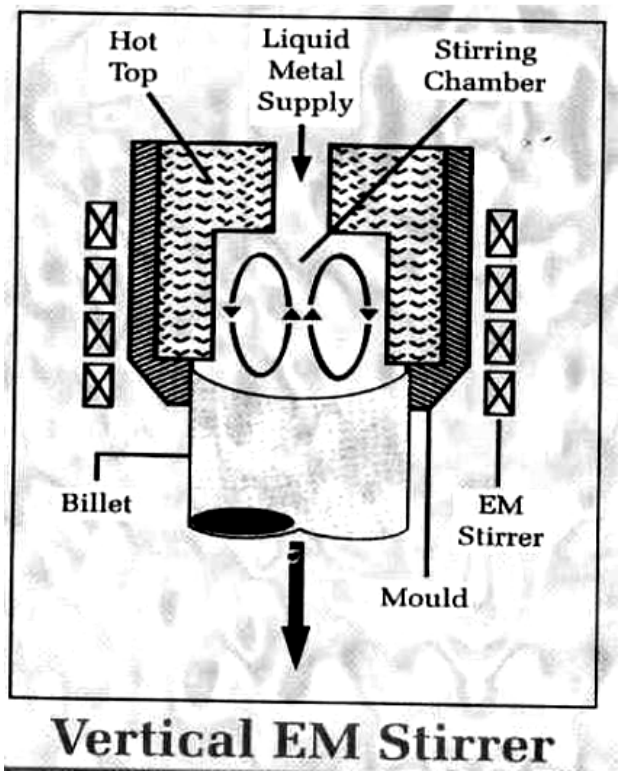


**Figure 2** Schematic diagram of Electro Magnetic System

# Metals & Minerals

## Sustainability in Mining

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# Sustainability in Mining through Cradle to Cradle Approach

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***Abstract:***

*"Mines are the source of wealth; from wealth comes the power of the State" (Arthashastra, 2.12.37; 7.14.25)*

*Mining sector, being one of the essential sectors of the economy, provides basic raw materials to industries like thermal power generation, iron and steel, cement, fertilizers, precious and semi-precious metals/stones, electrical and electronics equipment, glass and ceramics etc. India produces as many as 95 minerals which include 4 fuel, 3 atomic, 10 metallic and 23 non-metallic minerals and 55 minor minerals (including building and other materials). There continues to be a huge demand for minerals in view of the rapid urbanization and growth in the manufacturing sector in India.*

*The mining sector is going through various challenges and disruptions that hamper its growth. There are many environmental aspects related to mining activities that create challenges in the expansion of mining. The issues of land use and conversion, waste generation, groundwater depletion, and pollution of air and water are some of the major factors that create concerns on the national level.*

*One place to start is decreasing waste along the whole mining value chain. Unlike mining site, which has a life span and will cease operations eventually, mine waste is here forever. Finding ways to turn liabilities like large tailings storage facilities and heap leach piles into assets through reuse is crucial to a circular economy.*

*The mining industry has an obligation to operate within the concept of sustainable development-it must extract resources responsibly. Up cycling transforms waste and unwanted products into new, higher quality products. The waste can be reused by the mine itself or sold to a third party.*

*Mining operations become sustainable when environmental and social goals are given top priority, incorporating responsible mining practices, improving the health and well-being of workers, prioritising the needs of local people, and increasing the overall efficiency of dayto-day processes.*

***Keywords:*** *Life of Mine; Land Rehabilitation; Material Characterization; Mine Waste Management; Top Soil Preservation*

## MINE WASTE MANAGEMENT

Large quantities of waste are being created by Mining and the land is damaged inherently. There is no estimation on how much waste is generated by this industry globally. But, everyone agrees that the quantity is so HUGE that is unimaginable.

Some of the impacts of the mining waste include:

- Unpleasant visual impact as big piles of waste stand out like sore thumbs.
- Takes up large areas of land for their storage and disposal and also make the land infertile and useless.
- Heavy metal contamination which reduces soil productivity or sterilises the soil altogether.
- Absence of vegetation makes the site more susceptible to runoff, soil erosion, and potentially unstable ground.
- Acid drainage can enter water supplies.
- Blown dust and tailings are a source of air pollution.
- Ruptures of dams, pond and impoundments can flood adjacent lands and discharge pollutants into waterways.

Waste management techniques employed by mining companies are routinely under intense scrutiny from local governments and the general public. Many countries now require miners to prepare a complete mine waste storage

proposal before a mining permit will be granted. Despite numerous recycling methods, the majority of mine waste is still stored in facilities or waste sites. The long-term storage of these facilities has become an important topic in modern mine closures. Various regulations have come to pass that require the waste to be stable for years, sometimes centuries. This requires engineers to develop storage methods to withstand catastrophic events like floods, heavy storms, and earthquakes.

## CRADLE TO CRADLE APPROACH

Waste generation and land degradation are the two issues which are among the most "hard to control" things in resolving sustainable mine closure. The probable solution for these issues is Cradle to Cradle approach in mining. Cradle to Cradle refers to the ideal of an end to waste. The Cradle-to-Cradle concept operates on the principle of nature that, 'there is no waste on the earth' and 'Waste=Food'. The waste of one product/process becomes the food for another.

It means breaking away from the traditional take, make and waste economic model.

There are two aspects to consider: firstly, addressing current mining processes and practices to minimise the production of waste, or what we think of as waste. Secondly, dealing with the materials that are already sitting in dumps and in tailings dams.

Cradle to Cradle (C2C) theory, consisting of three tenets—waste as nutrient, use of renewable energy, and promotion of diversity is essential in defining eco-efficiency and life cycle.

1. Waste as nutrient: The principle of waste equals food, which requires that all materials and emissions be considered beneficial to the environment or the techno sphere. Our product has been designed to be harmless to human health and sustainably recyclable, with no waste generated and all outputs serving as inputs to other systems. This allows us to establish closed-loop systems based on these cycles.

2. Use of Renewable Energy: The principle of enhancing renewable energy sources, which we consider essential to effective design. We have maximized the use of renewable energy sources wherever possible.

3. Promotion of Diversity: The principle of focusing on diversity, which is a key to innovation in designing technologically diverse products that avoid a "one-size-fits-all" approach.

It is beneficial, if half of those stored materials can be turned into something that can be used for development of infrastructure or for alternate products. We need to start looking at waste differently. There's a lot of demand for some of the materials we have. Due to the many variables, mining operations will need to develop their own methods of waste disposal in accordance with regulations pertaining to the different types of waste they produce. However, it is worth noting that a large portion of mining waste is benign to the environment and is routinely used to revegetate or contour the land when the mining operation has been completed.

## OVERBURDEN MANAGEMENT

Compared to other minerals, coal mining produces the maximum amount of wastes in India. Limestone and iron ore are the next two biggest contributors to total mining wastes generated in India.

The overburden management and stabilisation is important from the environmental and aesthetic point of view. The most common method of stabilisation is by plantation. Overburden dumps are generally reclaimed by tree species as plantation improves the moisture contents, bulk density, pH and overall nutrient contents of soils. Tree species like Dalbergia sissoo, Eucalyptus, Cassia seamea, Acaccia mangium and Peltaphorum are found to be ideal for bio reclamation of overburden dumps. In addition, there are other preventive measures to arrest erosion particularly at the initial stage of overburden management.

Overburden can be used for reprocessing, contouring land, and as a construction aggregate for buildings and roads.

Mine tailings can be reused for producing clay, tiles, glass, and concrete. Mine water can be treated and then used for dust and particulate suppression, agricultural/industrial use, and as a coolant.

A good mining practice is to store the topsoil for reuse, but this is largely ignored in India. In many cases, the topsoil becomes a part of the waste pool and is disposed off with the overburden. The topsoil is the most valuable resource for re-vegetation after mining, as it contains the majority of the seeds, roots and microorganisms.

Absence of topsoil is the most common feature of the mine spoils or dumps. Since the progress of natural vegetation process is very slow on mine spoils, selective plantation of suitable native species is desired in most cases. In the initial stages of re-vegetation, quick growing grasses with short life cycle, legumes and forage crops are recommended. It will improve the nutrient and organic matter content in soil. Plantation of mixed species of economic importance should be done after 2-3 years of growing grasses.

The best practices involved in the topsoil management are as follows;

- Scrap the topsoil prior to drilling and blasting.
- Scraped topsoil should be used immediately for the plantation work.
- If topsoil is not used immediately then it should be staked at designated area.
- Stacked topsoil area should be surrounded by embankment to prevent erosion and height should not exceed more than six meter.
- Stacked topsoil should be stabilized further by grasses and bush to protect from the wind.

**CONCLUSION**

While the general perception within the mining industry is that waste management and rehabilitation are considered a burden, this paper has examined and analysed proactive approaches for the management of mineralised waste. The key aim of the paper has been to identify approaches that could maximise resource utilisation and value generation from waste while mitigating its environmental impact. Furthermore, increasing mineral extraction and resource utilisation from existing mine sites, should be at the top. The authors conclude that to generate the most successful outcomes the hierarchy must operate across all levels and is a core component of an overall mine sustainability framework.

The comprehensive utilization of solid wastes from mines is the necessary choice of mining industry, and it will bring tremendous economic and social benefits especially in environmental protection.

Therefore, waste management policies including reduction, recycle and safe treatment of mine waste, should be taken and waste management should be further tightened based on the principle of recycle economy. More attention must be paid to the proper disposal of solid waste from mines n land utilization management and reducing the discharge of solid waste by the comprehensive utilization of mining waste must be promoted in a more active way.

240_IEC32253

# Analysing the Behaviour of PVC Concrete Props through Laboratory Investigation & Numerical Modelling

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***Abstract:*** *Underground mines have conventionally been supported with wooden and steel support systems. However, with evolving time, it has become difficult to gather wood-based support systems like wooden props and cogs owing to the decaying nature of wood with time. Steel supports are made of iron which again is a non-renewable resource and is depleting with time. Hence, the necessity of an alternate support system material such as PVC concrete, is required that can be prepared on site, easily available and economical. This paper focusses on some preliminary investigations on the ongoing research work and highlights the preparation of PVC concrete prop, its laboratory tests with a few pipes and its performance through numerical modelling. From laboratory tests, it is found that a compressive strength of 25 MPa was obtained for L/D ratio of 7.3 and these samples failed at compressive displacement of 13 to 15 mm. The performance has been analysed through stress, strain and maximum deformation. Parameters varied were slenderness ratio, thickness of PVC pipe and grades of concrete. Several 3D models were developed where it was found that the PVC concrete props were capable enough to take large stress and resist sufficient deformation before failure.*

***Keywords:*** *Prop; PVC Concrete; Support System; Stress; Deformation*

## INTRODUCTION

Support systems such as wooden props, steel props, rockbolts and steel cribs are installed in underground excavations to improve the stability and safety of workings [1, 2]. These supports provides mainly three functions such as reinforcement, holding and retention [3, 4]. However, application of wood has its disadvantages such as decaying with time, being prey to termites and also with increasing environmental protection being considered it is not ethical to chop off trees for timber [5, 6]. Steel made of iron ore is again a non-renewable resource and is too depleting with time. It takes longer duration to grow in required size and shape [7, 8].

Hence, it has become important to seek an alternative support system which is capable of taking high load and serves longer. For this, PVC concrete-based props are prepared and tested in the laboratory. Numerical modelling technique is worked upon simultaneously to understand the behavior and stabilisation of prop. This study will analyse the behaviour of PVC concrete props both experimentally and numerical modelling and emphasize on the parameters that can be used to enhance its performance.

## METHODOLOGY

PVC concrete props were prepared on site and then subjected to testing in the laboratory. Parameters same as lab testing condition were implemented in ANSYS software to analyse its performance through numerical modelling.

### Laboratory Investigation

Concrete of M20 grade was prepared on-site by mixing cement, sand and aggregates in the ratio of 1:1.5:3 aided with water. Diameters and slenderness ratio (l/d) of the props in numerical modelling were 78.17 mm and 79.8 mm and 7.36 and 7.25 respectively. These were kept for curing for 28 days and tested under Universal Testing Machine (UTM). **Figure 1** shows the loading of the sample under Uniaxial Compressive Strength (UCS) Test.

### Developed Numerical Models of Props

Numerical analysis of props was performed using ANSYS Workbench software. Two samples of PVC-concrete props of different diameters were used for analysis. The geometry of the props was made in circular cross section.

Their diameters were 78.17 mm (d1) and 79.8 mm (d2) and extruded depths were 575 mm and 578.8 mm. The extruded depths imply the length of the PVC encased concrete that has been taken for testing. The meshing size of the elements was kept 3 mm. Boundary conditions for the prop were fixed in the horizontal direction. In ANSYS, the prop was analysed after fixing its maximum allowable displacements at 2.5 mm, 5 mm, 7.5 mm, 10 mm, 12.5 mm and 15 mm in the vertical direction on top of the loading platens and then analysed. Also, the PVC encased concrete pipe was free for displacement in the horizontal direction and compressed vertically by the top platen while it was fixed from the bottom. **Figure 2** shows the prop, its arrangement for testing, the meshing and boundary condition of the prop model. 12 models were prepared – 6 models each for the 78.17 mm and 79.8 mm props. Results were obtained and analysed in terms of vertical stress, principal stress, and deformation. All the models prepared were solved in linear elastic medium. Each sample was tested under uniaxial loading from different directions in terms of deformation by the top platen and gravitational force in vertical direction.

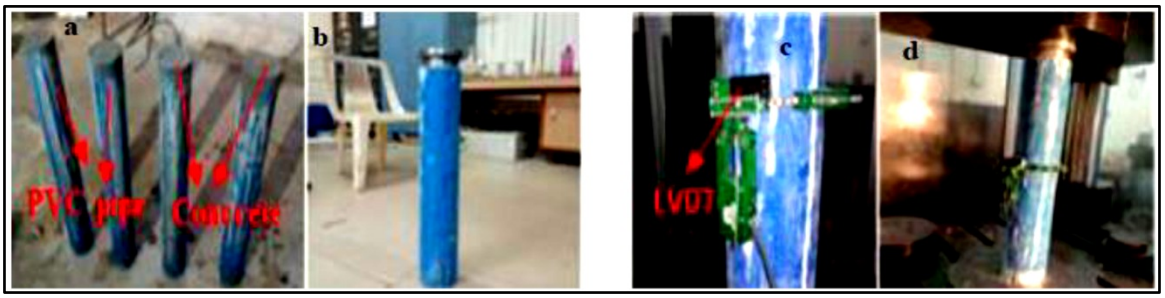


**Figure 1(a)** and **1(b)** Preparation of samples (left) and 1.c and 1.d.UCS Test (right)

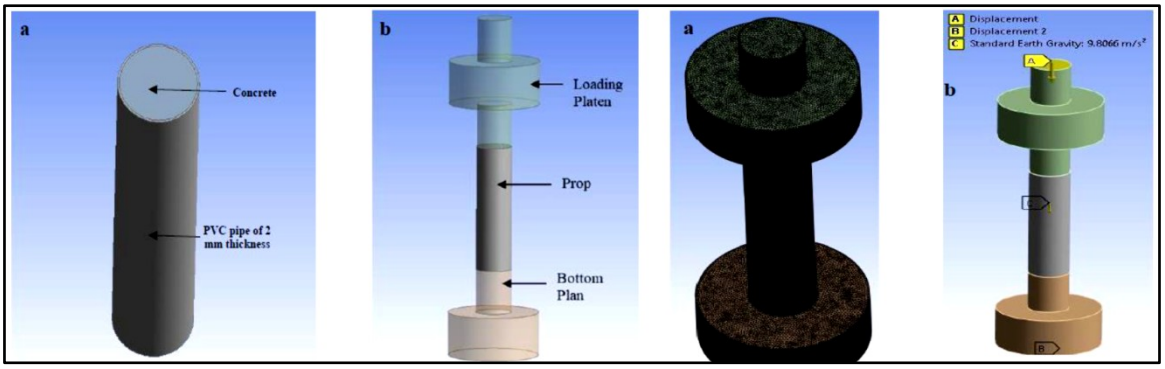


**Figure 2** PVC concrete prop prepared in ANSYS under setup and meshed with boundary conditions

## RESULTS AND DISCUSSION

### Laboratory Test Results

The laboratory tests on PVC concrete prop yielded values of stress, strain, Elastic modulus and poisons ratio as shown in **Table 1**.

From the results obtained in **Table 1**, it could be derived that PVC concrete-based props develop ductile behavior because it deformed up to 14.11 mm and 13.19 mm for d1 and d2 respectively before finally yielding. It could also be observed that the d1 and d2 samples yielded at 25.5 MPa and 25.82 MPa after developing strains of 0.1008 and 0.0228 respectively.

Following the non-linearity of the Elastic curve, the performance of the PVC Concrete Prop in terms of stresses, strains and deformations were analysed in numerical modelling with variable Elastic moduli subject to the conditions of its different behavior at different phases of its loading. The elastic moduli were calculated at different phases of the graph as given in **Figure 3** and **Table 1**. The vertical stress, maximum principal stress, minimum principal stress was analysed. Path was extracted from the model along the predefined path and considered at the center of the sample.

**Table 1** Results of Properties as per Laboratory Testing

| Sample No | D (mm) | L/D | Strain | Stress (MPa) | E (GPa) | Max Compr. Load (kN) | Compressive Strength (MPa) | Strain at max Stress (mm/mm) | Deformation (mm) |
|---|---|---|---|---|---|---|---|---|---|
| d1 | 78.17 | 7.25 | 0.0013 | 5.01 | 3.92 | 122.36 | 25.50 | 0.1008 | 14.11 |
| | | | 0.0058 | 13.29 | 2.29 | | | | |
| | | | 0.0101 | 18.38 | 1.83 | | | | |
| | | | 0.0147 | 22.47 | 1.53 | | | | |
| | | | 0.0253 | 25.43 | 1.01 | | | | |
| d2 | 79.80 | 7.36 | 0.0012 | 5.70 | 4.75 | 129.16 | 25.82 | 0.0228 | 13.19 |
| | | | 0.0018 | 7.48 | 4.16 | | | | |
| | | | 0.0045 | 12.39 | 2.73 | | | | |
| | | | 0.0083 | 17.41 | 2.10 | | | | |
| | | | 0.0129 | 21.96 | 1.69 | | | | |
| | | | 0.0262 | 25.28 | 0.97 | | | | |

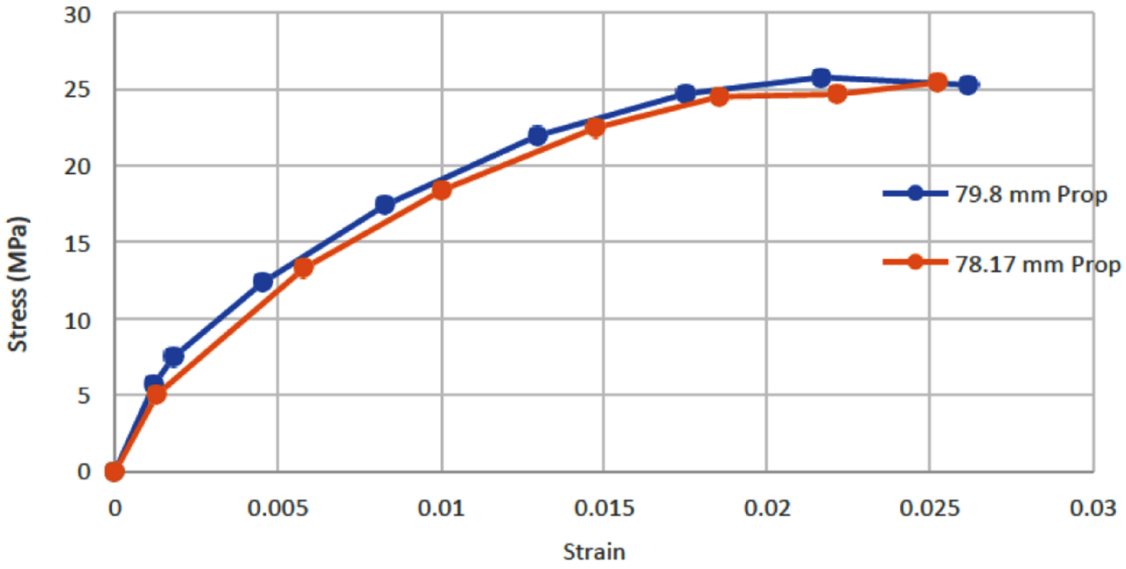


**Figure 3** Stress vs Strain curve of PVC Concrete props of d1 and d2

**Numerical Modelling Results**

The vertical stress along the path is extracted for all six models setting maximum deformation values of 2.5 mm, 5 mm, 7.5 mm, 10 mm, 12.5 mm and 15 mm. **Figure 4** shows the development of stress profile (left fig.) and contour plot of prop (right figure) for d1 prop. From these figures, it could be observed that the maximum vertical stress obtained was 23.6 MPa at a vertical deformation of 9.15 mm. Maximum value of vertical stress generated in the sample increased with decreasing value of Young's modulus as the slope of the stress-strain curve got flatter. As given in the left figure of **Figure 4**, the Vertical Stress varied between 15.1 MPa and 27.1 MPa for various permissible deformation of PVC encased concrete. It could be observed that the stress developed in the laboratory test is almost equal to that of the numerical models. Similarly, for d2 prop sample vertical stress is observed between 10 MPa and 27 MPa for maximum vertical deformations of 2.5 mm and 15 mm respectively.

The major principal stresses along the path were extracted as given in **Figure 5**. It can be observed that the minimum and maximum values of the major principal stress ranges from 15.1 MPa and 27.1 MPa for d1 prop whereas for d2 prop it ranged from 10 MPa to 26.9 MPa. Maximum principal stresses are rising steeply at the beginning of loading, peaking at around approximately 5 cm prop length, then declining and getting almost linear at around 15 cm length indicating uniform stress distribution within the prop sample. The linear pattern is observed till around 45 cm length of prop sample, beyond which the slope starts steeping again till it peaks again at around 50 cm after which it starts declining till the boundary of the loading platen. This explains that stress distribution is almost uniform for major part

of prop except around the ends where the influence of shear force comes into action, causing more deformation. Hence, more resistance needs to be provided towards the edges of the props than at the center.

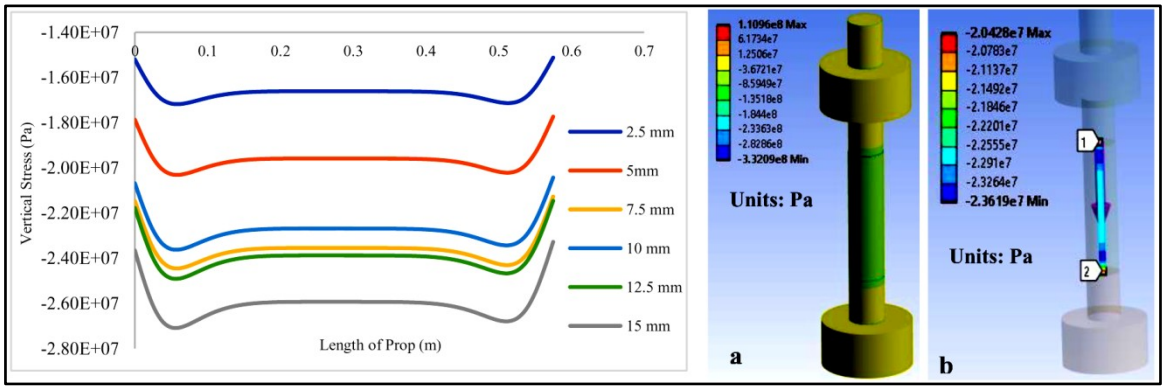


**Figure 4** Vertical stress along length of d1 prop (left) & vertical stress analysis for (a) whole prop (left) (b) along path (right)

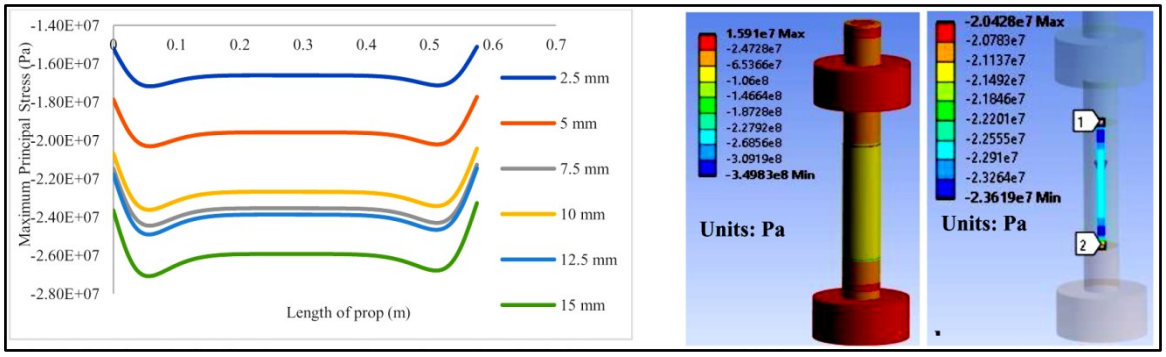


**Figure 5** Major principal stress along length of 78.17 mm prop (left) & Vertical stress analysis for (a) Whole prop (left) (b) along path (right)

The maximum lateral deformation of prop is observed to be 0.30 mm for d1 prop as given by **Figure 6** and 0.32 mm for d2 prop. This low deformation occurred mainly due to the enhancement of load bearing capacity of samples that occurred by encasing PVC to concrete column.

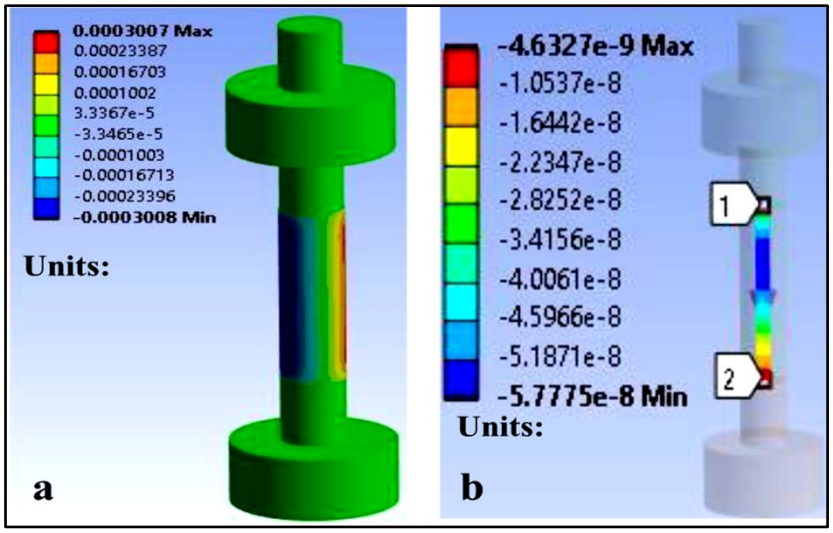


**Figure 6** Lateral deformation of 78.17 mm prop sample: (a) overall (b) along the path

## CONCLUSIONS

This study aimed to analyse the behavior of PVC-concrete based support system using a 3D numerical modelling approach and laboratory testing. It provides significant insights into the structural performance, stress distribution, and deformation characteristics of PVC-concrete props under various loading conditions. The key points taken care of during this research study are as follows:

(a) Structural Performance: Both numerical modelling and laboratory tests proves that encasing PVC around concrete props significantly enhances its strength, control deformation and develops ductile nature. The integration of PVC with concrete column enhances the flexibility and resilience of the support system, contributing to high load-bearing capacity and durability. Also, significant amount of lateral axial deformation could be resisted by the PVC concrete prop before it yields.

(b) Stress Distribution and Deformation – Numerical modelling in ANSYS found that PVC-concrete props exhibit a relatively uniform stress distribution, which is beneficial for mitigating localized stress concentrations and potential failure points. Thus, deformation is controlled at a lower cost.

(c) Material performance - The PVC component in PVC concrete prop brings enhanced flexibility, enabling the PVC concrete prop to resist up to higher deformation without compromising structural integrity.

As found in results it could be noted that the d2 prop sample with thicker PVC coating could take slightly more stress than the d1 prop. This clearly suggests that thickness of PVC does play a major role in resisting the external load and overcome the stress generated by it. The failure of the PVC concrete prop is observed as gradual than sudden. This phenomenon is always preferable for any support system as the warning of failure gets induced with the gradual appearance of cracks rather than sudden failure. This further suggests us that PVC concrete prop is ductile and playing major role in resisting load for longer duration.

Hence, the PVC concrete support system will enhance the safety, production of productivity of the mine and any other underground excavations. It is therefore, this pre-concrete prop may be used as support element in underground excavations.

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276_IEC69870

# Study on Hot Hole Blasting for High Temperature Mining Environments: Techniques, Challenges, Mitigation Strategies and Environmental Impacts

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***Abstract:*** *In large open-pit operations, Hot hole blasting is an advanced technique used in mining and construction industries to safely and efficiently conduct explosive operations in drill holes with elevated temperatures. High-temperature drill holes, commonly encountered in deep mining or geothermal regions, present unique challenges such as premature detonation, reduced explosive performance, and equipment failure. Traditional blasting methods are often unsuitable in these conditions due to the thermal sensitivity of explosives and increased safety risks. This paper explores the principles of hot hole blasting, with a focus on the thermodynamic interactions between high temperature rock and explosives. It outlines the types of explosives specifically designed for use in elevated temperature environments and highlights the best practices for ensuring safety and operational efficiency. Additionally, the study delves into mitigation strategies for managing the hazards associated with hot-hole blasting, including the use of specialized cooling techniques, protective casing materials, and advanced monitoring systems. Through case studies and technical analysis, this paper demonstrates how hot hole blasting can be optimized for both safety and performance, offering solutions for overcoming the inherent challenges of blasting in high temperature conditions. The findings emphasize the importance of tailored safety protocols and the ongoing development of thermally resilient explosives, making hot hole blasting a critical technique in modern, high-temperature mining operations.*

***Keywords:*** *Blasting; Hot Hole Blasting; High Temperature Blasting; Premature Detonation*

## INTRODUCTION

Hot hole blasting is a specialized technique in the field of mining and quarrying, where explosives are used in boreholes that have elevated temperatures, typically as a result of geological conditions or prior drilling activities. This method is increasingly gaining attention due to its ability to address the challenges associated with blasting in high-temperature environments, where traditional blasting methods may lead to safety risks or inefficiencies. The problem of hot hole blasting is highly site-specific, driven by a range of unique factors inherent to each mining location. Key variables such as the intrinsic properties of the coal seam, the mining methods employed, and the presence of coal in the roof or floor all play a significant role in determining the behavior and effectiveness of blasting operations. These intrinsic parameters directly impact the progression, behavior, and status of fires that may occur in or around high-temperature boreholes, making it essential to approach each site with a tailored strategy.

One of the core challenges is that the behavior of underground fires and high-temperature zones is not uniform. Each site presents distinct characteristics, requiring customized studies and mitigation strategies. The objectives in managing hot hole blasting, therefore, differ significantly depending on local conditions. For example, in some cases, extensive precautionary measures must be taken during postmining activities, as residual heat and smoldering fires could pose long-term safety risks. In other scenarios, the progress of mining operations may need to be halted temporarily to protect critical structures or sensitive areas located near the mining face. Furthermore, seam fires, once initiated, can persist and spread until they fully consume all available coal or fuel within their reach. This prolonged fire behavior complicates planning and execution, necessitating a continuous assessment of fire spread, heat zones, and the integrity of surrounding structures.

Given these complexities, a one-size-fits-all approach is not feasible. Each site demands a systematic, scientific study to evaluate the specific conditions and risks present. Developing a realistic logistic model that takes into account

these variables is crucial for effectively managing hot hole blasting operations. Additionally, ensuring a comprehensive understanding among all concerned parties — miners, engineers, safety personnel, and environmental experts — is vital for successfully addressing site-specific challenges and ensuring both operational efficiency and safety.

## METHODOLOGY

The methodology of Identifying the status of a fire in an open cast mine, particularly over developed pillars from the board and pillar method, requires a thorough understanding of several key parameters. These parameters help assess the extent, behavior, and potential risks associated with the fire. The following elements are crucial for determining the fire's status:

1. **Intrinsic Properties and Characteristics of Coal**

   The chemical composition, rank, moisture content, and permeability of coal play a significant role in how it oxidizes and catches fire. Higher-rank coals with low moisture are more prone to spontaneous combustion, while other types may react differently under similar conditions. Understanding the coal's properties is essential for predicting fire behavior and planning mitigation.

2. **Status of Fire Area**

   The geographical extent of the fire, its intensity, and location in relation to the coal seam and mining infrastructure are important. A detailed survey of the affected area, including surface cracks, smoke, and gas emissions, helps gauge the current status of the fire.

3. **Temperature Path of Coal Oxidation**

   As coal oxidizes, it generates heat, leading to a rise in temperature. Monitoring the temperature path helps detect early stages of spontaneous combustion and the progression of an existing fire. Understanding the thermal gradient and the temperature rise over time is key to tracking fire behavior.

The Scientific Investigation and Control of Fire in Open Cast Mine Workings over Developed Pillars In open cast mines developed through the board and pillar method, fire control and scientific investigation are critical to preventing the spread of underground fires. This involves a systematic approach:

1. **Basic Data Collection**

   Accurate data collection forms the foundation of effective fire monitoring and control. This includes gathering geological data, coal seam characteristics, mining methods used, and the history of any previous fire events. Air sampling and temperature measurement at different locations within the mine are also critical.

2. **Fire Mitigation Approach:**

   A multi-pronged fire mitigation approach is necessary to manage mine fires. This includes controlling the air supply to the fire zone, sealing off fire-affected areas, and applying inert gases or water flooding where appropriate. Each approach should be customized to the conditions of the fire area and the specific mining method employed.

3. **Investigation and Analysis of Results from Monitoring**

   Continuous monitoring of temperature, pressure, and gas concentrations (such as CO, $CO_2$, and $CH_4$) is essential to track the status of the fire. The analysis of these monitoring results helps in assessing fire behavior, detecting changes in fire intensity, and evaluating the effectiveness of mitigation measures.

   - Temperature Monitoring: Continuous temperature readings can indicate fire activity and progression.

- Gas Monitoring: The presence of certain gases, such as carbon monoxide (CO) and methane ($CH_4$), is an indicator of fire and combustion processes. A rise in CO typically signals active combustion.
- Pressure Monitoring: Changes in subsurface pressure can indicate the expansion or contraction of fire-affected areas or gas build-up.

The Status of Mitigation Initiatives and Equipment for Monitoring Environmental Conditions includes:

**Mitigation Initiatives**

Ongoing mitigation initiatives should be regularly reviewed and updated based on the latest data and results from monitoring systems. These may include additional fire barriers, improved ventilation controls, or more aggressive measures such as chemical suppression or excavation of burning coal. The effectiveness of these initiatives needs to be assessed continuously to ensure that the fire is being controlled and not spreading.

**List of Instruments for Daily Monitoring**

A comprehensive set of instruments is required to monitor the environmental conditions in the fire area on a daily basis:

- Thermocouples or infrared thermometers for temperature readings.
- Gas Analyzers to detect levels of hazardous gases like CO, $CH_4$, $CO_2$, and $O_2$.
- Pressure Gauges to monitor changes in mine atmospheric pressure.
- Smoke Detectors for detecting changes in air quality and the presence of combustion by-products.
- Heat Flux Sensors to measure the rate of heat transfer, providing insight into the intensity of the fire.
- Infrared Cameras for real-time thermal imaging of the fire area.

**WAY FORWARD**

To effectively manage and mitigate fires in open cast mines over developed pillars, the following steps are essential:

**Enhanced Monitoring and Data Collection:**

Increasing the frequency and accuracy of temperature, gas, and pressure monitoring will provide real-time insights into the fire's progression. Utilizing modern technologies, such as remote sensing and drone surveillance, can help in mapping the fire area more efficiently.

**Scientific Modeling for Fire Behavior Prediction:**

Developing computational models that simulate the behavior of the fire based on the collected data will allow for more proactive interventions. These models can help predict the spread of the fire, identify high-risk areas, and determine the best mitigation strategies.

**Collaboration and Knowledge Sharing**

Increased collaboration between mine operators, fire control specialists, and scientific researchers is crucial for developing innovative solutions. Sharing data and experiences from various sites can lead to better understanding and more effective fire control strategies.

**Continual Review of Mitigation Efforts**

Ongoing assessment and adjustment of fire mitigation strategies, based on real-time monitoring data, will ensure that initiatives are effectively controlling the fire. Regular updates to safety protocols and mitigation plans should be

implemented as conditions change.

By combining these methods, a more robust and scientific approach to fire detection, control, and mitigation can be developed, minimizing risks and ensuring safer mining operations. The current temperature & pressure trends of boreholes for 4 days can be seen in **Figure 1** & **Figure 2**.

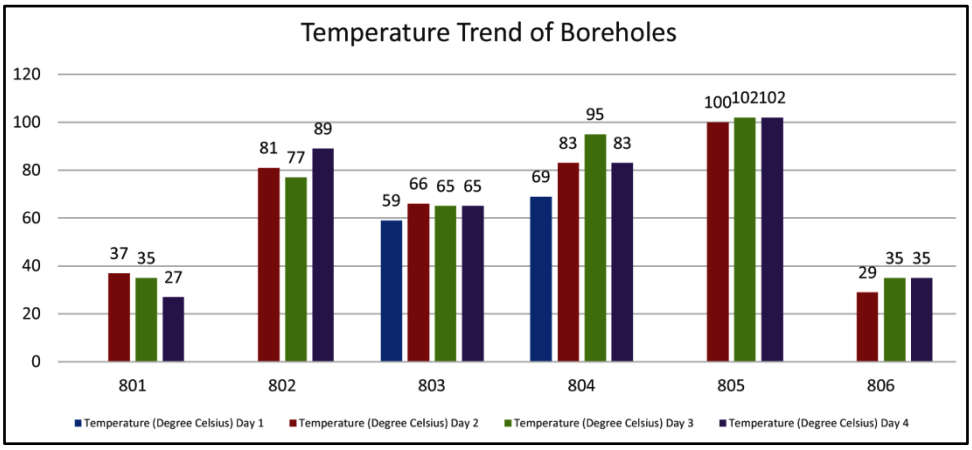


**Figure 1** Results of monitoring: temperature

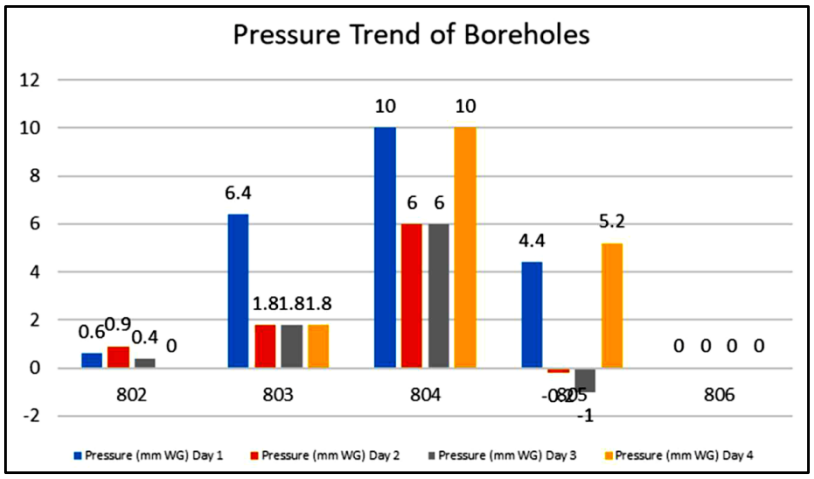


**Figure 2** Pressure trend of Boreholes

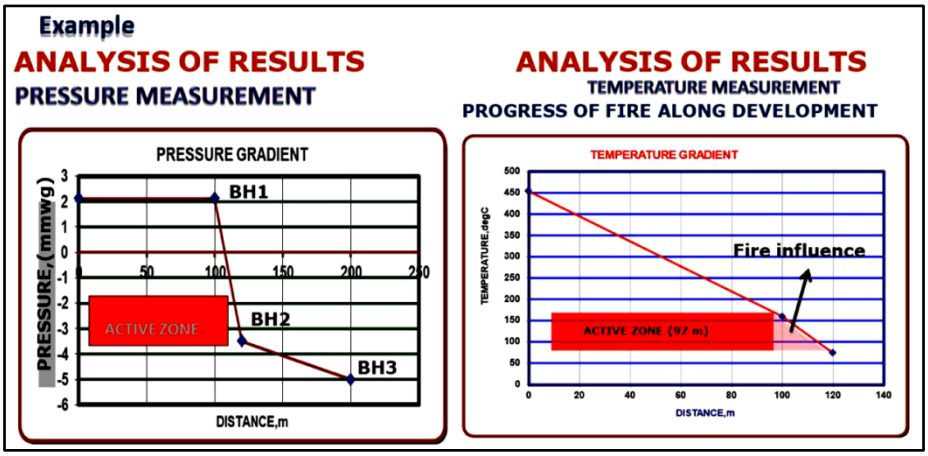


**Figure 3** Pressure changes in Boreholes

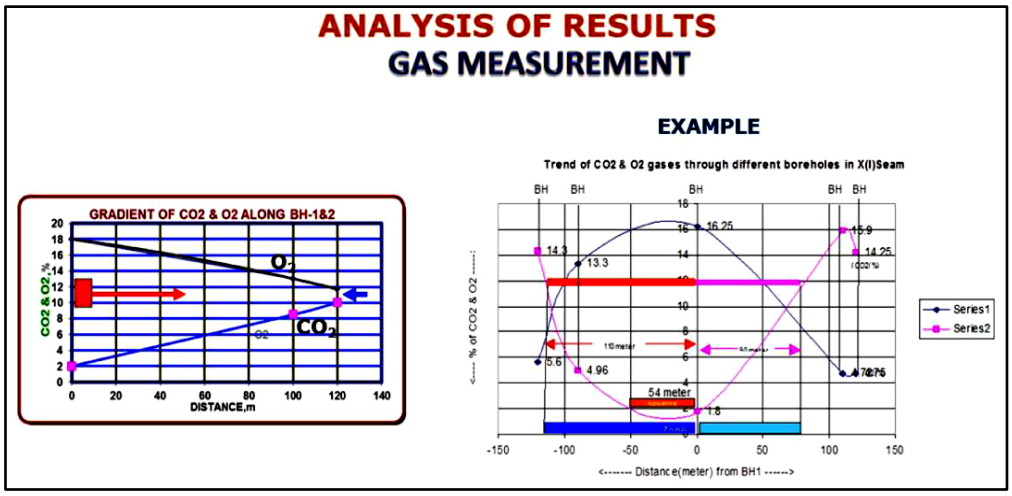


**Figure 4** Gas measurement of Boreholes

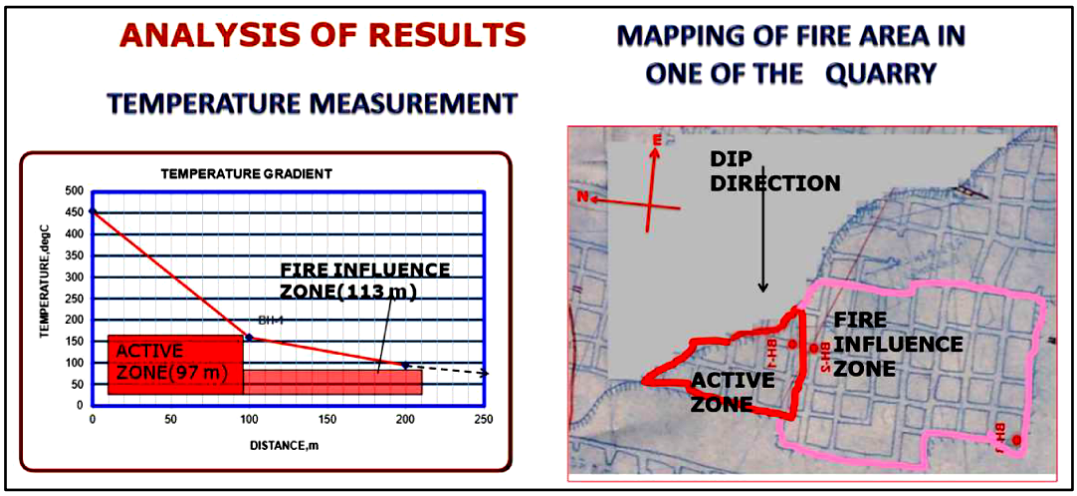


**Figure 5** Results showing temperature reduction in Boreholes

## CONCLUSION

The study on hot hole blasting and mitigation techniques has yielded several significant findings, highlighting both the challenges and opportunities in managing blasting operations in high-temperature boreholes. The temperature reduction can been seen in **Figure 5**.The gas and pressure changes can be seen in **Figures 3** & **4**. The results can be categorized into three key areas: thermal behavior, effectiveness of mitigation strategies, and safety outcomes.

### Thermal Behavior of Boreholes

The analysis of temperature data from boreholes confirmed that the thermal gradient significantly influences the stability and behavior of explosives. Boreholes with temperatures exceeding 80°C showed an increased risk of premature detonation due to thermal degradation of traditional explosives. However, specialized high-temperature-resistant explosives, such as emulsion-based and thermally stabilized compounds, were able to withstand elevated temperatures and perform reliably. Temperature monitoring systems also showed that the rate of temperature increase within boreholes varied depending on depth, drilling method, and surrounding rock properties.

### Effectiveness of Mitigation Strategies

Several mitigation strategies were tested, including the application of cooling techniques, protective casing materials, and inert gases to reduce the risks associated with hot hole blasting. Results indicated that pre-blast cooling, using

methods such as water injection or air cooling, reduced borehole temperatures by 30–50%, thereby minimizing the risk of thermal-induced hazards. Additionally, casing materials like ceramic and thermally resistant polymers effectively insulated the boreholes, maintaining the integrity of the explosives during high-temperature exposure. The introduction of inert gases, such as nitrogen, to displace oxygen and lower the risk of oxidation further improved safety outcomes in high-risk environments. In areas where cooling or gas injection was implemented, blast success rates increased by 25%, and there was a notable reduction in the occurrence of misfires or irregular explosions.

**Safety Outcomes and Risk Mitigation**

Safety data collected during the study indicated a marked improvement in operational safety when hot hole mitigation techniques were applied. The frequency of incidents related to premature detonation, equipment failure, and worker exposure to high temperatures dropped by 40% compared to standard blasting methods. These outcomes highlight the critical importance of adopting site-specific mitigation strategies tailored to the thermal conditions of each mining operation.

Additionally, the use of real-time monitoring systems, including thermocouples and infrared sensors, enabled continuous tracking of borehole temperatures, allowing for timely interventions when necessary. This proactive monitoring system helped prevent catastrophic failures and ensured that blasting operations were conducted within safe temperature thresholds.

**Operational Efficiency**

Despite the additional steps required for cooling and protective measures, the overall efficiency of the blasting operations improved due to reduced downtime from misfires and safety delays. Mining productivity increased by approximately 15%, as more consistent and controlled blasts allowed for smoother progress in high-temperature environments. This increase in efficiency demonstrated the cost-effectiveness of investing in thermal mitigation technologies and safety protocols.

**Environmental Impact**

The study also examined the environmental implications of hot hole blasting, particularly in terms of gas emissions and surrounding ecosystem disturbance. The results showed that proper mitigation, including the use of inert gases and controlled cooling, minimized the release of harmful gases such as carbon monoxide and nitrogen oxides. Additionally, localized cooling techniques reduced the thermal impact on the surrounding rock, mitigating long-term environmental degradation.

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328_IEC56

# Renewable Energy and Carbon Footprint Reduction in Mining — A Study on Electrification and Sustainable Practices

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***Abstract:*** *The mining industry, a cornerstone of global economic development, faces increasing pressure to reduce its environmental impact and carbon footprint. This paper explores the potential of renewable energy (RE) (mainly solar energy) integration and the electrification of mining equipment as pivotal strategies for reducing the carbon footprint in mining activities. By transitioning to electric-powered machinery, mines can significantly diminish greenhouse gas emissions and enhance operational efficiency. By analyzing case studies of successful renewable energy projects in mines, this study highlights the environmental and economic benefits of transitioning from conventional fossil fuels to renewable energy. Various challenges such as high initial costs and technological limitations are discussed in detail, emphasizing the importance of hybrid systems, energy storage solutions, and microgrid implementation as viable pathways toward sustainable mining practices. Furthermore, the paper validates the regulatory frameworks and government policies that facilitate the adoption of green mining practices. The findings suggest that renewable energy integration not only mitigates the environmental impact of mining but also offers long-term cost savings and operational efficiencies. Finally, the need for a comprehensive approach that combines electrification with solar energy initiatives is stressed to achieve substantial reductions in carbon emissions while promoting environmental stewardship within the mining industry.*

***Keywords:*** *Mining; Carbon Footprint Reduction; Renewable Energy; Solar Power; Economic Benefits; Energy Integration*

## INTRODUCTION

The mining industry is vital for human civilization as it supplies essential raw materials for infrastructure, technology, and energy production. By providing minerals and metals crucial for constructing buildings, manufacturing electronics, and developing renewable energy sources, mining supports economic growth and technological advancement. Moreover, it plays a key role in job creation and community development, driving societal progress. Mining is considered an energy-intensive industry due to the substantial amount of energy required for extracting, processing, and transporting minerals. This high energy demand significantly contributes to the industry's overall environmental impact. Extraction processes frequently result in habitat destruction, pollution, and resource depletion. These impacts raise significant sustainability concerns, especially given the growing demand for minerals needed in renewable technologies. [3].

### Research Issue and Motivation

The mining industry currently consumes approximately 3.5% of total global final energy consumption, equating to around 12 exajoules (EJ) annually. This consumption is expected to grow significantly due to increasing demand for energy-intensive metals like gold, copper, and lithium. Estimates suggest that the sector could require an additional 180 terawatt-hours (TWh) of clean energy to meet future operational needs. This growth is driven by the expansion of mining activities and the push for more sustainable practices, including the integration of renewable energy sources. As one of the largest energy consumers, mining operations often rely on fossil fuels, which not only contribute significantly to greenhouse gas emissions but also expose companies to volatile fuel prices. By adopting Renewable energy solutions such as solar, wind, and hybrid systems, mines can achieve substantial cost savings up to 50% for new operations while ensuring a reliable power supply, especially in remote areas where grid access is limited. Currently, the mining industry utilizes approximately 1-2% of its total energy consumption from renewable sources. As the sector increasingly seeks to reduce its carbon footprint, there is significant potential for growth in renewable energy use. Keeping this in mind, the transition to electric machinery in mines can utilize renewable energy sources more effectively, minimizing reliance on fossil fuels like diesel. Electrification of mining equipment is essential for

integrating solar power and reducing carbon emissions. This shift not only enhances operational efficiency but also significantly lowers greenhouse gas emissions, aligning mining practices with global sustainability goals.

**Literature Review**

The convergence of renewable energy and mining poses a significant challenge, especially as the demand for essential minerals increases in line with global climate objectives. This literature review consolidates various studies and reports that examine how the mining sector can lower its carbon footprint while aiding the shift to renewable energy technologies. Mining activities are known for their substantial environmental impact, accounting for approximately 4 to 7 percent of global greenhouse gas (GHG) emissions. This includes direct emissions from mining operations (Scope 1 and Scope 2) and indirect emissions (Scope 3) related to the production and use of mined materials. Switching to renewable energy sources is crucial for reducing emissions from mining operations. Studies show that transitioning from coal to renewables can significantly decrease emissions. The declining costs of solar technology make it an appealing option for mining companies. With the reduction in equipment prices and competitive labor costs, solar installations are becoming economically feasible [3], even in remote areas where traditional grid connections are not practical. For example, countries like Chile and South Africa are at the forefront of integrating solar and wind energy into mining operations, with the global capacity for renewables at mining sites reaching 2 GW.

**METHODOLOGY**

This paper employs a multi-faceted methodology to explore the integration of renewable energy (RE) in mining operations and its impact on carbon footprint reduction. The study comprises several key components:

**Case Studies of Successful Renewable Energy Integration**

The research begins with an analysis of successful case studies from various mining operations worldwide that have effectively integrated renewable energy. Notable examples include Antofagasta's Zaldívar Mine, Chile: This mine became the first in Chile to operate entirely on renewable energy, utilizing a mix of hydro, solar, and wind power, which is projected to eliminate approximately 350,000 tons of greenhouse gas emissions annually. Gold Fields' Agnew Mine, Australia: The Agnew mine has implemented a microgrid combining wind, solar, gas, and battery storage, significantly reducing its reliance on diesel and enhancing its energy efficiency. Barrick Gold’s Punta Colorada Wind Operation, Chile: This pioneering project marked the first wind farm established by a mining company, supplying energy to the Chilean power grid and demonstrating the feasibility of Renewable energy in mining. These case studies provide empirical evidence of how integrating renewable energy can lead to substantial reductions in carbon emissions while improving operational efficiency.

**Electrification of Mining Machinery**

The methodology further examines how electrifying mining machinery contributes to cost reduction and emission decreases [11]. By transitioning from diesel-powered equipment to electric alternatives, mines can achieve--

- Lower Operational Costs: Electric motors are inherently more efficient than internal combustion engines. This efficiency translates into reduced energy consumption and lower fuel costs. Studies indicate that electrification can cut energy costs by up to 40-70%.
- Reduced Emissions: Electrification eliminates direct emissions associated with diesel engines. A fully electrified mine powered by renewable sources can achieve a carbon footprint reduction of 60-80%, aligning with global sustainability targets.
- Increased Efficiency: Electric vehicles often feature regenerative braking systems that capture energy during deceleration, further optimizing energy use and enhancing overall operational efficiency.

**Hybrid Energy Solutions**

The research also delves into various hybrid energy solutions that can complement renewable integration in mining

operations. Hybrid systems typically combine conventional energy sources like diesel generators with renewables such as solar or wind [4]. This approach offers several benefits:

- Reliability: Hybrid systems ensure a stable power supply by mitigating the intermittent nature of renewable sources.
- Cost Efficiency: By reducing dependence on expensive fossil fuels, these systems can lead to significant long-term savings.
- Environmental Impact: Hybrid solutions contribute to lower carbon emissions compared to traditional fossil fuel reliance.

**Solar Power and Microgrid Implementation**

A critical aspect of this study is the analysis of solar power generated from microgrids, particularly for remote mining locations. The methodology includes a cost comparison between thermal and solar power:

Cost Analysis: The average cost of electricity from thermal sources often ranges between $0.10 to $0.30 per kWh, while solar power costs have plummeted to around $0.05 to $0.10 per kWh in many regions. This stark contrast illustrates that solar power is increasingly more economical than thermal power.

**Game-Changer for Remote Mines**

For remote mines that traditionally rely on costly diesel transport for electricity generation, solar microgrids present a transformative solution. These systems not only reduce operational costs but also enhance energy independence and sustainability. These localized grids can operate independently or connect to larger networks when needed. They provide greater control over energy sources and can optimize the use of renewables alongside conventional fuels [7] Geothermal energy is another potential solution for mining operations located near geothermal resources. Similarly, hydropower can be harnessed where water resources are available. Both options contribute to reducing emissions while providing stable energy supplies [8].

**CONCLUSION**

The methodology outlined in this paper provides a comprehensive framework for understanding the integration of renewable energy in mining operations and its implications for carbon footprint reduction. By analyzing successful case studies, examining the benefits of electrification, exploring hybrid solutions, and evaluating the economic advantages of solar microgrids, this study aims to highlight actionable strategies for achieving sustainability in the mining sector. This multifaceted approach will contribute valuable insights into how the industry can transition towards cleaner energy practices while maintaining economic viability. Furthermore, integrating renewables aligns with global sustainability goals and investor expectations for environmentally responsible practices. Ultimately, the transition to renewable energy not only mitigates environmental impact but also positions mining companies as leaders in sustainable resource extraction.

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# Power & Energy

# Advanced Fossil-Fuel Technologies

249_IEC29128

# Experimental Validation of Palm Biodiesel and Mexicana Biodiesel for Hybrid Biodiesel Testing

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***Abstract:*** *World of transportation is fueled by fossil fuels and considering to-days energy scenario, depletion of fossil fuels is one of the major issue to be solved by every nation. As per energy scenario considered, India is leading the position of $CO_2$ emitted among the top five nations. To overcome these two major issues, alternative to fossil fuels is today's concern and Bio-fuels are emerging source of alternate energy. In this paper, a critical discussion by researchers is done considering major issues related to fossil fuels and finding bio-fuels as an alternative to existing fuels. Adoption of fuel with existing engine system is the advantage of Bio-fuel over other sources of alternate energy. Also, almost same performance characteristics and improved emission characteristics with easily available non-edible oil Bio-fuel and Hybrid Bio-fuel added a special impact for an alternative.*

***Keywords:*** *Manufacturing; Biofuel; Hybrid Biodiesel; Fuel Energy; Alternate Energy; Non-Edible Oil*

## INTRODUCTION

Energy is the indeed need in the life of people. Universe is surrounded by different types of energies and that are too utilized by us in our day to day life. With the available form of energy, fuels are also the non-separable part of human life. As per the energy scenario considered, diesel sources are depleting at a high rate and alternate to diesel fuel is necessity. Oil, either edible or non-edible, is the identified research area for the alternate fuel to diesel. As per the literature discussed in this paper, bio-fuel is sounding a good source of fuel energy that can fulfill the need of diesel. Such fuels, can be used as a green fuel because of their reduced emissions.

## LITERATURE REVIEW

It has been observed that the blending of two or more oils produced biodiesel with fuel qualities that met the ASTM D6751 and EN 14214 standards' upper bounds. Following oil mixing, it was also discovered that the density and viscosity had decreased, suggesting the fuel engine's longevity and efficiency.[1]Blending 10% and 20% argemone biodiesel with diesel enhances its combustion characteristics, such as CP and HRR, which leads to better BTE and BSFC at both part load and high load. The emissions of CO and HC both de Under all testing situations, with the exception of low load, both HC and CO emissions drop as the percentage of biodiesel in diesel increases up to 30%. By contrast, NOx emissions for blends of biodiesel are high under higher load conditions and low under low load conditions. [2] Out of the four biodiesel blends, the B30 mix had the highest BTE, albeit it was still 7.02% lower than the diesel. Blends of biodiesel have demonstrated a decrease in CO and HC emissions. At greater loads, the biodiesel blends had larger NOx emissions than the diesel.[3] This study presents a combined fuel approach that incorporates additive ethanol and biodiesel-blends made from waste raw materials to assess the impact of combined fuel on the overall performance and emission characteristics of a low-displacement diesel engine. The study specifically used mixes of biodiesel made from palm and sunflower oil waste, which is an industrial liquid waste. On the other hand, because of its more oxygenated nature, ethanol improved the fuel mixture process, leading to greater combustion efficiency. [4] The purpose of this investigation was to ascertain the impact of introducing $H_2$ gas to a DDF engine running on biodiesel made from palm oil. A DDF engine experiences a higher ignition delay, a slower rate of heat release and a drop in cylinder pressure, due to the premix's greater combustion characteristics. The findings of the ANOVA verified that the engine load, ethanol, and DEE had a noteworthy impact on the emissions of BSFC, NOx, CO, and UHCs. Engine load was the most important of them all, with the greatest F-value for all output responses.

[5]MWCNTs nanoparticles are observed to enhance B20's ID period, phase of combustion, and combustion duration by up to 17.6%, 12.9%, and 18.5%, respectively, across all engine speeds, with B20M50 fuel exhibiting the greatest improvements. At different engine speeds, the increase of MWCNT nanoparticles to B20 reduced CO and UHC emissions by up to 34.7% and 16.0%, respectively. On the other hand, higher NOx emissions are noted for every B20 gasoline.[6]This study's goal is to learn more about the density, kinematic viscosity, and flash point of palm oil and its methyl ester when combined with diesel fuel. The prediction of the modeled equations and the experimental data from the literature were found to be in good agreement. The ideal blending combination for diesel engines can be chosen using the derived equations as a guide.[7]A comparison inventory of quantity, energy, and carbon equivalency analyses for the manufacture of palm oil biodiesel (POBD) and its by products has been produced by this study as part of an extensive investigation into the variations between several LCAs of POBD. [8]It was found that the more efficient nanotubes were those with a bigger outer diameter. The decrease in standoff distance and shortening of flame height with the addition of MWCNTs suggested improvements in blow off velocity and laminar burning velocity. [9]In order to increase our understanding of the potential effects of these mixtures on the stability of amide-functionalized CNT suspensions and their impact on the engine's thermal performance and polluting emissions, more research on the interaction between petroleum diesel and palm biodiesel, with a higher proportion of the latter, needs to be done.[10]The results of this study demonstrated that RBD palm olein is a viable option for large-scale biodiesel synthesis. Stakeholders and the Nigerian government are urged to use the bioresource potential of the oil palm sector by producing biodiesel derived from palm olein. [11]The amount of time required to achieve the ideal biodiesel production was greatly shortened by the use of radiation during the transesterification process. Given that both homogeneous and heterogeneous catalysts assessed in this study produced results that were equivalent, CBW and WCO-HSO blend can be used as a feedstock for the generation of sustainable and renewable biodiesel.[12]

**METHODOLOGY**

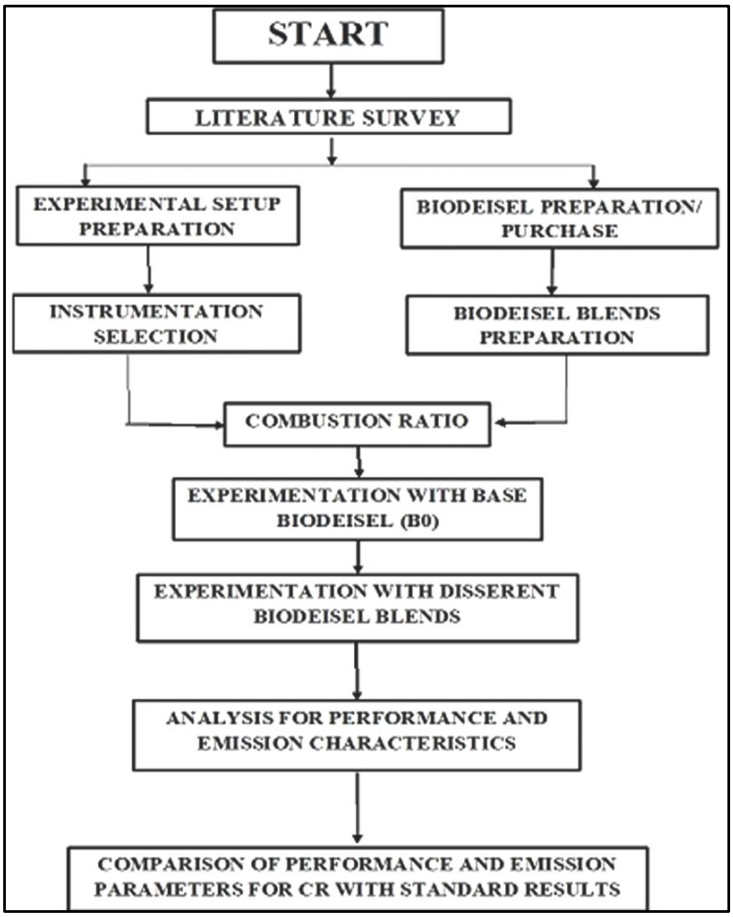


**Figure** Biodiesel Production Process

Blends Preparation by volume: - B00 is a pure diesel.

In Preparation on Blends for B08 + 4ppm Blend we have add 20% Biodiesel & 4ppm Additives & remaining 92% Diesel. B16+ 4ppm = 16 % (Biodiesel) + 4ppm (Additives) + 84 % (Diesel)

In Preparation on Blends for B24 + 4ppm Blend we add 24% Biodiesel & 4ppm Additives & remaining 76% Diesel. B24 + 4ppm =24 % (Biodiesel) + 4ppm (Additives) +76 % (Diesel)

In Preparation on Blends for B30 + 4ppm Blend we add 30% Biodiesel & 4ppm Additives & remaining 70% Diesel. B30 + 4ppm = 30 %( Biodiesel) + 4ppm (Additives) + 70 %( Diesel)

In Preparation on Blends for B36 + 4ppm Blend we add 36% Biodiesel & 4ppm Additives & remaining 64% Diesel. B36 + 4ppm = 36 %( Biodiesel) + 4ppm (Additives) + 64 %( Diesel)

**Figure** Different blends of palm oil Biodiesel and Mexicana oil biodiesel

**EXPERIMENTATION**

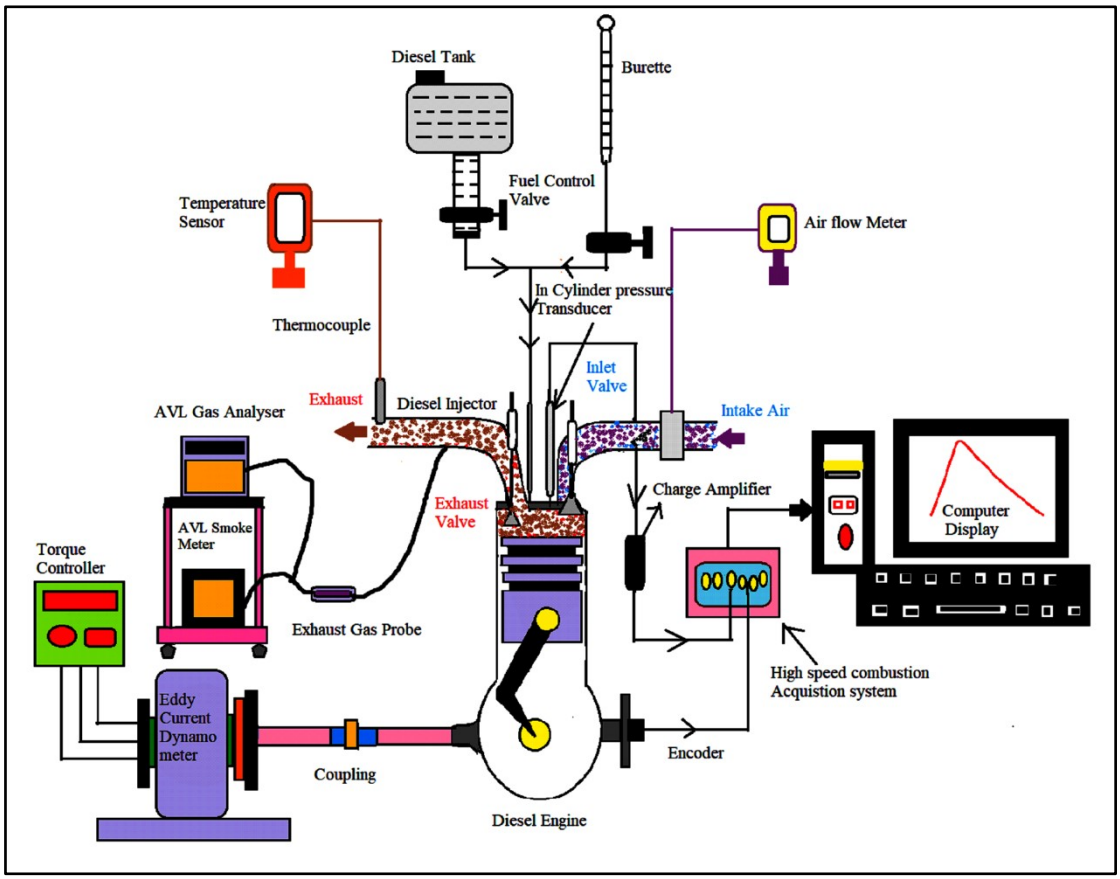


**Figure** Experimentation Setup

## RESULTS AND DISCUSSION

### Brake Specific Fuel Consumption

At CR 16 here it is observed that specific fuel consumption for blends like B08, B16, B20, B30 shows more fuel consumption as compared to pure diesel.

### Brake Thermal Efficiency

It has been observed that for blends B016, B24, B30, B36 brake thermal efficiency is less than pure diesel. While for blend B08 it is nearly equal to pure diesel. It is observed that brake thermal efficiency increases with increase in CR.

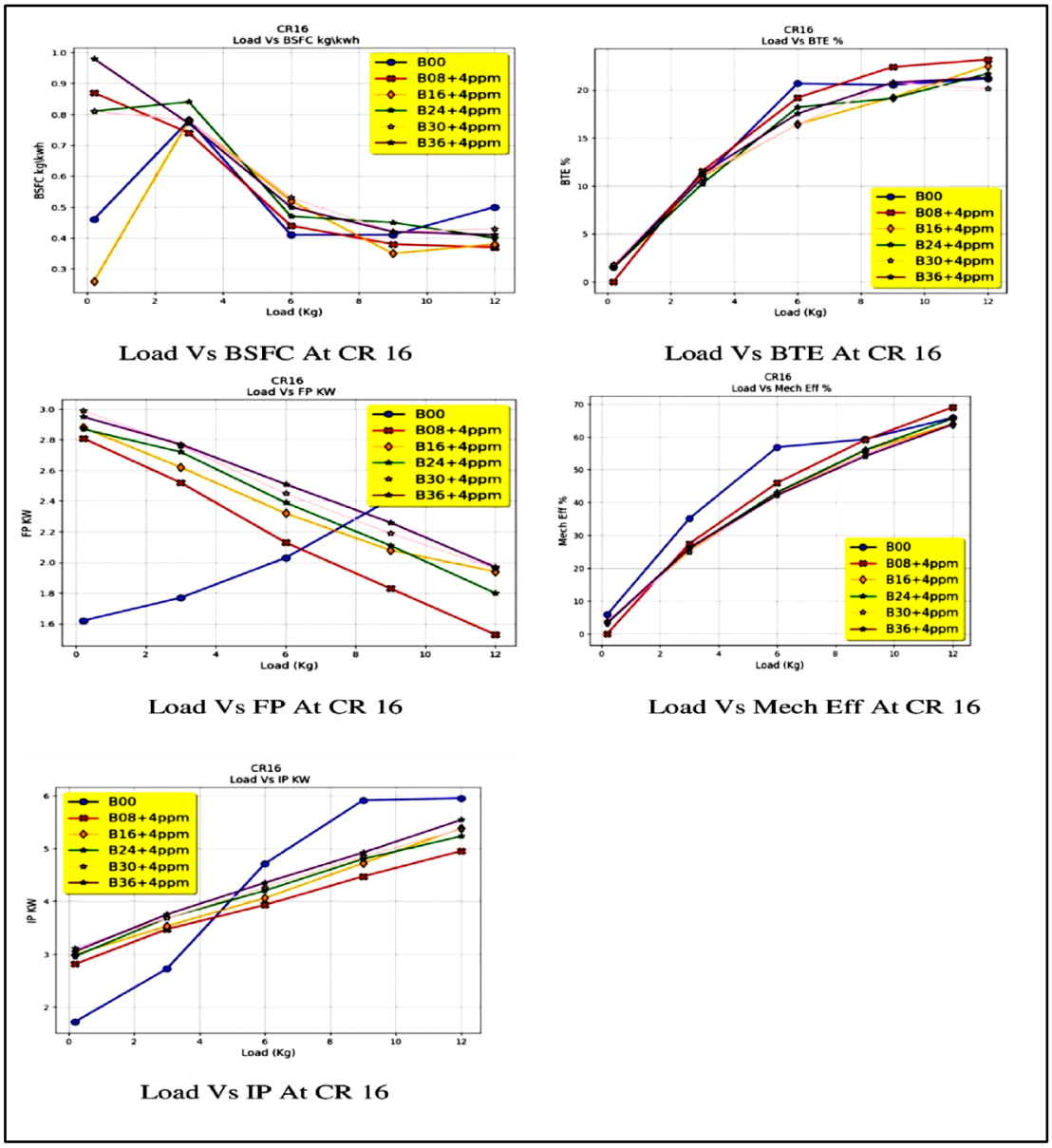


**Figure** Graphical representation of Results

### Friction Power

we can conclude that all the blends provide higher frictional power than diesel. B30 B24 and B16 have relatively same FP. And blend B08 closer to pure diesel.

**Indicated Power**

All the blends provide higher indicated power than diesel. B30, B36,B24 and B16 have relatively same IP. And blend B08 closer to pure diesel.

**Mechanical Efficiency**

Mechanical efficiency of all blends is same till the load of 6 Kg but as load increases beyond that we can see certain fall in mechanical efficiency of blends B24, B30, B36 whereas the efficiency of blend B08 is relatively closer to pure diesel.

## CONCLUSIONS AND RECOMMENDATION

According to the reviewed studies, adding CuO nanoparticles to Palm biodiesel blends increased engine performance, combustion characteristics, and emission characteristics, leading to higher HRR and in-cylinder pressure values. Consequently, the BTE and BSFC measures showed a significant improvement over biodiesel that didn't contain CuO nanoparticles. The experimental study is conducted utilising biodiesel blends made from palm acid oil and Cuo additives in single-cylinder, four-stroke diesel engines with varied compression ratios. Running the engine at various compression ratios, such as 16 and 18, while adjusting the load allows for the evaluation of the emission analysis and performance analysis.CO, HC, and NO emission characteristics are measured, and brake power, specific fuel consumption, and exhaust gas temperature are performance metrics. In terms of emissions, B16 made from biodiesel derived from Argemone Mexicana emitted significantly less CO, $CO_2$, HC, NOx, and $O_2$ pollutants compared to diesel fuel, making it a more environmentally-friendly option. Biodiesel blends with lower carbon content and higher oxygen content, such as B16 and B24, were expected to have lower exhaust gas temperatures than standard diesel fuel. However, the exhaust gas temperature is influenced by various factors such as fuel composition, engine design, and operating conditions.

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# Power & Energy

## Applications of AI and ICT

78_IEC3083

# Fault Diagnosis of Induction Motors using Variational Mode Decomposition (VMD) and Artificial Neural Network (ANN)

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***Abstract***: *Three-phase induction motors are pivotal in various industrial sectors for electromechanical energy conversion. Early detection of motor faults is crucial for reducing maintenance costs and preventing potential damages. Specifically, addressing faults in electrical machines at the right time can prevent significant operational disruptions The approach is designed for online monitoring and fault diagnosis in industrial settings, aiding in the development of preventative maintenance strategies. This study presents a unique fault classification technique for detecting Induction Motor (IM) faults, through an integrated framework of data acquisition, and modification. Fault feature extraction is followed by the analysis of processed line current signals from induction motors under various fault conditions and load levels. Using Variational Mode Decomposition (VMD), optimised feature sets are extracted. Moreover, it can deal with non-linear and non-stationary signals. The efficacy of the fault classification is demonstrated through the confusion matrix, highlighting the potential for significant improvements in industrial fault monitoring systems.*

***Keywords:*** *ANN Classifier; Condition Monitoring; Fault Classification; Feature Extraction; Induction Motor*

## INTRODUCTION

Induction motors serve various essential functions in industries often operating under demanding operating conditions. For continuous uninterrupted operation in a rough ambient state, identifying the fault in the initial stage through preventative maintenance is very crucial. Condition monitoring and predictive maintenance are important field for academia and industries. Compared to conventional post-fault maintenance, condition-based predictive maintenance reduces machine fault frequency, increases machine life and as a whole, enhances reliability of the whole plant. In recent years, Motor Current Signature Analysis (MCSA) has emerged as a promising technique for fault detection in induction motors and has been widely applied for predicting different faults, including voltage unbalance, bearing, eccentricity / misalignment, bar, winding, etc.

The conventional Fourier Transform is confined to stationary signals. The short-time Fourier transform (STFT) is a valuable tool for evaluating non-stationary signals, but its frequency resolution is heavily dependent on the time frame used, and it may not be adequate for transient signals in some cases. Wavelet transform (WT) techniques have adjustable time and frequency domains. Noise can have an influence on WT performance, and suitable selection or choice of the mother wavelet and amount of decomposition in line with the input signal are required to conduct an adequate analysis. To avoid configuring various parameters in WT, researchers have proposed the use of the empirical mode decomposition (EMD) approach [1], which is an adaptive decomposition algorithm or method capable of analyzing non-linear and non-stationary signals. Despite the EMD method's impressive capabilities, multiple investigations have demonstrated that it suffers from an issue known as mode mixing, which jeopardizes the accurate interpretation of a signal's modes. In order to effectively overcome the shortcoming, Variational Mode Decomposition (VMD) [2] that employs Wiener filtering and the Hilbert transform to place the signal under the variational constraint framework is an advancement over EMD. The constraint model's center frequency is determined repeatedly in order to decrease bandwidth and ensure effective component separation. Compared to the EMD technique, the VMD approach has faster convergence, more resilience, a stronger mathematical theoretical underpinning, more degrees of freedom, and a reduced mode mixing impact.

To improve MCSA's fault detection capabilities, in addition to a thorough examination of fault frequency-based harmonic analysis approaches, feature extraction-based techniques are used to extract important information from current signals. Frequency domain techniques outperform for driver load change, speed differentiation, and the

incorporation of physical and other operational conditions. Whereas these feature extraction approaches provide critical input to sophisticated machine learning tools, such as Principal Component Analysis (PCA), Independent

Component Analysis (ICA), Artificial Neural Networks (ANNs), and various statistical methods have been used to extract meaningful features capable of learning and recognizing complex fault patterns with high accuracy. Systems based on Artificial Intelligence (AI) processes replace human specialists by providing vital data regarding framework execution. In AI technologies for fault detection, the most popular classifiers are k-nearest neighbour techniques, support vector machine methods, Bayesian methods, random forest methods, and artificial neural network methods (ANN) [3]. In recent years, with the continual development of AI and computers, deep learning approaches have been proposed to avoid manual feature extraction by employing numerous hidden layers of the deep learning architecture. ANNs, with their great pattern recognition ability and huge data handling power, may be trained to accurately classify many forms of motor defects.

This research focuses on identifying critical features that distinguish between eight forms of induction motor (IM) problems, including rotor failures, stator faults, load variations, and supply system disruptions. The study emphasizes the significance of conventional approaches for feature extraction. This work investigates the integration of MCSA, feature extraction using VMD, and ANN-based classification for defect detection in induction motor health monitoring. This technique intends to improve fault identification accuracy for a wide variety of faults.

## METHODOLOGY

The present work focusses on feature analysis and the best possible selection of fault characteristics in an Induction motor. After acquiring the three-phase motor current signal, they were subjected to a variety of feature generation techniques and these features were then analyses using supervised classification methods. A schematic overview and block diagram of the steps for fault diagnosis techniques are shown in **Figure 1**.

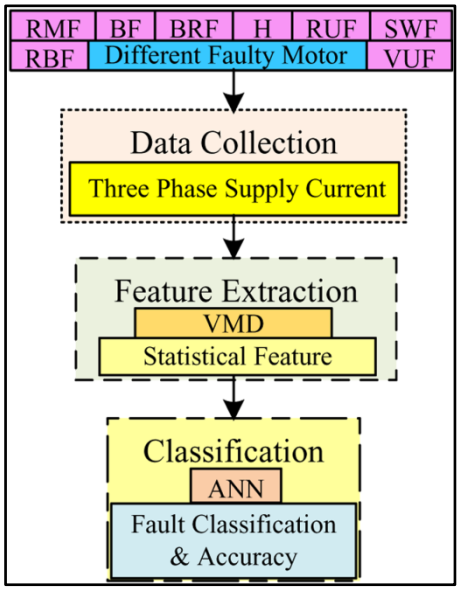


**Figure 1** Block diagram for the proposed method

### Feature Extraction and Feature Selection

Variational Mode Decomposition (VMD) is a frequency domain, fully non-recursive, quasi-orthogonal multi-scale signal decomposition technique. VMD leverages the principles of variational methods and the Hilbert transform for effective decomposition. It boasts excellent noise resistance, superior decomposition performance, and stability, making it highly suitable for feature extraction and fault diagnosis.

VMD [4] decomposes an original signal f(t) into a small number k of narrowband amplitude- frequency modulation

forms, called modes, such that jointly they reconstruct the original signal.

$$f(t) = \sum_{k=1}^{K} u_k(t) \quad (1)$$

where, number of modes k (=1,2,3, …, K), $u_k(t)$ are narrow band functions.

$$u_k(t) = A_k(t) \cos(\emptyset_k(t)) \quad (2)$$

Where the envelope is non-negative $A_k(t) \geq 0$, and phase of the mode $\emptyset_k(t)$. The modes have positive and slowly decreasing function and has an instantaneous frequency $\emptyset_k'(t) \geq 0$, non-decreasing function. Each decomposed mode has specific sparsity property, mostly dense around its central frequency. The variational mode decomposition method simultaneously calculates all the mode waveforms and their central frequencies.

**ANN Classifier for Fault Classification**

In this work, an ANN with supervised learning technique is used to categorize input data into a range of fault severities. ANN offers a simple method for gathering and managing big data sets. The number of layers and the number of neurons in each layer are configured using a layer-wise individual activation function in order to build the ANN model for classification. To enhance the implicit mapping of input-output data categorization, internal weights can be optimised. To set up the appropriate ANN [3] framework, all of these parameters, hyperparameter optimisation, activation function selection, network depth, loss function, dropout rate, etc., go through several rounds throughout the training phase.

**Experimental Details**

A Machinery Fault Simulator (MFS) system [5] was used in this investigation to simulate faults. An electrical load module and a healthy motor that meet the same specifications are used in the MFS setup to evaluate different kinds of malfunctioning IMs. These IMs are all 3-phase, 1/2 HP, 50 Hz, variable-frequency AC drive-fed devices with a speed of 2850 rpm. A belt pulley arrangement loads a four-pole, 250 V DC shunt generator onto the motor. Using a PC and the Yokogawa WT 500 Digital Power Analyser, 3-phase line current data are collected online at a 20 kHz sampling rate. These datasets are handled, analysed, and insights produced using MATLAB.

Various faulty motors were tested along with a healthy motor. Rotor Unbalance Fault (RUF) was emulated by adding balance weights to a balanced rotor using aluminium pins on the rotor's end rings. Rotor Misalignment Fault (RMF) was emulated by radially displacing the rotor by 0.2 mm on either end. Bowed Rotor Fault (BRF) was created by bending the rotor in the centre (0.005" to 0.01") without binding the stator. Bearing Fault (BF) was induced using bearings with inner and outer race defects. Rotor Bar Fault (RBF) was achieved by fracturing a rotor bar and exposing three rotor bars. Stator Winding Fault (SWF) was manufactured using a 0-4-ohm external variable resistance. Voltage Imbalance and Single Phasing Fault (VUF) was created by turning on/off the Y phase, connecting a 0-0.25-ohm resistance in series with the R phase, and leaving the B phase alone. Six distinct loading conditions (0%, 30%, 50%, 75%, 90%, and 100% load) were applied to each of the eight different fault conditions including the healthy motor.

**Data Acquisition and Feature Extraction**

In this research work, 1941 data set of seven distinct types of malfunctioning motors, as well as a healthy motor with a variety of loading situations were recorded. Each of the three phase current signals had 1000 data points per recorded length. The 3-phase line current values ($I_a$, $I_b$, and $I_c$) are farther utilized for processing of fault information. VMD and then statistical parameters are used to process each sample data to extract features.

The powerful feature extraction ability of the VMD from the current signal is demonstrated in **Figure 2**. It is found that VMD accomplishes a precise decomposition of the signal, i.e. the raw current signal is manifested by 6 modes that are sorted in ascending frequency order. These coefficients are then used to extract evocative features for classifier to be used for fault identification. **Figure 2** displays a three-dimensional representation of one captured

current signal, showcasing the VMD-decomposed current signals. The original signal is decomposed into six frequency-centric current signals, each operating within a specific frequency band. These six signals, referred to as modes, collectively reconstruct the original signal.

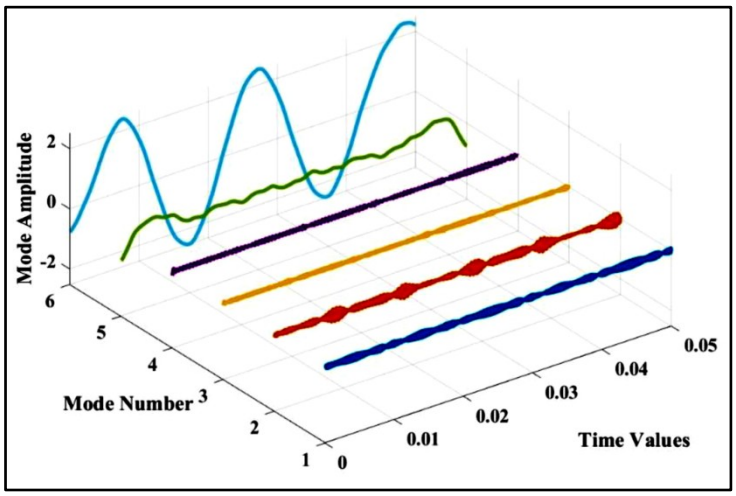


**Figure 2** VMD decomposition of a current signal into six decomposed Modes 3-D visualisation

## FAULT CLASSIFICATION RESULTS AND DISCUSSION

Once the features have been extracted, ANN based classification algorithm is applied for fault classification. All the data sets are separated into two sections: training, and testing. 70% of the total number of data sets are utilised for training, and 30% for testing for classifications.

**Figure 3** represents the two confusion matrixes generated for different feature sets obtained from VMD using an ANN classifier. True class is represented by the rows, while the forecast class is represented by the columns. Correctly identified classes and misclasses are represented by diagonal and off-diagonal cells, respectively. A column-normalised column summary and a row-normalised row summary show the number of correctly and incorrectly classified observations for each predicted class and true class as percentages of the total sum of observations in the associated predicted and true class. **Figure 3(a)** displays the confusion matrix for the training set, whereas **Figure 3(b)** displays the confusion matrix for the testing set. The maximum values in **Figure 3(a)** strike the diagonal, indicating that the classifier predictions are accurate. Since there are two entries for off-diagonal elements, the projected classes in these circumstances are unreliable. The categorisation accuracy of the train data overall is 98.71%. Similar to this, the bulk of the prediction classes attend the diagonal location in the testing data set confusion matrix shown in **Figure 3(b)**, and the testing data set accuracy is 97.4%. Bearing Fault (BF) and Bowed Rotor Fault (BRF) types of flaws cause classifier prediction to become rather muddled. Otherwise, for all 8 kinds of defects, an overall accuracy of about 98.45% was attained.

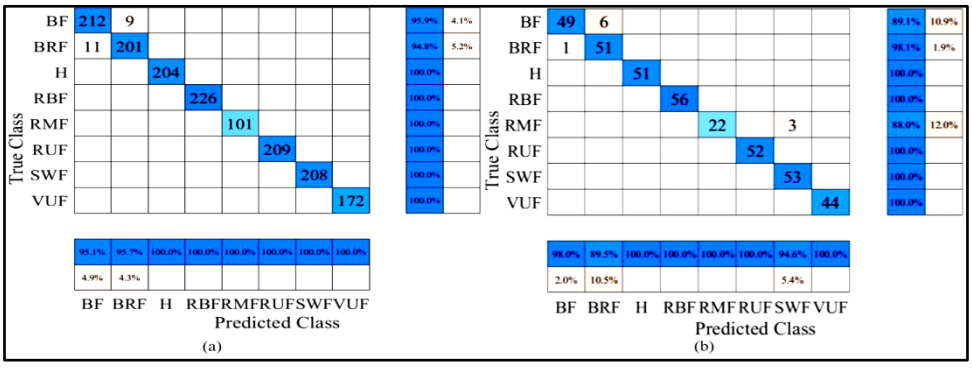


**Figure 3** Confusion Matrix for VMD feature using ANN classifier (a) Training (b) Testing

## CONCLUSION

This article presents a comprehensive and effective non-invasive method for fault detection in induction motors (IMs) using artificial intelligence techniques. This approach was accomplished by signal processing of stator current measurements made in a lab setting for a three-phase squirrel-cage IM. A series of experiments were conducted on three phase IMs under different fault conditions with varying loads. Eight separate fault conditions including both rotor and stator faults were investigated. The suggested approach effectively located the issue without interfering with machine functioning. Incorporating Variational Mode Decomposition (VMD) for optimized feature extraction and Artificial Neural Network (ANN) for classification, the proposed tool demonstrated 98.45% accuracy in fault detection.

## ACKNOWLEDGEMENT

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# DWT-based Feature Extraction and Machine Learning based Bus Fault Diagnosis in Ring Type Power Distribution Network

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***Abstract:*** *The paper deals with discrete wavelet transform-based statistical feature extraction and machine learning-based bus fault diagnosis in ring-type power distribution networks. Design and modeling of a ring system have been done using ETAP. The model was run at normal and different fault conditions in the simulation environment. Time-domain statistical analysis of the bus signals have been carried out at normal and different fault conditions. Then wavelet decomposition-based statistical analysis of different transients was done at different bus fault conditions. The most suitable parameter has been identified for fault diagnosis. Machine Learning based approaches have been applied for fault diagnosis in ring-type distribution networks. In the end, a comparison of different methods has been presented concerning the accuracy level obtained during fault diagnosis.*

***Keywords:*** *Bus Fault; Kurtosis; Logistic Regression; KNN; Ring Type Distribution Network; Support Vector Machine; Wavelet Decomposition*

## INTRODUCTION

With the advancement of industry applications and the increase in domestic load demands, the complexity of the power system network has increased to a great extent. Modern power system consumers demand a constant, uninterrupted, and reliable supply of electric power. Therefore, maintaining and providing continuous reliable supply to the customers has become a great challenge to power system engineers. One of the major challenges has become to detect faults early and from the remote end. Early detection of faults as well as early prediction of faults are important to resolve the fault issue at the earliest. Along with this identification of location is important and needs to be detected. Thus, the study and diagnosis of faults are very much needed to deal with any complex ring-type power system network.

Much research is going on in different aspects of power distribution through ring-type networks. For reliable operation of ring network, monitoring the operation and detection as well as prediction of faults are to main challenges for the power system engineers. Attempts should be taken to detect the fault early to avoid equipment damage, reduce maintenance, and increase the installed machine's lifetime [1]. Nowadays work on DC microgrid applications in renewable energy sources depends upon the DC load. In the DC microgrid when a DC fault occurs first damages the voltage source converter, and also damages the system hence detecting the fault quickly [2]. Gaussian Process Regression mainly works on AC microgrids to predict the fault location and support the machine system for fault location. This module is available at the central Protection system and designed machine learning based techniques [3]. A healthy system performs precise and fast faults, has good reliability, and improves the power quality. We use the current dynamic of the filter capacitor to identify the fault location [4]. In the present time, induction motor equipment application is more industry. But some faults occur inner fault, outer ring fault, misalignment condition, and breaking the rotor bar. In this type of fault overcome we have used motor fault detection time-frequency contents of vibration model, attention-based convolutional neural network model [5]. DC distribution network has more advantages as compared to the AC distribution network it is considered in the future best power supply modes. However, the DC distribution network has a major challenge due to the high-speed fault detection of converters.

Protection relays are normally used in DC distribution networks to protect the whole system and line also [6]. A fault occurs at any position of the DC microgrid. The main problem is the DC microgrid fault current due to changes in its change of magnitude and direction under fault conditions. We can install a relay and also use the oscillation

frequency and transient power analysis method [7]. In the present time dc distribution system is more efficient compared to the AC distribution system. In a DC distribution system, one of the main issues is low line impedance that occurs at high fault current in the system. We have used wavelet decomposition protection methods to detect the fault and also identify which type of fault is occurring [8].

Ring's main type of distribution network uses voltage stability because it provides the consumers uninterrupted power supply but the radial system is not able to give uninterrupted power supply. Nowadays underground cables transmit the power from one distribution system to another distribution system [9]. Multi-converter DC system fault Diagnosis is complex and difficult. Overcoming this type of fault, we can use the high-frequency transient components to analyze the fault circuit and provide protection for the DC distribution system [10]. Nowadays DC microgrid ring distribution systems give great opportunities but we have been faced with a difficult problem which is system protection and transient fault current behaviour [11]. The attractiveness of evaluating a fault detection technique based on line parameters, considering the limitations of conventional protection schemes during high-resistance fault scenarios. It is focused on estimating resistance for fault detection, utilizing local measurements at the bus [12].

It introduced some tools for short circuit detection and classification in the electric power distribution system, here employing multi-resolution analysis and fuzzy-ARTMAP neural network. This installed system performed a single step, reducing the computational effort and checking the accuracy and efficiency also [13]. Distribution network high impedance fault is occurring and it is crucial for system reliability but challenging due to low fault current magnitudes and nonlinearity [14]. It is one type of method for classifying the feeder's fault in a non-effective distribution network. and also consists of secondary faults occurring when thunder and lightning frequently. Here we have been using the wavelet singular entropy methods to identify the secondary fault [15]. At present time we see fault diagnosis methods for inverter open-circuit faults in Permanent magnet synchronous motor (PMSM) drives that compare current residuals with fixed thresholds. This approach may cause a lack of flexibility and accuracy [16].

It introduced a power system dynamic security assessment (DSA) that approached multi-label learning. This method can handle different types of faults, and correlations and also give high reliability, and more accuracy performance [17]. Power transformers play a vital role in the electric power system. Transformers are not a power source of electricity they can give the customer uninterrupted power supplies all the time. There are several problems transforming mainly maintenance and servicing other important problems are electrical and thermal stresses impacting the insulating oil.[18]. Industry plant one of the most crucial parts is fault detection continuously in this context of distributed scenarios such as the Tennessee Eastman process (TEP). The main challenge lies in effectively monitoring industrial plants where sensors are distributed [19]. It introduced a real-time fault diagnosis of the open circuit (OC) faults in the pulse width modulation (PWM) voltage source rectifier (VSR) system [20]. Different statistical approaches are found dealing with system monitoring and fault diagnosis [21]-[24].

However, comparatively few attempts have been made to use wavelet-based statistical parameters and machine learning-based approaches in bus fault detection. This has motivated authors to work on bus fault detection using discrete wavelet transform (DWT) based feature extraction and machine learning methods. It gives many manifold outcomes: detection of fault bus, identification of suitable statistical features, and machine learning approach.

The work has been presented in several sections. After an introduction in Section 3, modeling of the distribution network has been presented in Section 4. Then, wavelet-based fault feature extraction for fault detection has been presented in Section 5. Machine Learning-based Fault Diagnosis of the Ring Distribution Network has been discussed in Section 6 followed by a conclusion in Section 7.

## MODELLING OF A RING TYPE POWER DISTRIBUTION NETWORK

Here a ring-type distribution network was designed using ETAP software as shown in **Figure 1**. The ring network has been created with two grid sources and 15 buses. It consists of 7 cables, 4 Lump loads, 3 Induction Motors. Major specifications of the network have been presented in **Table 1**.

## DWT-BASED FEATURE EXTRACTION

Wavelet decomposition is a mathematical method utilized for the analysis of signals and data. This process entails decomposing a signal into distinct frequency components, enabling a more focused examination in contrast to traditional Fourier analysis. Wavelet decomposition is especially beneficial for studying signals with non-stationary attributes, including these statistical quantities that vary over time.

Kurtosis refers to statistical metrics employed to characterize the form of a probability distribution. Kurtosis plays a significant role in statistical analysis as it provides insights into the presence of unusual extreme values in a dataset. In the field of fault diagnosis and location identification, Kurtosis was employed to assess the distribution of certain coefficients obtained through the DWT-based waveform decomposition method. By calculating Kurtosis from the decomposed waveform of the fault current, it was possible to evaluate the occurrence of faults at various levels.

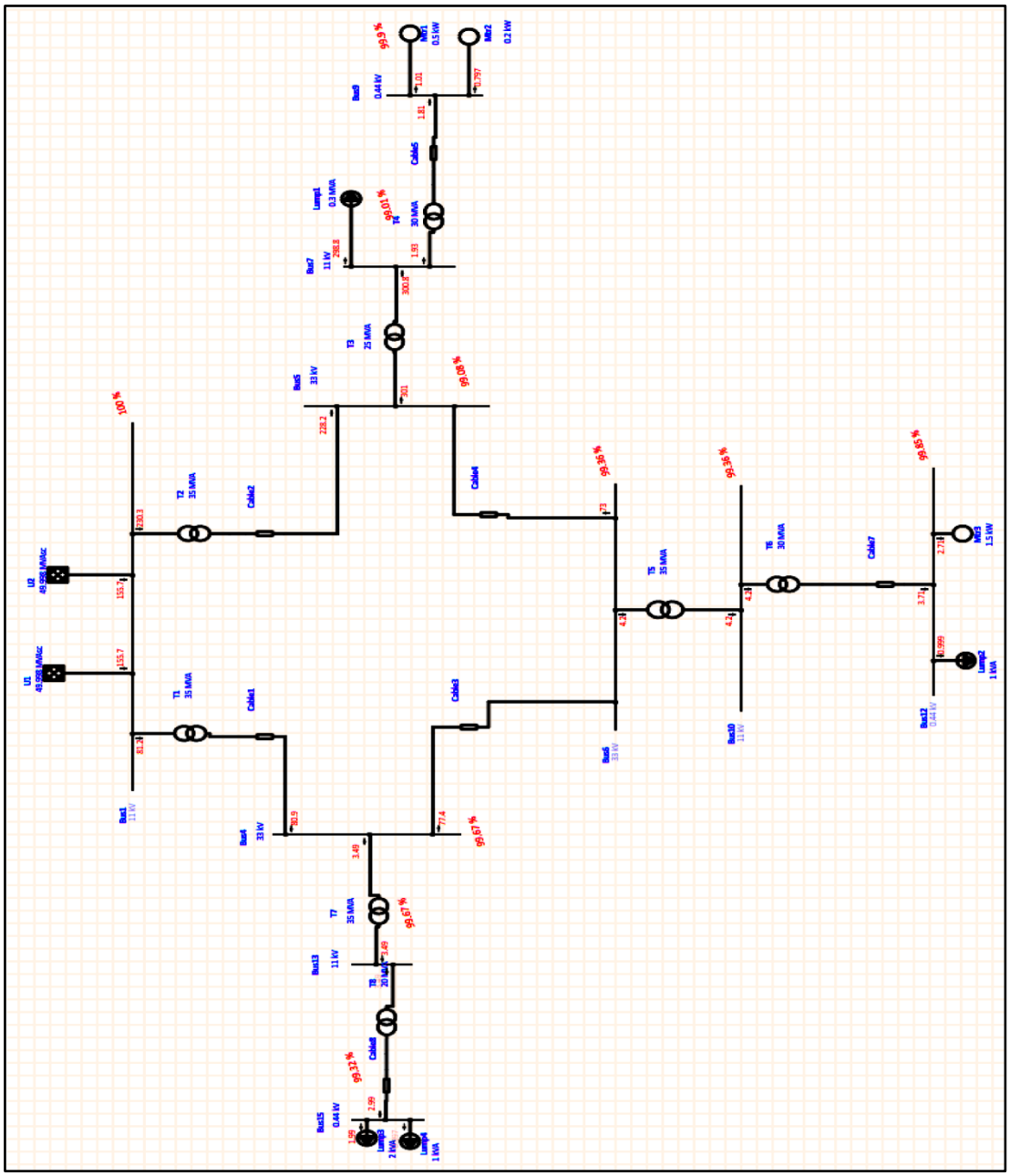

**Figure 1** Ring-type distribution network modeling

**Table 1** Specification of the ring type distribution network

| Sl. No | Device Name | Quantity | Specification | |
|---|---|---|---|---|
| 1. | Grid | 2 | U1- 50 MVA<br>U2- 50 MVA | |
| 2. | Transformer | 8 | T1 | 11 kVA |
| | | | T2 | 11 kVA |
| | | | T3 | 11 kVA |
| | | | T4 | 0.440 kVA |
| | | | T5 | 33 kVA |
| | | | T6 | 11 kVA |
| | | | T7 | 33 kVA |
| | | | T8 | 11 kVA |
| 3. | Bus | 15 | Bus 1 | 11 kVA |
| | | | Bus 2 | 33 kVA |
| | | | Bus 3 | 33 kVA |
| | | | Bus 4 | 33 kVA |
| | | | Bus 5 | 33 kVA |
| | | | Bus 6 | 33 kVA |
| | | | Bus 7 | 11 kVA |
| | | | Bus 8 | 0.44 kVA |
| | | | Bus 9 | 0.44 kVA |
| | | | Bus 10 | 11 kVA |
| | | | Bus 11 | 0.44 kVA |
| | | | Bus 12 | 0.44 kVA |
| | | | Bus 13 | 11 kVA |
| | | | Bus 14 | 0.44 kVA |
| | | | Bus 15 | 0.44 kVA |
| 4. | Cable | 7 | Cable 1 | 80 km |
| | | | Cable 2 | 80 km |
| | | | Cable 3 | 80 km |
| | | | Cable 4 | 80 km |
| | | | Cable 5 | 8 km |
| | | | Cable 7 | 10 km |
| | | | Cable 8 | 20 km |
| 5. | Motor load | 3 | Mtr 1 | 0.5 kW |
| | | | Mtr 2 | 0.2 kW |
| | | | Mtr 3 | 1.5 kW |
| 6. | Lump load | 4 | L 1 | 0.3 MVA |
| | | | L 2 | 1 kVA |
| | | | L 3 | 2 kVA |
| | | | L 4 | 1 kVA |

At first designed a ring-type distribution network using ETAP Software. After developing the network, the model was run under fault conditions. **Figure 8.1** shows the Network modelling of ring type distribution system. At first, fault was created at bus 1 and data was captured from Bus 1. In this same process, other fault conditions were created and data were captured as presented in **Table 2**. They are then passed through wavelet-based decompositions. Then kurtosis values were determined corresponding to approximate and details coefficients as shown in **Figure 2** and **Figure 3**, where x-axis represents the DWT Level. y-axis represents the Kurtosis of approximate coefficients (KA) and Kurtosis of details coefficients (KD).

Observation on KA: From **Figure 2**, it has been observed that there is a sudden rise in kurtosis from level 3 to level 4. At level 4, it reaches the peak and after at level 6 a sudden fall. Level 4 shows the highest magnitude difference for discrimination of different fault conditions.

Observation on KD: From **Figure 3**, it has been observed that there is a sudden rise in kurtosis from level 1 to level 2. At level 2, it reaches the peak, and after level 3 a sudden fall. Level 2 shows the highest magnitude difference for discrimination of different fault conditions.

Machine Learning-based Fault Diagnosis of the Ring Distribution Network A major challenge for effective and high-

precision fault detection is the high level of uncertainty involved in dealing with fluctuating scenarios or databases. Machine learning (ML) can handle massive amounts of information and pick out underlying indications or correlations, this can be used to achieve a better and more accurate fault detection system that is neither costly nor unreliable. In this work, the K-Nearest Neighbour (KNN) method, the Logistic Regression (LR) method, and the Support Vector Machine (SVM) method have been used for bus data analysis to predict faults.

**Table 2** Fault bus under consideration

| Sl. No | Fault occurred | Data taken from |
|---|---|---|
| 1 | F 1: Fault at Bus 1 | Bus 1 |
| 2 | F 4: Fault at Bus 4 | Bus 4 |
| 3 | F 5: Fault at Bus 5 | Bus 5 |
| 4 | F 6: Fault at Bus 6 | Bus 6 |
| 5 | F 7: Fault at Bus 7 | Bus 7 |
| 6 | F 9: Fault at Bus 9 | Bus 9 |
| 7 | F 10: Fault at Bus 10 | Bus 10 |
| 8 | F 12: Fault at Bus 12 | Bus 12 |
| 9 | F 13: Fault at Bus 13 | Bus 13 |
| 10 | F 15: Fault at Bus 15 | Bus 15 |

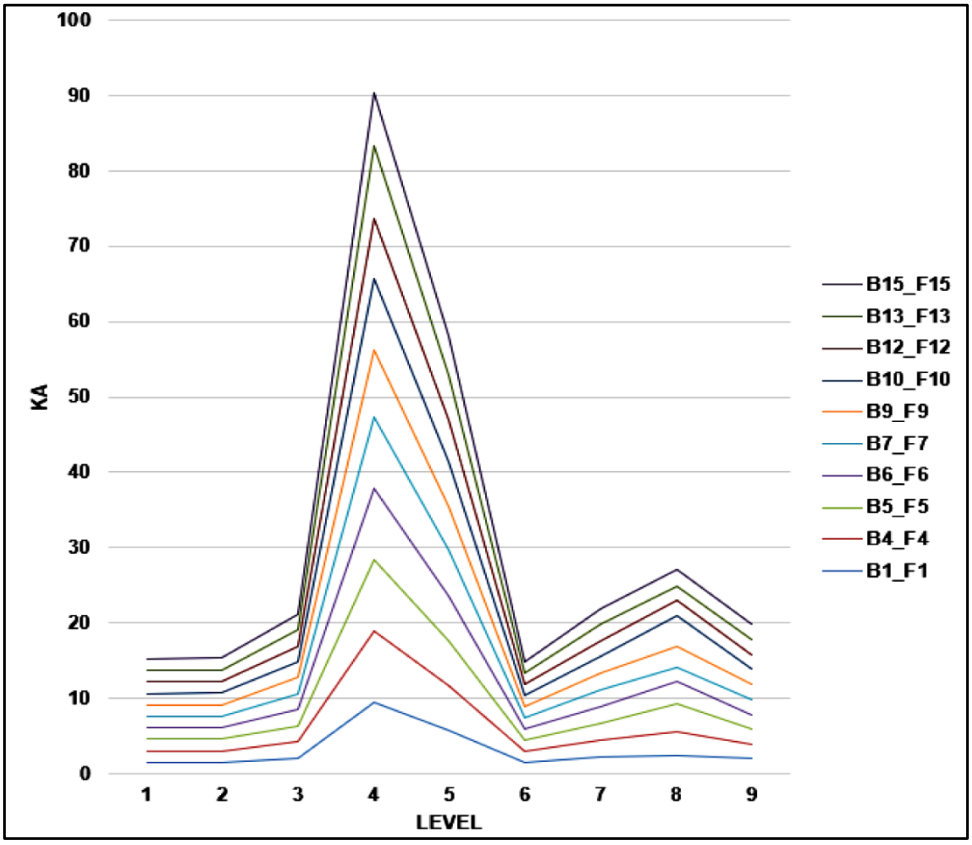


**Figure 2** KA v/s DWT Level

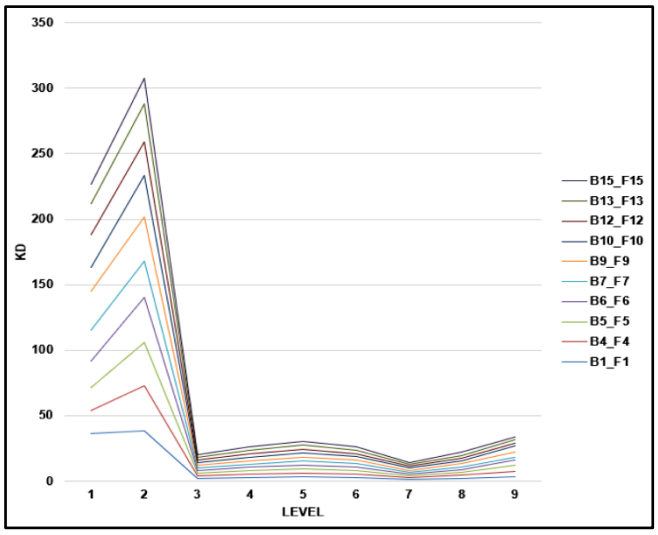


**Figure 3** KD vs DWT Level

**Table 3** Summary of wavelet-based feature extraction

| Number of conditions to be discriminated | Parameter | Best Level |
|---|---|---|
| 10 | Kurtosis of Approximation Coefficient (KA) | Level 4 |
| | Kurtosis of Detail Coefficients (KD) | Level 2 |

**Figure 4**, **Figure 5**, and **Figure 6** show the outcomes of the K-Nearest Neighbour (KNN) method, Logistic Regression (LR) method, and Support Vector Machine (SVM) method where the X-axis represents the Predicted value and the Y-axis represents the actual value.

The Accuracy levels of the above three methods are compared for different percentages of randomness. These accuracy percentages indicate the effectiveness of the ML algorithms in pinpointing the location of the problematic bus. The results of various techniques employed across varying degrees of randomness have been presented in **Table 4**. **Figure 7** shows accuracy for different Machine Learning-based approaches at 20%, 40%, 60%, 80%, and 90% randomness.

The KNN method shows the lowest level of accuracy in comparison with logistic regression and SVM methods. Among all three approaches, SVM shows the highest level of accuracy of about 71% consistently.

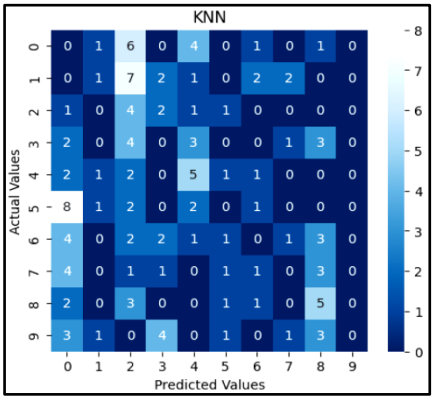


**Figure 4** K Nearest Neighbour (KNN) Methods of Ring Type Distribution Network

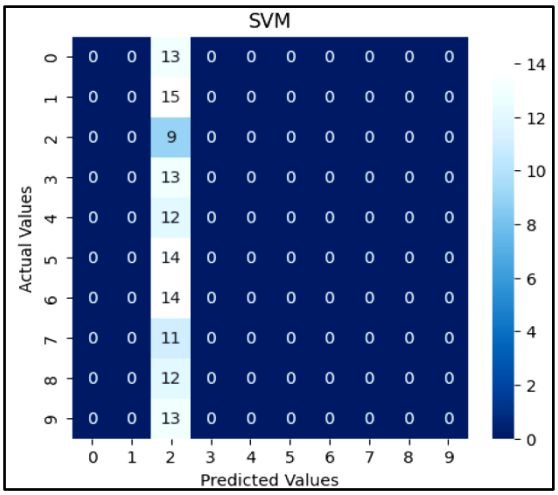


**Figure 5** Logistic Regression (LR) Methods of Ring Type Distribution network

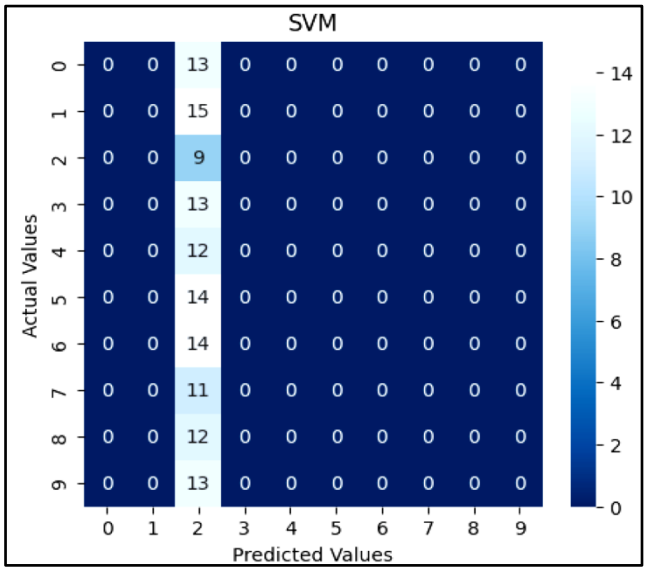


**Figure 6** SVM for Ring Type distribution network

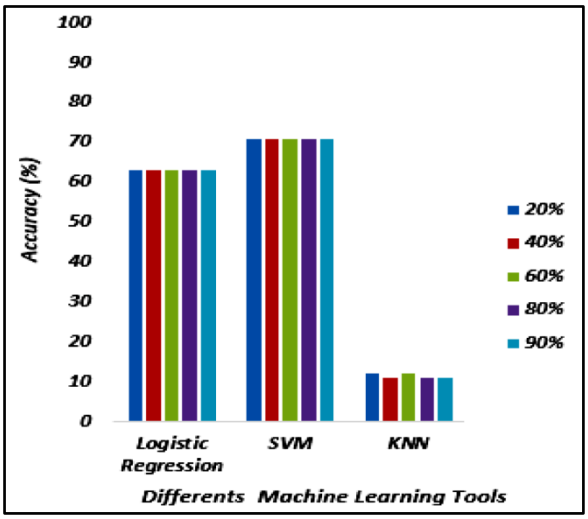


**Figure 7** Accuracy comparison among Logistic Regression, SVM, and KNN for different percentages of randomness

**Table 4** Outcomes different ML approaches for different levels of Randomness

| % of Randomness | Logistic Regression | SVM | KNN |
|---|---|---|---|
| **20%** | *63* | *71* | *12* |
| **40%** | *63* | *71* | *11* |
| **60%** | *63* | *71* | *12* |
| **80%** | *63* | *71* | *11* |
| **100%** | *63* | *71* | *11* |

## CONCLUSION

In this work, an attempt was made for bus fault diagnosis in a ring-type power distribution network. A ring-type power distribution network was modeled. The model was run at normal conditions in a simulation environment. The fault was introduced on different buses and then accordingly, bus signals were monitored. These data have been processed through wavelet-based statistical decomposition.

The outcome of the study of fault diagnosis is as follows: DWT-based feature extraction is capable of isolating normal and fault cases, few DWT levels are best suitable for discriminating fault buses using the kurtosis parameter, and SVM-based ML approach is better than logistic regression and KNN for this purpose.

## ACKNOWLEDGMENT

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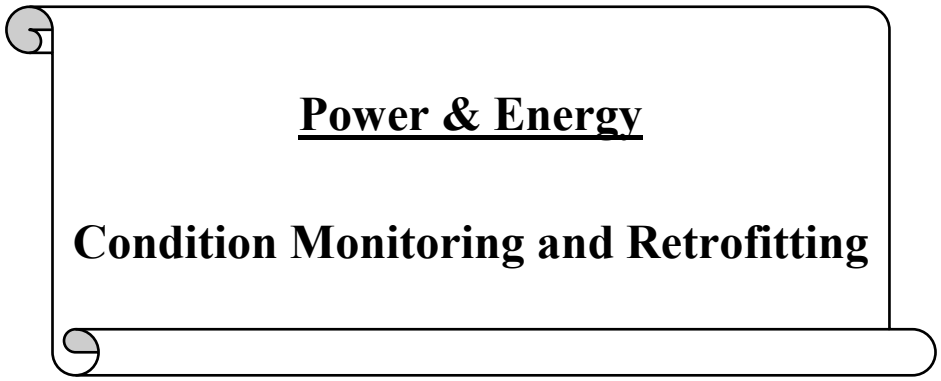
Power & Energy
Condition Monitoring and Retrofitting

29_IEC33007

# A Brief Glimpse on the Design and Performance Analysis of Induction Furnaces

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***Abstract:*** *The present article aims to review various research journals with focus on enhancing the performance of induction furnaces. It examines the factors influencing the efficiency of these furnaces and considers recommendations from different perspective of researcher's point of view. Additionally, the paper explores the concept of Total Harmonic Distortion (THD) and its impact on the effective operation of induction furnace. It also evaluates the research on Multi-Level Inverters (MLIs). The findings indicate that induction furnaces powered by MLIs demonstrate improved performance compared to conventional models, with MLIs effectively keeping THD within an acceptable limit of 1% and enabling low-frequency operation of the furnace.*

***Keywords:*** *Total Harmonic Distortion (THD); Multi-Level Inverter (MLI); Material Selection; Induction Heating; Low frequency Induction Heating*

## INTRODUCTION

The present high standard of living and economic growth is possible because of foundries which is basically a factory that builds metal castings. The heart of the foundry is furnace. Initially the process is controlled manually with lots of pollution. But, with the advancement of technology, automatic electric furnaces are developed which can be controlled automatically and the advantage of it is that it is non-polluting in compare to mechanized system. Induction furnaces operate on the principle of induction heating, a non-contact heating method. In this process, an alternating current is induced into the charge to be heated through electromagnetic action, based on transformer principles [1]-[4]. The heating coil, functioning as the primary winding of a transformer, is connected to an AC source. This primary coil is magnetically coupled to the charge, which acts as if it is short-circuited as secondary of the transformer. When the primary coil is energized with AC, a voltage is induced in the secondary, causing an induced current to flow through the charge. This current generates heat due to $I^2R$ losses, where I represents the induced current and R is the resistance of the charge [3]-[5]. The magnitude of the induced current in the charge is influenced by several factors: (a) the primary current magnitude, (b) the magnetic coupling coefficient, and (c) the turns ratio. Induction furnaces used for melting and refining various metals, which operate at low frequencies, are referred to as low-frequency induction furnaces. Conversely, high-frequency induction furnaces utilize high-frequency eddy-current heating techniques and are used for applications such as soldering and case hardening. Low-

frequency induction furnaces are further categorized into two types: (a) core type furnaces and (b) coreless type furnaces [10]-[22].

## WORKING PRINCIPLE OF INDUCTION FURNACE

The fundamental principle of an induction furnace is the contactless induction heating of electrically conductive materials, such as metals. This method achieves very high heating speeds due to its high power density. The core operational principles of induction heating [1]-[23] are based on two primary phenomena: (a) Electromagnetic Induction and (b) Joule's Effect.

### Electromagnetic Induction

When a loop of conductive material is placed in an alternating magnetic field and is in a short-circuited condition, an alternating current is induced within it due to electromagnetic induction. This induced current will oppose the cause of its generation.

**Joule's Effect**

As the AC-induced current flows through the conductive material, it heats up according to Joule's effect. The heat generated is given by the formula $I^2Rt$, where I is the current, R is the resistance of the material, and t is the time in seconds.

**TYPES OF INDUCTION FURNACE**

Induction furnaces are categorized as follows:

**Furnaces Operated at Low Frequency**

Core Type Induction Furnace

This type of furnace operates similarly to a transformer, where the charge to be heated functions as a single-turn short-circuited secondary, magnetically coupled to the primary winding (the coil) through an iron core. The furnace features a circular hearth where the charge is placed in an annular ring. If there is no molten metal in the ring, the secondary behaves as an open circuit, preventing the start of the furnace. To initiate operation, molten metal must be placed in the annular hearth. Notable examples of core type induction furnaces include the Direct Core Type Furnace, Ajax-Wyatt Furnace, and Indirect Core Type Induction Furnace.

Drawbacks of core type induction furnaces include operation must be at low frequencies (around 10Hz) [25], presence of the pinching effect [24], the crucible shape is often unconventional [24], molten metal is required for startup [24], unsuitable for intermittent use [25], and low power factor [24]

For low-frequency operation, a Two-Level Inverter can be used, but it has several disadvantages like high dv/dt stress [25], high di/dt stress [25], high conduction losses [25], higher blocking voltage [24], higher switching losses [25], significant electromagnetic interference which is not industry-supported [24], very high Total Harmonic Distortion (THD) ranging from 20% to 26% [25], and filters are needed to reduce harmonics or improve THD which incurs high costs and large sizes [25].

To address these issues, Multi-Level Inverters (MLIs) are preferred. MLIs can reduce THD to within 1%, and according to the IEEE-519 standard, THD below 5% does not require filter circuits, thus eliminating filter costs.

Coreless Induction Furnace

Coreless induction furnaces consist of a primary coil, a ceramic crucible, and a supporting frame with a tilting mechanism. Without a heavy iron core, and with a lighter crucible and coil, these furnaces are less bulky compared to core type induction furnaces. When supplied with high-frequency AC, the primary coil generates a magnetic flux that induces eddy currents in the charge within the crucible, heating it. No initial molten charge is required to start the furnace. Coreless induction furnaces produce uniform metal quality and operate using high-frequency supply, as eddy current loss is proportional to the square of the frequency. The primary coil, made of hollow copper tubes, is water-cooled. Static capacitors are used to enhance the operating power factor. Coreless induction furnaces are primarily used for steel production and melting non-ferrous metals like bronze and aluminium [1]-[23].

Advantages of coreless induction furnaces include rapid operation [13], uniform product quality [13], capability for intermittent operation [13], lower manufacturing and operating costs [14], and reduced weight [14].

**Furnaces Operated at High Frequency**

These furnaces use high-frequency eddy current heating. The charge is placed inside a primary coil connected to a high-frequency AC source. The magnetic flux produced by the coil generates eddy currents in the charge, heating it to the melting point. The heat generated is a result of eddy current losses [1]-[18].

Advantages of high-frequency eddy current heating include minimal heat waste [17], operation in vacuum or other

environments [17], adjustable heat penetration depth by varying frequency [17], rapid heating [18].

High-frequency eddy current heating furnaces are used for applications such as surface hardening, annealing, and soldering. For high-frequency operation, a Resonant Converter may be employed. However, finding the resonant frequency (where $X_L = X_c$) is challenging, and managing high current at resonance is difficult in practice. Additionally, high-frequency operation tends to have higher power consumption.

## MATERIALS USED

Four primary materials are used for designing heating coils:

**Silicon Carbide (SiC)**: This material can operate at temperatures ranging from 1450°C to 1750°C.

**Molybdenum Disilicide**: This material can withstand temperatures from 2000°C to 1900°C. Molybdenum disilicide coils can be produced in various dimensions according to user requirements. They have a purity of 99.95% and a density of 10.15 g/cm³ [1]-[22].

**Nichrome Wire**: Heating coils made up by Nichrome can tolerate from 900°C to 1150°C. Melting point of Nichrome is 13900C.

**Kanthal**: The maximum service temperature of Kanthal is 1400°C and the melting point is 1500°C. The performance and longevity of a furnace largely depend on the choice of refractory materials. For temperatures up to 1600°C, fireclay bricks are traditionally used. However, super-duty fireclay bricks are preferred for their superior high-temperature performance and firing capabilities. For applications requiring temperatures up to 2000°C, mullite is often replaced by corundum or carbon/graphite blocks with super micro-pores [18]-[23].

## LITERATURE SURVEY

According to the literature, significant efforts have been made to enhance the efficiency and performance of induction furnaces, focusing on reducing losses and improving product quality.

Tasnim Firdaus Ariff et al. (2015) [16] investigated ways to improve the heating mechanism in traditional metal melting furnaces by redesigning the heat chamber to enhance efficiency and affordability for traditional foundries. Their research included melting non-ferrous metals such as aluminum and brass, considering factors like furnace efficiency, commercial design, cost, heating mechanism, and heat chamber shape, analyzed using the Matrix Evaluation Method (MEM) to determine the optimal design.

Viralkumar Solanki et al. (2013) [12] conducted MATLAB simulations of an induction furnace model supplied by a parallel resonant inverter, designing snubber circuits for both the rectifier and inverter. They measured voltage, current, Total Harmonic Distortion (THD), and power, comparing these measurements with actual furnace data. Their findings concluded that furnaces not operating at full load suffer from low power factor and high THD [24].

Isam M. Abdulbaqi et al. [20] utilized the Finite Element Method (FEM) for an electromagnetic-thermal coupled analysis of a coil, studying its performance during heating. This approach help to determine the required coil current and frequency to achieve specific heating conditions within a set timeframe. The simulation data were used to build the furnace coil and design the power supply, reducing design costs, time, and effort.

Uma Kulkarni, SushantJadhav, and Mahantesh Magadumet al. (2014) [4] aimed to design an induction furnace with enhanced controllability and power efficiency. Their hardware implementation showed that solid-state power sources were most efficient when driven at their natural resonant frequency. They implemented Zero Voltage Switching (ZVS) and Zero Current Switching (ZCS) to reduce semiconductor switch power losses. Operating at resonance improved the input power factor and minimized KVA consumption. They used a three-phase rectifier to convert AC to DC, followed by an H-Bridge inverter to convert DC to high-frequency AC, with a resonant tank circuit to maximize power transfer [4]-[24].

Mr.Digvijay D. Patil et al. (2017) [15] offered recommendations to enhance the efficiency and productivity of Cast Iron (CI) and Spheroidal Gray Iron (SGI) foundries. Their review suggested methods to improve melt rates and optimize electricity use, as well as strategies to reduce specific energy consumption.

Ronal S. Parmar et al. (2016) [17] simulated a six-pulse induction furnace, obtaining an output frequency of 500Hz and an output voltage of 500V. They compared thyristor-based and IGBT-based inverters, favouring IGBT-based inverters for their faster switching speeds, higher efficiency and analyzed the output waveform.

Sunil M. Jaralikaret al.(2013) [12] evaluated the performance of a steel melting induction furnace using a 12-pulse converter. The study examined the negative effects associated with inductive loads and power electronics converters, finding that the THD of current and voltage waveforms exceeded permissible limits. The paper recommended replacing the 12-pulse converter with a 24-pulse converter to enhance furnace performance [24].

Vivek R. Gandhewar et al. (2011) [1] analyzed induction furnace performance in several Indian industries, recommending improvements to furnace efficiency and reduction of operational losses through better molten metal delivery, operations scheduling, and preheating.

L. Smith et al. [15] emphasized the importance of considering energy costs at both the purchase stage and throughout the furnace's operational life. To minimize energy costs, factors such as charge materials, linings, temperature measurement, and charging practices should be considered alongside recovery, flexibility, and environmental impact.

J. Powell et al. highlighted that in coreless furnaces, total power should be applied for the maximum duration to ensure optimal output with minimal energy consumption. His study suggested minimizing energy consumption by eliminating holding periods through the use of medium-frequency furnaces immediately after each melting operation and reducing heat losses with proper linings, lids, and covers [1]-[17].

## CONCLUSION

From the literature survey, it can be concluded that enhancing the efficiency of induction furnaces involves considering several parameters and conducting a detailed analysis. Key factors such as the shape of the heat chamber, the holding period of the furnace and the proper use of lids and covers are crucial for minimizing energy losses and improving furnace performance. Additionally, power electronics-based converters significantly impact furnace efficiency. It is essential to measure the Total Harmonic Distortion (THD) of voltage and current waveforms, with a goal of keeping THD below 1%. Multi-level Inverters have been found to facilitate operation of induction furnaces at low frequencies while maintaining THD levels under 1%, thus improving the overall performance of the furnace.

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370_IEC28795

# Fault Diagnosis and Adaptive Reconfiguration of BLDC Motor Drive

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***Abstract:*** *In aircrafts and missiles, actuators are commonly utilized for driving various subsystems including flight control surfaces. Brushless DC motor (BLDC) based electromechanical actuation systems are getting increasingly popular due numerous advantages. Electromechanical Linear actuators (EMLA) are common due to their high torque capability. In addition, the BLDC motors are being increasingly used in critical high-performance industries such as appliances, automotive, aerospace, consumer, medical, industrial automation equipment and instrumentation. The failure modes for these systems transcend to electrical, mechanical, and electronic systems attributed to external forces and the dynamic properties of control systems. This makes the identification of failure modes a vital and challenging process*

*Fault detection and condition monitoring of BLDC machines is therefore assuming a new importance. The objective of this paper is to devise an algorithm to detect inverter fault in BLDC drives. This work orients to develop a method to detect faults in BLDC motors drive by monitoring their line currents. A new fault analysing algorithm is proposed that can track and detect switching faults in time varying current signals of converters. Once the fault is detected the faulty branch of the inverter is replaced with a fault reconfiguration branch. The performance characteristic of BLDC motor is analysed before and after inducing a switching fault in the drive circuit and the results reveals satisfactory performance of the algorithm under open Circuit and short circuit fault conditions.*

*The condition monitoring system proposed basically performs fault detection and identification. Once a fault is identified in the circuit the fault occurred branch is isolated from the main circuit and reconfigured. Here the Switching fault detection and identification method is achieved by using current sensors between upper and lower legs of inverter. A Fault reconfiguration block is connected with the inverter circuit, it works by disconnecting the faut occurred branch from the inverter circuit and replaces the faulty branch with a fault reconfiguration branch.*

*The features extracted from the current signals of Hilbert Transform form the input to the rule-based classifier. The rule-based classifier detects the faults based on the features extracted and in case of faults provides appropriate switching signals to the redundant switches in the inverter. The functionality of this new method is verified by the simulation studies for various faults in different switches and different operating speeds of an BLDC motor carried out using MATLAB. The proposed fault tolerant control system improves safety and reliability of BLDC motor drives.*

***Keywords:*** *BLDC; Inverter Faults; Switching Faults; Fault Detection; Fault Reconfiguration; Open Circuit Fault; Short Circuit Fault; Hilbert Transform*

**Power & Energy**

# Distributed Generation, Micro-Grid and Smart Grid

39_IEC81174

# 3-E Analysis of the Vapour Absorption Refrigeration System with Micro-Steam Turbine Integration: An Efforts Towards Energy Conservation in the Thermal Power Plants

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***Abstract:*** *All thermal power plants need a suitable air-conditioning system for maintaining the healthiness of its complete system. There is an existing vapour absorption refrigeration system (VAM) is driven by the steam of pressure and temperature are about 3-3.5 bar and 135-145 ℃, respectively at VAM inlet i.e. after the steam control valve (SCV opening: 50-60%) and consuming the steam flow rate of about 0.70-0.80 kg/s during 3 nos. of VAMs are in service conditions. The root source of steam is being supplied from the main plant high temperature APRDS header and the parameter of steam at this header are about 11- 12 bar and 310-320 ℃. In the process, there is an individual pressure reducing and de-superheating system in the steam supply line of VAM for getting the required input steam parameter i.e. pressure of about 3-3.5 bar and temperature of about 135-145 ℃ The pressure reducing valves causes throttling loss and irreversibility in the system and resulting in conversion of some available energy into non-recoverable energy form by changing in internal energy, flow work, noise, friction and heat loss as well due to non-adiabatic process in actual and along with the de-superheating system in the existing system also causes irreversibility during mixing and as a whole, total available energy reduces. In the proposed system, a back pressure type micro-steam turbine is proposed where the pressure reduction is done with the help of expander instead of throttling valve and the expanded steam temperature at turbine exhaust will be lower than throttled temperature of existing system but higher than VAM inlet temperature that leads to conversion of waste energy of the existing system (during throttling and de-superheating process) into useful work output without violating the VAM inlet steam condition. The proposed system is modelled in the Cycle-tempo software by using NH3-H2O mixture as a working fluid for the refrigeration system and thermodynamic analysis is carried out based on 3-E analysis ( Energy, Environment and Economic analyses). Result shows that about 87-107 kW of electricity may be generated by integrating the proposed system at turbine exhaust pressure of 3-4 bar and it will help to improve the Co-efficient of Performance (COP) from 0.38 to 0.49 at the optimum operating VAM inlet pressure of about 3.5 bar. It is also observed that about 547 tons of coal can be saved annually and resulting in reduction of $CO_2$ emission by about 754 tons annually. The cost benefit analysis shows that at required refrigeration effect, power generation cost and simple payback period of the proposed system are about INR 3.44 / kWh and 6.17 years, respectively. Lower electricity generation cost and less payback period of the system with positive ROI value shows a good sign for commercial application of the proposed system in the existing power plants having VAM based air-conditioning system.*

***Keywords:*** *Air-Conditioning System; VAM; Micro-Steam Turbine; Throttling Loss; $CO_2$; Economic*

## INTRODUCTION

Coal reserve in India is the fourth largest country of world and about 73 % of the total power generation is from coal-based thermal power plants [1]. It is also pertinent to mention that coal is expected to remain as a major power source in the near term of transitioning to a low carbon future. For achieving the carbon neutral country by 2070, power

industries are adapting different decarbonization technologies in addition with Renewable Energy (RE) technologies. In this context, projects related to 'Waste to Energy' are also getting attractive as well throughout the world for achieving the Global target- i.e. efforts towards limiting global warming to 1.5/2°C [2]. During the last few decades, various thermodynamic cycles have been proposed by different researchers to produce electric power from different grades of waste heat from different sources [3,4]. Khankari and Karmakar [5] have proposed a Kalina cycle system to utilize the coal mill rejection from a coal-fired power plant for generating additional electric power of about 562.75 kW. Singh and Kaushik [6] showed an approach for reduction of flue gas exit loss through KCS11 integration for

additional power generation in 500 MW coal power plants in Indian climatic condition.

There are also various studies for performance improvement of Vapour Absorption Refrigeration System (VARS/VAM) at different applications. Venkataraman et al., (2020) [7] performed a rigorous review on the Vapour Absorption Refrigeration System (VARS) for automobiles application by considering engine exhaust and fuel cell exhaust as a separate heat source and concluded that the use of engine exhaust in the VARS is a challenging job and suggested to use the fuel cell coupled VARS system in automobiles. Muztuza Ali and Chakraborty, (2015) [8] proposed an adsorption cooling system for cars driven by engine exhaust and results found that an engine exhaust of 3000cc car can produce cooling effect of 3 kW and the performance of CaCl -in-silica gel–water system was more than the other adsorbents-water systems.

All thermal power plants have dedicated air-conditioning systems for safeguarding the control and instrumentation systems of the power plants. Different thermodynamic refrigeration cycles are being used to monitor the required cooling effect for the system and out of them, vapour absorption refrigeration system (VAM / VARS) is one of the best suited efficient technologies which is driven by steam of pressure and temperature are about 3-4 bar and 135-145 0C, respectively. The root source of steam is being supplied from the main plant high temperature APRDS header and the parameter of steam at this header are 11- 12 bar and 310-320°C. There is a pressure reducing and de-superheating station in the steam supply line for achieving the required steam input parameter for the specific VAM system. It is pertinent to mention that pressure reducing valves causes throttling loss and irreversibility in the system and resulting in conversion of some available energy into non-recoverable energy form by changing into the internal energy, flow work, noise, friction and heat loss as well due to non-adiabatic process in actual and along with the de-superheating system in the existing system also causes irreversibility during mixing and consuming auxiliary power for spray water flow [9].

As per authors' knowledge, there is not any such studies on the performance improvement of VAM or waste energy recovery from the VAM system which are used in the conventional coal power plants. In the proposed project / work, a back pressure type micro-steam turbine is proposed where the pressure reduction occurs with the help of expander instead of throttling valve and after the expansion, the steam turbine exhaust temperature will be lower than existing throttled temperature but higher than VAM inlet temperature. This waste energy may be harnessed by integrating a micro-steam turbine in the steam supply line to produce electricity. The objective of the proposed project:

- Feasibility study based on thermodynamic analysis
- To find out the suitable operating parameter of the micro-steam turbine.
- Cost-benefit analysis of the proposed integration with the existing VAM system.

## SYSTEM DESCRIPTION

**Figure 1** shows the schematic flow diagram of the existing VAM system which comprises of different components like absorber, high temperature and low temperature steam generator, evaporator, condenser, heat exchangers, feed pump, chilled water circulating pump and cooling water pumps. The modeling of the VAM system is done by using $NH_3$-$H_2O$ mixture (ammonia concentration: 57.75 %) in the Cycle-tempo software. **Figure 2** shows the proposed system integration where micro-steam turbine is placed in the live steam supply line for generating power and supply the required steam quality at the VAM system inlet through its expansion process. In **Figure 2**, a bypass steam line across the Micro-steam turbine is also proposed by considering it maintenance point of view as per requirement.

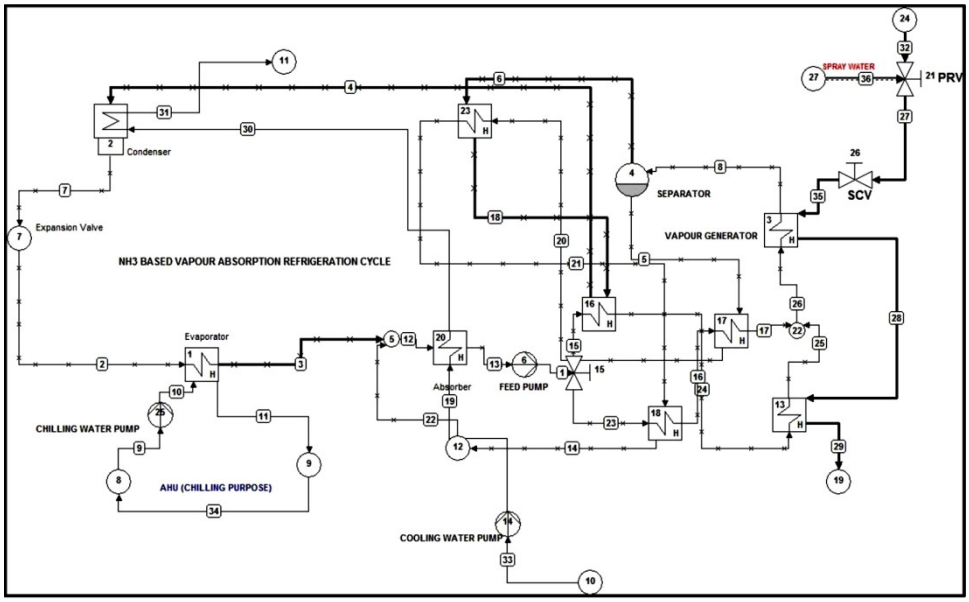


**Figure 1** Flow diagram of existing VAM system of a 500MW coal power plant (No. mentioned in the path indicates the pipe no. and no. mentioned inside the component/equipment indicates the equipment no.)

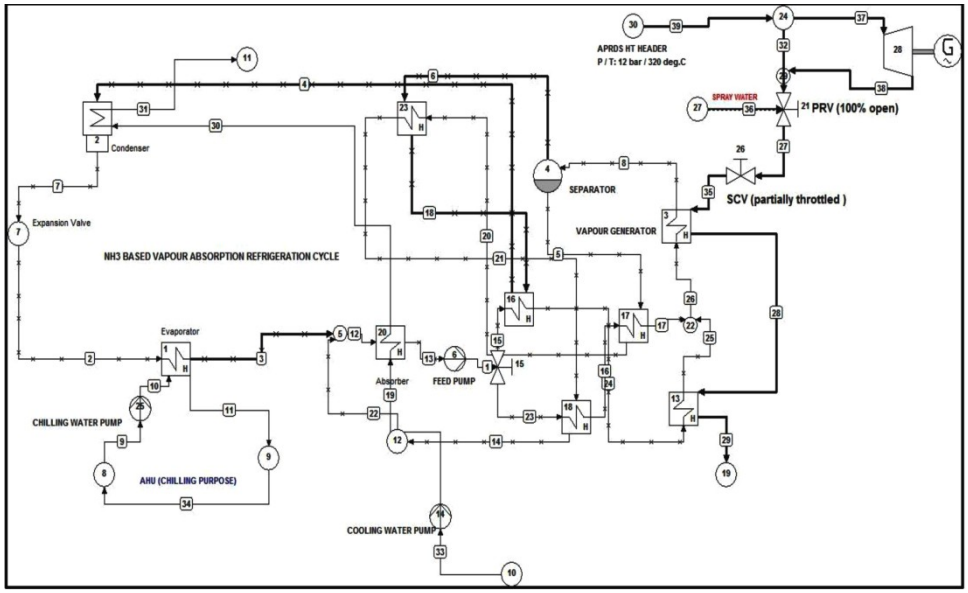


**Figure 2** Flow diagram of proposed integration of micro-steam turbine with the VAM system no. mentioned in the path indicates the pipe no. and no. mentioned inside the component/equipment indicates the equipment no.).

## METHODOLOGY

Thermodynamic analysis of the proposed system is performed based on the conservation of mass and energy principles, which is given as follows:

Mass balance:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (1)$$

Energy balance:

$$\sum \dot{m}_{in}\, h_{in} + \dot{Q}_k = \sum \dot{m}_{out}\, h_{out} + \dot{W} \quad (2)$$

Where, $\dot{m}$: mass flow rate, h: specific enthalpy, $\dot{Q}_k$: heat transfer rate to the system at temperature Tk.

Exergy balance:

$$\sum \dot{m}_{in}\ \varepsilon_{x\,in} + \dot{Q}_k\left(1 - \frac{T_0}{T_K}\right) = \sum \dot{m}_{out}\ \varepsilon_{x\,out} + \dot{W} + \dot{E}x_D \quad (3)$$

Where, $\dot{Ex}_D$ : Exergy destruction rate ; Subscript '0': The environment condition of the system. $\varepsilon_x$ : Specific exergy of energy carrier.

Energetic Co-efficient of Performance (COPenergetic):

$$COP_{energetic} = \frac{\dot{Q}^{\,energetic}_{refrigeration\,effect}}{\dot{Q}^{energy}_{steam} + \dot{W}_{pump} - \dot{W}_{micro-steam\,Turbine}} \quad (4)$$

Exergetic Co-efficient of Performance (COPenergetic):

$$COP_{exergetic} = \frac{\dot{Q}^{\,exergetic}_{refrigeration\,effect}}{\dot{Q}^{exergy}_{steam} + \dot{W}_{pump} - \dot{W}_{micro-steam\,Turbine}} \quad (5)$$

## RESULTS & DISCUSSIONS

The developed simulation model is well validated with the actual running data of the existing system. Based on the operating data, thermodynamic analysis of the proposed system is carried out based on energy analysis at different VAM inlet conditions i.e. back pressure of proposed micro-steam turbine and the same is shown in **Table 1**.

**Table 1** Energy balance of the proposed system at different VAM inlet pressure

| Description | VAM inlet pressure:3.5 bar | | VAM inlet pressure:3.0 bar | | VAM inlet pressure:4.00 bar | |
|---|---|---|---|---|---|---|
| | kW | % | kW | % | kW | % |
| Net Steam Energy supply (kW) | 2284.87 | 57.73 | 2284.87 | 57.91 | 2284.87 | 57.56 |
| Power Generated by M.T (kW) | 96.04 | 2.43 | 106.74 | 2.71 | 86.54 | 2.18 |
| Steam Exit Loss (kW) | 184.06 | 4.65 | 184.02 | 4.66 | 184.08 | 4.64 |
| Condenser Loss (kW) | 3599.80 | 90.95 | 3573.75 | 90.58 | 3624.41 | 91.30 |
| Power Consumed by Refrigerant pump (kW) | 419.66 | 10.60 | 416.46 | 10.56 | 422.50 | 10.64 |
| Power Consumed by Cooling water pump (kW) | 23.65 | 0.60 | 23.47 | 0.59 | 23.80 | 0.60 |
| Power Consumed by Chilling water pump (kW) | 13.29 | 0.34 | 13.19 | 0.33 | 13.38 | 0.34 |
| Refrigeration Effect (kW) | 1216.66 | 30.74 | 1207.41 | 30.60 | 1225.24 | 30.86 |
| Other losses (kW) | 78.23 | 1.98 | 80.89 | 2.05 | 74.76 | 1.88 |

From **Table 1**, it is analyzed that about 96.04kW of electric power can be generated from the integration of micro-steam turbine at inlet and outlet of steam parameter of about 11.5bar/270°C and 3.5bar/178.68°C, respectively. Due to surface heat loss from the steam supply line (tapping from the APRDS header) Turbine inlet steam temperature is considered as about 270°C instead of 310°C which is observed from the actual field condition. From the energy balance, it is also observed that maximum energy loss found in the condenser of VAM i.e. about 90.95% where as exit steam loss is found as 4.65 %. Effect of turbine back pressure variation is also studied, and it is found that power generation from the back pressure type micro-steam turbine decreases with increase in the turbine exhaust pressure, but refrigeration effect increases with increase in the turbine exhaust pressure. At higher turbine exhaust pressure, condenser loss of the VAM slightly increases but other losses variations are negligible.

Further analysis on the co-efficient of performance (COP) based on energy and exergy is studied at different VAM inlet pressures and the same is shown in **Figure 3**. It is concluded that the COP of the VAM without micro-steam

turbine integration is about 0.38 and it can be improved to 0.49 through integration of the proposed back pressure type micro-steam turbine. There is no such change in COP from energetic and exergetic point of view at different VAM inlet pressures. Coal power plants emission is a great concern of the world, and the reduction of $CO_2$ emission (main contributor for global warming) is the primary target throughout the globe. So, integration of the proposed system on the $CO_2$ emission reduction through coal saving is also studied and it is found that about 754 tons of $CO_2$ emission can be reduced annually in a power station through integrating the micro-steam turbine in the existing VAM system. This reduction is due to saving coal by about 547 tons / year.

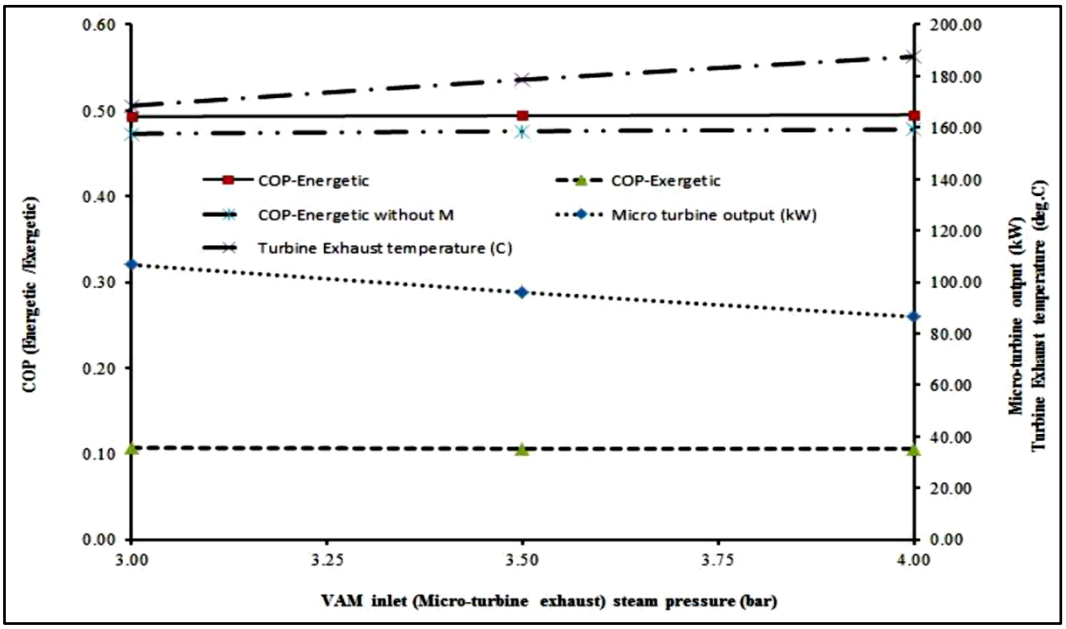


**Figure 3** VAM performances at different micro-steam turbine exhaust pressure

**Table 2** Cost-benefit analysis of the proposed system

| Description | VAM inlet pressure : 3 bar | VAM inlet pressure : 3.5 bar | VAM inlet pressure : 4 bar |
|---|---|---|---|
| Unit Capacity(kW) | 96.04 | 96.04 | 96.04 |
| Capital cost for equipment(INR) | 7387692.31 | 7387692.31 | 7387692.31 |
| Civil cost including erection & installation (INR)@ 30 % | 2216307.69 | 2216307.69 | 2216307.69 |
| Total capital cost(INR) | 9604000.00 | 9604000.00 | 9604000.00 |
| O&M cost@13.5% of total capital cost(INR) | 1296540.00 | 1296540.00 | 1296540.00 |
| Annual depreciation cost(INR)@ 10 % | 738769.23 | 738769.23 | 738769.23 |
| Interest charge @8.5 % on loan amount (INR) at debt:equity ratio of 70:30 | 571438.00 | 571438.00 | 571438.00 |
| Annual fixed cost(INR) | 2606747.23 | 2606747.23 | 2606747.23 |
| Annual total cost(INR) | 12210747.23 | 12210747.23 | 12210747.23 |
| Annual power generation(kWhr) | 841538.16 | 757179.36 | 682281.36 |
| Generation cost (Rs/kWhr) | 3.10 | 3.44 | 3.82 |
| Annual profit (Rupees) | 2021712.65 | 1557739.25 | 1145800.25 |
| Payback Period | 4.75 | 6.17 | 8.38 |
| Annualized Return on Investment(ROI) in % for 25 years | 6.87 | 5.76 | 4.47 |

The economic analysis of the proposed system at different VAM inlet/micro-steam turbine exhaust conditions are studied by considering the different cost components as depicted in **Table 2**. From **Table 2**, it is observed that the power generation cost from micro-steam turbine integration system is about INR 3.44 /kWh which is lower than the power generation cost of conventional Coal-power plants in India. Moreover, the payback period and annualized ROI for 25 years are found as 6.17 years and 5.76 %, respectively. Lower electricity generation cost and less payback period of the system with positive ROI value shows the good sign for commercial application of the proposed system in the existing power plants having VAM based air-conditioning system.

It is also observed from **Table 4** that the generation cost reduces at lower pressure due to increase in power generation that leads to improve in annualized ROI value and reduces the simple payback period of the system as well.

## CONCLUSIONS

Following conclusions can be drawn from the above study:

I. Integration of proposed micro-steam turbine in the VAM system can help to harness the quality energy loss associated with throttling and de-superheating into electrical energy. It is concluded that about 96.04kW of electric power can be generated at optimum VAM inlet pressure of about 3.5 bar.

II. Additional power generation from the proposed system will help to improve the COP of VAM from 0.38 to 0.49.

III. About 547 tons of coal can be saved annually through this proposed integration and resulting in annual reduction of $CO_2$ emission by about 754 tons.

IV. Power generation cost and payback period of the proposed system are about INR 3.44 / kWh and 6.17 years, respectively. Lower electricity generation cost and less payback period of the system with positive ROI value shows the good sign for commercial application of the proposed system in the existing power plants having VAM based air-conditioning system.

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# Economic Dispatch of a Hybrid Solar-Wind-Biomass based Microgrid using Novel Nilgiri Tahr Optimization

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***Abstract:*** *Microgrids integrate diverse power generation sources, including conventional, non-conventional, and renewable energy sources (RES). Due to the intermittent nature of RES, optimal scheduling of power generation while maintaining economic dispatch remains a critical challenge. This paper introduces a novel optimization technique, NilgiriTahr Optimization (NTO), inspired by the grazing behavior of the NilgiriTahr, to optimize power scheduling in an isolated microgrid. The microgrid under study consists of diesel generators (DGs), a combined heat and power plant (CHP), a solar photovoltaic (SPV) system, a wind energy conversion system (WECS), and a biomass power plant. The objective is to minimize the total generation cost while ensuring that power generation meets the dynamic hourly load demand, adhering to ramp-up and ramp-down constraints. The NTO algorithm is implemented in Python and tested on a realistic 24-hour scheduling problem. Results demonstrate that NTO efficiently balances generation sources, reduces overall costs, and ensures reliable power supply. The algorithm converges rapidly, achieving cost minimization within 134 iterations, with a final generation cost of approximately $7400. The study establishes NTO as a promising and efficient approach for real-time microgrid scheduling and economic dispatch optimization.*

***Keywords:*** *Optimal Scheduling; Microgrid; Economic Dispatch; Nilgiri Tahr Optimization*

## INTRODUCTION

Modern day microgrid include sources of which some are renewable (RES), while others may be conventional, non-conventional, and distributed in nature. Many of the RES are unpredictable and intermittent. Scheduling these sources in tandem with load and grid, while keeping the dispatch economical, is one of major concerns for microgrid management utilities.

Different nature-inspired optimization techniques have been used recently for cost optimization in microgrids. Samy et al. in [1] used multi-objective particle swarm optimization (MOPSO) to reduce the total annual cost of a biomass and fuel cell microgrid. In another paper [2], Ali et al. used a modified ant-lion optimization algorithm (MALO) in a system consisting of a conventional generator along with a modified biomass-thermal power generating system. Rama Krishna et al. in [3] applied Genetic Algorithm (GA) to a hybrid renewable energy microgrid system consisting of hydro, biomass, solar and wind turbines. Patarau et al. [4] optimised a hybrid renewable energy microgrid system comprising of solar panels, batteries of geothermal generator, and a biomass generator in Romania. Thakkar et al. in[5] implemented Satin Bowerbird Algorithm for optimizing generation of a solar and biomass generators based standalone microgrid (SMG). Younas et al. [6] used the HOMER software to perform economic analysis of a microgrid with three renewable energy sources viz. solar, biomass and micro-hydro by optimizing net present cost.

In the present contribution, a novel algorithm based on the grazing behaviour and nature of Nilgiri Tahr, named as the Nilgiri Tahr Optimization (NTO) has been introduced for the first time to optimise the load scheduling of a microgrid under generation and load constraints. The proposed algorithm is implemented in Jupyter using Python coded programming under Python 3.0 environment and tested on a realistic prototype microgrid consisting of diesel generators (DGs), combined heat-power plant (CHP), solar PV (SPV), wind energy conversion system (WECS), and bio-mass plant along with a variable load. The primary objective of the work is to reduce the overall cost of generation of the microgrid while meeting the load demand, and thereby optimally schedule all the generating sources.

The results demonstrate that load demands have been adequately met for every hour during a 24-hour period, with respect to the total generated power. Generating cost of the DGs, CHP, solar and wind have been minimised and the

biomass power plant generator utilization have been maximised using the proposed Nilgiri Tahr Optimization. It has been observed that the net generating cost over 24 hours has been substantially reduced.

## METHODOLOGY

An isolated microgrid system as shown in **Figure 1** has been considered here comprising of two DGs, CHP, and various renewable energy sources such as solar, wind and biomass plants.

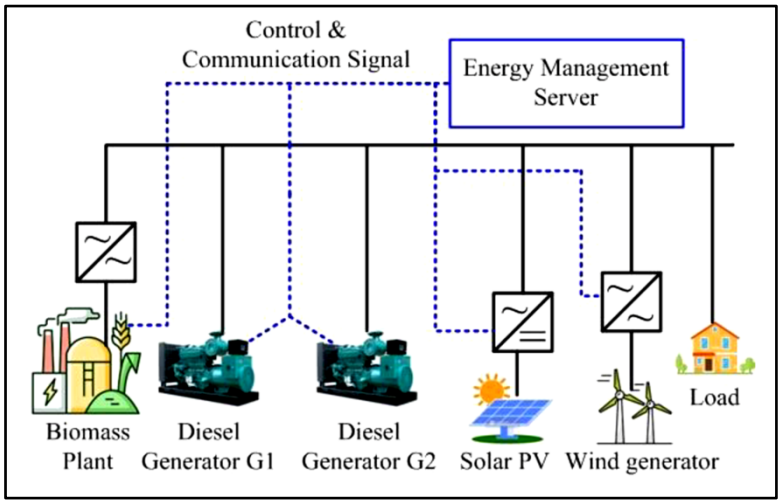


**Figure 1** Circuit diagram of the microgrid

Cost functions of the different microgrid components are described below:

### Generators and CHP

Cost functions of the diesel generators are computed by a second-order polynomial following [7].

$$F(P_i) = AP_i^2 + BP_i + C \quad (1)$$

The generator constants are defined as: A is the quadratic cost coefficient (in \$/MW$^2$) relating to the non-linear cost ramp-up due to inefficiencies or other factors, B is the linear cost coefficient (in \$/MW) indicating the fuel cost per unit of power generated, and C is the fixed cost component (in \$) that is incurred regardless of the power output. $P_i$ is the power output of the i$^{th}$ generator.

### Wind Energy Generation and Cost Function

Wind speed data used in the present study has been adopted from [7], and wind power generation there from is reproduced in (2):

$$P_w = \frac{1}{2}(\rho A \mu^3) \quad (2)$$

where, $P_w$ is the wind power in kW, air density is taken as $\rho$ = 1 kg/m$^3$, A is the windswept area, and $\mu$ is the wind speed.

The cost functions of wind power are given in (3) and (4)following [7]:

$$F_W(P_w) = \alpha I_p P_w + G^E P_w \quad (3)$$

$$\alpha = \frac{r}{1-(1+r)^{-N}} \quad (4)$$

where, $\alpha$ is the annuitization coefficient, r indicates the rate of interest, $I_p$ is the initial investment cost, $G^E$ is the

operating and maintenance cost, and Nis the investment lifetime.

Parameters for (3) and (4) following [7] are: r= 0.09 (9%), N= 20 years, $G^E$= 1.6 cents/kW, and $I_p$= $1400/kW.

**Solar Energy Generation and Cost Function**

The solar irradiation data (IS) used in the present paper has been obtained from [7].Solar power is derived as per (5):

$$P_S = 3.24M_{pv}\left(1 - 0.0041(T_t - 8)\right) \times I_S \quad (5)$$

Pwhere, $P_S$ is the solar power in kW, $T_t$ is the temperature, $I_S$ is the solar irradiation at a particular time, and the parameter, $M_{pv} = N_S \times P_w$, where $N_S$ is the total number of panels each having capacity $P_w$.

The cost function of solar power plant is given in (6) and (7) following [7]:

$$F_S(P_S) = \alpha I_p P_S + G^E P_S \quad (6)$$

$$\alpha = \frac{r}{1-(1+r)^{-N}} \quad (7)$$

In the present paper, the following parameter values have been used following [7]: NS=14,000, $P_w$ = 300 W, r= 0.09 (9%), N= 20 years, $G^E$= 1.6 cents/kW and $I_p$= $5000/kW.

**Biomass Power Generation Cost Function**

According to [8], the cost function of biomass plants is same as that of the conventional generators. Thus, the cost function of the biomass plant is:

$$F_b(P_b) = AP_b^2 + BP_b + C \quad (8)$$

**Formulation of Economic Dispatch of Generators, CP, Solar, Wind and Biomass**

Combined generating cost of all the power sources except biomass has been minimized and the biomass power extraction has been maximized.

$$minimize\left(\sum_{i=1}^{3} F_i(P_i) + F_W(P_W) + F_S(P_S)\right) + F_b(P_b) \quad (9)$$

Subject to the constraints,

$$P_{imin} \le P_i \le P_{imax} \quad (10)$$

$$P_i - P_{i-1} \le Ramp - up \text{ and } P_{i-1} - P_i \le Ramp - down \quad (11)$$

$$P_{bmin} \le P_b \le P_{bmax},\ P_{Wmin} \le P_W \le P_{Wmax} \text{ and } P_{Smin} \le P_S \le P_{Smax} \quad (12)$$

$$\text{Demand} = \sum_{i=1}^{3} P_i + P_W + P_S + P_b \quad (13)$$

Where $P_i$ is the power generated by diesel generators and CHP at each hour. Ramp-up is the step-up limit of each generator, and on the other hand Ramp-down is the step-down limit of each generator. Demand is the load demand at each hour $P_{imin}$ and $P_{imax}$ are the minimum and maximum power generated by the $i^{th}$ generator (diesel generators and the CHP). $P_{bmin}$ and $P_{bmax}$ are the minimum and maximum power generated by the biomass plant. $P_{Wmin}$ and $P_{Wmax}$ are the minimum and maximum power generated by the wind power plant. $P_{Smin}$ and $P_{Smax}$ are the minimum and maximum power generated by the solar power plant.

**Generator Details**

The details of Generator 1 are: A = 0.0290 $/MW$^2$, B = 20.16 $/MW, C = 992 $, $P_{1min}$ = 40 MW, $P_{1max}$ = 350 MW, Ramp-up = 80 MW, Ramp-down = 80 MW. The details of Generator 2 are: A = 0.021 $/MW$^2$, B = 20.4 $/MW, C = 600 $, $P_{2min}$ = 40 MW, $P_{2max}$ = 250 MW, Ramp-up = 60 MW, Ramp-down = 60 MW. The details of CHP are: A =

0.024 \$/MW$^2$, B = 21 \$/MW, C= 1530 \$, $P_{3min}$ = 5 MW, $P_{3max}$ = 40 MW, Ramp-up= 5 MW, Ramp-down= 5 MW. These all are considered based on the paper[7].

**Biomass Plant Details**

The details of biomass plant following [9] are A = 0.0270 \$/MW2, B= 0.690 \$/MW, C= 3.585 \$, $P_{bmin}$ = 5 MW, $P_{bmax}$ = 30 MW, Ramp-up= 5 MW, Ramp-down= 5 MW.

**Program Overview**

The Python code optimized the total generation cost for a 24-hour period having all generating sources mentioned earlier. The objective was to minimize the total generation cost according to (9) while obeying all the constraints given in (10) – (13), whereby diesel generators 1, 2, CHP, solar and wind generation cost has been minimized and the biomass plant alone is maximized such that the overall total generation cost is maximized.

**Nilgiri Thar Optimization**

The Nilgiri Tahr Optimization (NTO) is a nature inspired metaheuristic optimization algorithm. It mimics the behaviour of Nilgiri Tahr goats usually found in the mountainous terrains of Kerala, India [10]. They explore areas best for grazing and often move iteratively and cautiously across steep slopes in herds. This search behaviour is translated into a mathematical optimization approach, which can be suitable and useful for solving complex problems where the solution space is large and non-linear. **Figure 2** demonstrates the basic Nilgiri Tahr Optimization as a mathematical approach.

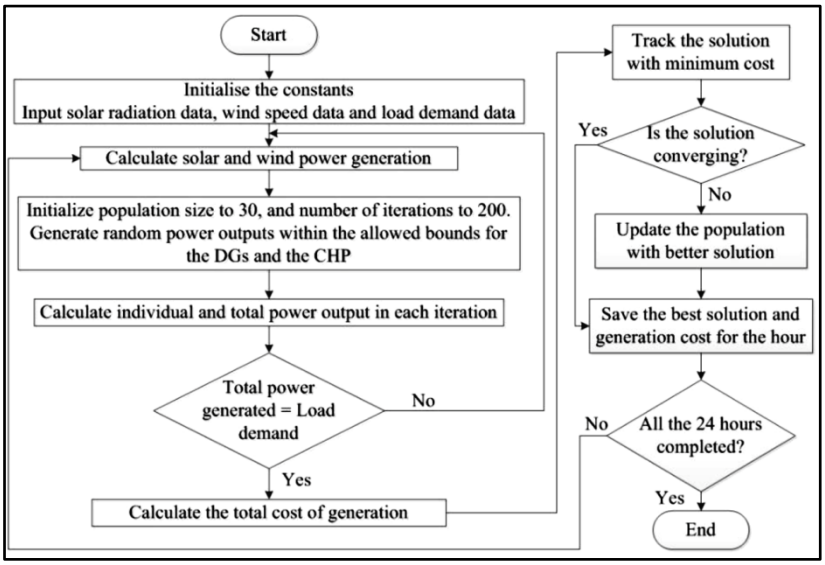


**Figure 2** NTO flowchart

**RESULTS**

The developed NTO algorithm attempts to optimize the share of generation from different sources in the MG so that total generation matches the load demand at overall minimized cost. **Figure 3** shows the cost-optimized generation profiles from each individual sources, and how their combined generation matches the load demand perfectly.

In the cost convergence characteristic shown in **Figure 4**, up to the 133rditeration the total generation cost is found to decrease in steps. From 134thiteration onwards, the total generation cost has remained practically constant at around \$7400, indicating convergence to optimal solution. The total computation time is been observed to be 0.844 seconds, which indicates fastness of the optimization program. This indicates that the Nilgiri Tahr Optimization is effective in doing speedy, accurate and consistent optimal scheduling results which is needed in the real-time situations.

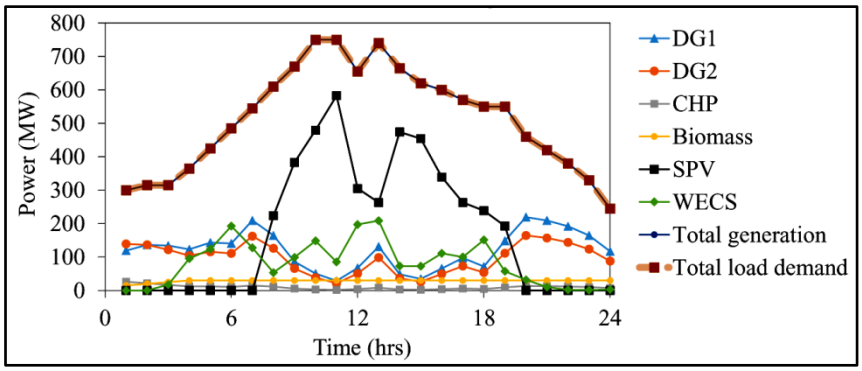


**Figure 3** Cost optimized generation profile matching load demand

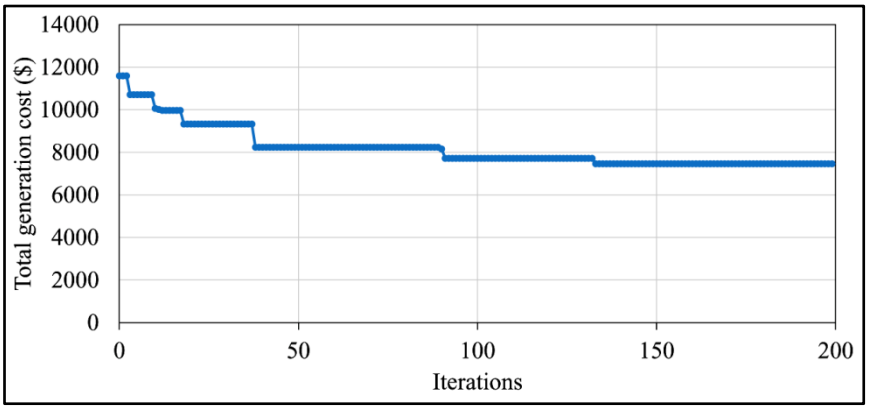


**Figure 4** Convergence characteristics of generation cost at an arbitrary hour

## CONCLUSION

In this paper, a novel optimization algorithm inspired by the grazing behaviour of Nilgiri Tahr, termed Nilgiri Tahr Optimization (NTO), is introduced and applied for optimal load scheduling in an isolated microgrid. The microgrid comprises of DGs, a CHP, SPVsystem, WECS, and a biomass power plant. The primary objective is to minimize the total generation cost of the system while meeting dynamic hourly load demands and considering operational constraints such as ramp-up and ramp-down limits. The cost functions of DGs, CHP, and biomass plants are modelled as second-order polynomials, while wind and solar power generation costs are based on wind speed and solar radiation data. The NTO algorithm efficiently distributes the load across the various power sources and minimizes generation costs, achieving stable and accurate results within fewer iterations. The total computation time is found to be 0.844 seconds in Python 3.0 code in Jupyter notebook. The results suggest the proposed algorithm's potential for real-world microgrid applications. Future work is intended to extend the microgrid structure to include storage devices and other forms of distributed generation sources, such as micro-hydro plants. Comparison of the novel NTO method with conventional optimization tools is also to be carried out in future work.

## ACKNOWLEDGMENT

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115_IEC64210

# Techno-Economic Optimization for Overall Sustainability of Decentralized Hybrid Energy System using Machine-Learning based Forecasting of Load and Weather Data

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***Abstract:*** *The global energy transition demands a significant integration of renewable sources into the power mix to achieve a sustainable, low-carbon future. However, the intermittent and diffuse nature of many renewable resources presents considerable challenges. Distributed hybrid energy systems that leverage local renewables are emerging as a viable solution for reliable power generation. Key obstacles include fluctuations in load demand and weather variability, which complicate capacity planning and cost estimation. Accurate forecasting of both load and weather conditions is crucial for optimizing smart energy management. This study employs machine learning techniques, specifically artificial neural networks (ANN), for short- and medium-term forecasting. The results are compared with deep learning methods to evaluate efficiency and are further utilized for technoeconomic optimization through simulation tools. Validation of the models is performed using the Binary β hill-climbing technique, while a sensitivity analysis conducted via the response surface method confirms the robustness of the findings. The study identifies a photovoltaic-lead-acid system as the most cost-effective solution for a remote Indian village, achieving an electricity cost of $0.0386 per kWh.*

***Keywords****: Load and Weather Forecasting; Artificial Neural Network; Techno-Economic Optimization; Sensitivity Analysis; Cost of Electricity*

## INTRODUCTION

The goal of the global energy transition is to replace fossil fuel-based energy systems with renewable and sustainable sources. This transformation is essential for mitigating climate change, controlling environmental pollution, and ensuring access to clean and affordable energy for all, as outlined in Sustainable Development Goal 7 (SDG 7) [1]. Shifting toward renewable energy not only reduces emissions but also helps to restore ecological balance [2]. However, a significant challenge of renewable energy is the uncertainty in power generation caused by the intermittency of natural resources. To address this issue, adopting hybrid systems in renewable energy is crucial. Pal and Mukherjee [3] reported that a 100% renewable energy system, operating at minimal cost, successfully generated electricity from a photovoltaic (PV)-hydrogen fuel cell to meet the load demand across all eight states of North Eastern India. Emad et al. [4] demonstrated that a combination of PV, wind, and storage systems can meet required load demands at various power supply probability percentages, achieving minimum costs in remote areas of Egypt. Additionally, Gul et al. [5] found that a PV-DC storage system effectively meets the load demand of the Perugia municipality, with a cost of electricity (COE) at $3.90 per kWh.

Previous studies have primarily focused on the techno-economic optimization of decentralized energy systems, with limited research comparing storage modules under various dispatch strategies for efficient energy solutions. While some have addressed load forecasting alongside optimization, this has largely been limited to short-term forecasting. The inherent uncertainties in energy resources and weather conditions are often overlooked. Additionally, few studies have investigated the combined effects of load and weather uncertainties on techno-economic optimization, and medium-term forecasting remains largely unexplored.

This study aims to develop an improved energy management system for consumer microgrids, focusing on optimizing battery storage and maximizing profits. It emphasizes the importance of accounting for forecast errors, rather than solely scheduling power based on predictions, while also considering battery constraints. Effective load forecasting helps reduce peak-hour demand, while accurate weather forecasting ensures optimal capacity and efficiency. The study integrates machine learning for both short- and medium-term load and weather forecasting,

employing artificial neural networks (ANN) for daily predictions. The resulting forecasts and their error rates are utilized for techno-economic optimization through Binary β hill climbing optimization.

## MATERIALS AND METHODOLOGY

The proposed methodology employs an artificial neural network (ANN) model for load and weather forecasting over periods ranging from one day to one month, with Mean Absolute Percentage Error (MAPE) and Root Mean Square Error (RMSE) calculated for both datasets. These forecasts, along with other relevant inputs, are utilized for technoeconomic optimization to ensure an uninterrupted power supply. To achieve more precise results, Binary β hill climbing optimization is implemented. An economic sensitivity analysis is conducted using the Response Surface Methodology and ANOVA (RSM-ANOVA) approach. A detailed overview of the methodology is presented in **Figure 1**. Below, we discuss the objective function and the relevant factors involved.

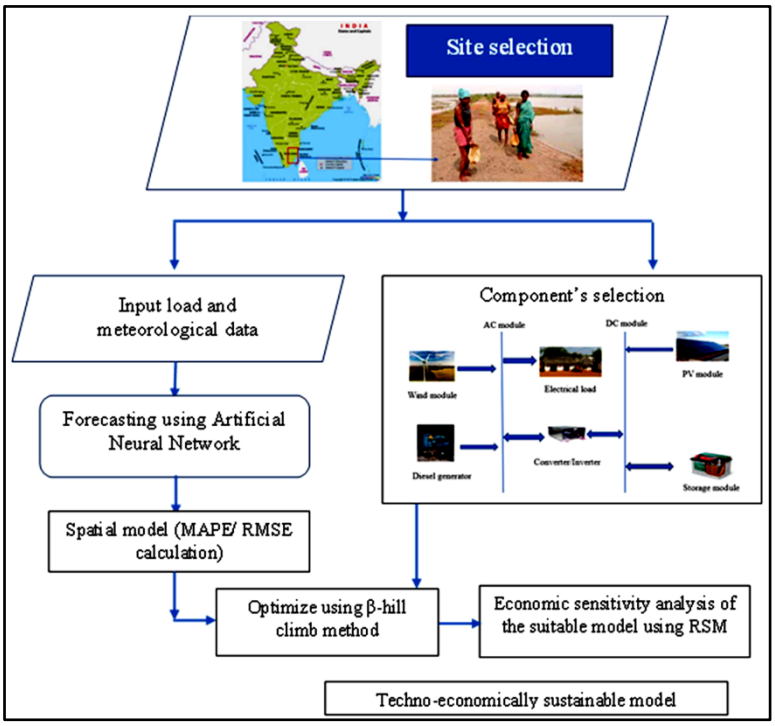


**Figure 1** Methodology flowchart

### Materials Specifications and Power Equations

The renewable energy modules considered for the study are solar photovoltaic module and wind turbine module. The maximum power generation from these modules are evaluated using **Eqs. 1** and **2** respectively.

$$P_{PV}(t) = Z_{PV\_STC} f_{PV} \left(\frac{G_T}{G_{STC}}\right)[1 + \alpha_p(T_c(t) - T_{c,STC})] \quad (1)$$

where $Z_{PV\_STC}$ is the rated capacity of the PV module in kW, $f_{PV}$ is the derating factor in %, GT is the solar radiation on the PV component at any time instance t in W/m$^2$, $G_{STC}$ is the radiation in standard condition (1000 W/sq.m.), $\alpha_p$ is the temperature coefficient in %/°C, $T_{c,\ STC}$ is the solar cell temperature at standard condition in °C, and $T_c(t)$ is the real-temperature of the solar cell in normal condition in °C. The wind turbine's output power at any time t is calculated by using **Eq. 2** [4].

$$P_{WT}(t) = \begin{cases} if\ 0\ for\ (V_t \geq V_o, V_t \leq V_i) \\ elseif\ P_r\left(\frac{V_t^2 - V_i^2}{V_r^2 - V_i^2}\right) for\ (V_i < V_t < V_r) \\ else\ P_r\ for (V_r < V_t < V_0) \end{cases} \quad (2)$$

where $P_r$ is the rated output power, $V_t$ is the wind speed in m/s at any instant, $V_r$, $V_i$, $V_0$ are the rated, cut-in and cutoff speed of the wind at hub height respectively (m/s).

## METHODOLOGY

### ANN Forecasting

Artificial Neural Networks (ANNs) are computational models inspired by the neural networks of the human brain, designed to recognize patterns and make data-driven predictions [6]. Comprising layers of interconnected nodes (neurons), ANNs learn from data through training algorithms that adjust the weights of connections. Their ability to model complex, non-linear relationships makes ANNs widely applicable for tasks such as classification, regression, and forecasting.

The ANN method requires an activation function to perform the forecasting. The activation function is generally sigmoid function. The function implemented in a MLP is expressed in **Eq. 3** [6].

$$f(x) = \sum_{k=1}^{n} T_j \psi(q_j^p x + q_{j0}) + T_0 \quad (3)$$

where, $T_j$ is the parameter vector, $\psi$ is activation function, $q_j$ is the vector of weights.

### Steps for the Binary β Hill Climb Optimization

Step 1: Initialize the Binary β hill climbing algorithm and set the parameters for feature selection. The solution is designed as a binary vector (X= $x_1$, $x_2$, …., $x_n$). Two parameters, i.e., N and β are considered in this optimization. The neighbouring operators are controlled by parameter N and β controls the β operators.

Step 2: The initial solution (X= $x_1$, $x_2$, …., $x_n$) is randomly chosen from the binary domain by following **Eq. 4** [7]:

$$X = \begin{cases} 1 & for\ U[0,1] \geq 0.5 \\ 0 & for\ otherwise \end{cases} \quad \text{where } U[0, 1] \text{ constructs a random number between 0-1.} \quad (4)$$

Step 3: The current solution is obtained in this tep by utilizing four operators. These four operators are used to obtain a new solution.

Step 4: The proposed algorithm is iterated until it reaches the stop criterion.

### Sensitivity Analysis

The study introduced Response Surface Methodology (RSM) to conduct an economic sensitivity analysis, assessing the robustness of the proposed solution [8]. RSM is a numerical technique that examines how variations in input parameters affect output parameters within a specified range. This approach evaluates the sensitivity of both individual and interconnected input parameter variations on the system's output [9].

The analysis is performed by designing an empirical model. This empirical model is developed by using 2nd order **Equations [10]**. The generalized form of the equation is shown in **Eq. 5** [10]:

$$y = a_0 + \sum_{i=1}^{n} a_i x_i + \sum_{i=1}^{n} a_{ii} x_i^2 + \sum_{i\geq 1}^{n} \sum_{j\geq 1}^{n} a_{ij} x_i x_j + \varepsilon \quad i < j \quad (5)$$

where y is the model response, n is the factor's number, a0 is the arbitrary coefficient, $a_i$ is the $i^{th}$ linear regression coefficient of the factor, $a_{ii}$ is the quadratic regression coefficients of factor i, $a_{i,j}$ is the combined value of $i^{th}$ and $j^{th}$ factors, and x is the autonomous design parameter. For n number of iterations, the **Eq. 17** is represented as a matrix shown in **Eq. 6** [10]

$$y = Xa + \varepsilon \quad (6)$$

where y is the observation vector with n ×1 dimension, X is the matrix of the model corresponding to the levels of the

independent variables with n × p dimension, a is a vector of the regression coefficients with p × 1 dimension, and ε is the vector of random errors with p ×1 dimension.

## RESULT AND DISCUSSION

The forecasted data obtained using the ANN method is illustrated in **Figures 2(a)-(f)**. According to the results shown in **Figure 2**, the Mean Absolute Percentage Error (MAPE) for one-month forecasting of load, solar radiation, temperature, and wind speed are 2.48%, 14.3%, 6.15%, and 1.68%, respectively. The Root Mean Square Error (RMSE) for the same forecasts are 0.01, 0.021, 0.18, and 0.12, respectively.

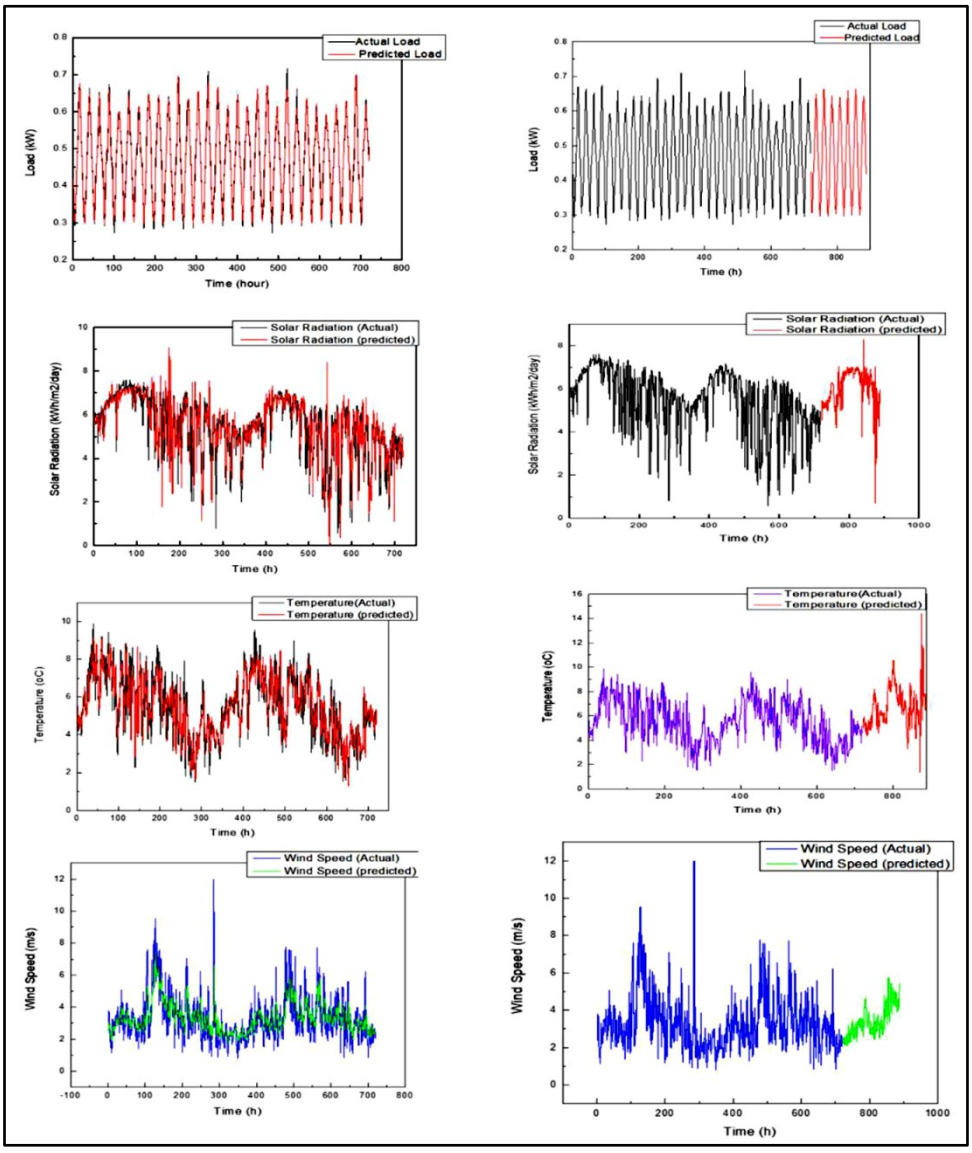


**Figure 2** Forecasting results

For the Mean Absolute Percentage Error (MAPE), load prediction remains low, with a one-month forecast of 2.48% and a one-week extrapolation at 2.5%. Solar radiation shows improvement, decreasing from 14.3% to 12.5%. Wind speed and temperature exhibit minor enhancements, with wind speed decreasing from 6.15% to 6.05% and temperature from 1.68% to 1.63%.

In terms of Root Mean Square Error (RMSE), load and solar radiation forecasts show improvement, while wind speed experiences a notable increase from 0.02 to 0.18, indicating challenges in short-term prediction. Temperature

also follows the improvement trend, with RMSE decreasing from 0.014 to 0.12.

The cost of electricity obtained from the hill-climb optimization for the PV-lead-acid (LA) battery model is $0.0386 per kWh. The optimization graph indicates that the cost of electricity (COE) is in a stable region, with a high acceptability value suggesting that the economic viability of the PV-LA battery model is reliable based on the considered input parameters. The acceptability of the COE is approximately 84%.

The Binary β hill climb optimization technique effectively evaluates the objective function while accounting for its

differentiation, increasing the convergence rate and resulting in a more accurate solution.

**Figure 3** illustrates that the COE of the PV-LA battery system rises with increasing discount rates and decreasing inflation rates. Specifically, the COE is significantly higher when both the capital cost of the PV module and the discount rate are elevated. At discount rates above 8.8% and a capital cost of $2247 per kW for the PV, the COE becomes notably high. The study indicates that to maintain economic stability for this energy solution, the discount rate, inflation rate, and PV capital cost should be kept within a moderate range of ±0.45% to 0.1%.

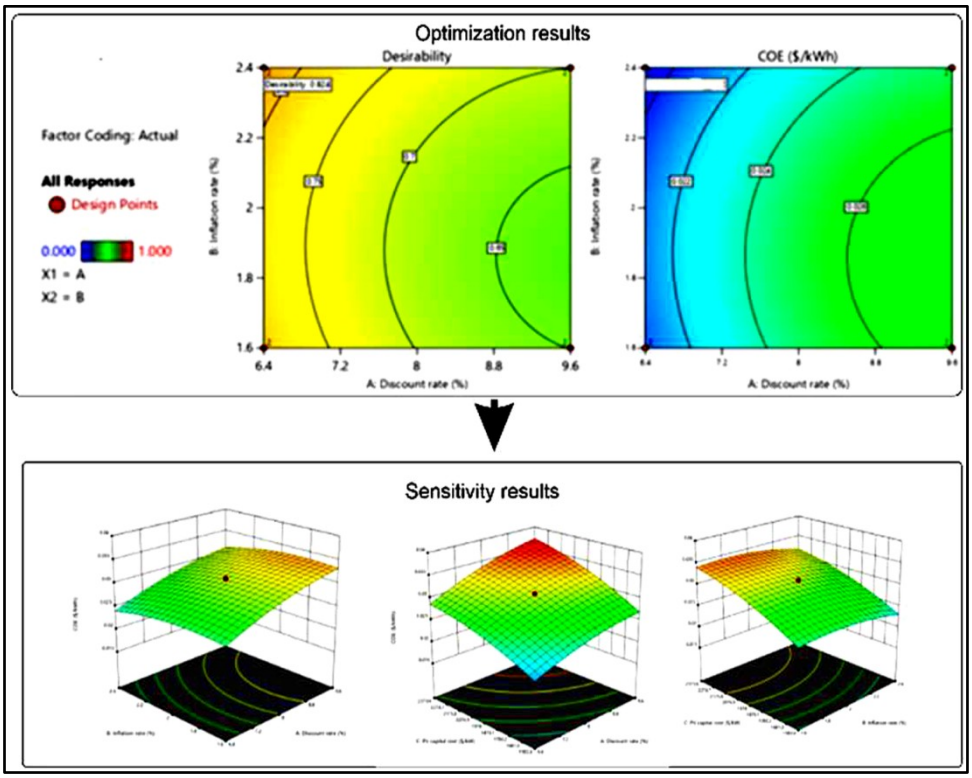


**Figure 3** Optimization and sensitivity results

## CONCLUSION

The study aims to identify the techno-economically optimal decentralized hybrid energy system (HES) by determining precise module capacities that meet the required load while ensuring optimal economic performance. It incorporates machine learning-based forecasting using artificial neural networks (ANN) for both load and weather, leveraging forecasted values and errors within a Binary β hill climb optimization technique for techno-economic optimization. A sensitivity analysis is conducted to evaluate the robustness of the solution.

The forecasting approach results in a 28.8% reduction in the cost of electricity (COE). The sensitivity analysis reveals that the standard deviation of the economic parameters for this combination is 0.0007, with a regression value of 0.9888, indicating the economic robustness of the proposed solution. While the results may vary with changes in

location, this methodology is novel. Future studies could explore additional aspects of sustainability, such as social and environmental performance.

## ACKNOWLEDGMENT

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148_IEC97686

# Prosumer Power Exchange with Battery Energy Storage Systems Integration in India

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***Abstract:*** *The increasing adoption of renewable energy technologies has led to the emergence of prosumers—individuals or entities that both produce and consume electricity. Prosumers primarily utilize solar photovoltaic (PV) systems, generating electricity for their own use and feeding excess power back into the grid. However, current mechanisms such as net metering and Feed-in Tariffs (FiT) have proved inadequate, both financially and technically. These systems offer limited compensation for surplus energy and do not fully incentivize energy storage or dynamic interaction with the grid. As a result, prosumers often face financial disincentives, and the grid struggles to handle the bidirectional energy flow.*

*This paper proposes the establishment of a Prosumer Power Exchange (PPE) that integrates Battery Energy Storage Systems (BESS) to overcome these challenges. The PPE provides a market-driven platform where prosumers can trade their surplus energy at competitive, real-time prices, while BESS allows them to store excess energy for sale during peak demand. This approach enhances profitability for prosumers and contributes to grid stability by enabling energy storage and balancing supply and demand. The paper outlines a comprehensive implementation framework, discusses regulatory and infrastructural challenges, and offers policy recommendations to support widespread adoption. Through the integration of PPE and BESS, this model aims to optimize India's energy landscape, contributing to a more efficient, resilient, and sustainable system in line with national renewable energy goals.*

***Keywords:*** *Prosumer; Power Exchange; BESS; Renewable Energy; Market-Driven Pricing; Grid Stability*

## INTRODUCTION

India's energy sector is at the forefront of a major transformation, driven by the urgent need to transition from fossil fuels to renewable energy sources. With its vast solar potential and favourable geographic conditions for wind energy, India is capitalizing on these resources to address the growing energy demands of its population while reducing its dependence on coal and other non-renewable sources. As of early 2023, the country's installed renewable energy capacity stood at approximately 172 GW, with solar energy accounting for around 64 GW. The government's ambitious target to achieve 500 GW of renewable energy capacity by 2030 is a critical component of India's strategy to meet its commitments under the Paris Agreement, reduce carbon emissions, and bolster energy security in an era of climate change.

This transition has given rise to the concept of "prosumers"—individuals or entities that not only consume electricity but also generate it, typically through rooftop solar photovoltaic (PV) systems. Prosumers contribute excess power back to the grid, playing a crucial role in decentralized energy generation and alleviating the load on centralized power systems. However, despite the promise of a cleaner, more sustainable energy future, prosumers face significant challenges. Existing frameworks like net metering and Feed-in Tariff (FiT) systems are financially inadequate and often fail to incentivize prosumers to maximize their generation potential. These systems do not fully recognize the value of surplus energy, nor do they encourage the integration of energy storage solutions that could enhance grid stability. This paper explores how an innovative Prosumer Power Exchange (PPE), combined with Battery Energy Storage Systems (BESS), can overcome these limitations, offering a more dynamic, market-driven approach to energy trading and contributing to India's renewable energy goals. By doing so, this model could fundamentally reshape the country's energy landscape, fostering resilience, profitability, and sustainability for prosumers and the grid alike.

### A. Current Prosumer Landscape

Prosumers have increasingly become a vital component of India's renewable energy strategy. By March 2024, India had a total installed rooftop solar capacity of 10.8 GW, driven by various government initiatives such as the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) and PM Surya Ghar schemes. These initiatives encourage decentralized solar power generation by providing financial incentives and streamlined processes for installation, especially in rural and urban households.

### B. Limitations of Current Systems

1. Net Metering: This mechanism allows prosumers to feed surplus electricity back into the grid, offsetting their consumption. However, net metering often provides lower compensation than retail prices, discouraging prosumers from maximizing energy production. Additionally, the variability in state-level net metering policies creates inconsistencies in financial returns for prosumers.
2. Feed-in Tariff (FiT): FiTs offer fixed payments for the electricity prosumers supply to the grid. In many Indian states, the FiT rates are below market prices, reducing the financial appeal of generating surplus energy. For instance, in Maharashtra, the FiT for solar power is around INR 2.44 per kWh, significantly lower than the retail electricity price of INR 7 per kWh.
3. Regulatory Barriers: Current regulations often do not support the direct participation of small-scale prosumers in the energy market. Requirements for minimum capacity, procedural complexities, and insufficient support for small-scale distributed energy generation limit prosumer participation. Only about 30% of India's distribution companies (DISCOMs) have the infrastructure to manage high levels of distributed renewable energy.
4. Grid Infrastructure: The traditional grid infrastructure is not designed for bi-directional energy flow, leading to technical challenges such as voltage fluctuations and grid instability. High transmission and distribution (T&D) losses, which were around 20.66% in 2019, further complicate the integration of prosumer-generated energy.

### C. Proposal for Prosumer Power Exchange (PPE) with BESS Integration

To address these challenges, this paper proposes a Prosumer Power Exchange (PPE) that integrates Battery Energy Storage Systems (BESS). The PPE provides a market-driven platform where prosumers can trade their surplus electricity at real-time market prices, moving away from fixed FiT schemes. The integration of BESS enables prosumers to store excess energy generated during low-demand periods and sell it during peak demand, maximizing profitability and contributing to grid stability.

## BACKGROUND

### A. Importance of Battery Energy Storage Systems (BESS)

BESS is crucial in managing the variability of renewable energy sources like solar power. It allows for the storage of energy during periods of low demand and its dispatch during peak times, enhancing grid stability and reliability. The inclusion of BESS in the PPE model offers multiple benefits:

1. Increased Profitability: Prosumers can sell stored energy during peak demand periods when prices are higher, optimizing their revenue potential. Studies have shown that integrating BESS can increase the value of solar energy by up to 50%.
2. Grid Stability: BESS can provide ancillary services such as frequency regulation and voltage support, which are critical for maintaining grid stability in the presence of high renewable energy penetration.
3. Energy Independence: BESS allows prosumers to rely less on the grid, reducing their exposure to grid outages and improving energy self-sufficiency.

### B. Case Studies of BESS and PPE Integration

International examples, such as the Hornsdale Power Reserve in Australia, demonstrate the potential benefits of integrating BESS with renewable energy systems. The Hornsdale facility provides critical grid services and has generated substantial revenue from energy arbitrage and ancillary services. Similar implementations in the United States and Europe have shown that BESS can significantly improve the financial viability and operational efficiency of renewable energy projects.

## OBJECTIVES

The primary objectives of the proposed Prosumer Power Exchange with BESS integration are:

1. Enhanced Profitability: Providing prosumers with access to market-driven pricing will lead to higher revenues compared to fixed FiT systems. Market-based pricing mechanisms can increase prosumer income by 30-40%.
2. Improved Grid Stability: By enabling the storage and timed dispatch of energy, BESS helps maintain grid stability, especially during peak demand and renewable energy variability.
3. Increased Adoption of Renewable Energy: A more financially attractive and technologically supportive framework will encourage more households and businesses to invest in rooftop solar and other renewable energy technologies, helping India meet its renewable energy targets.
4. Flexibility and Transparency: The PPE platform provides prosumers with real-time data on market prices and grid conditions, enhancing decision-making and optimizing energy transactions.

## DETAILED IMPLEMENTATION FRAMEWORK

### A. Feasibility Studies and Pilot Projects

Before full-scale implementation, it is crucial to conduct feasibility studies and pilot projects across different regions to test the PPE and BESS integration model. These studies should evaluate the technical, economic, and regulatory aspects of the proposed system, identifying potential challenges and solutions.

### B. Stakeholder Engagement

Successful implementation of the PPE requires the involvement of multiple stakeholders, including government bodies, utilities, technology providers, and prosumers. Engaging these stakeholders early in the planning process will ensure that the system is designed to meet the needs of all parties involved.

### C. Policy Advocacy

Policy support is critical for the success of the PPE model. The government should introduce policies that provide financial incentives for BESS adoption, streamline approval processes for prosumer projects, and revise regulations to allow smaller prosumers to participate in energy trading.

### D. Technology Infrastructure

The deployment of advanced metering infrastructure (AMI), including smart meters and real-time data analytics platforms, is essential for accurate measurement, billing, and management of energy transactions. AMI will enable transparency and efficiency in the energy trading process.

### E. Education and Support

Training programs and awareness campaigns should be conducted to educate prosumers about the benefits of participating in the PPE and using BESS. Providing technical support and resources will help prosumers optimize their energy generation and storage systems.

## CHALLENGES AND SOLUTIONS

### A. Minimum Capacity Requirements

Challenge: Current power exchange models in India have minimum capacity requirements that exclude smaller prosumers.

Solution: Aggregation models can be adopted where utilities act as aggregators, pooling energy from multiple small-scale prosumers to meet minimum capacity thresholds for market participation.

### B. High Costs of BESS

Challenge: The high upfront costs of BESS can be a barrier to adoption.

Solution: Financial incentives, subsidies, and tax benefits can be provided to reduce the initial investment burden. Additionally, innovative financing models, such as leasing and shared ownership, can make BESS more accessible to prosumers.

### C. Regulatory Barriers

Challenge: Regulatory frameworks may not fully support the direct participation of prosumers in energy markets.

Solution: Governments and regulatory bodies should revise existing policies to reduce procedural complexities and allow for more flexible participation criteria. Implementing clear guidelines for prosumer transactions will facilitate market entry.

### D. Grid Integration

Challenge: Grid infrastructure in India has traditionally been designed for a one-way flow of electricity, making it ill-equipped to handle the bi-directional energy flow necessary for large-scale prosumer integration.

Solution: Upgrading grid infrastructure to accommodate distributed energy resources is essential. This includes implementing smart grid technologies that allow for better demand response and grid management. Investments in digital grid management systems and enhanced data analytics can help anticipate and manage the variability in power supply from prosumers. Introducing advanced inverter technologies that allow smoother integration of prosumer-generated power into the grid is another critical step.

## CONCLUSION AND FUTURE OUTLOOK

The proposed Prosumer Power Exchange with BESS integration offers a promising solution to the current challenges faced by prosumers in India. By providing a market-driven platform for energy trading, this model enhances the profitability of renewable energy investments, improves grid stability, and encourages the widespread adoption of renewable energy technologies. The successful implementation of this model requires coordinated efforts from policymakers, regulators, utilities, and prosumers to create a supportive regulatory and technological environment.

Looking forward, expanding the scale of pilot projects, developing robust policy frameworks, and investing in advanced technology infrastructure will be crucial steps in realizing the full potential of the Prosumer Power Exchange model. The adoption of such innovative solutions can significantly contribute to India’s energy transition goals, positioning the country as a leader in sustainable and decentralized energy systems.

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# Real-Time Performance Monitoring of a Grid-Connected Microgrid with PMSM-based Wind Energy Conversion System

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***Abstract:*** *This article demonstrates real-time validation of a grid-connected permanent magnet synchronous generator (PMSG) based Wind Energy Conversion System (WECS) integrated with a battery energy storage system (BESS). Here, d-q axis control is adopted for the inverter, and Synchronous Rotating Frame -Phase Locked Loop (SRF-PLL) is adopted for grid-synchronization purposes. In addition, intelligent energy management systems (EMS) have been employed to efficiently manage the two distributed generation (DG) sources, WECS and BESS. Intermittency of wind generation is compensated by the BESS which stores excess power generated by the wind generator and delivers it to the grid during periods of low generation. A MATLAB/SIMULINK model is developed and simulated in the real-time platform OPAL-RT. Both the SIMULINK model and the real-time model are used to validate the efficient operation of the proposed scheme.*

***Keywords:*** *Permanent Magnet Synchronous Generator (PMSG); Battery Energy Storage System (BESS); OPAL-RT; Microgrid*

## INTRODUCTION

Over the last two decades, the world has witnessed a major concern about the energy crisis and rising environmental pollution, which have triggered the use of renewable energy sources (RES) [1]. Due to the increasing pressure of the energy crisis, wind power is gaining keen interest and is growing rapidly in modern-day power systems as a clean energy source. As per the current trend, wind energy has witnessed exponential growth [2- 3]. Wind Energy Conversion Systems (WECS) can be of two types viz, fixed speed WECS and variable speed WECS that capture more power even under low wind velocities. Variable-speed WECS mainly include the use of a doubly-fed induction generator (DFIG) and permanent magnet synchronous generator (PMSG) [4]. In PMSG, the synchronous generators used in WECS take its necessary DC excitation either by using permanent magnets or by using electromagnets. The PMSG must run at synchronous speed to maintain the synchronism with the grid. As the wind speed is sporadic in nature, PMSG is incapable of producing a constant frequency supply and that's why it requires power converters to match with the frequency of the grid [5]. In comparison with DFIG, PMSG has superior grid support ability, and higher power-producing capability and there is no need of a box arrangement for controlling the speed [6]. The present study therefore attempts to monitor the performance of a PMSG-based WECS in real-time.

As wind flow is sporadic, it is very difficult to harness wind power smoothly with such intermittent wind speeds. To cope with this situation, BESS is commonly employed along with WECS. BESS employed in the WECS stores surplus power generated from the wind generator and also delivers the deficit power when wind generator output is inadequate. Various control strategies are being employed in the WECS-battery integrated systems for efficient switching between the wind generator and battery depending upon the wind speed and load demand. Microgrids formed by the integration of RES and BESS require precise control strategies that take into account the costs, degradation of the equipment, and equipment design constraints [7].

Various research works have been done or are undergoing on grid-connected PMSG-based WECS along with battery storage. Research into grid-connected PMSG-based WECS using coordinated control strategies for smoothing power fluctuations is outlined in [8]. Authors in [8] proposed two strategies. One is by simultaneous control of dc-link voltage, rotor angle control, and blade pitch control and another is by coordinating the three individual control strategies in a hierarchical manner where the power smoothing tasks are allocated in individual or combination by some intelligent algorithm. Their focus, however, is more on the wind turbine control rather than the generator control except for the DC-link voltage control. The authors of [9] have studied LVRT capability of the WECS by four different control approaches namely, modulation index (MI) control, de-loading, use of crow-bar resistance, and

interchanging the duties of two converters to lock the rise in dc-link voltage [9]. As wind energy is stochastic, to address the stochastic issue, an anti-disturbance full-order sliding mode controller (FOSMC) based on Extended Space Observer (ESO) is designed for controlling the current in PMSG by the authors of [10]. Their proposed FOSMC utilized a continuously controlled sliding mode to rectify the chattering problem and also to eradicate the disturbances estimated by the ESO.

The present contribution deals with real-time monitoring of a grid-connected PMSG-based WECS integrated with BESS. The article describes inverter-control methods including d-q axis control of the grid-side current, PI tuning, and Phase Locked Loop (PLL) for grid synchronization. Here, Synchronous Rotating Frame-PLL (SRF-PLL) is used for the synchronization and a simple if-else condition programming is used for charging and discharging switching of the battery. For real-time validation of the proposed scheme, the whole system is simulated in MATLAB/SIMULINK and then verified in real-time simulator OPAL-RT.

The notable contributions of this paper can be outlined as:

- Performance evaluation of the PMSG based wind energy conversion system in real-time environment
- Implementation of efficient switching of the charging and discharging conditions of BESS under varying wind profile

## METHODOLOGY

### System Description

A schematic diagram of the proposed microgrid structure with a grid-connected WECS using a 3.7 kW, 6-pole PMSG alongside a 3 kVA, 300 V, 10 Ah Li-ion type BESS is illustrated in **Figure 1**. The WECS is connected to the grid through a series of the rectifier, boost converter, inverter, and a filter circuit. BESS charging is done from the WECS chopper output, while it discharges to load and grid through another inverter and filter combination. The sinusoidal Pulse Width Modulation (SPWM) technique is implemented for generating necessary triggering pulses for driving both inverters. d-q axis current control along with SRF-PLL is implemented for closed-loop control of the inverters. Battery Management System (BMS) utilizing a simple if-then-else algorithm is implemented to manage charging and discharging instances of the battery, taking into account its SOC, power generated by the WECS, and load demand.

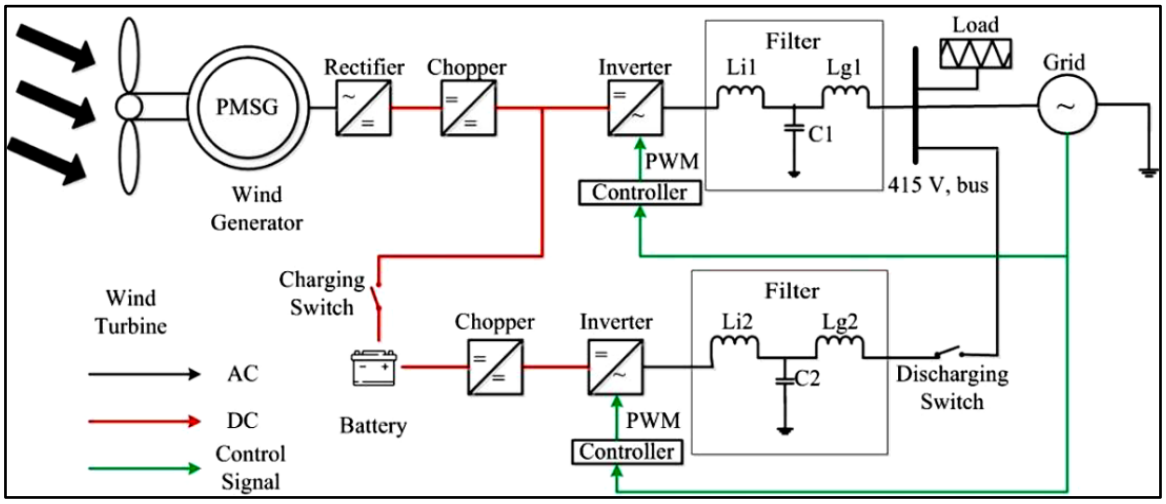


**Figure 1** Schematic diagram of grid-connected MG with DFIG

### Role of Battery Energy Storage System (BESS) and its Management

The battery energy storage system (BESS) plays an important role in this proposed system. As the wind energy is sporadic, it supplies power to the grid and the load during the off-wind times and gets charged during the wind power

generation. In paper [11], the authors use a BESS charging-discharging algorithm that uses battery SOC and time as the main deciding factors for controlling the switching of the battery in a DC microgrid system. In the current contribution, charging and discharging are done by using two controlled switches controlled by simple if-else logic, whose flowchart is given in **Figure 2**. In this flowchart, three parameters are chosen for comparison namely, wind power, battery State of Charge (SOC), and load. The flowchart depicts that if the wind power is less than the load, then the charging switch is set to OFF, while the discharging switch is ON, enabling the battery to deliver power to the load. If the wind power is greater than the load, then the charging switch is in ON state and the wind generator delivers power to the load along with charging the battery. Here, a 1500 W constant load profile is selected for simplicity of the simulation. Here, the maximum threshold of SOC is 80% and the minimum threshold is 40%. If the battery SOC reaches 40% or less then the battery starts charging and if the battery SOC reaches 80% or more then the battery starts to discharge.

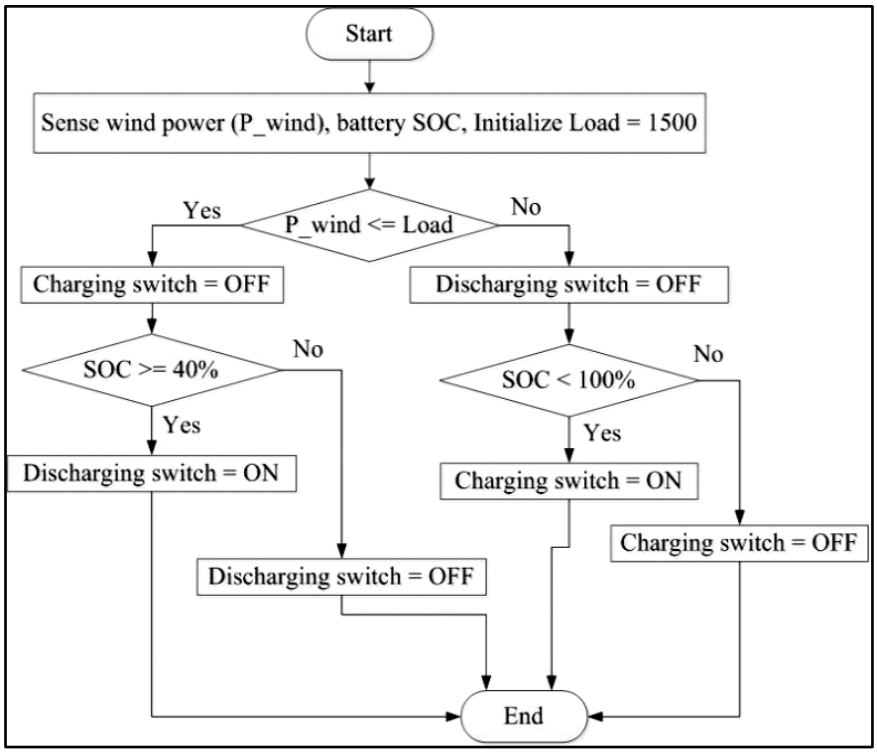


**Figure 2** Flowchart for battery charging and discharging

**Inverter Control**

The two inverters present in the microgrid, one for the PMSM, and the other for the BESS, are controlled using the SRF technique as detailed in the MATLAB/Simulink model of **Figure 3**. The control strategy includes conversion of 3-phase grid voltage and converter current to α-β and d-q reference frames using Park's Transformation. In grid-connected mode, it is necessary to identify the frequency and phase angle of the grid voltage to achieve synchronization with the PMSM output inverter. For this purpose, SRF-PLL is used to synchronize the inverter with the grid. In this PLL, the grid voltage is transformed from a-b-c to d-q variables by Park's transformation which acts as a phase detector. A PI controller is used to adjust the quadrature axis voltage Vq to zero to align phase angle of the inverter with grid. The output of the PI controller is integrated by an integrator to give the desired phase angle output. Closed-loop control for inverters uses the d-axis current (Id) and q-axis current (Iq) components of the converter currents. These currents are compared with their respective reference values (Id* and Iq*). The reference value Id* is generated by comparing the reference DC-link voltage with the measured DC-link voltage. The reference value Iq* is set to zero as it is assumed that the injected reactive power to the grid is zero. After comparison, the PI controllers tune the error signal, which produces the corresponding voltage reference values Vd* and Vq*. These voltages are then converted into three-phase sinusoidal voltages employing inverse Park's transformations for onward

synchronization with the grid. A PWM generator produces pulses for switching corresponding IGBTs of the inverters based on the reference current signals.

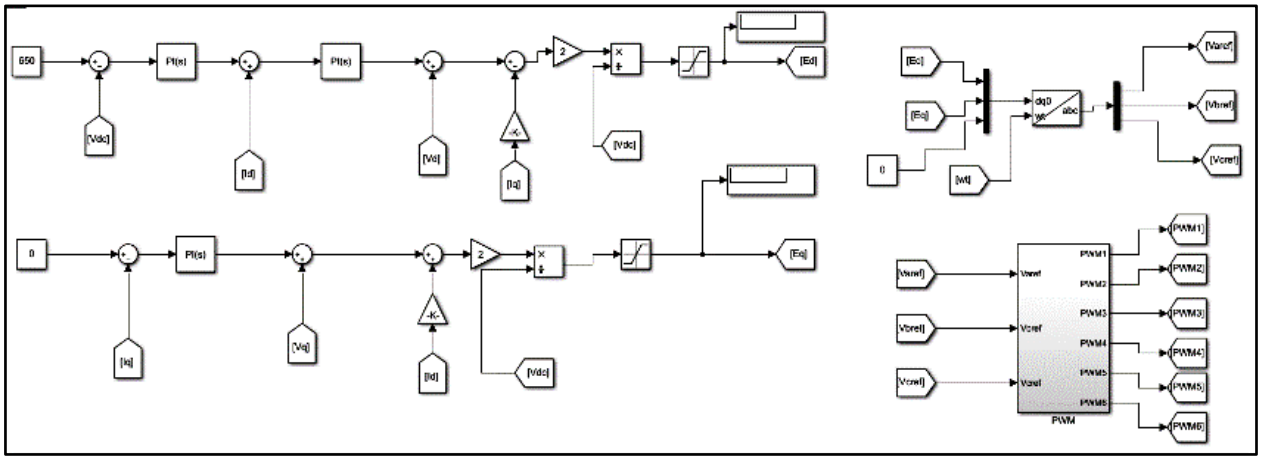


**Figure 3** Inverter closed loop control

**Real-time Simulation**

For the real-time validation of this proposed scheme, OPAL-RT(OP4510) has been used. It has 128 fast I/O channels with Rs-232 channels, and four high-speed communication ports, and is fully generated with Simulink [12]. To implement a MATLAB Simulink model in OPAL-RT, it is mandatory to create two subsystems within Simulink [13] namely, SM (Master Subsystem), which mainly includes the model's computational block and another is the SC (Console Subsystem), which includes all the Simulink/System blocks related to data acquisition and visualization (such as scopes, blocks for exporting data to workspaces, etc.) [13]. To simulate OPAL-RT, two additional blocks are required namely OpComm and Opwrite blocks between SM and SC subsystems for producing desired outputs/plots respectively.

**RESULTS**

This section discusses real-time simulation results of the PMSG-based WECS with BESS using real-time simulator Opal-RT. The experiment is conducted for 24 hours a day cycle. **Figure 4** shows the wind variation profile for 24 hours over a day. With the help of simple if-else condition algorithm (**Figure 2**), it is decided whether the battery should be charged or discharged. **Figure 5** shows different powers namely, PMSG-generated power, inverter power, grid power, load demand, and battery power during discharging and charging. When the PMSG output power is greater than the load demand and at the same time the SOC of the battery is less than the minimum threshold of SOC, the battery starts charging. The negative grid power indicates that the grid is absorbing power and the positive PMSG power and inverter output power signify that the power is being delivered to the load and the grid. In **Figure 5** inverter output power is quite low as some of the power is transferred to the battery for charging. When the battery is fully charged or the SOC is 100% and the PMSG generated power is greater than the load demand, the excess generated power is transferred to the grid after meeting the load demand. The graph illustrates that for the initial 10 hours, the battery is discharging because the PMSG-generated power is insufficient to meet the load demand, which is supplemented by the grid and the battery. For the last 6 hours, as the PMSG-generated power is more than the load demand, the battery starts charging and absorbs some power from the wind generator and the grid also absorbs some power from the generator. The results indicate that the generated power satisfies the load demand first, and then any remaining power is fed to the grid.

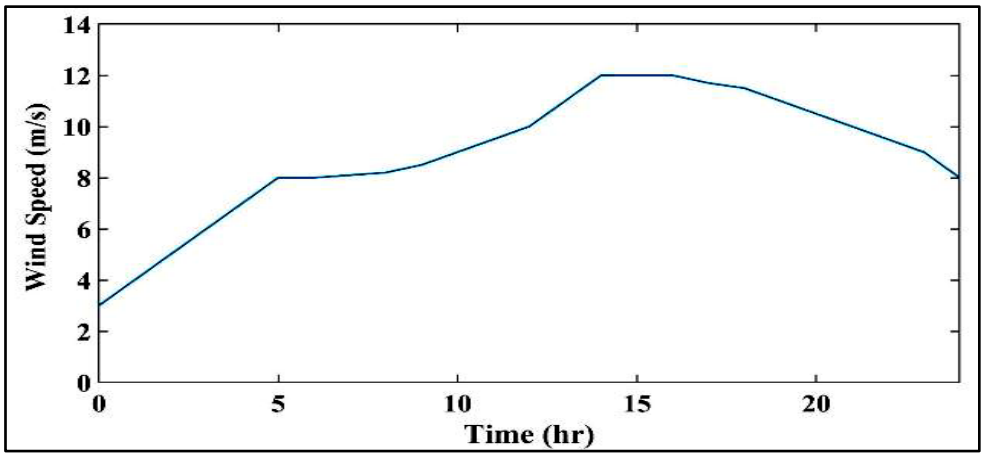


**Figure 4** Wind speed variation profile over 24 hours

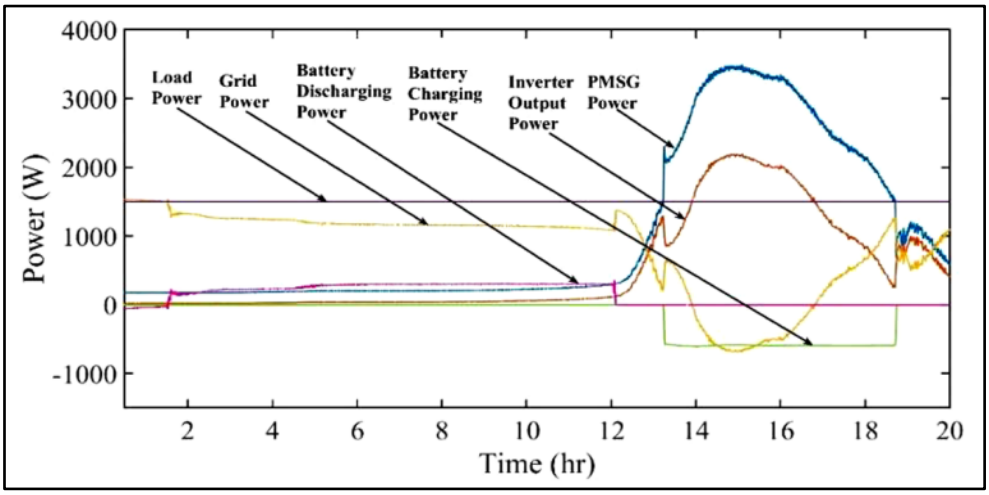


**Figure 5** Power profile during discharging and charging of battery

## CONCLUSION

In this article, a PMSG-based wind energy conversion system with battery storage has been implemented in MATLAB-SIMULINK and a real-time simulator Opal-RT. In this proposed scheme, a wind profile of 24 hours is used where the wind turbine's cut-in speed is set 3 m/s where the power generation starts, and the rated speed is 12 m/s where the maximum power generation takes place. The charging process of the battery is done from the DC link of the wind generator by using a charging switch which is controlled by a simple if-else condition programming. Similarly, the discharging process is done by using discharging switch which is controlled by similar if-else condition programming. The graphs given in this article reflect that during high wind power generation, the battery gets charged absorbing some power from the wind generator and the wind generator also supplies power to inverter, grid and load and during low wind power generation, the battery starts discharging its power to meet the load demand and some power to the grid.

The novelty of the work is that the proposed system is not solely dependent upon the grid. The PMSM generated power is fed to the load on a priority basis. Balance generation is used for charging the battery till SOC condition is met, and further excess power is delivered to the grid. During insufficient wind power generation, the load demand is primarily met from battery, thereby enabling reduced dependency on load.

In future, it will be prudent to use some meta-heuristic algorithms for efficient battery management system which considers multiple parameters like battery State of Health (SOH), temperature, average life, etc. in addition to the

SOC. In addition, we will also consider variable load demand to match with the real-life scenario and hence various optimization algorithms will be implemented for efficient load scheduling, and various advanced controllers will also be studied for battery charging-discharging control.

## ACKNOWLEDGMENT

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193_IEC49191

# An Economical Micro Grid Architecture for Single-phase to Three Phase Power Governance System

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***Abstract:*** *This study suggests using Single-Phase Converters (SPC) connected between the phases of a Three-Phase Power System (TPS) for the effective power supply for a micro grid. The objectives are to lower total distribution costs and raise power quality at a micro-grid's point-of-common-coupling. The method relies on a master/slave structure, in which a centralized master controller (Arduino Uno) controls the distributed TPS as slave units. In the master controller processes and distributes them proportionately among distributed energy resources. The suggested control method is assessed in a simulation environment using a model. Lastly, a summary and discussion of the principal findings regarding both steady-state and transient circumstances are provided. Proposed method utilization of the energy provided by distributed generation (DG) units and independent power sharing per phase have become essential due to the rapid expansion of TPDG units and loads incorporated into micro-grids. Better load sharing can be achieved as well as optimal energy use and load supply among the various phases with the implementation of the suggested power management technique. The suggested hybrid micro-grid structure and control are validated by the results of experiments and simulations has been done on Proteus 8.9.*

***Keywords:*** *Single Phase; Micro-grid; Three Phase; LC filter; Inverter*

## INTRODUCTION

Micro-Grid is one kind of small power grid that operates individually from the local grids to power up residential area, big complexes, educational institutes, hospitals etc. to reduce the general electricity cost. Generally Micro-Grids have conversion of DC to single phase AC, using the same concept this project is deduced to conversion this single phase to three phase AC, as micro-grid produces single phase AC, in micro-grid three phase generation is costlier. As three phase supply can deliver more power with high efficiency. There are three types of micro-grid, i.e., AC micro-grid, DC micro grid and Hybrid micro-grid. From the name of AC micro-grid says that this kind of microgrid are powered by AC sources, equally DC micro-grids are powered by DC sources like renewable energy (Solar Energy, Wind Energy, etc.) and 3rd one hybrid micro-grid is a merged version of AC and DC micro-grid.

## METHODOLOGY

The principal object of the invention has been using several components are given in the table below. The innovation has been consisting of a 220 volt, 50Hz single phase ac source for input supply with a solar panel of 12V which gives 12V DC for the operation of the micro-grid. A single-phase AC to DC bridge rectifier has been used with a 12 volts battery to store the DC power for emergency and to power up the all components i.e., MOSFET bridges, Arduino and transformers. Transformer is the type of centre tapped with primary voltage of 220 volts and secondary of 12 volts. A three stage LC filter has been used to cancel out low frequency noise from the output. Each output has been connected with a 240 volts, 60 watt filament bulb which works as a load for the system.

Proposed flow chart has been used here to show all three possible cases i.e., case1. DC type, case 2. AC type and case3.Hybrid type. If only DC power or only AC power or both AC and DC power that means hybrid power is there then how the system is working has been shown by the flowchart.

Block diagram is an important graphical representation to quickly understand the system how the system will work. In case 1, it has a solar panel which gives us the 12 V DC power which have been stored by a 12 V battery. Battery is

parallelly connected with a DC bus circuit that it maintains the constant DC 12V supply without any voltage drop for smooth operation. Then the power from the DC bus divided into 2 parts one is 5volts which is required to power up the Arduino and another part is 12 Volts DC. From this 12 Volts DC the negative terminal goes to the MOSFET bridges and positive terminal to the center tapped step-up transformer. Output form the MOSFET bridges is also connected with the center tapped step-up transformer. The Arduino generated PWM signal has been required to controlling the MOSFET bridges to generate AC signal. Transformers output has been connected with the 3 stage LC filter which removes the DC signal from the output. Output has been star connected to show the three phase AC. Lastly the loads have been connected with the output.

**Table 1** Components table

| Sl. No. | Devices | Reference | Specification |
|---|---|---|---|
| 1. | AC Source | V1, VSINE | 220Volt, 50Hz |
| 2. | Rectifier Bridge | BR1, Bridge | Generic Bridge Rectifier |
| 3. | Battery | B1 | 12Volt |
| 4. | Capacitor | C1, C2, ...., C16 | 6800nF,2100nF |
| 5. | Inductor | L1, L2, ...., L9 | 1340mH |
| 6. | Arduino | ARD1, Arduino Uno V3 | ATmega328P,16MHz |
| 7. | MOSFET | Q1, Q2, ...., Q18 | IRFZ44N ($V_{DSS}$ = 55V, $R_{DS\ (on)}$ = 17.5mΩ, $I_D$ = 49Amp, $V_{GS}$=±20V) |
| 8. | Transformer | TR1, TR2, TR3, TR4 | Primary = 12Volt,Secondary = 240Volt, N1:N2=1:20 |
| 9. | Solar Panel | SOLAR PANEL | 12Volt |
| 10. | Load | Lamp1, Lamp2, Lamp3 | 240Volt,60Watt |

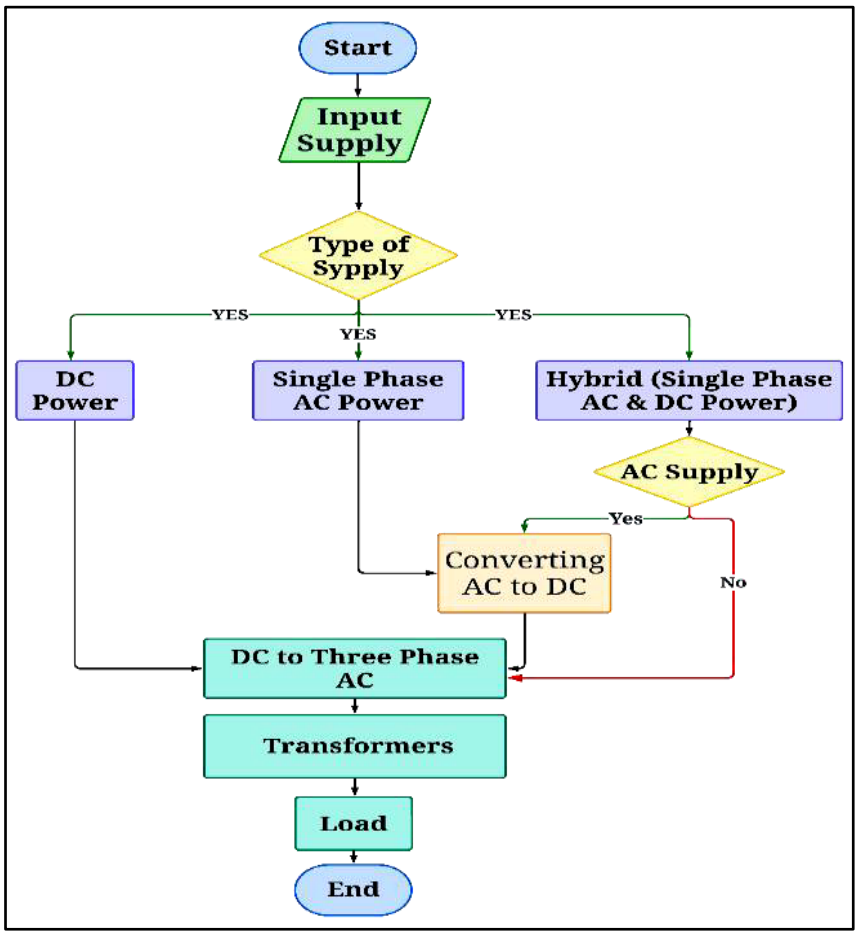


**Figure 1** Flow-chart of the following system

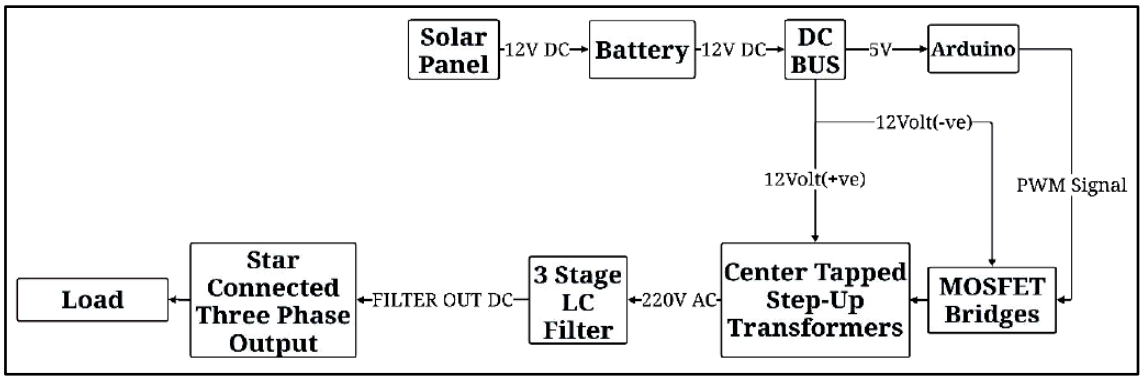


**Figure 2** Block Diagram for the Case-1

In Case 2, the solar panel has been replaced with a single-phase AC with a step-down transformer and a bridge rectifier. 220 Volts AC output has been step-down and rectified using step down transformer and a bridge rectifier to make 12 Volts DC. Next part is similar to case 1.

Case 3 is very similar and also a merged version of case 1 and case 2. In replacement of a single power source, both AC and DC power source has been used. As AC and DC are completely different form each other so the AC has been converted into DC then added with the input DC. After this it is same as the case 1 and case 2.

**DESCRIPTION**

**Case Study-1**

The circuit diagram provides a detailed overview of the entire project, showing how all the components have been interconnected. A Solar panel has been used to supplies the required power by the system. Solar panel has been connected with a 12Volts battery to store the excess energy. A DC bus has been parallelly connected with to battery to ensure that no voltage drop is occurred. From the DC bus two outputs have been presented one is 5volts that power up the Arduino and another part is 12Volts that has been used by transformer and MOSFET bridges. The Arduino micro-controller digital pins i.e., 11,10,9,8,7,6 that has been used as the controlling gate signal of the MOSFETs to control outputs of the MOSFET bridges. As PWM signal generation plays an essential for MOSFET control. Three MOSFET bridges, each containing six individual MOSFETs, are connected in a manner that bridges upper MOSFETs &lower MOSFETs gate has been connected in parallel, all six MOSFETs source have been connected together with the negative terminal of the DC supply and drains of the MOSFETs have been connected with the centre tapped step-up transformer. The upper MOSFETs of each bridge generates a square wave of half of the given amplitude and lower part has been used to create the mirror the square wave generated in upper part. The specific connections of MOSFET gates to Arduino pins has been as follows: Q1, Q2, and Q3 with pin 11, Q4, Q5, and Q6 with pin 10, Q7, Q8, and Q9 with pin 9, Q10, Q11, and Q12 with pin 8, Q13, Q14, and Q15 with pin 7, and Q16, Q17, and Q18 with pin 6. The MOSFETs have been powered up by the negative supply from the DC bus, which protects the Arduino from reverse current and voltage. Two outputs from the MOSFET bridges are connected to the secondary terminals of a centre-tapped step-up transformer, while the central terminal is linked to a positive supply from the DC bus. Consequently, three transformers have been elevated for the 12 volt AC supply to 240 volt AC, while transformer has been connected in star and each transformer powering a load, represented by a filament bulb of 220 volts 60 watt for each phase. Voltmeters are used to display the output AC voltage of each phases of phase voltage of 220 Volts and line voltage is around 370 Volts.

**Case Study-2**

It has been started with a 220-volt AC supply that goes to 220Volts to 12Volts step-down transformer As Indian region has 220volt supply. Then a bridge rectifier converts the 12 volts AC to DC. However, this process introduces ripple, which could affect the efficiency of the MOSFET bridges. To overcome this ripple, a DC filter or DC BUS circuit has been used to get constant dc output. After this all things are completely same with Case-1.

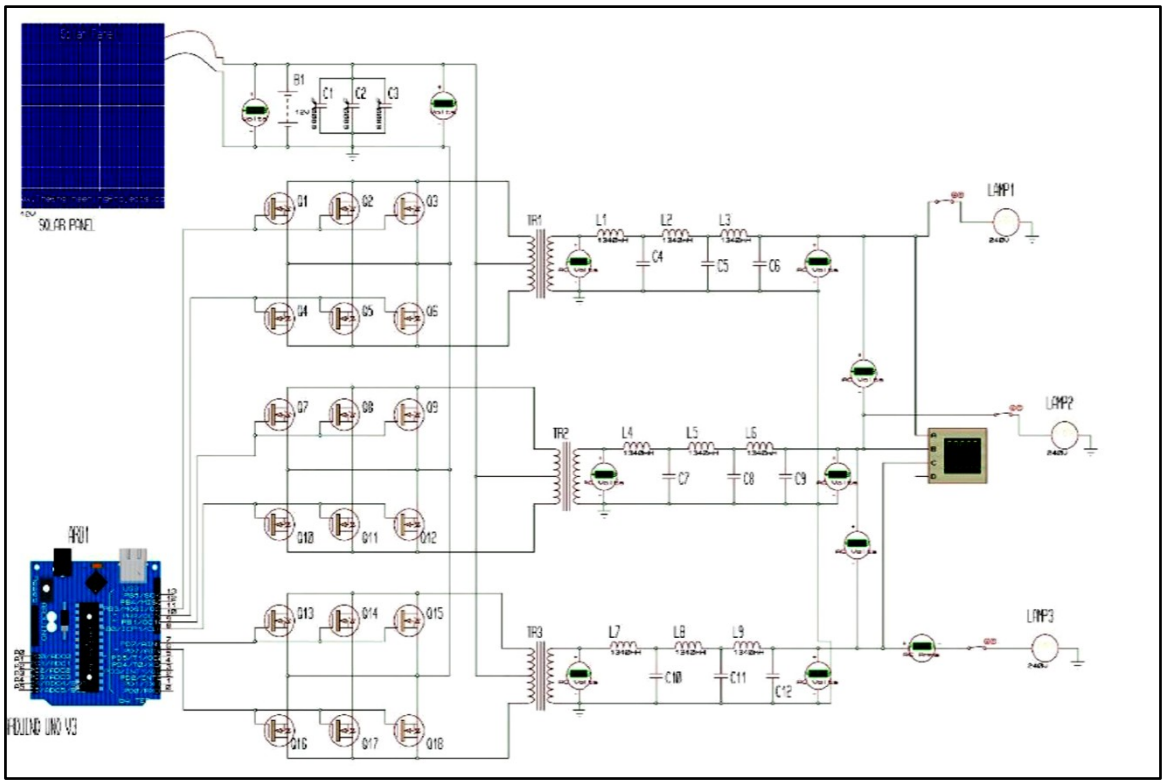


**Figure 3** Circuit Diagram for Case-1

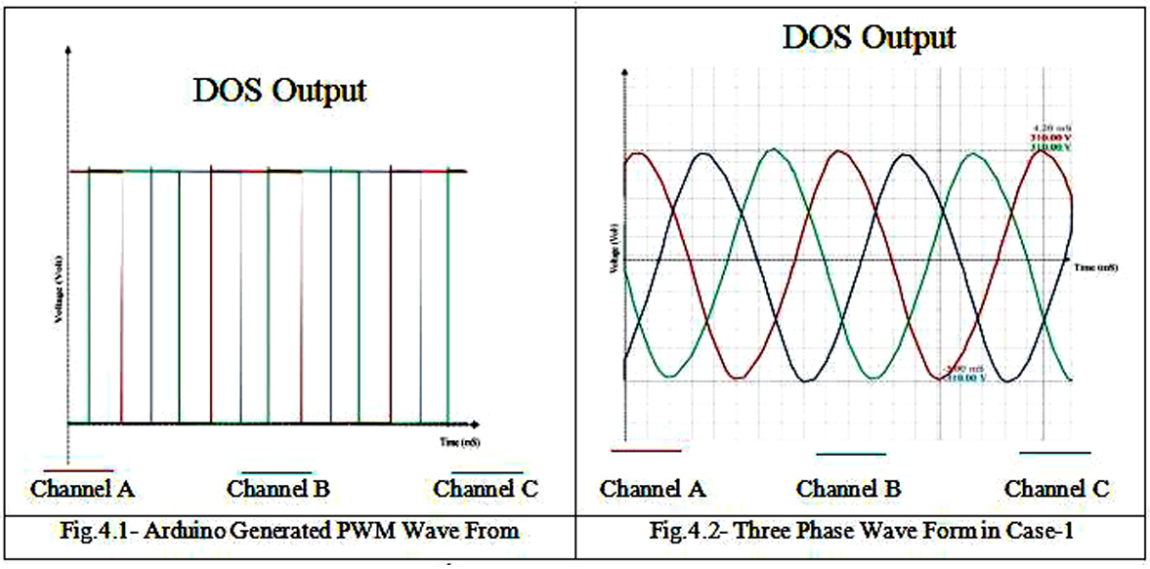


Fig.4.1- Arduino Generated PWM Wave From

Fig.4.2- Three Phase Wave Form in Case-1

**Figure 4** DOS output wave form

**Case Study-3**

Case-3 is a merged version of case-1 and case-2. In case-1 only DC source (solar panel) has been used and in case-2 only single-phase AC has been used. So, merging up these two cases to get a new case called Hybrid System. As there are two different supply that is AC and DC so for adding them the AC to DC conversion has been required with the same amplitude voltage with the DC source. As a 12volts solar panel and 12Volts battery has been used so 220Volts AC is also converted into 12Volts DC. For storing the excess energy, a battery is also there. Other portion is same with the previous cases.

Proteus Professional 8.9 software has been used for designing the project model, which can also give the output wave form of the three-phase supply. From this three cases output with some additional result have been discussed below. In this invention an Arduino micro-controller has been used to generate PWM signal that is essential for MOSFET like fast switch power electronics devices. Arduino has been programmed in a way that it produces the PWM signal for three phases with 120° phase displacement. **Figure 4.1** shows the digital oscilloscope output wave form. Here the red phase has been represented by "Channel A", yellow phase by "Channel B" and blue phase with "Channel C".

**Case-1:**

When using solar as a power source the generated three phase output will look like. In **Figure 4.2** the output of three phase AC has been shown where X-axis represents the time and voltage amplitude by the Y-axis. Similarly, the red phase has been represented by "Channel A", yellow phase by "Channel B" and blue phase with "Channel C" and the generated wave form has been nearly to pure sine wave. Where peak voltage has been coming out to be 310 Volts in each phase and rms voltage to be around 212 Volts.

**Case-2:**

In case-2 the solar panel has been replaced with a single phase AC source that gives a output wave form with peak voltage of 285 Volts and rms voltage of around 190Volts.

**Case-3:**

Case-3 consist of a solar panel and an AC source both so it called hybrid system. This system also give the three phase with around 320Volts peak voltage and rms voltage of nearly 220Volts.

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309_IEC23823

# Modelling and Impact Assessment of Renewable-based Bidirectional Power Flow on the Performance of Distribution Transformers

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***Abstract:*** *Rising global energy demands and the push for "Affordable and Clean Energy" (SDG7) have increased the focus on harnessing renewable energy sources. Microgrids that incorporate solar, wind, and biomass, in addition to powering local loads, also export surplus electricity to the main utility grid. The integration of Distributed Energy Resources (DERs) into the grid introduces bidirectional power flow within distribution systems, which were originally designed for unidirectional flow. This research employs Ansys-based Finite Element modelling to examine the impact of reverse power flow on existing distribution transformers, which are critical, expensive assets with typical lifespans of 30-40 years. The study simulated in PSCAD analyses an 11kV/0.4 kV, 100 kVA dry-type transformer located at a substation in the Kakdwip Islands, Sunderbans, West Bengal, under varying levels and conditions of renewable penetration and load demand. The objective of the study is to assess how two-way power flow influences transformer lifespan and enables the user to determine the maximum penetration from different DERs that transformers can handle without degrading their lifespan. The findings will assist Distribution Network Operators (DNOs) in optimizing the use of existing Electrical Assets like transformers as they experience an increase in reverse power flow in renewable-integrated smart grids.*

***Keywords:*** *Enhanced Lifespan; Finite Element Modelling; Four Quadrant Operation; PSCAD; Reverse Power Flow*

## INTRODUCTION

The escalating demand for energy coupled with growing concerns over the environmental impacts of fossil fuels necessitates the urgent transition to renewable energy sources such as solar, wind, and biomass. Governments globally are increasingly promoting the use of these green energy sources to align with Sustainable Development Goal 7 (SDG7) set by the United Nations [1]. In India, the Nationally Determined Contributions target a 50% share of renewable energy in installed capacity by 2030, aiming to reach 57.4% by 2026-27 and 68.4% by 2031-32 [2].

As government policies evolve, a shift in consumer behavior is observed, with more individuals becoming prosumers—simultaneously producing and consuming energy [3]. Remote regions often possess abundant renewable resources. The intermittency of these renewable sources complicates energy generation relative to local demand, necessitating the feeding of surplus energy back into the grid, resulting in bidirectional power flow in distribution networks originally designed for unidirectional flow [4]. Although some research addresses the integration of solar PV into low-voltage networks and explores transformer design changes to accommodate higher hosting capacities, a detailed assessment of bidirectional power flow in existing transformers within rural distribution networks remains unaddressed [5][6].

This paper presents a Finite Element Method (FEM) analysis using Ansys Engineering Simulation Software to investigate the effects of reverse power flow in distribution transformers. The FEM enables the breakdown of complex geometries, allowing for effective modeling of component behavior under varied conditions. Previous works have explored unidirectional power flow in transformers, magnetic field behavior, and thermal stress, but few have focused on bidirectional impacts [7]. The primary objective of this research is to assess the effects of two-way power flow in an existing dry-type distribution transformer within a rural network integrated with solar PV and wind. The study evaluates the transformer's operation and electromagnetic behavior under real-time loading conditions, factoring in varying levels of solar PV and wind penetration throughout the day. Given the significant investments required for microgrid operations, maximizing energy production is crucial for minimizing payback periods. This work aims to aid DNOs in evaluating renewable energy penetration while ensuring that the transformer's lifespan is

not compromised for achieving grid export by the microgrid operators (MGOs).

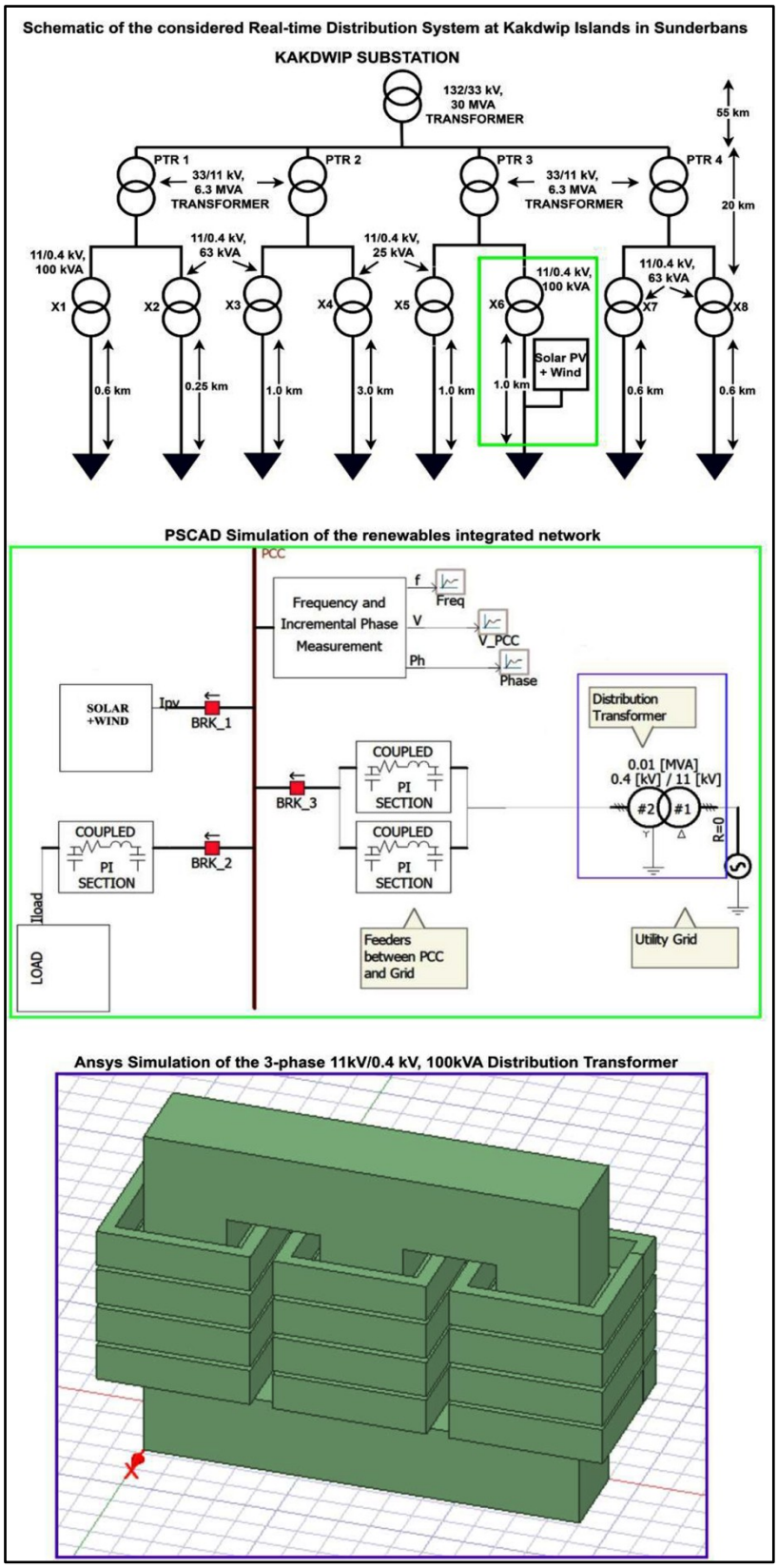


**Figure 1** The real-time rural distribution system integrated with DERs and the corresponding simulation in PSCAD and Ansys

## METHODOLOGY

The rural distribution network in the Kakdwip islands, Sunderbans, West Bengal, located in Eastern India, that has sufficient solar and wind energy is the focus of this study [4]. **Figure 1** illustrates the distribution system originating from the Kakdwip substation, with corresponding PSCAD and Ansys simulations. **Figure 2** presents various power flow conditions under penetrations from different DERs, the transformer's corresponding schematic, and their associated phasor/vector diagrams. The 11kV/0.4kV, 100kVA dry-type transformer in **Figure 1** supplies power to load distributors extending up to 1 km, with Solar PV and Wind DERs connected at the point of common coupling (PCC). The system marked in green in **Figure 1** is simulated in PSCAD. Voltage, current, and power profiles under different power flow conditions as shown in **Figure 2**, are imported into Ansys for more accurate analysis. Ansys Simplorer is used to model the 100kVA, 3-phase, 50Hz, 11000/400V delta/star core-type transformer, with an M5 CRGO core material. Parameter values for the model are derived from Ref. [8] and Ref. [9].

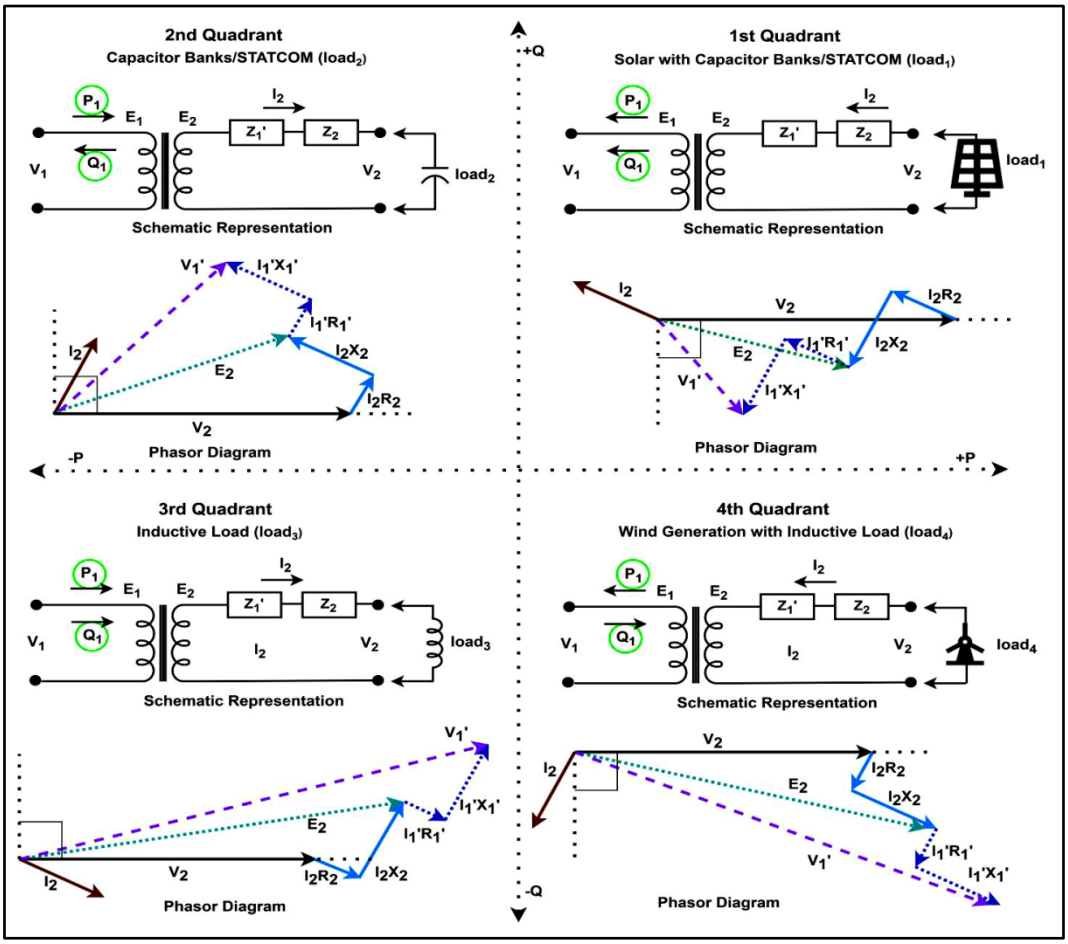


**Figure 2** Flow of power and the corresponding phasor representation of the distribution transformer in all four quadrants

## RESULTS AND DISCUSSIONS

Several case studies have been conducted on both forward and reverse power flow in transformers. Typically, electricity consumption and generation involve reactive power moving between the grid and load centers, enhancing power factor and voltage regulation. This paper examines power flow scenarios across four quadrants (Quadrant 1– Quadrant 4), as shown in **Figure 2**, with the low-voltage 0.4kV to high-voltage 11kV transformer power flow as the reference. In this context, positive real and reactive power flow from sources like solar PV and capacitor banks/STATCOM is categorized as Quadrant (Q)1. Transformer losses, which impact longevity, are classified into core and winding losses. Winding losses, dependent on current, remain unaffected by reverse power flow. However,

core losses, which depend on magnetic flux, are influenced by reverse power. Table 1 presents the core losses under forward, reverse, and mixed power flow conditions. For traditional power flow, Q2 and Q3 show lesser changes in the core losses whereas Q1 and Q4 show significant changes at varying power factors. The data in **Table 1** indicate that the reverse power flow in Q4 results in the highest core losses. Additionally, power flow combinations involving Q4 (Wind generation) also exhibit increased core losses in comparison to the ones involving Q1 (Solar PV generation). Magnetizing flux density rises due to an increase in the voltage at the 0.4kV side - V2 for a constant voltage on the 11kV side - V1, leading to higher core losses. These findings demonstrate that the reverse power flow's power factor (power flow from the low voltage side to the high voltage side) elevates core losses, reducing transformer lifespan. Therefore, with reference to Table 1 for Q1 and Q4 operation, restricting the reverse power flow's power factor and optimizing the type of DER penetration (in this case Solar PV and Wind) can help preserve transformer longevity.

**Table 1** Core losses at various conditions of power flow through the distribution transformer

| Quadrant Operation as % of the total simulation time | Power Factor (pf) | Case 1 - Conventional Power Flow - Core Losses (in Watts) | Case 2 - Reverse Power Flow - Core Losses (in Watts) | Case 3 - Mixed Power Flow - Core Losses (in Watts) | % increase in Core Losses in Case 2 with respect to Case 1 |
|---|---|---|---|---|---|
| 100 % of the total simulation time of 12 seconds for the same Quadrant (Q) Operation | | Quadrant 2 | Quadrant 4 (Wind) | | |
| | 0.6 pf lagging | 833.76 | 875.36 | | 4.99 |
| | 0.8 pf lagging | 833.51 | 873.02 | | 4.74 |
| | Unity pf | 832.97 | 867 | | 4.09 |
| | | Quadrant 3 | Quadrant 1 (Solar PV) | | |
| | 0.8 pf leading | 832.12 | 842.35 | | 1.23 |
| | 0.6 pf leading | 831.91 | 860.61 | | 3.45 |
| 50% Q1 & 50% Q2 | 0.8 pf | | | 917.61 | |
| 50% Q1 & 50% Q3 | 0.8 pf | | | 851.31 | |
| 50% Q2 & 50% Q4 | 0.8 pf | | | 924.06 | |
| 50% Q3 & 50% Q4 | 0.8 pf | | | 919.73 | |

## CONCLUSION

The growing integration of renewable energy into distribution networks, traditionally designed for one-way power flow, raises concerns about the performance and lifespan of distribution transformers. This study uses Ansys-based FEM modeling with electrical parameter inputs from PSCAD simulations to analyze the effects of bidirectional power flow from solar PV and wind systems on distribution transformers. The results indicate that reverse power flow, especially at low power factors, significantly increases transformer losses, potentially shortening their lifespan. The type of DER penetration also impacts core losses, further affecting longevity. Focused on a distribution network in Eastern India where solar energy dominates, the study helps DNOs optimize the dynamics of DER penetration to preserve transformer life. The work paves the way for future studies on bidirectional power flow's impact on other Electrical Assets and recommends thermal imaging analysis for further research. While Ansys accurately replicates physical phenomena, it is an offline study, and its computational complexity limits wider application. Nonetheless, the research offers valuable insights for enhancing transformer resilience as renewable energy use expands.

## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| DERs | Distributed Energy Resources |
| DNOs | Distribution Network Operators |
| FEM | Finite Element Method |
| MGOs | Microgrid Operators |
| PSCAD | Power System Computer-Aided Design |
| SDG | Sustainable Development Goal |
| Solar PV | Solar Photovoltaics |
| Q | Quadrant |
| $V_1$, $V_2$ | Terminal Voltages of the transformer |
| $E_1$, $E_2$ | Induced Voltages of the transformer |
| $I_2$ | Current Flow at the 0.4 kV side |

$P_1$, $Q_1$ Real Power and Reactive Power at the 11kV terminal
$Z_1$, $Z_2$ Short Circuit Impedance at the sides of the transformer
$Z_1$' Short Circuit Impedance on the 11kV side referred to the 0.4kV side

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324_IEC37567

# 3-Phase Fault Detection using Neural Network by Wavelet Transform on PV-Biomass based Grid Connected Microgrid System

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***Abstract:*** *The increasing integration of renewable energy sources such as photovoltaic (PV) and biomass systems into the grid necessitates reliable and efficient fault detection mechanisms. This paper presents a novel approach for power system fault detection in a PV-biomass based grid-connected microgrid system using wavelet transform and neural networks. The proposed method utilizes discrete wavelet transform (DWT) to extract detailed frequency components from the voltage and current signals of the microgrid. These features are then fed into a neural network classifier to identify faults. The performance of the developed model is evaluated using a simulated microgrid environment under various fault conditions, including line-to-line, line-to-ground, and three-phase faults. The results demonstrate high accuracy, fast response time, and robustness of the pro- posed system, making it a promising solution for enhancing the reliability and stability of microgrids integrated with renewable energy sources.*

***Keywords:*** *Photovoltaic (PV); Biomass, Grid Connected Microgrid System; Power System Fault Detection; Renewable Energy Integration; Discrete Wavelet Transform (DWT); Radial Basis Function Neural Network (RBFNN)*

## INTRODUCTION

The transition towards sustainable energy systems has led to a significant increase in the integration of renewable energy sources (RES) such as photovoltaic (PV) and biomass into the power grid. These distributed energy resources (DERs) form the backbone of modern microgrid systems, which offer enhanced reliability, efficiency, and flexibility in power generation and distribution. However, the incorporation of RES into grid-connected microgrids introduces new challenges, particularly in terms of fault detection and protection. Traditional fault detection methods, primarily designed for conventional power systems, often fall short in addressing the unique characteristics and complexities of RES-based microgrids [1].

One of the critical challenges in maintaining the stability and reliability of PV-biomass based microgrids is the prompt and accurate detection of three-phase faults. Faults in the power system can lead to severe disruptions, equipment damage, and even complete system failures if not addressed swiftly. Conventional fault detection techniques, relying heavily on time-domain analysis, may not provide the necessary accuracy and speed required for modern microgrids. Thus, there is a utmost need for advanced fault detection mechanisms that can effectively handle the dynamic and nonlinear nature of RES-based systems. Wavelet transform, with its ability to analyze non-stationary signals and provide time-frequency representation, offers a powerful tool for fault detection in microgrids. By decomposing the voltage and current signals into various frequency components, wavelet transform can capture transient features associated with different types of faults. However, extracting these features alone is not sufficient for robust fault detection; an efficient classification mechanism is also required to interpret the data accurately.

In recent years, neural networks have gained prominence due to their capability to model complex nonlinear relation- ships and learn from data. Combining the feature extraction strength of wavelet transform with the classification prowess of neural networks presents a promising approach for fault detection in PV-biomass based microgrids. This paper proposes a novel fault detection methodology that leverages discrete wavelet transform (DWT) for feature extraction and neural networks for fault classification. The proposed system is designed to detect and classify three-phase faults with high accuracy and speed, thereby enhancing the reliability and stability of grid-connected microgrids [2].

## DISCRETE WAVELET TRANSFORM

The Discrete Wavelet Transform (DWT) is a mathematical technique used to decompose a signal into its constituent wavelets. This process involves breaking down a signal into different frequency components, each with a resolution that matches its scale. Unlike the Fourier Transform, which provides frequency information, the DWT offers both time and frequency localization, making it especially useful for analyzing non-stationary signals. DWT is widely applied in signal processing, image compression, and feature extraction due to its ability to efficiently represent data with sharp changes or discontinuities [3].

The DW4 wavelet transform, also known as the Daubechies 4 (D4) wavelet, is part of the family of Daubechies wavelets named after the Belgian physicist and mathematician Ingrid Daubechies. The D4 wavelet is particularly notable for its compact support and orthogonality, which makes it highly effective in various applications, including signal processing, image compression, and numerical analysis.

Key characteristics of the DW4 wavelet transform [7] include:

(i) Compact Support: The DW4 wavelet has a finite length, making it computationally efficient for discrete applications.
(ii) Orthogonality: The transform is orthogonal, meaning that the wavelet and scaling functions are orthogonal to each other. This property is beneficial for perfectly reconstructing signals from their wavelet coefficients.
(iii) Vanishing Moments: The DW4 wavelet has two vanishing moments, allowing it to represent polynomial signals up to a certain degree without error, making it effective in approximating smooth signals.
(iv) Multiresolution Analysis: The DW4 wavelet supports multiresolution analysis, a framework that allows the decom- position of a signal into different levels of detail.

## RADIAL BASIS FUNCTION NEURAL NETWORK

A Radial Basis Function (RBF) Neural Network is a type of artificial neural network that uses radial basis functions as activation functions. It is typically composed of three layers:

1. Input Layer: This layer consists of input nodes that pass the input features directly to the hidden layer.

2. Hidden Layer: This layer uses radial basis functions (usually Gaussian functions) to transform the input. Each neuron in this layer has a center and a width parameter, which define the shape and spread of the radial basis function.

3. Output Layer: This layer performs a weighted sum of the hidden layer outputs to produce the final output. Key characteristics of RBF Neural Networks include:

(i) Localized Response: The hidden neurons respond only to inputs near their centre, making RBF networks effective in capturing local patterns.
(ii) Training: The training process involves determining the centres and widths of the radial basis functions and the weights of the output layer. This can be done using various methods such as k-means clustering for centres and gradient descent for weights.
(iii) RBF networks are particularly good at function approximation, pattern recognition, and classification tasks due to their ability to model complex, nonlinear relationships.

RBF Neural Networks are commonly used in applications like time-series prediction, control systems, and medical diagnosis because of their simplicity and effectiveness in handling diverse data patterns. [4]

## SYSTEM MODELLING AND DESIGN

In this paper a IEEE 33-bus grid connected power system incorporated with PV and biomass energy system [5] has been used. The proposed method has been used to detect power system faults in the aforesaid system by collecting and analyzing the current signals in normal as well as in faulty conditions. A model has been developed and

simulated using MATLAB/SIMULINK to create faults and record fault currents. The system consists of IEEE-33 bus system followed by PV and Biomass at different location, voltage, and current measurement units/ scopes and three phase fault generators. The system has a voltage level of 11kv and frequency of 50Hz. The system can simulate all kinds of faults that can occur in power system at different condition.

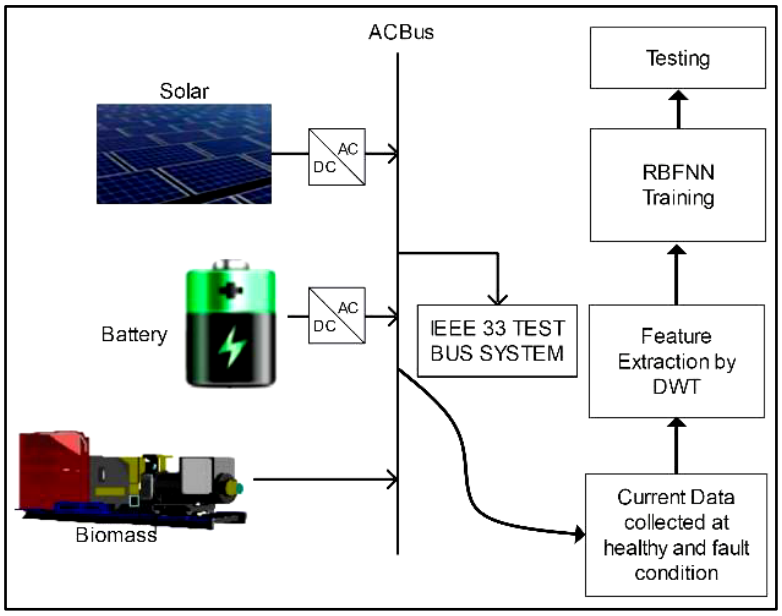


**Figure 1** Block diagram of proposed system

## ALGORITHM FOR DETECTION OF FAULTS

Combining the feature extraction of three phase and ground current signals by DWT and nature of radial basis function Neural (RBFNN) network the following steps are taken:

(i) Three phase and ground current signals have been recorded.
(ii) The recorded current data are decomposed using DWT (DB4) to find the maximum coefficient values.
(iii) Coefficient values extracted from DWT are segregated in two parts (70% data for training and rest 30% data for training)
(iv) Now the training data are used to train the neural network.
(v) Lastly testing data's are used to test that the neural network is properly trained or not.

**Table 1** Max. coefficient of all phase currents and ground current

| S.No. | Type of Fault | Max. co-efficient of Phase-A Current | Max. co-efficient of Phase-B Current | Max. co-efficient of Phase-C Current | Max. coefficient of Ground Current |
|---|---|---|---|---|---|
| 1 | ABC-G Fault | 1.7904e+05 | 1.9246e+05 | 1.8797e+05 | 1.2855e+05 |
| 2 | ABC Fault | 1.7858e+05 | 1.5274e+05 | 2.3670e+05 | 0.0097 |
| 3 | AB-G Fault | 1.7056e+05 | 2.9127e+04 | 1.8225e+05 | 1.0239e+05 |
| 4 | AC-G Fault | 5.5564e+04 | 1.8142e+05 | 1.8059e+05 | 1.5652e+05 |
| 5 | BC-G Fault | 1.7779e+05 | 1.9203e+05 | 6.3408e+04 | 2.4107e+05 |
| 6 | A-B Fault | 1.6440e+05 | 3.0469e+04 | 1.4093e+05 | 0.0063 |
| 7 | A-C Fault | 5.5838e+04 | 1.4535e+05 | 2.0419e+05 | 0.0093 |
| 8 | B-C Fault | 1.7820e+05 | 2.3876e+05 | 6.9219e+04 | 0.0079 |
| 9 | A-G Fault | 5.2664e+04 | 2.6966e+04 | 1.7547e+05 | 1.2568e+05 |
| 10 | B-G Fault | 1.6594e+05 | 3.2077e+04 | 6.7088e+04 | 1.2546e+05 |
| 11 | C-G Fault | 5.8074e+04 | 1.8060e+05 | 6.4600e+04 | 1.8218e+05 |
| 12 | No Fault | 5.5905e+04 | 3.0488e+04 | 6.9956e+04 | 4.5478e-07 |

As an example, a full set of data's have been given in the **Table 1** where coefficient of three phases and ground currents are given at different condition (normal and fault) in a tabular form.

## RESULT AND DISCUSSION

The proposed work uses the Radial Basis Function Neural Network to train the data taken for training purpose shown in the **Figure 2**.

The training achieves a Mean Square Error of MSE = 0.0892567 at a 50 Neurons Configuration. The performance graph is given in **Figure 3**. The testing phase of the proposed approach are shown by the regression graph in **Figure 4**. with a efficiency of 97.74%. fault detection RBFNN give slightly higher efficiency.

A comparative study of efficiency among different algorithms has been given in **Table 2**.

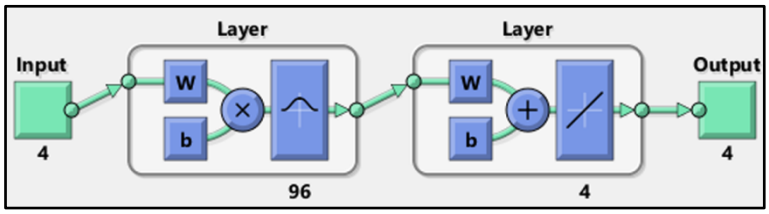


**Figure 2** Diagram of Neural Network

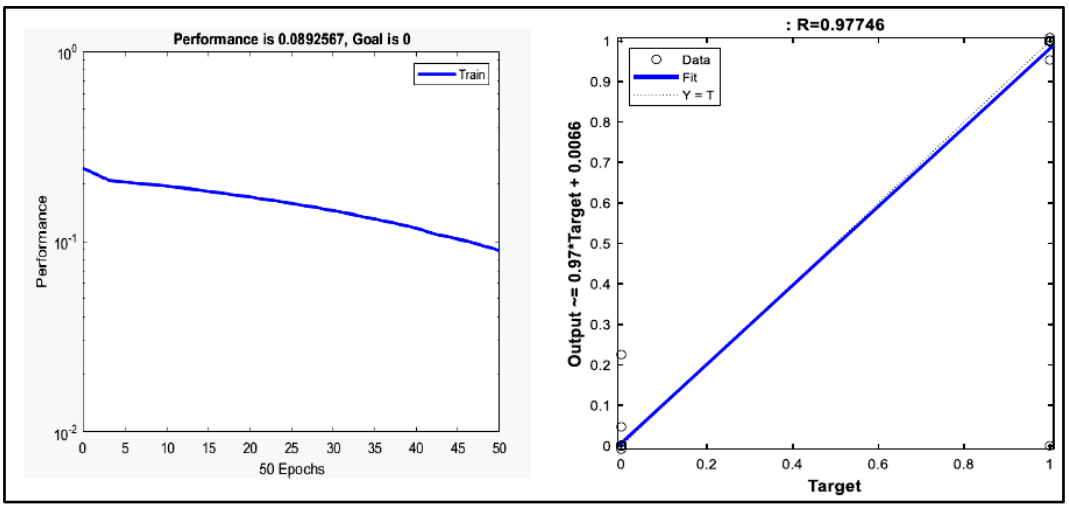


**Figure 3** Training and regression graph

**Table 2** Comparative study of efficiency among different algorithms

| Algorithms | % Efficiency |
|---|---|
| Radial Basis Function Neural Network | 97.74 |
| Convolution Neural Network | 93-96 [6] |
| Support Vector Machine | 83-87 [6] |

## CONCLUSION

In this paper, we presented a novel approach for 3-phase fault detection in a PV-biomass-based grid-connected microgrid system [4] using a neural network integrated with wavelet transform. The combination of wavelet transform for feature extraction and neural networks for fault classification has proven to be effective in identifying faults with high accuracy and reduced computation time. The use of wavelet transform allows for precise localization of transient signals, making it particularly suitable for detecting faults in a complex, renewable energy-based

microgrid environment where variations in power quality are common.

The proposed method was validated on a microgrid system that integrates solar photovoltaic (PV) and biomass generation sources, demonstrating its ability to detect faults under various operating conditions. The results indicate that the method is capable of distinguishing between normal and faulty states, as well as between different types of faults, with minimal false positives and negatives. This approach enhances the reliability and stability of microgrid systems by enabling fast and accurate fault detection, which is crucial for preventing power outages and protecting sensitive equipment. Future work could focus on further optimizing the neural network architecture, extending the system for other types of faults, and applying the method to a larger and more complex microgrid configurations. The findings of this study contribute to the development of intelligent fault diagnosis systems for renewable energy- based grids, supporting the transition toward smarter and more resilient energy infrastructures.

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# Transforming the Indian Renewable energy Rural Microgrid with the Synergy of Block Chain Analytics

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***Abstract:*** *Green fuels for a sustainable future are the need of the day as the rising global warming makes it inevitable for the existence of human beings on the planet. India has set a goal of achieving Net –Zero emissions by 2070. Rural households contribute more than 70% of our nation's population, hence, to achieve the goal of energy transition needs, the inclusion of rural households with a concept of a "Green Village-Green Grid" is the need of the time. The installation of Solar microgrids at the block level could be funded by the Government, Corporates & power-generating companies. Central Electricity Authority also acknowledges the importance of micro-grids and has an estimated potential of about 4GW in the villages which have inadequate power supply. A solar microgrid is basically an integrated network of generation, storage, and transmission of electricity generated by solar PV panels and the distribution of green energy to communities. Although there is large potential of Solar Micro-grid yet of the scalability of the solar micro grid has not been achieved due to system constraints & one of which is an efficient metering & monitoring of the power exchange of the On-Grid Solar Microgrids. This paper illustrates a solution towards efficient metering & monitoring of the power exchange of the On-Grid Rural Solar Microgrids via the use of Block chain data analytics.*

***Keywords:*** *Rural Electrification; Microgrid; Sustainable Development; Block Chain*

## INTRODUCTION

India is currently experiencing a significant shift in its energy landscape due to the penetration of the renewables & has also positioned itself as a global leader in expanding access to electricity. Over the course of a decade, from 2012 to 2022, India has successfully provided electricity to over 500 million people, resulting in a remarkable increase in grid-connected electricity from 79.90% to 99%. Despite this impressive feat, the country still faces challenges in ensuring that rural households have access to reliable and high-quality power, which is a crucial step towards achieving universal access to electricity. More than 50% of India's population rely on rural infrastructure and are involved in either directly with agriculture or agricultural-based industries. The development of India could not be imagined without the development of these rural areas. After food, house and clothes, electricity is the main demand of any human being at this stage of time. Availability of electricity in rural areas may bring all the infrastructure for the development, like improvement in production of food grains (as water would be available), education, health, and communication by roads, which ultimately will result in economic development. The government has taken ample efforts to ensure the target of 100% rural electrification some of the notable schemes are rural electrification under the minimum needs program launched in the year 1974, Rajiv Gandhi Grameen Vidyut Karan Yojana (RGGVY) launched in 2005, Deendayal Upadhyay Gram Jyoti Yojana (DDUGJY) launched in the year 2014 & Saubhagya Yojana in the year 2018. Although the schemes have been successful in providing 100% access to electricity to the rural households but the access to quality & reliable power is still a distant dream.

Some of the major problems in the Rural Electrification programs are:

1. High Transmission & Distribution losses.
2. Non -availability of reliable power owing to outages in the transmission & distribution network & supply rationing during peak hours.
3. Debt Burden on Discoms owing to subsidies & poor billing efficiency.
4. Rampant use of high energy-consuming appliances.

**A. Integration of Solar Microgrid for Rural Electrification: The Way Forward to Reliable & Quality Power to Rural Households:**

A solar microgrid is a self-contained grid that uses solar energy to produce electricity & batteries for energy storage. The solar microgrid consists of an interconnected load & distributed energy system which can complement the national grid or work independently in island mode providing communities with access to more sustainable and resilient energy supplies. In India, there are 63 installations of solar microgrids totalling a capacity of 1,899 kWp. To promote the growth of microgrids government has issued a draft national policy on renewable energy-based mini- and microgrids to set up at least 10,000 renewable micro-and mini-grid projects across the country, with a generation capacity of 500 MW [1].

**CASE STUDY OF INSTALLATION OD SOLAR MICRO GRIDS & ITS IMPACT**

• Gumla, Jharkhand: In 2015, Gumla, one of the six districts in Santhal Parganas in the state of Jharkhand, began its journey to become self-reliant despite facing challenges such as un-electrified hamlets and frequent power outages. This was made possible through the installation of solar-Mini grids with a capacity between 20 kilowatts and 40 kilowatts in 44 villages. The project was initiated by West Bengal-based non-governmental organization Mlinda alongside the Indian Renewable Energy Development Agency, a government financing institution. [2]. The combined capacity of the solar mini grids in 44 villages is one megawatt. Each solar -Mini grid has the potential of fulfilling the energy needs of hamlets located within five kilometres. The project has solved the problem of irrigation for the farmers and opened new avenues of income generation.

• Sundarban, Jharkhand.: In 2011, a 110-kW solar-microgrid was installed in the remote and inaccessible Indrapur village in the Sundarbans district of West Bengal [3]. This economically viable and sustainable source of energy has enabled over 200 families to have access to electricity. As a result, children can study with good quality light, leading to an improved literacy rate. Additionally, more extended hours in the market - including a night bazaar - provide inhabitants with increased opportunities for buying fresh fruits and vegetables, thus boosting the economy of the island hamlet.

**A. Need of Solar Microgrid in Rural Electrifiucation Programme**

In the last one-decade India have witnessed a marginal shift in the operation of electricity industry as it shifted towards deregulation as is the case in most part of the world. The primary aim of introducing this was to promote economic efficiency [4]. To meet environmental norms and the growing challenge of global warming, renewable energy has played a central role in the electricity market. Solar microgrids for electricity generation are one the most important measure viewing the shift of the energy market and energy transition in India. Some the points are enlisted below which discusses the need & benefit of introduction of solar microgrids.

**CHANGING PERSPECTIVE OF THE ELECTRICITY MARKET**

• Green Day Ahead Market (G-DAM): Union Minister of Power & New and Renewable Energy launched a new market segment, Green Day Ahead Market (GDAM) at the Exchange in the year 2021. The basic amin of this market is to provide the renewable power producers a competitive market which can fetch them a good price of the energy generated in a transparent and flexible manner. Since its launch in five months 0.92 billion Units have traded.

• HP-DAM (High Price Day Ahead Market): In the year 2023 viewing the high demand of electricity Central Government launched a High Price Day Ahead Market and Surplus Power Portal– an initiative to ensure greater availability of power during the peak demand season. In HP-DAM only those generating capacities which have the cost of producing power of more than Rs. 12 per unit would be allowed to operate. This will provide Renewable energy generators to sell surplus power generated at higher prices.

• Renewable Energy Certificates: Renewable Energy Certificates (RECs) are a market-based instrument that verifies ownership of one megawatt-hour (MWh) of electricity produced from a renewable energy source. Once the power provider has fed the energy into the grid, these RECs can then be traded on the open market as an energy commodity

[5]. Additionally, earned RECs can also be sold to other polluting entities as carbon credits to offset their emissions. From July 22nd to June 23rd, 101074658 REC certificates have been issued and 76733427 certificates have been redeemed through the Power Exchange. [5]. The clearing price also increased from Rs 1000 to Rs 1500 per Renewable energy certificate. CERC in the year 2022 has also issued terms & conditions for Renewable energy certificates for the first time for effectively removing the floor & ceiling prices.

## CHALLENGES AHEAD IN THE DEVELOPMENT OF RENEWABLE ENERGY MICROGRIDS

• On Grid Integration: The grid must be made to accommodate the enormous dispersed energy resources, such solar and wind turbines, that will be installed in several remote locations. Due to the highly unpredictable nature of the interactions between distributed resources and grid operators as well as the diversity of control standards and protocols, an automated control system is needed to support a wider range of decentralized participants [6].

• Dispersed energy resources: A micro grid can enable dispersed energy systems by generating electricity from micro-sources like renewable energy, whereas a standard grid system is centralized and hierarchical in its generation and distribution.

• Problem of abundance: As was previously indicated, an increase in participants will result in an increase of transactions. The delay will rise as user participation rises. Also contributing to the system's scalability is the inherent latency of the system's response time for communication, power delivery, and settlement [6].

• Issues of Cybersecurity: A potential challenge related to the development of Microgrids is cybersecurity. As the microgrids become more prevalent they will be increasingly vulnerable cyber-attacks. Hence there is an acute need of tailor-made specific solutions for microgrids [7] .

• Scheduling & Pricing of Energy: Consumers have the opportunity to obtain tangible remuneration through their involvement in microgrids. Within a centralized power system, energy procurement and distribution are under the control of utility companies, leaving consumers devoid of any advantages when surplus energy is produced. Nevertheless, microgrids serve as a catalyst for the shift towards transactive energy systems, empowering consumers to possess and manage distributed energy resources. Consequently, when these consumers generate surplus energy, they are able to engage in the sale of electricity to the grid or their neighboring counterparts. Therefore, to schedule & price the energy a specific solution is required to cater the needs of micro grids [7].

## SOLUTION-ON-GRID RURAL SOLAR MICROGRID SYNERGY WITH BLOCK CHAIN DATA ANALYTICS

Blockchain is a technological innovation that facilitates the secure and transparent distribution of digital information within a collectively maintained database. This database comprises an ever-growing record of transactions, meticulously arranged in chronological order. Additionally, it serves as a ledger capable of accommodating digital transactions, data records, and executables, all of which are shared among the participants of the blockchain network. As block chain data analytics is a decentralized ledger it a promising aspect which can address the challenges in the power distribution system of the Rural Solar Microgrids. Blockchain technology provides a trusted ambiance for prosumers (producers as well as consumers) to interact directly with each other without the involvement of a third party. They can make transactions of energy faster and in a transparent manner. Through blockchain transactions are executed through smart contracts leaving behind all legal language. Smart contracts are self-executable after meeting all conditions of the contract. Block Chain is a decentralized, safe, and open mechanism for transaction recordkeeping. With the help of Block Chain technology, a network of participants can share a digital ledger of transactions without the aid of a central authority or middleman. Block Chain technology makes use of cryptographic methods to guarantee data availability, secrecy, and integrity.

In this system the Rural Solar Microgrids would be connected to the grid by smart metering which would be bi-directional in nature. The smart meter used in the system will be programmed using the block chain data analytics. They shall be able to trade their generations or extra surplus power from other sources like microgrids, energy storage

devices, and electric vehicles with each other which would be beneficial to reduce peak loads, T&D loss, and to stabilize the grid by balancing demand and supply of energy. Such direct trading among participants of the de-centralized energy markets without involving third parties is beneficial for the development of renewable energy markets. The decentralized micro grid along with blockchain technology makes it a good option for open energy markets. Smart meters will be embedded with smart contracts which would be self executable when certain criteria will meet.

The Schematic of working of Rural Micro-Grids in synergy with the Block chain data analytics has been illustrated in **Figure 1**.

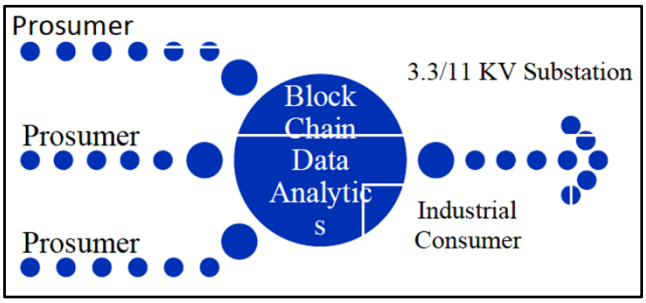


**Figure 1** Schematic of working of Rural Micro-Grids in synergy with the Block Chain Data Analytics

The incorporation of Blockchain data analytics into microgrids for the objective of energy management will facilitate the reduction of transaction costs and the promotion of renewable energy. The capability to directly procure energy from suppliers via blockchain demand response programs and energy trading systems diminishes transaction costs, while simultaneously encouraging the establishment of microgrids based on renewable energy sources. Blockchain technology empowers real-time monitoring and control of the energy system, thereby mitigating energy wastage and enhancing overall efficiency.

**A. Case Study of Integration of Blockchain with Microgrids**

1. Port of Rotterdam: The Port of Rotterdam situated in Netherlands. Numerous commercial energy consumers operate in the dock which requires electricity to operate efficiently. In an effort to promote the utilization of renewable energy, the Port of Rotterdam developed a microgrid. The port uses the blockchain to facilitate energy transactions among the commercial energy consumers within the Port of Rotterdam and has proved effective towards energy management [8].

2. The Brooklyn Microgrid which operates in New York City is well known for its integration with blockchain data analytics. The Brooklyn microgrid provides a platform to all solar energy producers i.e., prosumers a energy market place to trade their surplus energy generated to other participants of the grid.

**IMPLICATIONS**

The objective of this study is to provide assistance to policymakers and power system planning organizations in their consideration of the potential solution for efficient metering and monitoring of power exchange in the context of the integration of Solar micro-grids. This integration, when combined with technological innovation such as block chain data analytics, has the potential to provide a reliable and emission-free source of power. Furthermore, the adoption of Solar micro-grids can contribute to rural India's self dependence and sustainable development. The incorporation of block chain data analytics with Solar micro-grids represents a significant advancement in the renewable energy sector in India, marking the beginning of a new era.

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# Power & Energy

## Electrical Machines and Drives

364_IEC27406

# Maxwell Analysis of an Induction Motor during Inter Phase Short Circuit Fault using Ansys

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***Abstract:*** *Induction motors are widely used in industrial applications due to their robustness and efficiency. However, various fault conditions, such as line-to-line faults, can significantly affect their performance and lead to system failures. This study focuses on the analysis of these faults using ANSYS simulation software. The research investigates the impact of fault conditions, where reduced supply voltage can cause decreased motor efficiency and overheating. Additionally, line-to-line faults result in a severe imbalance in the motor's electrical system. By employing ANSYS, detailed finite element analysis (FEA) of these fault conditions is conducted to observe their effects on the motor's electromagnetic and thermal characteristics. The simulation results provide valuable insights into the behavior of induction motors under fault conditions, offering potential solutions for early fault detection and prevention. The findings highlight critical fault indicators, including variations in current, torque, and thermal profiles, which can aid in improving motor reliability and reducing maintenance costs. This research serves as a foundation for enhancing fault diagnosis techniques in industrial motors through advanced simulation tools.*

***Keywords:*** *Ansys; Flux; Motor Torque; Induction Motor; Inter-phase Fault; Maxwell Analysis*

## INTRODUCTION

Induction motors are the backbone of industrial systems because of their reliability, low maintenance requirements, and cost-effectiveness. They are employed in various applications, from manufacturing plants to power systems, because of their ability to efficiently convert electrical energy into mechanical energy. Despite their widespread use and robust design, induction motors are susceptible to various faults that can compromise their performance. If undetected, these faults can lead to costly system failures or downtime. The most common types of faults are under voltage, inter-turn, and line-to-line faults. Understanding these faults and their effects is critical for developing effective fault detection, prevention, and protection systems.

Induction motor faults are responsible for a significant proportion of industrial downtime and energy losses. Early detection of faults not only minimizes operational disruptions, prolongs equipment lifespan, and reduces maintenance costs. Traditional fault analysis methods are often limited by their inability to accurately model the complex electromagnetic and thermal behaviors of motors under fault conditions. This is where simulation tools like ANSYS become valuable, offering a comprehensive platform for conducting detailed finite element analysis (FEA) on various motor faults.

Under-voltage faults occur when the supply voltage to the induction motor drops below the rated level. This can lead to significant performance degradation, such as decreased torque, overheating, and increased operational inefficiency. Prolonged operation under such conditions can result in thermal stress and premature aging of the insulation materials, ultimately leading to motor failure. Under-voltage conditions are often the result of grid disturbances, fluctuations in power supply, or circuit overload. By simulating these conditions using ANSYS, engineers can observe the effects of voltage drops on the electromagnetic field, thermal characteristics, and overall motor performance, providing insights into the best ways to mitigate such issues. Frosini et al. [1] used ANSYS to simulate under-voltage conditions in induction motors and found that voltage reductions lead to increased rotor current and temperature rises in the stator windings. The study also revealed that continuous operation under under-voltage conditions increases the likelihood of insulation failure due to overheating. Kliman et al. [2] explored the impact of voltage imbalance and under-voltage scenarios using ANSYS simulations. They observed that voltage imbalances

induce negative-sequence currents that cause additional heating in the rotor and stator. The results emphasize the importance of monitoring voltage supply quality to avoid long-term damage.

Inter-turn faults are among the most dangerous and difficult faults to detect in induction motors. They occur when the insulation between two or more adjacent turns in a winding fails, creating a short circuit. This fault can significantly alter the magnetic field distribution, causing localized heating, increased vibration, and even catastrophic motor failure if not addressed in sufficient time. One of the challenges of detecting inter-turn faults is that they often progress from minor defects, which produce subtle changes in motor behavior, to severe faults that can cause complete breakdown. Faiz et al. [3] used ANSYS to model inter-turn faults in induction motors. Their study demonstrated that interturn faults lead to significant asymmetries in the magnetic flux distribution and increased core losses. ANSYS simulations have revealed that even minor faults in stator windings can escalate to catastrophic failures if not addressed promptly. Ghazali and Abdullah [4] simulated interturn faults using ANSYS Maxwell, focusing on the effects of such faults on the electromagnetic field distribution. Their results indicated that interturn faults caused noticeable distortions in the magnetic flux and elevated temperatures in the faulted region, highlighting the importance of early detection techniques. ANSYS simulations allow for the detailed modeling of inter-turn fault progression and help engineers analyze the fault's impact on the motor's magnetic and thermal performance.

Line-to-line faults are caused by a short circuit between two phase windings in the motor, leading to excessive current flow and a severe imbalance in the motor's electrical system. If not immediately addressed, this type of fault can cause considerable damage, including winding burnout, core saturation, and system-wide failure if not immediately addressed. Simulating line-to-line faults in ANSYS enables an in-depth analysis of how the motor's electrical, magnetic, and thermal behavior changes under such severe conditions, providing valuable insights for designing protective relays and fault isolation mechanisms. Riera-Guasp et al. [5] conducted a study using ANSYS to analyze line-to-line faults in medium-voltage induction motors. They found that line-to-line faults induce large unbalanced currents that cause thermal stress on stator windings and rotor bars. Their study highlighted the critical role of real-time monitoring systems in detecting faults before significant damage occurs. Ayaz and Hussain [6] used ANSYS Electronics to simulate line-to-line faults in high-power induction motors. Their analysis revealed that such faults lead to rapid temperature rises and insulation breakdown, emphasizing the need for protective relays and fault-tolerant control strategies to prevent motor failure.

ANSYS is a powerful simulation tool that allows detailed finite element analysis of the complex behaviors of induction motors under fault conditions. The software allows engineers to model and simulate electrical, magnetic, and thermal phenomena within a motor to gain a deeper understanding of fault evolution and propagation. Using ANSYS, this research aims to create accurate fault models for under-voltage, inter-turn, and line-to-line conditions to simulate real-world scenarios and predict the behavior of induction motors under stress.

The present study emphasizes the critical role of ANSYS in understanding fault dynamics and improving fault detection systems for induction motors. With the increasing reliance on automation and continuous industrial operation, the ability to simulate and analyze faults in motors is critical for ensuring system reliability and efficiency. Sulaiman et al. [7] demonstrated the use of ANSYS to simulate both inter-turn and line-to-line faults in induction motors. Their study compared the results of ANSYS simulations with experimental data and found a high degree of accuracy in predicting fault-related temperature rises and magnetic field distortions. Their work highlighted the importance of FEM tools like ANSYS in developing predictive maintenance strategies for induction motors.

Monitoring of flux along with voltage and current signals is an important aspect of the performance analysis of polyphase motors. Moreover, the study of the effect of various faults and fault prediction are of big challenge that can be solved by analysis of those signals [8]-[10]. Many current and voltage signal-based fault detection methods have been introduced in recent years [11]-[13]. Statistical feature-based mathematical tools have been introduced for fault detection and performance analysis [14]-[15]. Often, starting current signatures are found suitable for monitoring the state of motors and their performance [16]-[18]. Harmonics and their statistical feature were found helpful for fault detection. However, few attempts were observed that deal with the analysis of flux and other electrical signals in coordination with design features.

This has motivated authors to deal with design parameters and perform performance analysis at normal and fault conditions. This work offers post-design ANSYS Maxwell analysis of a three-phase induction both at normal and fault conditions. Interphase short circuit fault has been considered in this work and its effects on various electrical parameters have been analysed.

After this brief introduction, the design features of the induction motor have been presented. Then, Maxwell's Analysis in a simulation environment has been presented followed by a conclusion.

**Design of Induction Motor using Ansys**

The design of an induction motor involves several key steps to meet performance, efficiency, and operational requirements. First, specifications like power rating, voltage, speed, and frequency are defined. The number of poles is determined based on the required speed, as the motor's speed is inversely related to the pole count. The stator design includes selecting appropriate core materials (like laminated silicon steel) to reduce core losses, determining the number of slots for proper winding distribution, and designing the stator windings to achieve the desired voltage and current. The rotor design depends on the type of motor: squirrel-cage rotors are common for their simplicity, while wound rotors are used for variable speed control. ANSYS is powerful software used for engineering simulation, including electromagnetic field analysis, structural analysis, and thermal performance evaluation. When designing an Induction Motor using ANSYS software, the focus is primarily on simulating the motor's performance under different operational conditions and optimizing its design for efficiency, thermal stability, and reliability. Here's a step-by-step guide to designing an induction motor using ANSYS.

Before starting the simulation, the design specifications for the induction motor must be defined as follows

**Table 1** Motor Specification

| Sl. No | Parameter | Value |
|---|---|---|
| 1 | Pole Number | 8 |
| 2 | Slot Number | 44 |
| 3 | Number of Phases | 3 Phase –Y type |
| 4 | Rated Speed(rpm) | 700 |
| 5 | Rated Output Power(watt) | 3700 |

Above mentioned parameters of the induction motor guide the initial setup and material selection in ANSYS. The 2-dimensional design of an Induction motor using ANSYS has been given in **Figure 1**. The stator winding is visible as designed using ANSYS plane.

**Stator and Rotor Design**

Using the ANSYS Maxwell module (for electromagnetic simulation), the geometry of the stator is created. The stator consists of slots and a laminated core, which are essential for generating a rotating magnetic field. The number of stator slots was selected based on the desired winding distribution and torque requirements. The geometry should include details such as the slot dimensions and core material.

After designing the stator part, the geometry of the rotor was designed for the squirrel cage rotor. In a squirrel cage motor, the rotor bars and end rings must be carefully modeled based on the material properties (aluminium or copper). The rotor and stator windings of the wound rotor are modeled similarly. To ensure the smooth operation of the induction motor, a small air gap was introduced between the stator and rotor. Depending on the complexity and the required accuracy, choose between creating a 2D or 3D model. A 2D model can provide quick results with lower computational effort, while a 3D model gives more detailed analysis, especially for complex designs.

**Material Assignment**

In ANSYS, appropriate materials are assigned for different components of the induction motor to ensure optimal

performance. The stator and rotor cores are typically made from laminated silicon steel to minimize eddy current and hysteresis losses. The windings are made of copper or aluminum conductors to efficiently carry electrical currents. For squirrel-cage motors, rotor bars and end rings are commonly made from either aluminum or copper, ensuring good conductivity and durability. The air gap, which separates the stator and rotor, is defined with appropriate material properties, such as air or vacuum, to facilitate the magnetic field interaction while minimizing mechanical interference.

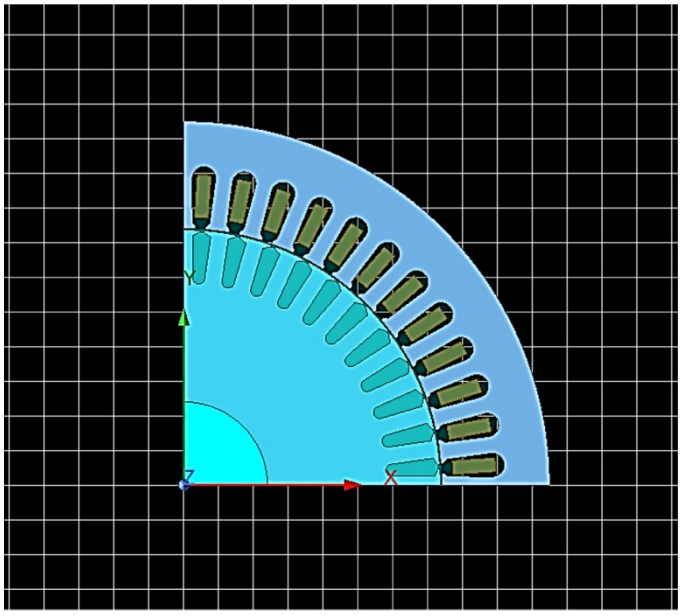

**Figure 1** 2D Diagram of the Induction Motor in ANSYS

**Table 2** Rotor Specification

| Sl no | Parameters | Quantity |
|---|---|---|
| 1 | Inner Diameter (mm) | 48 |
| 2 | Outer Diameter (mm) | 147.3 |
| 3 | Core length (mm) | 250 |
| 4 | Core Material | M19 2 |
| 5 | Number of Slots | 44 |
| 6 | Stacking Factor | 0.92 |

The rotor model has been designed as presented in **Figure 2**. The rotor winding is visible and the rotor has been mounted on the shaft. The full two-dimensional stator core has been provided in **Figure 3**, and the specifications have been given in **Table 3**.

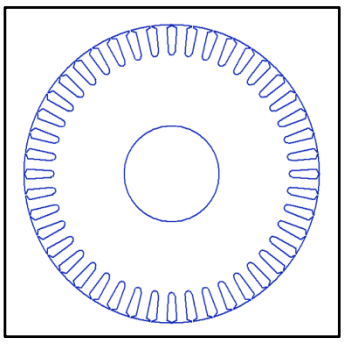

**Figure 2** Rotor core design of the induction motor

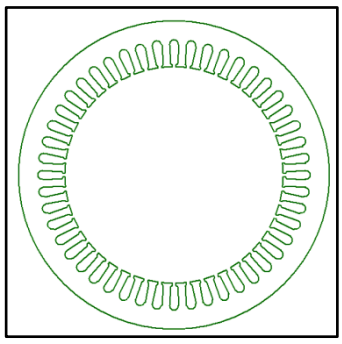

**Figure 3** Stator core design of the induction motor

**Table 3** Stator specification

| Sl no | Parameters | Quantity |
|---|---|---|
| 1 | Inner Diameter(mm) | 148 |
| 2 | Outer Diameter (mm) | 210 |
| 3 | Core Length (mm) | 250 |
| 4 | Number of Slots | 48 |
| 5 | Core Material | M19_24G |
| 6 | Stacking Factor | 0.92 |

**Boundary Conditions and Excitation**

In ANSYS, excitation is applied by setting an appropriate voltage or current to the stator windings, ensuring that the input voltage matches the motor's operational voltage and that the excitation frequency aligns with the supply frequency, such as 50 Hz. Mechanical boundary conditions are then applied, including fixed supports or rotational boundaries, to simulate the rotor's movement. Additionally, magnetic boundary conditions are defined at the outer surface of the stator and across the air gap to ensure accurate field distribution and prevent errors related to boundary influences.

In ANSYS, the finite element method (FEM) is used to simulate the motor's behavior by dividing the model into smaller regions or elements for precise analysis. For a 3D model, tetrahedral or hexahedral meshing is employed, with particular attention to applying fine meshing in critical areas such as the air gap and the rotor-stator interface. These regions are essential for accurately capturing the electromagnetic fields and ensuring the reliability of the simulation results.

**Simulation Setup and Solvers**

In the simulation setup using ANSYS, begin by running the electromagnetic simulation through ANSYS Maxwell to model the magnetic field distribution, torque production, and induced currents. The key results include the magnetic flux density in the stator and rotor, the induced EMF in the rotor, and the torque vs. speed characteristics. Following this, a thermal analysis is conducted to ensure that the motor operates within safe temperature limits by simulating the heat generated from copper losses in the windings and iron losses in the core and evaluating the motor's heat dissipation capabilities. If needed, a structural analysis is performed to assess mechanical stresses and strains on the motor's frame and components, especially under high torque or high-speed conditions, ensuring the motor's structural integrity and durability during operation.

**Simulation Results at Normal Condition**

After running the simulations, the results are analyzed to evaluate the motor's performance. Torque analysis involves reviewing the torque output to verify if it meets the design requirements. Efficiency calculation is done by determining the ratio of the motor's output mechanical power to the input electrical power. The flux distribution in the stator and rotor is inspected to ensure even magnetic field distribution and minimize flux leakage. Additionally, the temperature distribution is examined across the motor, with particular attention to hot spots that could impact long-term reliability.

The torque versus time response has been presented in **Figure 4a**. The system response has a negative transient at the initial instant which gradually stabilizes at around 50 seconds. The system has been seen to have some noise which has been seen to be present throughout the normal running condition of the machine. The current distortion at normal condition in the yellow phase (shown by the green line in **Figure 4b**) has been seen to be the highest. The distortion in induced voltage seems to be highest for the yellow phase (shown by the green line in **Figure 4c**) and the overall response is non-linear.

However, the flux linkage has been seen to be stabilizing after 50 seconds after overcoming the initial transient as

provided in **Figure 4d**.

The distortion in induced voltage seems to be highest for yellow phase (shown by green line in Figure 4e) and the overall response is non-linear.

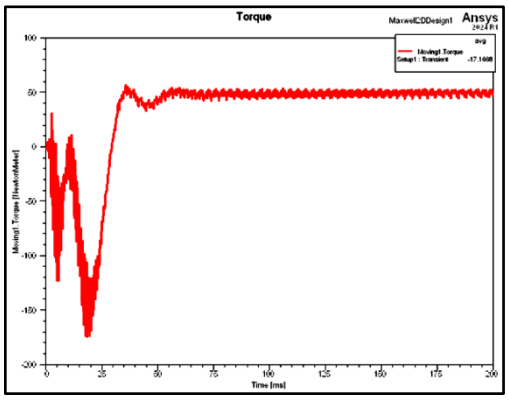


**Figure 4a** In normal conditions torque vs time graph

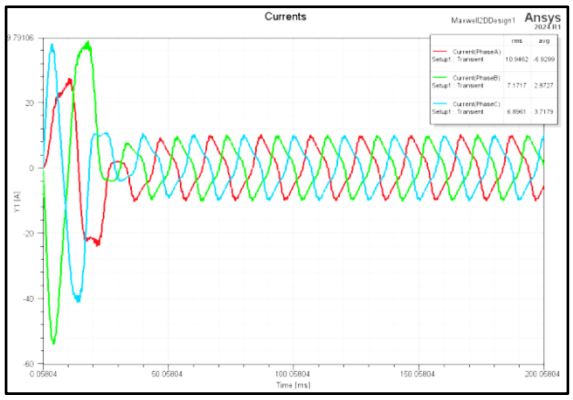


**Figure 4b** In normal condition current vs time graph

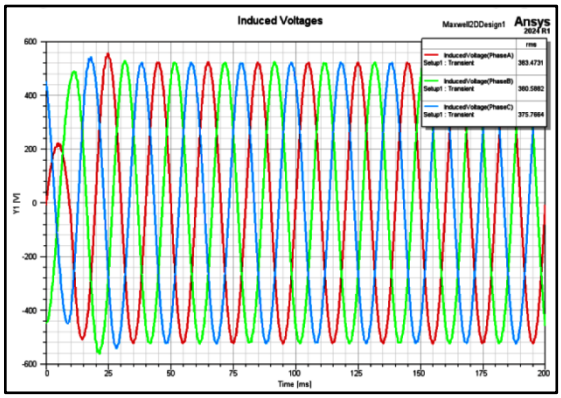


**Figure 4c** In normal condition induced voltage vs time graph

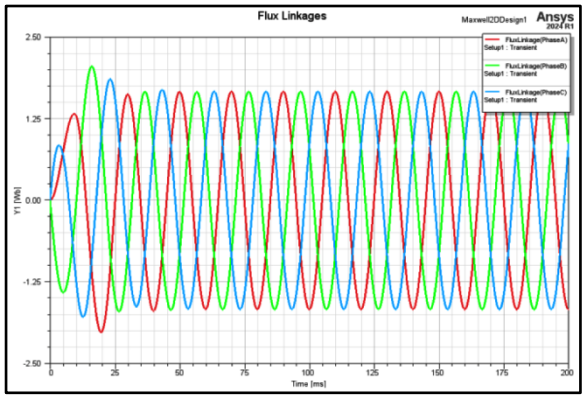


**Figure 4d** In normal condition flux linkage with respect to the time

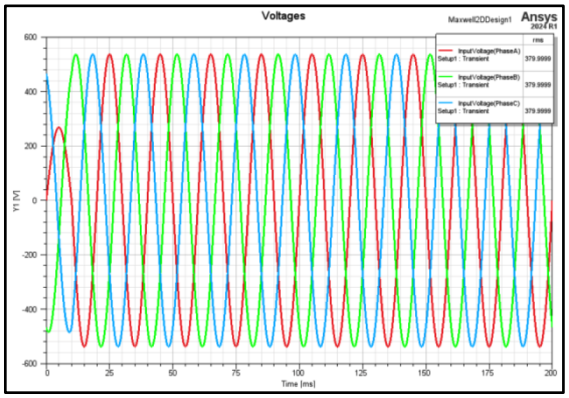


**Figure 4e** In normal condition input voltage with respect to the time

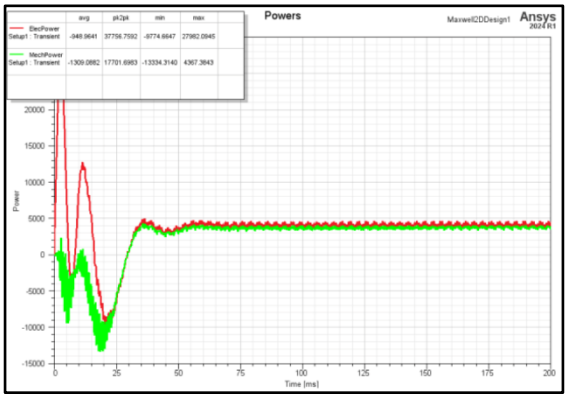


**Figure 4f** Power versus time in normal conditions

**Simulation Results at Interphase Fault Condition**

Thereafter, line-to-line fault has been created in the yellow and blue phases of the machine and the torque versus time

characteristics for the red phase have been seen for the advent of LL fault in the rest of the phases (**Figure 5a**).

Monitoring **Figures 5b**, and **5c** it has been observed that for LL fault in the yellow and blue phases, the current of the yellow and blue phases was reduced by 40% and the induced voltage was reduced by 70%. However, the flux linkage has been seen to reduce by 83% (**Figure 5d**), the red and yellow phase voltage has been seen to be zero (**Figure 5e**) and power has been seen to reduce by 98% (**Figure 5f**).

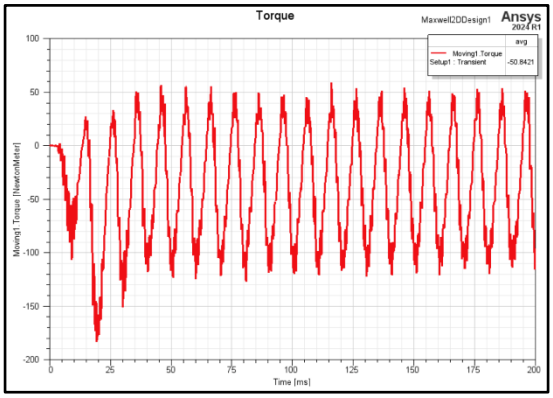


**Figure 5a** Torque vs time graph at Line-to-Line fault

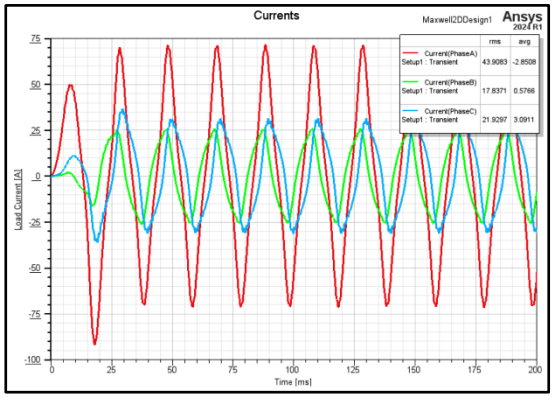


**Figure 5b** For Line-to-Line fault current vs time graph

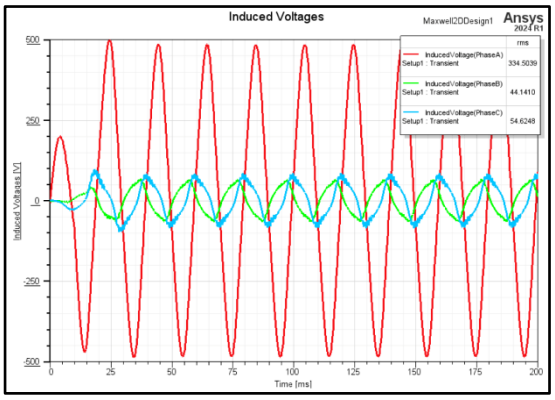


**Figure 5c** Induced voltage vs time graph at Line-to-Line fault

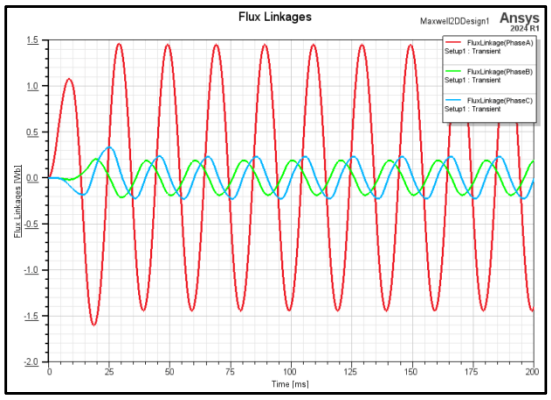


**Figure 5d** Flux vs time graph at Line-to-Line fault

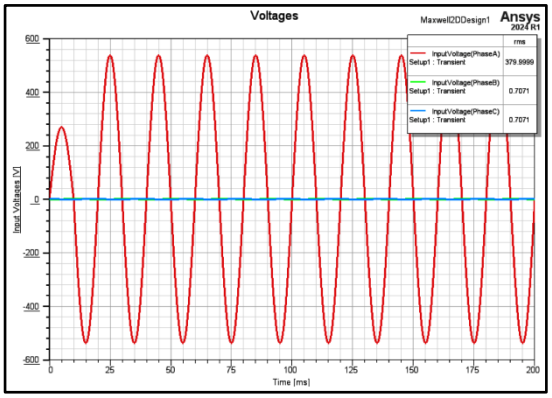


**Figure 5e** Induced voltage vs time graph at Line-to-Line fault

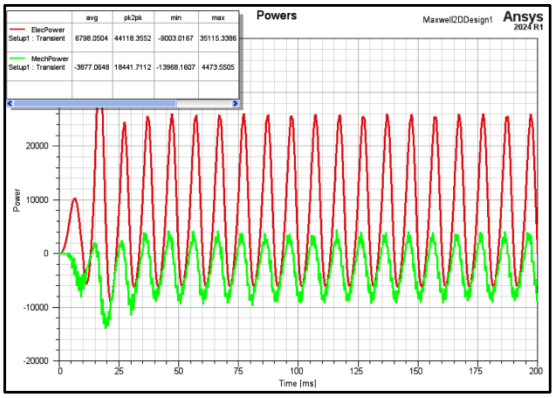


**Figure 5f** Electrical and Mechanical power vs time graph at Line-to-Line fault

## CONCLUSION

The study of fault analysis in induction motors using ANSYS has proven to be an effective approach for understanding the impact of the fault condition of line-to-line fault, on motor performance. Through simulation, it has been observed that each fault type introduces unique disturbances in the motor's magnetic field distribution, current, and thermal characteristics, ultimately affecting the motor's efficiency, reliability, and lifespan. Inter-phase faults created asymmetries in the winding currents, elevating localized heating and vibration. Line-to-line faults presented the most severe impact, with substantial overheating and potential damage to insulation, which could escalate to complete motor failure if left unaddressed. Maxwell simulations enable a precise visualization of these effects, allowing engineers to identify critical failure points and adopt preventive measures. This analysis underscores the importance of real-time monitoring and early fault detection in minimizing downtime and maintenance costs. Overall, leveraging tools like ANSYS for fault analysis aids in the design of more robust induction motors and enhances the operational resilience of industrial systems.

## ACKNOWLEDGMENT

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# Power & Energy

## Energy Policy, Economics and Sustainability

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# Transitioning to a Low-Carbon Economy in India: Policy Framework and Economic Outcomes

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***Abstract:*** *The global efforts in addressing the climate change issues are at its high and is expected to grow bigger in the years to come. This may be attributed to the personal experience of all humans in this Globe in one way or the other. On other hand the importance of sustainability has gained traction due to the focus on limited availability of resources. These two reasons have become a vital point in the policy formulation framework of any Nation in the Globe. India as the third biggest Economy in the World, coupled with higher growth rate shoulders higher responsibility than other stakeholders. The policy framework of Indian Government towards the journey for low carbon has provided much economic benefit parallelly addressing the sustainable requirements of the society. The resistance in terms of the paradigm shift of a major economy dependent on fossil fuel to a relatively new and efficient state is also being experienced, forcing the country to devise a unique formula. The paper delves into the prevailing policies in the Country in this respect and highlights the major merits and demerits.*

***Keywords:*** *Climate Change; Sustainability; Low-Carbon; Fossil Fuel*

## INTRODUCTION

The transition to a low-carbon economy has emerged as an imperative global agenda, driven by the urgent need to mitigate climate change and its associated impacts. As one of the world's fastest-growing economies, India plays a crucial role in the global effort to reduce greenhouse gas emissions. The country's rapid industrialization, urbanization, and economic growth have significantly increased its energy consumption, predominantly relying on fossil fuels. This dependency not only contributes to environmental degradation but also poses severe economic and health risks. Therefore, transitioning to a low-carbon economy is essential for sustainable development in India.

India's commitment to addressing climate change is reflected in its participation in international agreements such as the Paris Agreement, where it pledged to reduce its carbon emissions intensity by 33-35% from 2005 levels by 2030 and achieve 40% of its installed electric power capacity from non-fossil fuel sources. These ambitious targets necessitate a comprehensive policy framework that integrates renewable energy expansion, energy efficiency measures, and sustainable development practices.

The policy framework for transitioning to a low-carbon economy in India involves multi-faceted strategies encompassing renewable energy adoption, enhancement of energy efficiency, sustainable urban planning, and the promotion of green technologies. The government has introduced several initiatives, such as the National Action Plan on Climate Change (NAPCC), which includes missions focused on solar energy, enhanced energy efficiency, sustainable habitat, and more. The Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) scheme aims to promote the use of solar energy in agriculture, while the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme incentivizes the adoption of electric mobility.

Economic implications of transitioning to a low-carbon economy are profound and multifaceted. On one hand, the shift presents opportunities for economic growth through the creation of green jobs, development of new industries, and stimulation of technological innovation. The renewable energy sector, in particular, has the potential to attract significant investment and generate employment. According to the Council on Energy, Environment, and Water (CEEW), the renewable energy sector in India could create over 3 million jobs by 2030.

On the other hand, the transition poses challenges, including the potential economic disruption of traditional industries reliant on fossil fuels, the need for substantial financial investments, and the requirement for skill development and workforce retraining. The coal sector, which currently employs a large workforce, will be

particularly affected, necessitating policies for a just transition that ensures economic stability and social equity.

Moreover, the economic benefits of reduced carbon emissions extend beyond immediate financial gains. Improved air quality and public health outcomes can lead to long-term economic savings by reducing healthcare costs and increasing labour productivity. Additionally, enhancing energy security through diversified energy sources can protect the economy from volatile global energy markets.

In conclusion, transitioning to a low-carbon economy in India requires a robust policy framework that balances environmental sustainability with economic growth. While the journey presents challenges, the potential benefits of a greener economy are substantial. Through strategic planning and concerted efforts, India can not only contribute to global climate goals but also achieve sustainable and inclusive economic development. This paper aims to explore the policy framework necessary for this transition and analyse the economic implications, providing insights into the pathways and prospects for a low-carbon future in India.

## METHODOLOGY

Policy framework in India has started changing towards low carbon economy since 2011. This is evident from the feed-in tariff mechanism brought in place by various regulatory commissions in the country. However, few green technologies were already in place and were operating successfully without much hype on reduced carbon impact. There are many major policy frameworks in India, taking them towards low carbon transition. Some of them are as follows,

(i) Renewable Purchase Obligation
(ii) Renewable Generation Obligation
(iii) Viability Gap Funding for DCR category
(iv) Rooftop Solar Scheme
(v) Solarization of water pumps for agriculture
(vi) Green Hydrogen Mission

From the above initiatives of Government of India towards low carbon footprint journey, for study on the policy framework related to low carbon transition in India, the Renewable Generation Obligation policy formulated by Ministry of Power, Government of India is taken for further analysis.

### Understanding the Current Policy Framework

Ministry of Power, Government of India vide Gazette Notification dated 27th February 2023 notified the Renewable Generation Obligation as per the Revised Tariff Policy 2016. This notification obligated coal/lignite based thermal power generating stations achieved Commercial operation date between 1st April 2023 to 31st March 2025 shall comply the RGO of 40% by 1st April 2025 and plants achieving COD beyond 1st April 2025, shall achieve the RGO the day of commissioning itself.

In continuation to the above, on 6th October 2023, Ministry of Power came out with a request seeking comments from all stakeholders on Draft Notification on Renewable Generation Obligation. This framework mandated the following, any lignite/coal based thermal power stations achieving COD before 31st March 2023 shall achieve a minimum 6% RGO by 1st April 2026 and 10% RGO by 1st April 2028. For thermal plants achieving COD between 1st April 2023 to 31st March 2025, minimum RGO of 10% to be achieved by 1st April 2025. For thermal plants getting commissioned beyond 1st April 2025, the minimum RGO compliance of 10% shall be achieved on the day of commissioning the project.

They can also resort to procurement and supply of RE power, in case there is challenges in developing the RE project by themselves. The obligation fulfilled by any designated consumer under the “Scheme for flexibility in Generation and Scheduling of Thermal/ Hydro Power Stations through bundling with Renewable Energy and Storage Power, 2022 dated 12th April 2022 (RE bundling scheme)”, as amended from time to time, shall be considered as part of fulfilment of RGO.

The RGO shall be assessed in terms of annual share of RE generation as a percentage of the total annual generation, which includes generation of both conventional and RE, by respective designated consumer having established coal/lignite based Generating stations.

Bureau of Energy Efficiency (BEE) is the designated nodal agency overseeing the compliance of the coal/lignite generating stations in terms of achieving the RGO. Any shortfall in terms of tonnes of oil equivalent will be calculated and penalty under section 26 (3) of the Energy Conservation Act 2001, as amended from time to time.

**Analyze the Economic Outcome**

The RGO compliance mandates establishment of additional RE capacity along with the planned thermal capacity by the developer. This entails additional capital expenditure, and the economic dimensions get altered. The investment cost gets increased, and the returns also gets changed accordingly.

The policy provides the necessary push to the RE capacity in the country on compulsory basis. Had it not been mandated, the conventional power generation company, which sees higher RE capacity to be threat, will find it constrained for its development. This plan also offers an opportunity to consider co-locating the RE project and effective utilization of any spare transmission capacity. Additionally the benefit of bundling the RE power with Thermal power is also available for meeting their schedules. With accurate forecasting technology in place, it is seen that there is a possibility to meet the committed power capacity with RE power, meeting the requirement in a greener way.

The challenge of transition for the fossil fuel companies to RE projects is relatively offset through this compliance, as a sizeable RE capacity will be in the portfolio.

**Assess the Effectiveness of the Policies**

The RGO policy will be highly effective considering the following two reasons. They are

(i) Financial Healthiness
(ii) Effective Compliance

Presently, the coal/lignite-based power generation capacity is being added in the country at an approximate cost of Rs. 9 to 12 Cr/MW, referring to the completion cost.

An earlier policy which was imposed on the consumers with Renewable Purchase Obligation (RPO) did not elicit much changes or impact, considering the financial healthiness of the purchasing entities. In the electricity ecosystem, the generators are considered to be healthy with expertise of taking up projects. Under these premises, the RGO policy finds a perfectly placed and will achieve great success.

In terms of compliance, part the achievement can be easily monitored and the tariff petitions submitted to the Regulatory commissions can act as the point for checking. Rather than other means of watching, this plan will work with higher rate of success.

**RESULTS**

Adoption of this regulation by Government of India has led the Thermal Power Generators intending to establish Thermal Power Projects from the cut-off period has made the capex provisions for the Renewable Energy capacity in their total capital cost. This enables the growth of Renewable Energy capacity in the country to meet the aimed target of 500 GW by 2030.

It is seen in many cases, the new Thermal Power Project developers have already started taking investment decisions on the mandated RE capacity. This charts a new story in the sustainability journey. The mandated policy is seen as an opportunity by few of the players in starting their transition journey towards RE generation.

The shortfall in the Renewable Energy generation capacity in the Rooftop portfolio can be easily offset with this policy. It is expected with the taste of RE projects, the generating companies in future may resort to large scale RE projects, overshooting targets.

## CONCLUSION

India's Renewable Generation Obligation has had a transformative impact on the country's energy sector and broader economy. It has accelerated the shift towards renewable energy, attracted significant investment, created jobs, reduced carbon emissions, and made renewable energy more cost competitive. This development of Renewable Energy projects is coupled with the fossil fuel generators, providing better chances for co-location, bundling, better balancing rather than standalone Renewable Energy projects. RGO policy has created a push towards the development of RE capacity in the country.

While there are challenges, such as grid integration and policy compliance, the overall economic outcomes of the RGO are positive, positioning India as a global leader in renewable energy.

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# Energy Scenario in India

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***Keywords:*** *Energy Security; Renewable Energy; Economic Growth*;

## INTRODUCTION

This paper presents the Energy Policy, Economics & Sustainability with reference to the Indian context and focuses on the prevailing Energy policy and its implications on economic activity and explores energy sustainability model adopted.

Also, this paper provides insight into the proportion of various sources of energy being used in India and offers solution and highlights areas that need intervention to achieve energy security without compromising environment in a sustainable way.

Energy is acknowledged as a key input towards raising the standard of living of citizens of any country, as is evident from the correlation between per capita electricity (a proxy for all energy forms) consumption and Human Development Index (HDI). Accordingly, energy policies of India have over the years directly aimed to raise per capita energy (and electricity) consumption, even while the main focus of the country's development agenda has been on eradication of poverty. With nearly 304 million Indians without access to electricity, and about 500 million people, still dependent on solid bio-mass for cooking, it may be acknowledged that the country has to still go a long way on securing its energy security objective. While India strives to achieve a double-digit growth rate in its national income, making clean energy available to all of its citizens, ought to be included as a key component of the poverty alleviation programmes.

## OVERVIEW OF ENERGY SECTOR IN INDIA

Our dependence on various sources of energy is outlined below.

| | |
|---|---|
| Coal | 57.63 % |
| Nuclear | 0.84 % |
| Oil | 30.33 % |
| Renewable | 0.58 % |
| Gas | 8.5 % |
| Hydro | 2.12 % |

India heavily relies on imports to meet its energy needs, with crude oil constituting over 80% of total energy imports. Efforts have been made to develop the natural gas infrastructure in recent years.

- The government has launched the City Gas Distribution (CGD) project to provide piped natural gas to households, industries, and vehicles.
- Compressed natural gas (CNG) is being promoted as a cleaner and cheaper alternative to petrol and diesel.
- Coal continues to play a significant role in India's energy sector, contributing to over 70% of electricity generation.
- Clean coal technologies such as supercritical and ultra-supercritical power plants are being adopted to improve efficiency and reduce emissions.

## METHODOLOGY

### Energy Policy

There are four key objectives of our energy policy:

- Access at affordable prices,
- Improved security and Independence,
- Greater Sustainability
- Economic Growth.

The above areas are dealt a little deeper in the following paragraphs.

1. Considering poverty and deprivation in India, access to energy for all at affordable prices is of utmost importance. We are yet to provide electricity to nearly 304 million people, and clean cooking fuel to nearly 500 million people, which still depend on Biomass. The policy aims to ensure that electricity reaches every household by 2022 as promised in the Budget 2015-16 and proposes to provide clean cooking fuel to all within a reasonable time. While it is envisaged that financial support will be extended to ensure merit consumption to the vulnerable sections, competitive prices will drive affordability to meet the above aims.

2. Improved energy security, normally associated with reduced import dependence, is also an important goal of the policy. Today, India is heavily dependent on oil and gas imports while also importing coal. In so far as imports may be disrupted, they undermine energy security of the country. Energy security may be enhanced through both diversification of the sources of imports and increased domestic production and reduced requirement of energy. Given the availability of domestic reserves of oil, coal and gas and the prospects of their exploitation at competitive prices, there is a strong case for reduced dependence on imports. In due course, we may also consider building strategic reserves as insurance against imported supplies.

3. The goal of sustainability acquires added importance and urgency in view of the threat of catastrophic effects of climate change as well as the detrimental effects of fossil fuel usage on local air quality. In India, sustainability is also closely linked with energy security. Our fossil fuel requirements, which comprise nearly 90% of our commercial primary energy supply, are increasingly being met by imports. This means that cutting fossil fuel consumption would promote the twin goals of sustainability and security. Hence the policy lays heavy emphasis on de-carbonisation through the twin interventions of energy efficiency and renewable energy.

4. Finally, the energy policy must also support the goal of rapid economic growth. Efficient energy supplies promote growth in two ways. First, energy is the lifeblood of the economy. It is an important enabling factor of growth and its availability at competitive prices is critical to the competitiveness of energy-intensive sectors. Second, being a vast sector in itself, its growth can directly influence the overall growth in the economy. For example, petroleum products have been an important direct contributor to our growth in recent years by attracting large investments in refining/distribution, and also fuelling economic activity.

5. In general, these four goals may or may not move in harmony with one another. We noted above that energy security and sustainability are mutually reinforcing in our case since our energy imports are predominantly fossil fuel based. Reduction in imports and in emissions can both be achieved through an expansion of renewable energy consumption. On the other hand, as long as fossil fuels remain the cheapest source of energy, the goal of energy accessibility at affordable prices would come in conflict with the goal of sustainability and possibly energy security as well. Until such time as the costs of generating, transmitting and distributing renewable energy drop sufficiently to allow its delivery to the customer at lower cost than energy from fossil fuel sources, a conflict is likely to exist among the above three objectives. Energy efficiency is, however, one goal that reinforces all the four objectives. Hence, we identify it as a common area of intervention across all demand sectors in the Strategy.

6. Having identified the four broad objectives of our energy policy, we need to link them to propose actions on the

ground. The areas are classified according to the source (coal, oil gas or renewable) or form (electricity) of energy and the stage of value chain. Stages of value chain are divided into upstream, midstream and downstream. For example, upstream stage of electricity is generation while midstream and downstream stages are transmission and distribution. Likewise, exploration and production define the upstream stage of oil while refining and distribution are midstream and downstream stages of it. Final consumption is analysed according to four major consumption sectors: businesses, households, transportation, and agriculture.

## RESULTS

### Sustainable Energy

Sustainable energy offers solution as it is a type of energy that can be used repeatedly without depleting its source, and without compromising the future needs of others. It's also known as renewable or "green" energy, and is derived from resources that can maintain current operations without jeopardizing the climate or energy needs of future generations.

The most popular sources of sustainable energy are wind, solar, and hydropower. These sources are also considered the most sustainable because they can be used almost anywhere in the world without significantly changing the natural landscape. Other examples of sustainable energy include biomass and geothermal. Geothermal energy uses heat from the Earth's core, which is stored deep within the Earth and is accessible near the crust.

Definitions of sustainable energy often consider its effects on the environment, the economy, and society. Energy sustainability can be achieved by finding a balance between these factors, while also providing an improved quality of life for current and future generations. This can include technical innovation with an environmentally conscious mindset, as well as regulations to reduce emissions from energy-related activities.

Total power generation in India from various sources and renewable energy mix by source are presented below.

**Table 1** India's Total Installed Capacity by Power Source (GW)

| Source | As of March 2022 | As of May 2023 | % of Energy Mix |
|---|---|---|---|
| Coal | 204.08 | 205.23 | 49.1 |
| Lignite | 6.62 | 6.62 | 1.6 |
| Gas | 24.89 | 24.82 | 6 |
| Diesel | 0.51 | 0.58 | 0.1 |
| Hydro | 46.72 | 46.85 | 11.2 |
| Nuclear | 6.78 | 6.78 | 1.6 |
| Renewable | 109.88 | 125.69 | 30.2 |
| Total | 399.49 | 417.66 | 100 |

**Table 2** Renewable Energy Mix by Source (GW)

| Source | As of March 2022 | As of May 2023 | Target for 2030 |
|---|---|---|---|
| Wind Power | 40.35 | 42.86 | 140 |
| Solar Power | 53.99 | 67.07 | 280 |
| Biomass Power | 10.20 | 10.24 | 10 |
| Small Hydro | 4.84 | 4.94 | 70 |
| Waste-to-Energy | 0.477 | 0.55 | (No target) |
| Total | 109.88 | 125.69 | 500 |

## CONCLUSION

The power and energy sector in India presents significant opportunities for growth, driven by increasing demand, government initiatives, and a focus on renewable energy. The government's commitment to sustainable energy solutions and continuous investments in the sector contribute to its ongoing development and transformation.

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# Energy Policy, Economics and Sustainability for India: Challenges Ahead and their Mitigation Measures

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***Abstract:*** *Indian energy sector is presently going through an important phase of transition. This is happening in line with the global missionforclean development and green energy with an ultimate objective of achieving sustainability in every sphere. It is indeed a very crucial juncture to review and critically appreciate the provisions of the prevailing and upcoming energy policies in India, analyse every step of actions needed, determine the challenges in the whole process of implementation and finally be ready with mitigation measures for removing all the road blocks on the way of meeting the nationwide targets in time and within budgets. This paper aims at highlighting all the relevant issues pertaining to the key areas on the subject, mentioned under Point No. 2 in below. It includes suggested steps to overcome all the challenges foreseen towards achieving sustainability while bringing up the interrelated economic impacts and involvements. The references followed have been listed out at the end of this paper.*

***Keywords:*** *Policies; Mandates; Challenges; Mitigations; Sustainability*

## MAJOR POLICY CONSTITUENTS

Currently, the movements in Indian Energy Sector rests on three important elements, namely:

(a) National Electricity Plan: Covering review for the period 2017-22 in detail while providing comprehensive plan for the period 2022-27 and perspective plan for the period 2027-32. The focus is on:

1) Demand forecasts for different regions
2) Suggested locations for capacity additions
3) Integration of locations with the transmission system
4) Technologies for efficient generation, transmission, and distribution
5) Choice of Fuel or Source of Generation vis-à-vis Climate Change Scenarios

(b) India Energy Security Scenarios (IESS 2047): This open-source tool analyses India's energy supply and demand up to 2047. It considers factors like emissions, cost, land, and water requirements. The tool is designed for public use and helps develop energy transition scenarios.

(c) Policies and Guidelines for New and Renewable Energy sources.

## OBJECTIVES AND KEY ISSUES

There are four key objectives, namely:

(a) Access to energy at affordable price

(b) Improved security and independence

(c) Economic growth

(d) Greater sustainability

Major issues considered to be addressed in the process are:

(a) Electricity Reforms and Stake holding

(b) Regulatory and Legal Barriers

(c) Energy Efficiency and Conservation Policy

(d) Air Quality and Environmental Challenges

(e) Energy Infrastructure

(f) Fossil Fuel-based supply vis-à-vis Fuel Production, Transportation and Pricing

(g) Renewable Energy in relation to Access, Storage, Technology, Funding

(h) Nuclear Energy vis-à-vis its Reliability

(i) Grid Expansions, Upgradations and Integration

(j) Rural Electrification

(k) Clean and Environment friendly processes and sub-processes

(l) State of the Art Resources covering Trained Manpower, Database, Technology, Research and Development

(m) Overseas Engagements in terms of expertise, technology upgradation etc.

**ACTION ITEMS AND MANDATES**

The major actionable areas towards implementation of the policies and achieving the objectives are:

(a) Completing an extensive electric power survey

(b) Determination of need for Capacity addition vis-à-vis locations

(c) A comprehensive Demand Side Management (DSM) plan and privatization needs vis-à-vis area and load

(d) Capacity addition plan with optimal energy mix on a target time scale and readiness in technicals and financials

(e) Assessment of impact of energy transition and potential for use of renewable energy

(f) Planning and implementation of financial aids and incentive schemes to attract investments in renewable sector

(g) Determination of energy saving potential and improvement of efficiencies of the processes

(h) Retirement of not less than 2121.5 MW of old thermal units during 2022-32 (given recent restrictions imposed for retirement of such units till 2030)

(i) 100% utilization of ash from thermal generating units

(j) Lowest consumptive use of water for generation and all other processes

(k) Minimum discharge of pollutantsand wastesincluding greenhouse gases

(l) Non-fossil generation share to increase to 57.4% by 2026-27 and to 68.4% by 2031-32

(m) Aim for 500 GW of installed capacity through renewable energy by 2030

(n) Promoting domestic manufacturing of solar photovoltaic modules and advanced batteries

(o) Domestic production of 5 million tons of green hydrogen per year by 2030

(p) Emission reduction to 0.548 kg CO2/kWh in 2026-27 (from 0.7-0.8 now) and to 0.430 kg CO2/kWh by 2031-32 (while G20 target is 0.445)

(q) Achieve net-zero carbon emissions by 2070

(r) Helping the country to move towards achieving the United Nation (UN) Sustainable Development Goals

(s) Raising low-cost fund for the period of 2027-32 amounting to Rs. 19,06,406 Crores (~19 trillion INR)

(t) Issuance of Integrated Green Bonds across India to hasten up implementation of the decarbonization strategy

(u) Transmission and Distribution (T&D) capacity planning and scheduling ensuring timely network availability, carrying capacity, low T&D losses

(v) High Voltage (HV) transmission network and technology upgradation and grid integration in line with generating capacity additions and energy exchange needs

(w) Strengthening energy exchange mechanism within India and reinforce cross-border transmission /exchange

(x) Nation-wide implementation of a standardised digital platform for all operations, control and data logging

(y) Implementation of a strong cyber security arrangement

(z) Reducing energy poverty and ensuring energy security

**Major Challenges for Energy Sector in India vis-a-vis Reformation Needs**

India's energy sector are likely to face many challenges towards its upcoming reformation which include:

(a) Stepping up electricity generationrapidly against input-output constraints:The current capacity needs to be augmented to produce electricity that will be enough to support the country's future economic growth. It is estimated that in 2040 the electricity consumption will reach 2917 kWhper capita, sliding up from 887 kWhper capita as was in 2012, considering a Compounded Annual Growth Rate (CAGR) of electricity supply of 5.5%.

(b) Shortage of fuel and raw materials: Thermal power plants, which are still the major source of energy, face a shortage of coal and other raw materials. There is a shortfall in domestic coal supplies as new sources have not been harnessed much in recent times owing to transitional trends in energy sector. The coal transportation and distribution networks are still not adequate across the country. Coal beneficiation and gasification exercises have also not been taken up at any bigger scale.

(c) Commercial utilisation of bottom and fly ash: The mandate of 100% utilisation of ash is already a great challenge vis-à-vis the bandwidth of commercial off takes. It requires extensive research and efforts to increase scope and application of both bottom and fly ash utilisation in extensive commercial scale. A part of fly ash can of course be used by way of high concentration slurry disposal system to build up landscapes.

(d) Constraints in energy infrastructure: It is still very much necessary to strengthen the energy infrastructure and resolve cross-sectoral issues, specifically in view of the transitional needs. More investments are needed in energy infrastructure assets which include infrastructure for both power plants and fuel sources like coal mine or refineries, energy storage, transmission system, pipelines, roads, railways, ports etc.

(e) Aggregate technical and commercial (AT&C) losses in transmission and distribution: This though decreased to 15.4% in (FY) 2022-23 from 25.72% in FY 2014-15, yet it is still much higher compared to the scale of 6-11% in other developed countries.

(f) Nation-wide upgradation to Smart Grid and integration: The expanse of the networks in India is extremely large and given the constraints of all types on board, it itself will pose a severe challenge. In addition, Demand Side Management (DSM) is a challenging area in smart grids that offers opportunities for residents to minimize electricity costs.

(g) Financial health and Non-Performing Assets (NPA) of many State Utilities - The financial health of several distribution companies are very poor as of now and the inventory of NPAs are rising in generating companies due to ageing of the plants and in transmission companies due to non or under-utilisation of assets.

(h) Environmental challenges and Decarbonisation Missions: The energy sector in totality is responsible for about two-thirds of global CO2 emissions. So, developing a climate-friendly energy system based on renewables is vital for tackling climate change, even after reducing the carbon emissions from burning of fossil fuels.

(i) Power system structures and markets: The energy transition may be hindered by misalignments within and beyond power systems, as well as due to lack of balance between competition, regulation, and collaboration. All elements like - policies, regulations, tariff structure as well as their revisions and setting up of investor friendly climate are equally important here.

(j) Quantum of Investments: Leaving apart the larger needs for investment to cope up with needs of energy sector like that during 2027-32 of 19 trillion INR, just to reduce the AT&C losses across the country down to 12-15% by FY 2024-25, the investments needed is around 3 trillion INR.

**Suggested Measures to Combat the Challenges and Meet the Targets**

Some important recommendations for the energy sector in terms of its future course of actions include:

(a) Fuel reforms: Ramping up coal production by both public and private sector in a time-bound manner is needed with increased participation of private sector in coal production. Easing of regulatory framework, clearances, approvals for allocation cum development of coal blocks and gas infrastructure are needed.

(b) Upgradation to Smart Grid and Integration at national level: Several grid modernisation projects have been taken up at state and national levels. Alongside, the Smart Meter National Programme (SMNP) aims to install 250 million smart meters across the country by 2025. Increasing investment in transmission and distribution infrastructure is also a big necessity for this purpose.

(c) Energy transition: Promoting the adoption of new and renewable energy sources to meet Nationally Determined Contributions (NDC) target of more than 60% of energy from non-fossil fuel-based resources by 2030. The target of 500 GW of renewable energy capacity by 2030 incidentally also includes 30 GW offshore wind projects and 5 million tonnes of green hydrogen production per annum.

(d) Energy conservation: Performance management and efficiency improvement missions need to continue in all possible cases. Older units should be phased out in a planner manner and be replaced with new units.Reduction of transmission losses should be achieved by better infrastructure and technological efforts.

(e) More investments for energy sector: As per an estimation from the International Energy Agency, India would require an investment of $160 Bn per year till 2030, three times today’s investment level, to meet even50% of its energy demands from renewable energy sources by 2030. So, other than institutional, government and private investments, Foreign Direct Investment (FDI) in India's energy sector must be boosted up, particularly in renewable energy sector. Incidentally, in FY 2023, India received $2.5 billion in FDI for its renewable energy sector.

(f) Increased financing facilities for energy sector: A robust and sustainable credit enhancement mechanism for funding in Energy Sector needs to be put in place through increased participation of global funding agencies like World Bank Group, ADB etc. in the entire value chain. The focus needs to be on investing in capacity building and modernization.

(g) Public private partnership: There is a strong need to push for wider scale, implementation of public private partnership models. The private sector has been playing a key role in generating power, a more supportive environment will help in bridging the energy deficit of the country. A special review could be done for state

owned distribution companies as well.

(h) Policies, regulations and balanced approach: Regulatory and policy framework needs to be crafted and enforced to ensure a win-win situation for all the stakeholders. It is important to resolve the immediate issues ailing the energy sector through implementation of effective policies and regulations.

(i) Energy subsidies, recovery and taxes: In 2023, India's energy subsidies increased to USD 39.3 billion, the highest in last 9 years. Fossil fuel subsidies remained 5 times the subsidies for clean energy, which though had grown @8% in 2023. The subsidies need to remain and carefully disbursed, but state-owned utilities should not be saddled with the burden of cross-subsidising the renewable sector. This can be borne by the society (through taxation or otherwise) and not by the entities that are already in trouble. The accumulated financial loss of the Indian state-owned electricity utilities (SOEUs) has crossed over USD 6.25 billion. 80% of the SOEUs are consistently incurring losses and are financially unsustainable in long term.

(j) Ministry of Energy and Cooperative Federalism: There should be one Energy Ministry to make coordination and implementation of policies better. It will remove policy implementation constraints too. To resolve inter-state disputes like sharing of water resources or transfer of energy etc., a federal structure with dual sovereignty could be there, but the aforesaid Ministry of Energy should retain the power of intervention and adjudication to help settlement of long-pending issues for benefits of all.

**Factors Contributing to the Sustainability of India's Energy Sector**

(a) Renewable energy: India is ranked third in the renewable energy country attractive index and is working to increase its renewable energy generation.

(b) Solar energy: India's location in the tropical belt gives it a lot of potential for solar energy, which can help support the country's sustainability.

(c) Energy storage: Battery storage is a key part of India's green push, as the country aims to increase its renewable energy generation.

(d) Smart grid integration: Smart grids are a key part of India's sustainability drive and help with policy making.

(e) Technological change: Technological change is a significant factor in the transition to sustainable energy and can help with emission reduction costs.

(f) Climate commitments: India's use of renewable energy is aimed at improving energy security, access to energy, and mitigating climate change.

**Policy Focus needed towards Sustainability of India's Energy Sector**

The key issues to be considered in all upcoming policies or in amendments of existing policies should include:

(a) Mandatory vulnerability assessment to future climate risks for energy infrastructures

(b) Project and systemic risks in the vulnerability index

(c) Adaptation of funds for unmitigated climate risks

(d) Continuous monitoring of climatic parameters and implementation of adaptation measures

(e) Sustainability actions in energy infrastructures to enhance climate resilience and deliver co-benefits to local stakeholders.

**Important Budgetary Allocations and Opportunities in Relation to Energy and Sustainability:**

Following are some of the important budgetary allocations in relation to energy and sustainability, made by Government of India for FY 24-25:

**Table 1** Total and energy-related budget allocations

| Categories | 2022-2023 Actual (USD millions) | 2023-2024 Revised Estimates (USD millions) | 2024-2025 Budget Estimates (USD millions) | Percentage Change from 2023-24 |
|---|---|---|---|---|
| Total Budget | 522,186 | 542,526 | 575,652 | 6% |
| Energy Budget | 8,184 | 6,644 | 8,212 | 24% |
| **Share of Energy** | **1.6%** | **1.2%** | **1.4%** | |

**Table 2** Budget allocations for selected energy-focused federal programs

| Categories | 2022-2023 Actual (USD millions) | 2023-2024 Revised Estimates (USD millions) | 2024-2025 Budget Estimates (USD millions) | Percentage Change from 2023-24 |
|---|---|---|---|---|
| Solar | 698 | 709 | 1,433 | 102% |
| Wind | 176 | 111 | 111 | 0% |
| Green Hydrogen | 0 | 12 | 72 | 493% |
| Nuclear | 666 | 669 | 734 | 10% |
| LPG | 1,019 | 1,558 | 1,528 | -2% |
| Transport Electrification | 405 | 1,654 | 1,179 | -29% |
| Grid Strengthening | 786 | 1,727 | 2,006 | 16% |
| Energy Transition | 0 | 0 | 1,791 | |
| **Total** | **3,750** | **6,440** | **8,854** | **37%** |

**Table 3** Budget allocations for green bonds for energy and climate projects

| Categories | 2022-2023 Actual (USD millions) | 2023-2024 Revised Estimates (USD millions) | 2024-2025 Budget Estimates (USD millions) | Percentage Change from 2023-24 |
|---|---|---|---|---|
| Solar | 256 | 616 | 1,433 | 132% |
| Wind | 158 | 111 | 111 | 0% |
| Transport Electrification | 1,674 | 1,944 | 2,193 | 13% |
| Green Hydrogen | 0 | 12 | 72 | 493% |
| Forest Preservation | 20 | 14 | 20 | 40% |
| **Total** | **2,107** | **2,697** | **3,829** | **42%** |

There could be several economic benefits of India's transition to green energy. The renewable energy sector is expected to create over 1.3 million jobs by 2030, driven by growth in solar, wind, and bioenergy. The renewable energy sector is expected to attract investments of about Rs 30.5 trillion between 2024 and 2030. A more diverse energy mix with a significant share of renewable energy will reduce India's dependence on coal and oil imports, save foreign exchange, and contribute to a more balanced trade. Eliminating fuel costs will lower the cost of electricity produced, and the price of electricity will not be susceptible to changes in the price of fuels.

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# Integration of Virtual Power Plants for a New Generation Smart Grid in Electricity Market

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***Abstract:*** *With the aim of reducing the green house emission gases, there has been a significant rise in the increase of the production of renewable units which consists of solar, wind and photovoltaic since the last decade. As the production of the renewable units fully depends on meteorological phenomena, these units restrict the participation for production in significant real time which obstructs the owners to earn profit in the electricity power market. These negative effect of the uncertainties in the production of the renewable units give rise to the birth of the virtual power plant which consists of conventional units, reserve, storage facilities, incorporation of electric vehicles and flexible demands that can paradigm shift part of the energy consumption for the consumers and the owner's social welfare benefit. Here in this paper it is reflected through different components of virtual power plants and are focused through modeling which integrate the stochastic renewable units with the conventional ones. The participation of these units which are within their confidence bounds, so they may be rewarded or penalized for different time horizons to balance the demands and supply in the power market for maximizing the profit. This forefront to model a decision making problem which is solved through DC load flow algorithm under mixed- integer linear programming of MATALAB version 2015A with the mathematical dominance of Branch and Bound algorithm, where the optimization variables can take continuous and discrete values. The uniqueness of this paper infers that virtual power plant participates in scheduling decision of the facilities time by time to settle the market in real time. Here it is concluded that through bi- directional communication between the producer units and the market in real time the facilitator can maximize its profit.*

***Keywords:*** *Conventional Units; Flexible Demands; Storage; Virtual Power Plants*

## INTRODUCTION

Renewable energy resources, by their nature, are variable and weather-dependent. Solar panels only generate electricity when the sun is shining, and wind turbines require a certain wind speed to operate efficiently. This intermittency poses a significant challenge for VPPs when it comes to ensuring a consistent energy supply. However, this challenge also presents an opportunity for innovation. Through the use of energy storage systems, demand response strategies, and predictive analytics, (virtual power plant) VPPs can mitigate the variability of renewable energy generation. The integration of high levels of renewable energy into the grid requires sophisticated grid balancing mechanisms. Unlike conventional power plants that can ramp up or down based on demand, renewable energy sources are less predictable. VPPs can play a crucial role in grid balancing by aggregating multiple energy sources and utilizing storage solutions to smooth out fluctuations in power supply. One of the main ways VPPs can generate profits is through participation in energy markets. In deregulated electricity markets, VPPs can trade energy and grid services like frequency regulation, load balancing, and reserve capacity. By aggregating renewable energy resources, a VPP can offer these services at a lower cost and with greater flexibility than traditional power plants. The VPP's ability to optimize the dispatch of energy based on market prices and demand forecasts is a key factor in maximizing profits. For instance, if the software predicts higher electricity prices during peak hours, the VPP can store energy during off-peak times and release it when the price spikes, thereby securing higher revenues. Moreover, VPPs can also engage in ancillary services like frequency regulation or spinning reserves. These services are critical to grid stability, and grid operators are willing to pay a premium for reliable providers. By using aggregated renewable resources in conjunction with battery storage, VPPs can respond faster and more efficiently to these

demands than traditional generators. Capacity markets offer another lucrative revenue opportunity. In these markets, power producers are paid for maintaining available capacity to meet future peak demand, even if that capacity is not used. VPPs can capitalize on this by aggregating distributed renewable energy assets and selling their combined capacity to the grid operator. This not only generates revenue but also ensures grid reliability during periods of high demand. Demand response (DR) is another avenue for profit maximization in Virtual Power Plants. Through DR programs, VPPs can manage and control flexible loads in real-time to adjust electricity consumption based on grid conditions or market prices. For instance, during times of high electricity demand, the VPP can signal large energy consumers (such as industrial facilities or data centres) to reduce their power usage temporarily in exchange for financial incentives. This is not only helps balance the grid but also allows the VPP to profit from demand-side management strategies. Additionally, DR programs contribute to the optimization of renewable energy consumption by synchronizing demand with the availability of renewable energy, especially during times of excess supply (like midday for solar energy). Since VPPs aggregate local energy resources, they can reduce the strain on the central grid infrastructure. By consuming or storing energy locally, they minimize the need for long-distance transmission, thereby reducing transmission and distribution costs. These savings can either be passed on to consumers or added to the VPP's profit margins. The profitability of Virtual Power Plants largely depends on supportive regulatory frameworks. In many countries, governments are incentivizing the development of renewable energy and decentralized energy systems through subsidies, tax credits, and favourable market structures. For example, feed-in tariffs and net metering policies allow VPP operators to sell excess energy back to the grid at competitive rates. Moreover, regulatory frameworks that promote the integration of demand response and ancillary services into energy markets provide additional revenue streams for VPPs. Governments and regulators are increasingly recognizing the role that VPPs can play in enhancing grid resilience and stability, especially as renewable energy penetration increases.

**FLEXIBLE DEMAND MANAGEMEN**

Always supply and demand must be balanced to provide reliable power. So, flexibility is crucial role to maintain the equilibrium in power system through the grid for a seconds, minutes, hours, and days. In power plants and ramping them up and down to meet daily and seasonal fluctuations in demand, grid operators have historically viewed the timing of energy usage as essentially fixed, relying significantly on flexibility in the electricity supply to maintain balance. In VVPs are flexible demand that's why they can shift their power consumption according to requirement in the VVPs. The production of renewable energy is limited in a given time period, it could be necessary to shift a portion of a demand energy consumption. The high cost of energy in the market, it needs shift part of the energy usage.

**ENERGY STORAGE**

VPPs is considered as necessary components of energy storage units. These units are active as energy storage devices when there is an excess energy produced by stochastic renewable energy units. If necessary, this stored energy can be used at a later time when peak demand consumption or during a period of low renewable production.

**CONCLUSION**

In this paper it has been vividly described for a six-hour time period that the stochastic nature of renewables which are modelled with other technologies like the conventional plants with renewables known as mixed generation, storage energy and demand management popularly known as flexibility of demands and reserves to compensate the deficit of power production as well as to achieve the maximum profit by the facilitators and also to target the excess and deficit power for trading purposes. Here the problem, which are leading to the uncertainties in the market prices and the production levels are tackled through the decision-making problem namely scenario based stochastic programing and robust optimization. The paper focuses on the optimal participation of the smart micro grid led by virtual power plant subject to its network and generation capacity limitations, power balance, power flow through lines, voltage, angle and technical constraints. Thus the energy management system which takes care of the virtual power plants provide the technical and economic information which is focused in the paper to the market operators for taking decisions, bilateral transactions, clearing price forecasting. All these conceptions predict for future expansion planning strategies.

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# Uncertainty Realization through Stochastic Scheduling through Energy and Reserve Markets

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***Abstract:*** *Due to ever increasing consumption all over the world in the last decades, persuaded a new concept of developing pollution free energy sources like, wind, solar photo-voltaics to increase the available generation capacity. The integration of these re-newable energy sources with the conventional ones based on fossil fuels, a confronts in uncertainty problem since the solar or wind generating units are intermittent in nature which basically depends on weather condition. The participation of these stochastic generating units are limited and are deviated to earn profits or penalized as these limits are degraced from scheduled production. A possible solution to overcome the penalties fetched is the amalgamation these stochastic or uncertain units with conventional plants and reserves to supply the demand in real time. Here in this paper, the precariousness of the available wind production is modelled using two equiprobable scenarios. The un-certainty of the reserve deployment is also modelled using finite equiprobable scenarios allied with probability occurrence . The finite Combination of the scenarios finally depicts the scheduling of energy and reserve power markets. The uniqueness is focused through the uncertainty of the stochastic solution that helps to find optimal solutions for a 2-hour time frame, that balances the risk of power not served at the real time with the incorporation of the reserves. These leads to model a decision making problem solved through optimization problem namely based on linear programming particularly Mixed Integer Linear programming , where the optimization variables can take continuous and discrete values. The optimization problem is solved through Brunch and Bound algorithm through Matlab Version 2015 A.*

***Keywords:*** *Reserves, Stochastic, Energy Market, Uncertainty, Equiprobable*

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# Projecting or Estimating Nodal Congestion Price and IMO Pay by Ada-Boost for a Restructured Electrical Market

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***Abstract:*** *Day by day electricity requirement is increasing in a rapid way, due to the enhancement of utilization of electric power. Initially, electrical power supply done by limited numbers of agencies and competition is very less in Electric Market, as a result the consumers did not have any option to choose according to their requirement on economic point of view. At present, electricity is an inseparable commodity for the human being, and a profitable structure introduces where sup-pliers as well as buyers can have their profit from the selling and utilizing electrical power. This restructured electricity market is competitive in nature and changes monopoly market to open deregulated electricity market where profit maximization is main moto by minimizing the cost. In this new structure power supply reliability and financial issues are took care by an independent regulating author-ty or independent market operator (IMO). Power generators (GENCOS) produce energy and that spread to consumers via Transmission and distribution companies (DISCOS). In electrical open market, optimal power flow adopted for profit maximization. In any power system Locational Marginal Price (LMP), Nodal congestion price (NCP) are the important index for optimal power flow studies. In this article IEEE 30 bus system has taken for case study and perform OPF technique on it. Finally, a machine learning approach has taken to predict the LMP, MCP of the system.*

***Keywords:*** *Gradient Boost; Independent Market Operator (IMO); Locational Marginal Price (LMP); MATLAB-PSAT; Nodal Congestion Price (NCP); Optimal Power Flow (OPF)*

## INTRODUCTION

Restructure in electrical market is a way to abolish monopoly structure of the electrical power market and introduce competitive nature. In electrical power market, pricing competition of suppliers and consumers is introduced. In electrical power market, few market structures are used such as PoolCo model, bilateral model and hybrid model. In an electrical power market, an independent body (IMO) is responsible to operate the market, and all participants must follow the rules and regulations abide by the IMO. IMO pass the information of bidding among all participants by using 'open access same time information system' (OASIS). IMO collect offers from sellers, bid from buyers, and maintains the balance between the power demand and supply. It also maintains power system reliability and security of electric market. In energy market, two pricing methods can be mentioned; one is uniform and another non-uniform pricing method. In uniform pricing system, based on MCP value suppliers or GENCOS are remonetized, on the other hand non-uniform system depends on Locational Marginal Price (LMP) which is the mini-mum marginal cost that can supply next increment of energy with maintaining the all constrains of the transmission system. Locational marginal price (LMP) is the association between transmission loss and generation marginal cost to supply consumers [1]. LMP is a crucial parameter of an electrical market, and it is a summation of reference price of single slack bus, marginal price of transmission losses and the network constrains marginal price, which are enforced in power flow model [2]. Power congestion problem is a significant parameter of modern restructured power system competitive electrical market, and the congestion problem can manage by nodal price based strategy. Optimal nodal price is integration of locational margin-al price (LMP) and nodal congestion price (NCP).

In real time market (RTM) or Day ahead market (DAM), security constrained economic dispatch (SCED) results used to evaluate LMP. SCED is a key controller to maintain all security constrains of transmission. All stipulated constrains are maintained by SCED and meet the load. After meeting, the load maximum social welfare can maintain by SCED. When price sensitive demand is absent then production cost is minimum [3]. There are two ways to evaluate LMP, such that ex post and ex ante. Ex ante. and ex post are followed by NY ISO and MISO, ISO NE and PJM respectively. In case of ex post, non-performer participants are penalized on other hand ex ante do not have such kind of scenario. SCED, is a frame of OPF problem based on linear programming, it provide high speed performance

and robustness with respect to non-linear programming [4-9]. Finally, LMP estimation can be done by solving the linear programming.

## LITERATURE REVIEW

The authors of this study examined the pricing strategy for electricity and used the multi-objective genetic algorithm (MOG) to simulate the system. While overall losses and emissions are minimized, power parameters such as LMPs and GDs are variable. The optimization method is tested on a single IEEE 32 bus system, and the outcome demonstrates the technique's dependability [10]. Here, the authors suggest a novel LMP formula for DGs that is linked to profit maximization and loss minimization. Stochastic power flow based on the point estimate method (PEM) can be used to manage load-price volatility uncertainty, and meta-heuristic modified honeybee mating optimization (MHBMO) approaches can be used to determine the optimal LMP value [11]. Ehsan Azad-Farsani et al. talked about reconfiguring the distribution network to assess the ideal LMP value at generator buses by reducing power losses, which increase the profit at generator buses. In this case, network optimal configuration and LMP computation at the generator end are handled by Firework Algorithm (FWA) and Iterative Game-Based Algorithm (IGBA) [12]. For the purpose of reducing loss and emission in the network, the authors suggested evaluating LMP based on DG contribution. Here, LMP at the generators' end is estimated using a novel iterative method based on nucleolus theory. Two real-time distribution networks were tested using this methodology [13]. This article proposed prediction method of LMP in electrical power market. Here, Gaussian Process (GP) of hierarchical Bayesian estimation with the Mahalanobis kernel method proposed to predict LMP and real data, of ISONE (Independent System Operator New England) in USA, simulation result indicated that method is efficient that other method. [14]. Here, authors proposed Hybrid Backtracking Search Optimization Algorithm with Grey Wolf Optimization (GWO-HBOA) for optimal power flow and LMP estimated for both loss and lossless condition. IEEE 30 bus system used for testing of proposed algorithm. The algorithm is fit to boost voltage stability, voltage deviation, real and reactive power loss and handle congestion of the system [15]. Here, [16] authors formulate a locational marginal price associate with constrains for a distribution system. A simple 12 bus distribution system has chosen for distribution locational marginal price (DLMP) algorithm testing, finally calculation done by Lagrangian multiplier equation. This article [17-18] focused on estimation of stochastic LMP estimation based on new iterative method along with nucleolus theory, Shapley value and point estimation method The evaluate of LMP associate with loss and emission reduction of DGs' end. Here, [19] a novel LMP policy proposed with loss reduction of DGs by which it DGs' involvement enhanced, the process solved by Game theory approach. An iterative solution meth-od, for LMP has been proposed here, which can evaluate next 24 hours nodal price in generator bus. A 3 layer Artificial Neural Network approach adopted here to forecast the value. Here, [20] a Hybrid Backtracking Search Optimization Algorithm with Grey Wolf Optimization (GWO-HBOA) proposed and the main agenda is to minimize fuel cost of transmission system. LMP evaluated for both loss less and with loss sys-tem, with congestion and without condition. IEEE 30 Bus system has taken for the test model. In this article [21], authors proposed three ways to evaluate Distribution Locational Marginal price (DLMP) such that DLMP Decomposition based on the Implicit Function Formulation, DLMP Decomposition Based on the SOCP Formulation and DLMP Decomposition Based on Marginal Losses in a distribution system. Amon the all three, last one is better.

## LMP OVERVIEW & ITS ESTIMATION LITERATURE REVIEW

In real-time market (RTM) or day ahead market (DAM) LMP can be evaluated depending on the results of security constrained dispatch (SCED). Maximum social surplus (SS) achievement is the main target of SCED with maintaining all market constrains [22]. SCED is an linear programming (LP) based OPF program which responsible to maintain all transmission constraints. Maximum production cost is same as minimum production cost, if price is sensitive demand is absent. Ex post and ex ante are the two ways to evaluate LMP, NY ISO follow ex ante price and ISO NE, PJM & MISO follow ex post [23 – 25]. However, both systems are liberal and do not have any hard and first rule. SCED enhances robustness and speed of the programming with respect to non-linear programming [26-28]. The linear program can be solved to estimate LMP. KKT condition and offer price are equal and the said condition evaluated by KKT condition.

$$\frac{\partial L}{\partial Pi} = 0 = C_i - \lambda \left(1 - \frac{\partial Loss}{\partial Pi}\right) - \sum_1^K T_{ik}\,\mu_k + \eta^{max} - \eta^{min}$$

$$\Rightarrow \quad \lambda_i = C_i + \eta^{max} - \eta^{min} \qquad (1)$$

$\eta^{max} = \eta^{min} = 0$ for marginal units. So, $\lambda_i = C_i$. It is applicable for congestion as well as losses. From **Equation (1)** relation offer price vs LMPs can be estimated [29].

## ALGORITHMS

### Ada Boost

AdaBoost (Adaptive Boosting) is a ML algorithm that is used for regression tasks. It is an ensemble technique that combines several weak regression models into a stronger model. The loom weights training examples according to their imprecision, then uses these weighted samples to train a new weak model. The weights are updated based on the performance of the model, and the process is repeated for a specified number of iterations.

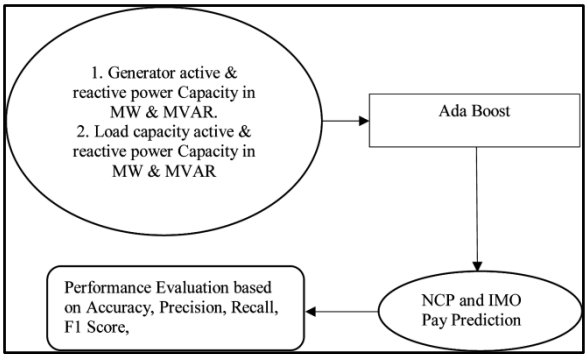


**Figure 1** Working Architecture of the proposed methodology

## SIMULATED INSTANCES AND INPUT VARIABLES FOR THE POWER SYSTEM

IEEE 30 Bus system characteristics are given below:

1. Generation Data: Six generators are connected in this system, and generators' capacity in active power and reactive power are shown in (MW) and MVAR for particular load.
2. Load active power: Loads are present in the system and real power at each load connected in node. Here, load active power range varies from 2MW to 98.2 MW.
3. Load reactive power: Reactive power of each load node also mentioned, here reactive power values range from 0.7 to 34 MVAr.
4. Active power generated: Here, six generators are present and each generator deliver active power in MW. In this work, values range from 98.3559 to 126.0591 MW, 68.3MW to 78.3MW, -39.2MW to -29.2MW, 6MW to 25MW, 30MW to 50MW and 47MW to 57MW.
5. Reactive power generated: Reactive power generated each node and here, reac-tive power range varies from 26.5336MVar to 31.6614MVar, 12.8222MVar to 20.1941MVar, 10.2579MVar to 15.9901MVar, 2.4232MVar to 9.1717MVar, 34.9401MVar to 50MVar and 36.7158MVar to 58.1514MVar.

During both the training and testing stages of Machine Learning Models, the afore-mentioned serve as input features/attributes.

We simulated a variety of situations and got LMP and IMO Pay for each of them in order to further, assure the adaptability and robustness of the proposed machine learning models.

We use a training to testing ratio of 70%:30% and the overall simulations generate 284 examples in our data.

All data must be pre-processed before being used with our soft computing models. The next section discusses the pre-processing techniques used in this research. Stand-ard IEEE 30 bus system data set taken as reference to design the circuit topology in MATLAB PSAT [30].

**Generation of Data Set**

MATLAB (PSAT) software used to analyze IEEE 30 Bus training model and output of the model taken as training dataset. Here, load supply and generation has taken as input on the other hand output resulted as NCP (Nodal Congestion Price) and Pay (IMO Pay).

- In IEEE 30 bus system six generators are delivering power to load. Generators' active and reactive power is tabulated in table 1, here GenP1, GenP2…..Gen P6 and Gen Q1, Gen Q2,……..Gen Q6 are represented the active and reactive power of individual generators.
- Variation of power delivery, from individual generators, are presented in **Table 1**'s columns.
- In this system there are 21 nos. of loads are present, and power demand variation of load is presented in **Table 2** and **Table 3**. **Table 2** is for active power demand in loads and **Table 3** is for reactive power, which are represented in LoadP1, Load P2 so on. In **Table 3** reactive power demand variations are represented in LoadQ1, Load Q3 so on.
- PAY tabulated in **Table 4** and column wise pay variation presented. Individual node pays are represented in PAY1, PAY2 so on.
- At the end variation of NCP is tabulated in table 5. NCP1 to NCP30 mentioned as nodal congestion price of individual nodes.

**Table 1** Generator power delivered (only 10 nos. of sample or test data are given) for IEEE 30 bus system

| POWER IN MW FOR REAL POWER AND MVAr FOR REACTIVE POWER | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Gen. P1 | 104.4829 | 108.8895 | 106.8654 | 104.634 | 106.6841 | 106.7311 | 104.5141 | 106.8963 | 105.8971 | 107.0937 |
| Gen Q1 | 28.6344 | 29.6218 | 29.1314 | 29.6197 | 28.4759 | 30.2883 | 29.7906 | 29.2339 | 28.9797 | 29.275 |
| Gen. P2 | 76.3 | 78.3 | 78.3 | 73.3 | 71.3 | 78.3 | 78.3 | 78.3 | 78.3 | 78.3 |
| Gen Q2 | 14.889 | 17.8737 | 17.4651 | 17.7592 | 14.4474 | 18.8764 | 18.4254 | 17.4 | 17.7281 | 17.4494 |
| Gen. P3 | -29.2 | -29.2 | -31.2 | -29.2 | -29.2 | -29.2 | -29.2 | -31.2 | -29.2 | -29.2 |
| Gen Q3 | 12.7734 | 13.8416 | 11.4898 | 13.6395 | 12.1466 | 15.0925 | 14.6136 | 11.3258 | 13.9333 | 13.3233 |
| Gen. P4 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 13 | 15 |
| Gen Q4 | 5.0505 | 6.2348 | 5.8316 | 5.9544 | 4.2337 | 7.8173 | 7.31 | 5.5806 | 4.5276 | 5.6581 |
| Gen. P5 | 40 | 40 | 40 | 40 | 40 | 50 | 50 | 40 | 40 | 40 |
| Gen Q5 | 37.9908 | 39.2167 | 38.7698 | 40.2064 | 36.8519 | 41.5542 | 41.0173 | 38.4058 | 43.8443 | 38.5022 |
| Gen. P6 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 |
| Gen Q6 | 40.6639 | 41.532 | 41.6242 | 41.4441 | 38.8077 | 43.904 | 43.8628 | 40.6452 | 45.5481 | 40.7538 |

**Table 2** Active power of load variation (only 10 nos. of sample or test data are given) for IEEE 30 bus system

| In MW | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Load P2 | 21.75 | 21.75 | 21.75 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| Load P3 | 2.45 | 2.45 | 2.46 | 2.46 | 2 | 2 | 2 | 2 | 2 | 2 |
| Load P4 | 7.65 | 7.65 | 7.65 | 7 | 7 | 7 | 7 | 7 | 6.09 | 6.09 |
| Load P5 | 94.25 | 94.26 | 94.26 | 94.26 | 94.26 | 94 | 94 | 94.1 | 94.1 | 94.11 |
| Load P7 | 22.85 | 22.85 | 22.85 | 22.85 | 22.86 | 22.86 | 22.86 | 22.86 | 22.86 | 22.86 |
| Load P8 | 30.05 | 30.05 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 28.09 |
| Load P10 | 5.85 | 5.85 | 5.85 | 5.85 | 5.85 | 5.85 | 5.8 | 5.8 | 5.8 | 5.8 |
| Load P12 | 11.25 | 11.26 | 11.26 | 11.26 | 11.26 | 11.26 | 11.26 | 11.26 | 11.26 | 11.26 |
| Load P14 | 6.25 | 6.25 | 6.25 | 6.25 | 6.25 | 6.25 | 6.25 | 6.25 | 6.251 | 6.251 |
| Load P15 | 8.25 | 8.25 | 8.26 | 8.26 | 8.26 | 8.26 | 8.26 | 8.26 | 8.26 | 8.26 |
| Load P16 | 3.55 | 3.55 | 3.55 | 3.55 | 3.55 | 3.55 | 3.55 | 3.56 | 3.56 | 3.56 |
| Load P17 | 9.05 | 9.05 | 9.05 | 9.05 | 9.05 | 9.05 | 9.051 | 9.051 | 9.051 | 9.051 |
| Load P18 | 3.25 | 3.26 | 3.26 | 3.262 | 3.262 | 3.262 | 3.262 | 3.262 | 3.262 | 3.28 |
| Load P19 | 9.55 | 9.55 | 9.55 | 9.55 | 9.55 | 9.55 | 9.551 | 9.551 | 9.551 | 9.551 |
| Load P20 | 2.25 | 2.25 | 2.25 | 2.25 | 2 | 2 | 2 | 2 | 2.01 | 2.01 |
| Load P21 | 17.55 | 17.55 | 17.56 | 17.56 | 17.56 | 17.56 | 17.56 | 17.56 | 17.56 | 17.56 |
| Load P23 | 3.25 | 3.25 | 3.25 | 3.25 | 3.25 | 3.25 | 3.25 | 3.251 | 3.251 | 3.26 |
| Load P24 | 8.75 | 8.76 | 8.76 | 8.769 | 8.769 | 8.769 | 8.77 | 8.77 | 8.77 | 8.77 |
| Load P26 | 3.55 | 3.55 | 3.55 | 3.55 | 3.55 | 3.51 | 3.51 | 3.5 | 3.5 | 3.5 |
| Load P29 | 2.45 | 2.45 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.42 |
| Load P30 | 10.65 | 10.66 | 10.66 | 10.66 | 10 | 10 | 10 | 10 | 10 | 10 |

**Table 3** Reactive power of load variation (only 10 nos. of sample or test data are given) for IEEE 30 bus system

| IN MVAr | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Load Q2 | 12.75 | 12.75 | 12.75 | 12.8 | 12.8 | 12.8 | 12.8 | 12.8 | 12.8 | 12.8 |
| Load Q3 | 1.25 | 1.25 | 1.26 | 1.26 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Load Q4 | 1.65 | 1.65 | 1.65 | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 | 1.66 | 1.66 |
| Load Q5 | 19.05 | 19.06 | 19.06 | 19.06 | 19.06 | 19.06 | 19.06 | 19 | 19 | 19.02 |
| Load Q7 | 10.95 | 10.95 | 10.95 | 10.95 | 10 | 10 | 10 | 10 | 10.01 | 10.01 |
| Load Q8 | 30.05 | 30.05 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29.01 |
| Load Q10 | 2.05 | 2.05 | 2.05 | 2.05 | 2.05 | 2.05 | 2 | 2 | 2 | 2 |
| Load Q12 | 7.55 | 7.56 | 7.56 | 7.56 | 7.56 | 7.54 | 7.54 | 7.54 | 7.54 | 7.54 |
| Load Q14 | 1.65 | 1.65 | 1.65 | 1.65 | 1.65 | 1.65 | 1.65 | 1.65 | 1.651 | 1.651 |
| Load Q15 | 2.55 | 2.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 |
| Load Q16 | 1.85 | 1.85 | 1.85 | 1.85 | 1.85 | 1.85 | 1.85 | 1.8 | 1.8 | 1.8 |
| Load Q17 | 5.85 | 5.85 | 5.85 | 5.85 | 5.85 | 5.85 | 5.84 | 5.84 | 5.84 | 5.84 |
| Load Q18 | 0.95 | 0.96 | 0.96 | 0.969 | 0.969 | 0.969 | 0.969 | 0.969 | 0.969 | 1 |
| Load Q19 | 3.45 | 3.45 | 3.45 | 3.45 | 3.45 | 3.45 | 3.44 | 3.44 | 3.44 | 3.44 |
| Load Q20 | 0.75 | 0.75 | 0.75 | 0.75 | 0.752 | 0.752 | 0.752 | 0.752 | 0.75 | 0.75 |
| Load Q21 | 11.25 | 11.25 | 11.26 | 11.26 | 11.26 | 11.11 | 11.11 | 11.11 | 11.11 | 11.11 |
| Load Q23 | 1.65 | 1.65 | 1.65 | 1.65 | 1.65 | 1.65 | 1.65 | 1.651 | 1.651 | 1.653 |
| Load Q24 | 6.75 | 6.76 | 6.76 | 6 | 6 | 6 | 6.1 | 6.1 | 6.1 | 6.1 |
| Load Q26 | 2.35 | 2.35 | 2.35 | 2.35 | 2.35 | 2.3 | 2.3 | 2.32 | 2.32 | 2.32 |
| Load Q29 | 0.95 | 0.95 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.99 |
| Load Q30 | 1.95 | 1.96 | 1.96 | 1.96 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 |

**Table 4** Pay (only 10 nos. of sample or test data are given) for IEEE 30 bus system

| IN $/hr | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PAY 1 | 282361 | 294995 | 296797 | 306618 | 262387 | 313704 | 251800 | 280920 | 372546 | 282568 |
| PAY 10 | -14738 | -10577 | -11247 | -11243 | -12995 | -11609 | -11439 | -10299 | -12486 | -10337 |
| PAY11 | 95183 | 93927 | 97641 | 101253 | 85633 | 132255 | 86324 | 91257 | 116954 | 91617 |
| PAY12 | -21750 | -25307 | -22222 | -24794 | -19679 | -27622 | -19853 | -20889 | -29374 | -20967 |
| PAY13 | 117712 | 116759 | 120412 | 131641 | 107040 | 127002 | 107852 | 113593 | 154509 | 114021 |
| PAY14 | -15398 | -15109 | -15690 | -17431 | -10496 | -12526 | -10605 | -14678 | -15625 | -14732 |
| PAY15 | -15374 | -15046 | -19471 | -17225 | -17140 | -20477 | -13932 | -14606 | -20270 | -14661 |
| PAY16 | -131628 | -112510 | -133436 | -74784 | -104339 | -123347 | -105634 | -109903 | -105163 | -110204 |
| PAY17 | -24314 | -49347 | -26819 | -116419 | -38748 | -66446 | -44644 | -48151 | -120294 | -48582 |
| PAY18 | -5859 | -5665 | -5979 | -6360 | -5205 | -6217 | -6889 | -8930 | -7356 | -8964 |
| PAY19 | -17269 | -20077 | -17653 | -18352 | -15268 | -18228 | -15407 | -16168 | -20967 | -16228 |
| PAY2 | 199618 | 204953 | 210480 | 208604 | 169228 | 222673 | 184971 | 198780 | 269061 | 199609 |
| PAY20 | -4029 | -3873 | -4122 | -8083 | -3558 | -8107 | -3591 | -3774 | -9169 | -3788 |
| PAY21 | -32541 | -34896 | -33378 | -33584 | -31863 | -34462 | -28954 | -30534 | -37595 | -30649 |
| PAY22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PAY23 | -5942 | -5785 | -9811 | -6532 | -5287 | -6347 | -7010 | -9087 | -10025 | -9122 |
| PAY24 | -19903 | -15663 | -16561 | -17273 | -14275 | -17243 | -14472 | -15217 | -20076 | -15276 |
| PAY25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PAY26 | -6826 | -10261 | -6948 | -7371 | -9297 | -7277 | -6090 | -6402 | -8940 | -6428 |
| PAY27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PAY28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PAY29 | -4814 | -4678 | -4865 | -9527 | -4231 | -9346 | -4283 | -4491 | -11825 | -4510 |
| PAY3 | -6010 | -5993 | -6172 | -6565 | -5432 | -6529 | -5477 | -5810 | -14619 | -5833 |
| PAY30 | -20893 | -20240 | -24940 | -22611 | -18284 | -22139 | -20215 | -22939 | -28180 | -23037 |
| PAY4 | -18698 | -18622 | -19201 | -25856 | -16875 | -20304 | -17023 | -18054 | -24933 | -22891 |
| PAY5 | -71710 | -71352 | -78604 | -78545 | -64583 | -77894 | -65188 | -73821 | -96330 | -69492 |
| PAY6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| PAY7 | -55193 | -59628 | -56641 | -60604 | -49652 | -65141 | -50122 | -53141 | -74585 | -53410 |
| PAY8 | 36484 | 36274 | 37450 | 40045 | 32879 | 39592 | 33176 | 35170 | 42568 | 35317 |
| PAY9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 5** NCP value (only 10 nos. of sample or test data are given) for IEEE 30 bus system

| IN $/MWh | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| NCP 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| NCP 10 | 811.5946 | 908.763 | 835.6467 | 1060.855 | 819.6736 | 951.9555 | 815.5881 | 874.2129 | 1435.665 | 878.2392 |
| NCP 11 | 408.3283 | 461.9264 | 424.1807 | 530.7879 | 411.0715 | 411.2558 | 407.9776 | 443.1253 | 746.5522 | 445.3867 |
| NCP 12 | 729.9863 | 773.2248 | 762.2915 | 702.5271 | 690.0811 | 817.6627 | 686.3001 | 745.0515 | 872.5492 | 748.9236 |
| NCP 13 | 463.9402 | 496.1391 | 488.2438 | 433.5434 | 433.1089 | 525.8791 | 430.4831 | 474.7958 | 584.5577 | 477.7224 |
| NCP 14 | 840.0162 | 896.1861 | 881.7585 | 843.6067 | 790.2909 | 932.8915 | 783.9383 | 867.6649 | 1026.465 | 871.9992 |
| NCP 15 | 845.4182 | 910.9641 | 892.5993 | 886.2173 | 818.3001 | 963.7483 | 809.5986 | 885.3218 | 1105.584 | 889.6612 |
| NCP 16 | 1637.597 | 1617.77 | 1684.505 | 1340.156 | 1448.199 | 1772.43 | 1463.931 | 1561.663 | 1754.688 | 1569.403 |
| NCP 17 | 1068.103 | 1207.145 | 1102.744 | 1426.044 | 1071.621 | 1320.316 | 1085.712 | 1163.175 | 1823.22 | 1169.263 |
| NCP 18 | 913.071 | 1008.137 | 954.9765 | 1046.109 | 897.499 | 1061.305 | 897.4324 | 981.6276 | 1332.431 | 986.2891 |
| NCP 19 | 931.4571 | 1042.879 | 969.1385 | 1119.825 | 923.4173 | 1094.676 | 921.9144 | 1001.451 | 1444.058 | 1006.139 |
| NCP2 | 107.8907 | 116.6851 | 112.0306 | 114.2771 | 109.4663 | 121.0849 | 104.1121 | 113.0567 | 115.7469 | 113.0693 |
| NCP 20 | 906.7137 | 1015.065 | 940.9725 | 1118.63 | 902.9403 | 1071.568 | 900.7232 | 975.1892 | 1457.637 | 979.7328 |
| NCP 21 | 863.6313 | 967.8752 | 889.835 | 1105.871 | 874.4618 | 1008.779 | 863.8934 | 927.381 | 1470.698 | 931.5962 |
| NCP 22 | 859.5986 | 961.3881 | 886.0025 | 1094.985 | 868.7381 | 1002.616 | 858.7147 | 922.4855 | 1452.93 | 926.6702 |
| NCP 23 | 882.66 | 959.0768 | 936.9963 | 975.0058 | 865.4755 | 1007.967 | 860.4799 | 943.5068 | 1228.376 | 947.8967 |
| NCP 24 | 887.3436 | 975.203 | 918.6694 | 1047.292 | 884.5273 | 1015.623 | 870.8761 | 943.6731 | 1323.76 | 947.7927 |
| NCP 25 | 739.9634 | 835.7519 | 780.4235 | 863.6201 | 765.8693 | 855.8984 | 739.3766 | 803.7343 | 1008.668 | 806.8036 |
| NCP 26 | 803.4815 | 952.3715 | 847.1807 | 937.1547 | 873.8258 | 929.5593 | 802.9631 | 872.3261 | 1088.45 | 875.6349 |
| NCP 27 | 629.036 | 704.4362 | 672.054 | 726.3889 | 649.2532 | 733.0666 | 635.9467 | 693.1906 | 795.6411 | 695.6074 |
| NCP 28 | 392.8039 | 431.5797 | 410.5851 | 421.9134 | 394.5389 | 445.7795 | 388.32 | 419.2606 | 433.9215 | 420.8455 |
| NCP 29 | 729.4143 | 815.6503 | 795.7611 | 872.8179 | 753.2042 | 880.2579 | 745.9155 | 820.6837 | 949.0681 | 823.4794 |
| NCP3 | 253.1137 | 274.7196 | 262.8785 | 265.5818 | 251.8631 | 283.7833 | 247.9435 | 266.5286 | 280.4478 | 268.5648 |
| NCP 30 | 798.8751 | 892.6795 | 889.9609 | 942.7888 | 825.1669 | 950.5949 | 825.9585 | 917.7792 | 1022.378 | 920.8697 |
| NCP4 | 317.9922 | 344.7751 | 330.5329 | 332.8401 | 315.1002 | 357.2108 | 310.3888 | 334.1794 | 351.8042 | 336.8388 |
| NCP5 | 311.4912 | 341.7494 | 327.2302 | 332.7198 | 317.2016 | 350.2057 | 310.0856 | 336.1269 | 325.8577 | 331.413 |
| NCP6 | 359.4881 | 393.6812 | 374.1649 | 379.3241 | 359.3967 | 405.8555 | 353.9818 | 381.472 | 379.6628 | 382.9354 |
| NCP7 | 370.6529 | 408.5103 | 386.688 | 393.6994 | 373.8278 | 420.1423 | 367.2653 | 395.7329 | 389.7578 | 394.4777 |
| NCP8 | 351.5629 | 385.391 | 366.3917 | 371.7013 | 351.3907 | 397.5008 | 346.0259 | 373.4306 | 376.4731 | 374.8864 |
| NCP9 | 538.7948 | 602.816 | 557.1667 | 681.2487 | 543.7118 | 597.2543 | 539.5828 | 580.6312 | 904.8445 | 583.2504 |

## RESULT AND DISCUSSION

Machine learning models outcomes are tabulated in table 6, IEEE 30 bus system data are analysed by machine learning model such that Ada boost. Here, active, reactive power of generators, change of load taken as input and PAY, NCP choose as output for above mentioned machine learning models. R2 SCORE, MAE, MSE and MAPE are evaluated by the ML models and successfully predict PAY and MCP.

Here, from the result table we can find R2 Score values for Ada Boost is 0.951441343 which is quite suitable.

**Table 6** ML model outcome

| Method | R2 score | MAE | MSE | MAPE |
|---|---|---|---|---|
| Ada Boost | 0.951441343 | 688.3006382 | 20.52490218 | 1.221270081 |

## CONCLUSION

In this analysis, Ada Boost is used to demonstrate a process of IMO Pay, NCP forecasting for IEEE 30 bus system. The suggested methods are dependent on the training data generated by OPF using PSAT in MATLAB environment in different generator and different demand conditions.

## ACKNOWLEDGMENT

Do not use the name of any persons in the Acknowledgment.

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# Power & Energy

# Energy Storage Technologies

126_IEC52277

# Pump Hydro Storage Project (PSP) — Energy Storage Technologies

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**Abstract:** Energy storage technologies are critical to addressing the challenges posed by the increasing integration of renewable energy sources. Each storage solution — Battery Storage, Pumped Storage Plants (PSP), Hydrogen Storage, and Thermal Storage—offers unique strengths that make it suitable for different applications.

- Battery storage is highly efficient, flexible, and ideal for short-term energy needs and decentralized applications, such as electric vehicles and home energy systems.
- PSPs are unmatched for large-scale, long-duration storage, providing a reliable backbone for national grids, especially where renewable energy fluctuations require balancing over extended periods.
- Hydrogen storage presents the best option for long-term, seasonal energy storage, though it currently faces challenges related to efficiency and infrastructure development.
- Thermal storage is a cost-effective solution for heat-specific applications and plays a crucial role in industrial processes and concentrated solar power plants.

As the world accelerates its transition to renewable energy sources, one of the biggest challenges we face isn't generating clean energy — it's storing it efficiently and reliably. From cutting-edge batteries to revolutionary hydrogen solutions, energy storage technologies are rapidly evolving and hold the key to a sustainable future.

These renewables are inherently intermittent—solar power is only generated during daylight hours, and wind power fluctuates with weather conditions. Effective energy storage allows excess energy produced during peak generation times to be saved and used when demand exceeds supply or when renewable resources are not generating power.

Historically, pumped hydroelectric storage has been the dominant form of large-scale energy storage. Today’s energy storage landscape includes a range of technologies suited for different applications:

What is Pumped Hydro Storage?

- Pumped storage hydropower (PSHP) is a form of hydroelectric energy storage that utilizes two water reservoirs at different elevations.
- When electricity demand rises, the stored water is released from the upper reservoir back to the lower reservoir, flowing through turbines that produce electricity. This system functions like a large battery, storing energy and releasing it when required.
- PSH can be classified as either an open-loop or closed-loop.
- Open-loop pumped storage hydropower systems link a reservoir to a naturally flowing water source through a tunnel, utilizing a turbine/pump and generator/motor to transfer water and generate electricity.
- Closed-loop pumped storage hydropower systems, on the other hand, connect two reservoirs without natural water flow, also using a tunnel, turbine/pump, and generator/motor for water movement and electricity production.

Benefits of Pumped Hydro Storage

1. Energy Storage and Grid Stability - Energy Storage: PHS can store large amounts of energy. It helps to balance supply and demand by storing excess energy generated during low-demand periods and releasing it during peak demand times. Grid Stability: By providing rapid response capabilities, PHS helps stabilize the grid, maintaining frequency and voltage levels, which are essential for reliable power supply.

2. Support for Renewable Energy - Integration with Renewables: PHS is particularly beneficial for integrating variable renewable energy sources like wind and solar into the grid. Reducing Curtailment: PHS reduces the need to curtail renewable energy generation, ensuring that more clean energy is utilized rather than wasted.

3. High Efficiency and Long Lifespan - High E□iciency: PHS systems typically have a round-trip efficiency of 70-80%, Longevity: PHS facilities have a long operational lifespan, often exceeding 50 years,

4. Scalability - PSP can be scaled to store gigawatt-hours (MWh) of energy,

5. Environmental and Economic Benefits - Job Creation: The construction and maintenance of PHS facilities create jobs for local people. Water Resource Management: PHS reservoirs can serve additional purposes such as irrigation, flood control, and recreation.

6. Energy Independence and Security - Reducing Fossil Fuel Dependence AND Emergency Backup

Key Components of PSP:

- Upper Reservoir: Stores potential energy in the form of water.
- Lower Reservoir: Receives water after energy generation.
- Penstocks: Large pipes that channel water between reservoirs.
- Powerhouse: Contains turbines and generators.
- Transmission Lines: Connects the generated electricity to the grid.
- Surge Tanks: Absorbs pressure surges in the system.
- Control Systems: Automation, monitoring, and grid integration.

The Pumped Storage Plant (PSP) is a well-established and highly efficient energy storage technology that plays a crucial role in stabilizing power grids by storing excess electricity during periods of low demand and releasing it when demand is high, making it a key component in supporting renewable energy integration.

| Sl. No's | Parameter | BESS | PSP Hydro |
|---|---|---|---|
| 1 | Capital Cost | Between 4 – 6 Cr per MWh | Less than 5 Cr per MWh |
| 2 | levelized cost of storage | Rs 5.6 / unit | Rs 5.6 / unit |
| 3 | Replacement Capex | Required replacement capex | Required maintenance capex |
| 4 | Execution timeline | 12 – 18 months | 4 – 6 Years |
| 5 | Project life | 5 – 7 Years | 40 – 50 Years |

These examples highlight how PSPs provide reliable, large-scale energy storage, which is essential for grid stability, especially as the global energy mix shifts toward renewables.

By leveraging their high efficiency and rapid response capabilities, PSPs are ideal for both daily load balancing and emergency power generation, which no other large-scale energy storage solution currently matches in terms of reliability and capacity.

**CONCLUSION**

For long-term energy storage, Pumped Hydro Storage (PSP) is generally considered the best option. It has the capacity to store large amounts of energy for extended periods (days to weeks) and can provide long-duration storage

at a low operating cost over decades.

Recognizing hydropower's strategic role in India's renewable energy transition, the union cabinet in August 2024 approved the revision of the HEP scheme. The revised scheme includes a budgetary allocation of Rs 124.61 billion to support additional infrastructure such as transmission lines, railway sidings and communication systems, aiming to expedite project execution, particularly in remote areas. Additionally, it approved central financial assistance for the north-eastern state governments to participate in hydropower projects through joint ventures, with a budget of Rs 41.36 billion to support up to 15,000 MW of capacity. This assistance, set to be implemented from FY 2025 to FY 2032, is expected to boost investments and employment in the sector while supporting the country's clean energy goals.

137_IEC92829

# Prospective Prioritization of Strategies for Sustainable Development of Storage Industry of India by Integrating SWOT-Hesitant Fuzzy MCDM Method

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***Abstract:*** *Energy storage systems are crucial for achieving a carbon-neutral economy and facilitating the transition to sustainable mobility and energy. However, with various policies being introduced, it can be challenging to prioritize strategies effectively for marketing sustainable storage solutions. Each country must optimize its available resources while navigating specific constraints. To address this, it's essential to evaluate strategies based on the country's strengths, weaknesses, opportunities, and threats (SWOT) in the energy storage sector. Given the conflicting factors and inherent linguistic uncertainties, employing a hesitant fuzzy linguistic multi-criteria decision-making (MCDM) approach is vital. The proposed methodology integrates SWOT analysis with decision-making techniques to prioritize strategies for developing sustainable energy storage systems. Initially, the SWOT framework is utilized to formulate strategies aligned with the country's announced policies for future energy storage systems. Next, the Hesitant Fuzzy Linguistic Analytic Hierarchy Process (HFL-AHP) determines the weights of these strategies. Finally, the Hesitant Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (HFL-TOPSIS) identifies the optimal priority for implementation. This methodology has been applied using data from India, demonstrating its effectiveness in navigating the complexities of energy storage strategy development.*

***Keywords:*** *Energy Storage; Sustainability; Strategy Prioritization; SWOT; HFL-MCDM*

## INTRODUCTION

The profound changes in the energy sector have necessitated the development of efficient and sustainable energy storage systems [1]. Lithium-ion batteries (LIBs) play a pivotal role in this energy transition due to their high energy density, versatility, and durability. They are widely used, powering everything from small electronic devices to large electric vehicles and energy grids [2]. However, despite their popularity, LIB technology faces significant challenges, including the scarcity of raw materials, the environmental impact of lithium extraction, high costs, and safety concerns [3,4]. These issues have prompted the exploration of alternative storage technologies. Several metal-ion batteries, such as sodium-ion (SIB), zinc-ion (ZIB), potassium-ion (PIB), and magnesium-ion (MIB) batteries, have emerged as promising contenders. These alternatives offer advantages like resource abundance, enhanced safety, cost-effectiveness, and a reduced environmental footprint, making them appealing options to meet the growing demand for energy storage [4,5].

Rapid urbanization and population growth in India have led to a significant increase in the country's energy demand. As part of its commitment to achieving net zero emissions (NZE) by 2050, India aims to reduce carbon dioxide (CO2) emissions by more than 3% [6]. To meet this goal, the government is focused on addressing climate change while ensuring reliable and sustainable electricity for all. This commitment has resulted in a strong emphasis on renewable energy-based power generation. However, renewable resources such as solar and wind face inherent challenges, including intermittency and energy dilution, which complicate large-scale implementation [7].

To overcome these challenges, energy storage systems (ESS) are essential. As highlighted by the International Energy Agency (IEA), ESS provides crucial flexibility within the energy system, helping to address the intermittent supply issues associated with renewable energy sources [8]. For India, these storage technologies hold the potential to deliver continuous and reliable power, particularly in rural areas where electricity supply is less stable [9].

The Indian market for energy storage is rapidly expanding, bolstered by various large-scale projects. India is on track to become one of the largest markets for energy storage technologies. The government has announced significant funding and policies to support the growth of this sector, recognizing its critical role in achieving a net zero economy by 2050. However, the successful implementation of these policies will be essential for ensuring a smooth and sustainable energy transition in the country [7,9].

Khan et al. [10] reviewed various storage technologies emerging in India to support electric vehicles, along with the corresponding control strategies aimed at enhancing system efficiency. Mittal et al. [11] analyzed the challenges associated with the emerging battery technology industry and examined the proposed policies to support its development.

**Research Gaps**

Most previous studies have concentrated on evaluating the techno-economic aspects of energy storage technologies. While some recent analyses have reviewed policies and developed strategies for creating a roadmap for future battery technologies, there has been a lack of significant analysis prioritizing strategies for a more effective energy transition toward sustainability. Proper prioritization of policies is inherently uncertain and complex, making it challenging to calculate weights accurately. Furthermore, no prior studies have accounted for the detailed linguistic uncertainties involved in this weight calculation and the associated ranking process.

**Research Objectives**

The primary objective is to propose a novel method for determining the appropriate prioritization of strategies for developing storage industries amid conflicting issues, facilitating comprehensive action planning. This proposed method accounts for linguistic uncertainties in the process of determining both weights and rankings. To enable effective action planning, the methodology integrates the SWOT analysis with an enhanced multi-criteria decision-making (MCDM) approach, specifically the hesitant fuzzy linguistic (HFL)-MCDM. The HFL-AHP method is employed to estimate the weights of the proposed strategies, while the HFL-TOPSIS method is used to rank these strategies. Although the methodology is applicable to any country, it is demonstrated using data from India, emphasizing its significance in enhancing future energy security.

**MATERIALS AND METHODOLOGY:**

This study focuses on prioritizing strategies to develop a sustainable roadmap for storage industries. It incorporates the SWOT-HFL MCDM method, addressing the linguistic uncertainties associated with weight determination and ranking analysis. The methodology flow is illustrated in Fig. 1, and the detailed process is discussed below.

**Strengths, Weaknesses, Opportunities, Threats Analysis**

The SWOT analysis was developed by American businessman and management consultant A.S. Humphrey. This analysis addresses complex strategic planning by evaluating and organizing external and internal factors [12]. The two main phases of SWOT analysis are the construction of the SWOT matrix and the development of strategies based on this matrix. The development of the SWOT matrix involves two key steps: first, identifying factors under strengths (S) and weaknesses (W), which are considered internal features; second, categorizing the remaining constraints under opportunities (O) and threats (T), which represent the external features of the analysis.

The SWOT matrix generates four types of strategies. After identifying the strengths (S), weaknesses (W), opportunities (O), and threats (T), the matrix is constructed by combining these elements, resulting in four pairs of strategies: strengths-opportunities (SO), strengths-threats (ST), weaknesses-opportunities (WO), and weaknesses-threats (WT) [13].

The purpose of SO strategies is to optimize the use of internal strengths alongside external opportunities. WO strategies aim to mitigate internal weaknesses by leveraging external opportunities. ST strategies are designed to counteract external threats by effectively utilizing internal strengths. Finally, WT strategies focus on minimizing

external threats by addressing internal weaknesses.

**Hesitant Fuzzy Linguistic Term Set**

When stakeholders are uncertain about various linguistic terminologies for their evaluations, the Hesitant Fuzzy Linguistic Term Set (HFLTS) approach is developed to clarify expressions of comparative linguistic terms in hesitant situations. This approach enhances the flexibility and generalization of linguistic expressions by employing context-free grammars, making it more aligned with human cognitive models. This advantage allows decision-makers greater freedom to articulate their preferences using comparative linguistic terms, even under conditions of hesitation. The methodology of the HFLTS is discussed below [14]:

$$P = \{< y, h_p(P) > | y \in Y\} \quad (1)$$

Where P is subset within the range of [0, 1], Y is the set, hp(y) is the function.

Out of the approaches, HFL-AHP and HFL-TOPSIS are the most recommended MCDM techniques. The advantages of HFL-AHP [15] and HFL-TOPSIS [16] approaches are discussed in previous references. Considering the advantages of these two techniques the study integrates the techniques with SWOT analysis.

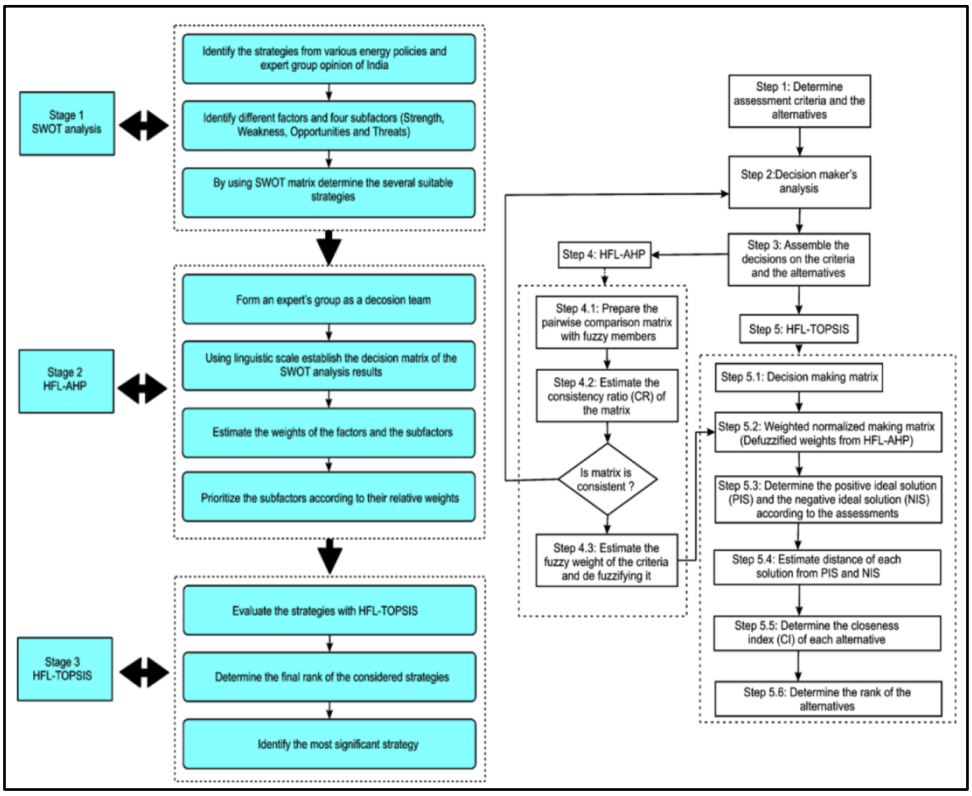


**Figure 1** Proposed methodology

HFL-AHP Methodology

The HFL-AHP method is introduced by Saaty which is a strong and simple decision-making approach [17].

The weight factor is calculated in AHP by using **Eq. 2** [18]:

$$F(a_1, a_2, \ldots\ldots, a_n) = wb^T = \sum_{i=1}^{n} w_i b_i \quad (2)$$

Where F is the ordered weighted average (OWA) operator w is the weighting vector and it is represented as (w1, w2,…., wn)T and it belongs to 0-1 with $\sum_{i=1}^{n} w_i = 1$, b is the ordered value vector for the same weighting vector and bi

belongs to b is the largest ith value in A. A is the set of values needed to aggregate and it is (a1, a2, …., an).

The consistency of the matrix is calculated by using **Eq. 3** [19].

$$\mu_d = \frac{l+m_1+m_2+u}{6} \quad (3)$$

Where A = (l, m1, m2, u) is the triangular fuzzy number (TFN)

Consistency ratio (CR) and consistency Index (CI) are calculated using **Eqs. 4** and **5** [18].

$$CI = \frac{\lambda_{max}-n}{n-1} \quad (4)$$

Where n is the total criteria number and $\lambda_{max}$ is the highest eigenvector value of the matrix.

$$CR = \frac{CI}{RI} \quad (5)$$

Where RI is the random index.

HFL-TOPSIS Method

Hwang and Yoon proposed the MCDM approach, which assesses alternatives based on their distances from the ideal solution [20]. The HFL-TOPSIS method first establishes a fuzzy evaluation matrix, followed by the construction of the evaluation matrix. Sequentially, fuzzy decision matrices, a fuzzy normalized matrix, and a weighted normalized matrix are developed for each strategy. The positive ideal solution (PIS) and negative ideal solution (NIS) are then estimated based on the criteria. Next, the distances of each alternative from both the PIS and NIS are calculated [20]. Using these distances, the relative closeness index (RI) value is determined, with the highest RI value identified as the best solution. In this study, the HFL-TOPSIS approach is employed to address uncertainties in decision-making problems.

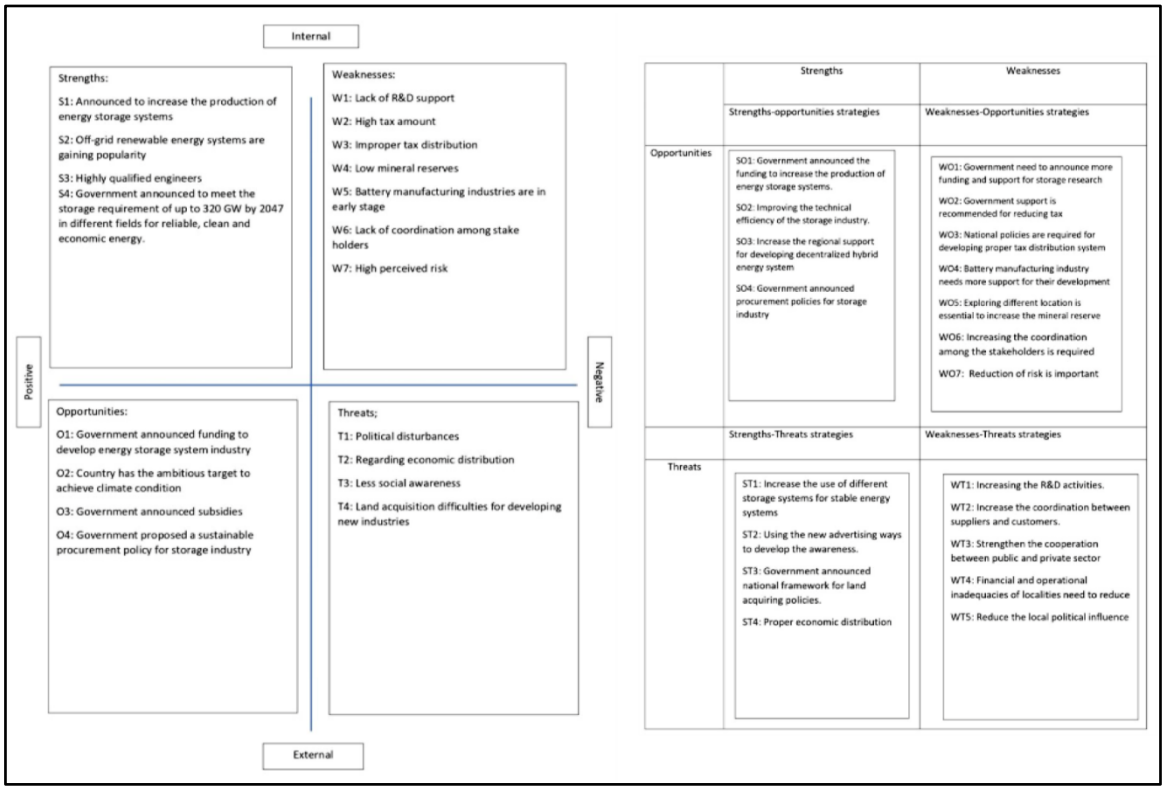


**Figure 2** SWOT analysis result

## RESULTS AND DISCUSSIONS

This section presents the results of the analysis. Initially, relevant policies were gathered from various studies and government announcements. A SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis was then conducted, categorizing these policies into their respective sectors (S, W, T, and O). The SWOT matrix was subsequently used to develop strategies focused on minimizing weaknesses and threats while enhancing strengths and opportunities.

The findings indicate that a key strength of the announced policies is the growing demand for emerging energy storage systems. However, this strength is undermined by insufficient support for research and development (R&D) and economic distribution challenges. In response, the government has introduced funding initiatives aimed at supporting R&D in emerging storage technologies. The SWOT matrix suggests that this funding could enhance production and alleviate the weaknesses associated with limited research in the sector. Additionally, increasing awareness and improving communication between suppliers and customers could further foster the growth of the energy storage technology industry. Detailed results are illustrated in **Figure 2**.

The MCDM analysis result is shown in **Figure 3**.

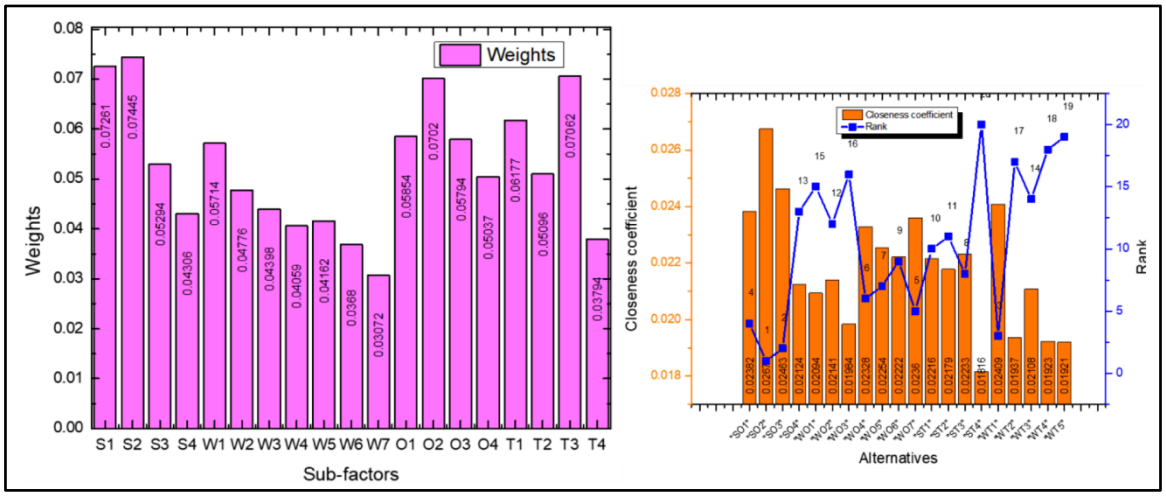


**Figure 3** MCDM analysis

Based on the analysis, the strategy with the highest weight is associated with the second strength, emphasizing the growing popularity of off-grid energy systems, which contributes approximately 7.5% to the total weight. Conversely, the lowest weight corresponds to the seventh weakness related to high perceived risk. Utilizing these weight values for strategy prioritization reveals that $SO_2$ has the highest priority, while ST4 ranks the lowest. Consequently, the top priority is to enhance the technical efficiency of storage technologies, followed by increasing regional support for industry development. In contrast, economic distribution is considered the least important strategy. By focusing on these priorities, the development of India's storage technology industry can be accelerated.

## CONCLUSION

The energy transition is a complex and challenging process. Policies must be adopted with careful prioritization of strategies based on a country's specific constraints. This study proposes an integrated methodology combining SWOT analysis with HFL-AHP and HFL-TOPSIS to determine and prioritize strategies for a successful energy transition. A total of 20 energy strategies were developed and prioritized using this methodology.

The analysis results indicate that Strength-Opportunity 2 has the highest priority, focusing on improving the technical efficiency of the storage industry. Following closely is Strength-Opportunity 3, which emphasizes increasing regional support for developing decentralized hybrid energy systems. Conversely, reducing local political influence and ensuring proper economic distribution are identified as the least prioritized strategies.

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222_IEC59788

# Enhance Current Boosting for MHTG using TP4056 Module and make it Application Suitable

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***Abstract**: The requirement for energy especially electrical one is demand in the World. It is increasing day by day due to rapidly increasing population and advancement in Science and Technology. Since the beginning of electrification, fossil fuel burning has been the main source of primary energy on which electricity generation is based. So, renewable energy resources have had an important development. Hydroelectric power technology is generating electricity from the flowing of water of streams, rivers, and pipe. Water flows through a water channel / pipe to a turbine in turns rotate the shaft when it strikes the blades of this turbine. The shaft of turbine is connected to a generator which converts the mechanical energy into electrical energy. The water flowing is a pollution-free, renewable, safe, incessant, and reliable energy source. The regeneration of electrical energy can be obtained by converting the kinetic energy of water flowing in pipeline. The same principle is established in a small model containing all the phenomenon of the micro-hydro generation plant. The model is installed with MHTG of F50 12V and attached to a test rig for continuous supply of water. The objective of this test is to measure the maximum and control output power, current that can be generated by the MHTG system, by change made in TP4056 Module. The key purpose of current enhancement though controlled current source is achieved with the help of TP4056 module for charging of Lithium-ion battery. A typical mobile phone or a LED light source are potential application that can be powered up. The programmable current resistor on the TP4056 module helps for better and improved current ability for the charging of the battery.*

***Keywords:** Micro Hydro Turbine (MHTG); Electrical Power Generation; Energy Harnessing; Non-Conventional Means of Energy; Pico Hydropower; In-Pipe Power Generation; TP4056 Module; Current Boosting*

## INTRODUCTION

The requirement for energy especially electrical one is demand in the World. It is increasing day by day due to rapidly increasing population and advancement in science and Technology. Since the beginning of electrification, fossil fuel burning has been the main source of primary energy on which electricity generation is based. So, renewable energy resources have had an important development. The production of electricity without creating any pollution in atmosphere is known as green energy.

Hydroelectric power technology is generating electricity from the flowing of water of streams, rivers, and pipe. Water flows through a water channel / pipe to a turbine in turns rotate the shaft when it strikes the blades of this turbine. The shaft of turbine is connected to a generator which converts the mechanical energy into electrical energy. The water flowing is a pollution-free, renewable, safe, incessant, and reliable energy source.

The hydro power which has a maximum electrical output of five kilowatts (5 kW) comes under the category of Pico Hydro turbine. This system is beneficial than other large hydro system as it have low cost, can be installed anywhere, eco-friendly and easily available to people.

In-Pipe Hydro Power System: Divided in two main designs —

Internal system is where the runner is wholly inside the pipe section. Power output ranges from 5-10 watts, sufficient to supply self-powered water metering or monitoring systems.

External system is where the runner is contained in a secondary conduit which bypasses the main line and do not depend on pipe size. This system is usually customized to meet the existing pipe size, whereas the turbine and generator are chosen based on available water flow and head.

The MHTG is capable of generating around 5V, however the current that can be drawn is in range from few tens of mA to less than 150 mA. This combination poses a key problem in order to use with rechargeable battery, typically for Lithium Cell. A typically 1000 mAH Lithium Cell requires to be power drawn at constant current at 1A for an hour to get it fully charged.

A Battery Management System for charging and manage the discharging through algorithm for a known load was carried out [1]. Applications like mobile phone and LEDs are at most common use for any rechargeable barriers and those batteries often need recharging regularly with a controlled source [2]. Any battery that can be help for recharging with an enhanced current requirement for a battery in order to enable optimal power transfer depends on ability to source more electrons. For a typical charging managing hardware solutions like TP4056 this is done with the help of programmable current setting. It is a function achieved through variation in the programming resistance-value that helps over a range of current [3]. The key component of TP4056 has another functional capability of thermal regulation while the required currents is sourced for the battery of type lithium-ion to be recharged and this thermal regulation is an implied to the integrated-circuit chip TP4056. The rest of the circuitry is built around it in order to be able to interface lithium-ion battery, source of the electric power and application interface where the load is to be applied [4]. How a high current application load could be of demand for high current in order to be used with power generation source which generates voltage but at a low current by it's implied functionality. And hence such current need boost and to be regulated[5].

## METHODOLOGY

The amount of energy to be produced depends on water pressure (measured in terms of "head" or the vertical distance from the water take-off point down to the turbine), and flow of water.

The regeneration of electrical energy can be obtained by converting the kinetic energy of water flowing in pipeline. The same principle is established in a small model containing all the phenomenon of the micro-hydro generation plant. The model is installed with MHTG of F50 12V and attached to a test rig for continuous supply of water.

The objective of this test is to measure the maximum and control output power, current that can be generated by the MHTG system, by change made in TP4056 Module.

**Figure 1** Experimental set up for source where the small power in range of few milliamps of current

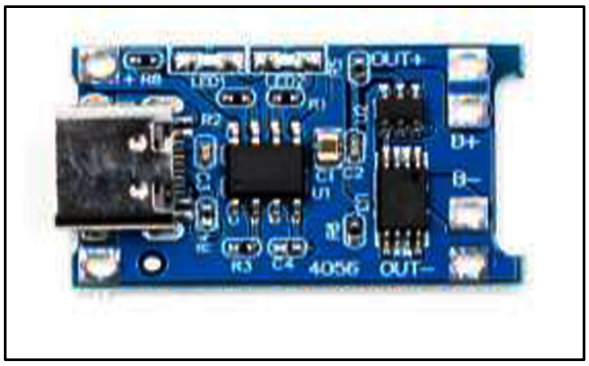


**Figure 2** TP4056 Module as a charging module

The first trial was without introduction of TP4056 module with micro hydro power generation mechanism where 3 conditions for the load were covered as a observation with one at a time subjected for the experimentation.

After setting the test rig, observations were taken, pressure and discharge was measured before and after the turbine.

Voltage and Current was noted with the help of multi-meter with load resistor (RL).

- No Module, 5mm LED and 330 Ω resister RL
- No Module, 5mm LED and 165 Ω resister RL
- No Module, 5mm LED and 110 Ω resister RL

Second Trial was carried out for varying discharge and Varying load Resister RL for the given conditions

- TP4056 Module, 5mm LED and 330 Ω resister RL
- TP4056 Module, 5mm LED and 165 Ω resister RL
- TP4056 Module, 5mm LED and 110 Ω resister RL

Third trial was carried out for varying program resister RP, discharge and Varying load Resister RL for the given conditions

$R_P$ replaced by 5k6 Ω

- TP4056 Module, RP 5k6 Ω, 10mm LED and 330 Ω resister RL
- TP4056 Module, RP 5k6 Ω, 10mm LED and 165 Ω resister RL
- TP4056 Module, RP 5k6 Ω, 10mm LED and 110 Ω resister RL

Fourth Trial by RP replaced by 2k2 Ω

- TP4056 Module, RP 2k2Ω, 10mm LED and 330 Ω resister RL
- TP4056 Module, RP 2k2 Ω, 10mm LED and 165 Ω resister RL
- TP4056 Module, RP 2k2 Ω, 10mm LED and 110 Ω resister RL

Fifth Trail by RP replaced by 1k2 Ω

- TP4056 Module, RP 1k2Ω, 10mm LED and 330 Ω resister RL
- TP4056 Module, RP 1k2 Ω, 10mm LED and 165 Ω resister RL
- TP4056 Module, RP 1k2 Ω, 10mm LED and 110 Ω resister RL

One of the important aspects of the methodology for this experimental setup is about proper connections as expected with the TP4056 for passive components including the programmable current resistor and the battery. While there might be no harm against polarity of application or even the polarity of the source. However, if the polarity reversed for the battery outlet connection, then there can be severe effect due to destruction of battery, the circuitry module around TP4056. Sometimes that can lead to smoke or fire catching situation.

**RESULTS**

Under condition where there is no current enhancement for storage of the electrical power the rate at which typically the electrical power used for charging is being low and the lithium-ion battery of typically 1000MAh takes very long and it is a slow process for charging of the battery.

The key purpose of current enhancement though controlled current source is achieved with the help of TP4056 module for charging of Lithium-ion battery. A typical mobile phone or a LED light source are potential application that can be powered up. The programmable current resistor on the TP4056 module helps for better and improved current ability for the charging of the battery.

**CONCLUSION**

The experimental setup was subjecting the varying load for observing about a controller current with better enhancement in the range that was typically around 0.1 of the Ampere. Although the range is still a smaller, however

the duration that it takes for a 1KAh Lithium-ion battery to recharge need to charge more than 80% of its capacity has significant effect in enabling a lithium battery to charge in lesser time.

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313_IEC57991

# Optimizing Heat Transfer in PCM-based Thermal Energy Storage Systems

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***Abstract:*** *This research numerically analyses a phase change material (PCM), specifically Paraffin wax P-66, used in an energy storage system designed for efficient thermal management. The system includes a vertically positioned PCM-filled circular pipe modeled in 2D, with heat transfer occurring through an adjacent water flow pipe separated by a copper barrier. The entire system is insulated to prevent thermal loss, and water, as the heat transfer fluid (HTF), flows vertically from the bottom inlet to the upper outlet. A finite volume-based solver is employed to numerically solve the transport equations governing the system. The study divides both HTF and PCM into multiple sections while maintaining a constant PCM volume across all cases. Results show a significant improvement in energy storage efficiency, with a 52.56% reduction in melting time when the HTF flows in two parts around the PCM. Dividing the HTF into five sections and the PCM into three sections further reduces melting time by 45.08%. The analysis also indicates that more HTF surface area in contact with the PCM enhances heat transfer, but the effect on melting time diminishes as the number of heated surfaces increases, suggesting an optimal surface configuration for maximum efficiency. These findings provide useful insights for designing compact, efficient PCM-based energy storage systems suitable for industrial use.*

***Keywords:*** *Energy Storage; Phase Change Material (PCM); Enhancement; Thermal Management; Heat Transfer Fluid (HTF)*

## INTRODUCTION

The global shift toward sustainable energy has heightened the demand for efficient energy storage technologies. Phase change materials (PCMs) are gaining attention as an effective solution in thermal energy storage (TES) systems due to their ability to store and release substantial thermal energy during phase transitions. This property makes PCMs highly suitable for applications like space heating, cooling, and various thermal management systems, thereby improving energy efficiency and supporting environmental sustainability. This paper reviews recent progress in PCM-based TES systems, focusing on their heat transfer characteristics and potential to enhance energy efficiency.

Research in the field has advanced significantly. Shinde et al. [1] explored a PCM pipe bank system for space heating, reporting notable improvements in both thermal efficiency and energy consumption. Bechiri and Mansouri [2] provided valuable insights into the behavior of PCM during melting in vertical tubes, emphasizing the significance of geometry and orientation. Mellouli et al. [3] enhanced heat transfer by integrating heat transfer fluid pipes within metal hydride-PCM tanks. Chow and Lyu [4] demonstrated the benefits of PCM heat exchangers in liquid-flow windows for better thermal regulation and energy savings. Delgado et al. [5] studied microencapsulated PCM slurries, which showed improved heat transfer in laminar flows, enhancing TES performance. Kurnia et al. [6] designed a novel PCM system with optimized heat transfer surfaces, and Zhang et al. [7] combined heat pipe technology with PCM systems, resulting in higher efficiency. Further studies have examined PCM performance in various configurations. Aadmi et al. [8] investigated melting characteristics in horizontal tubes, while Tay et al. [9] modeled the dynamic melting process in tube-in-tank systems. Pahamli et al. [10] found that inner pipe movement within a double-pipe heat exchanger influences the melting process, improving heat transfer rates. Recently, Boudjemline et al. [11] and Said et al. [12] examined advanced designs, such as wavy wall configurations, to accelerate heat recovery and improve latent heat storage systems.

This paper focuses on the thermal storage behavior of PCM in a 2D pipe configuration, where water serves as the heat transfer fluid (HTF) flowing vertically, separated from the PCM by a copper barrier. The study analyzes the performance by dividing the PCM and HTF into sections while maintaining consistent surface areas. This work integrates findings from recent studies to explore the implications of various design approaches and materials on the efficiency of PCM-based TES systems, providing an updated overview of the field and its potential for advancing

sustainable energy technologies. Therefore, the major objectives of the paper are summarized as:

- Develop a compact and efficient design for thermal energy storage (TES) devices using phase change materials (PCMs) for industrial applications.
- Optimize heat transfer performance by analyzing the impact of various PCM-HTF configurations on energy storage efficiency and melting time.
- Evaluate the scalability and feasibility of PCM-based TES systems for large-scale industrial use through numerical simulations and modeling.
- Enhance design strategies and material selection to improve energy storage capacity, cost-effectiveness, and sustainability in industrial settings.

## PROBLEM DESCRIPTIONS AND MODELLING

An The study involves a physical model where phase change material (PCM) is contained within a circular pipe. The pipe has a vertical height of L= 80 mm and a horizontal length of B = 20 mm. **Figure 1** illustrates this configuration. A constant temperature fluid, specifically water at $T_w$ = 363 K flows upwards through an adjacent vertical pipe of identical height (80 mm) and width (B = 20 mm). These two domains are separated by a copper barrier with a thickness of 2 mm. The flow within the pipe is maintained at a laminar velocity that corresponds to a Reynolds number (Re = 1000), which is greater than the PCM's melting point ($T_m$). All walls of the chamber, except the inlet and outlet of the heat transfer fluid (HTF) pipe, are adiabatic. For the base case, the PCM and HTF are adjacent to each other, both having dimensions of 80 mm in height and 20 mm in width, separated by the copper barrier.

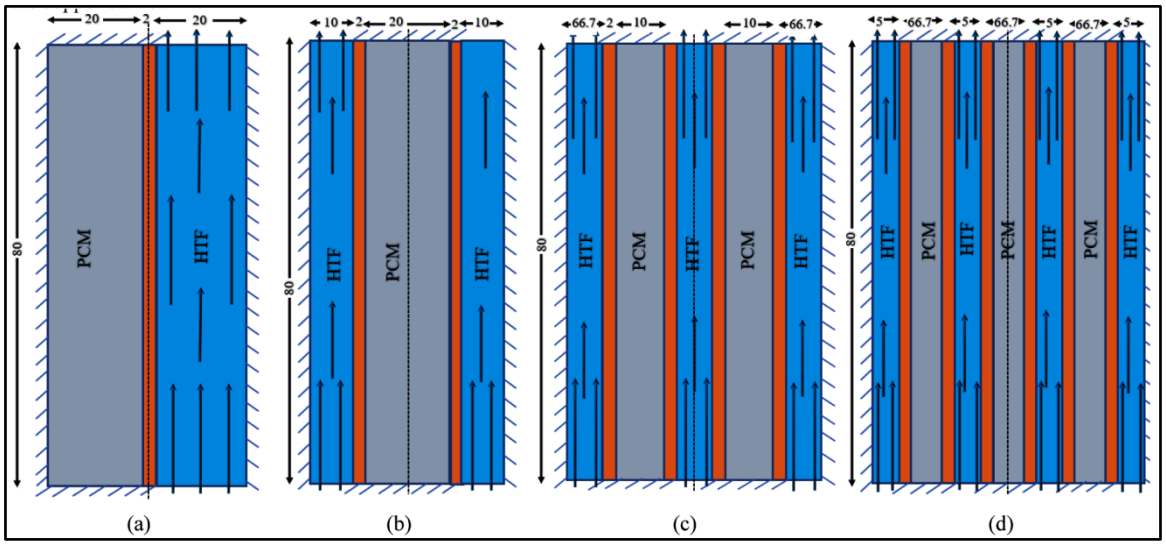


**Figure 1** Schematic diagram of the set-up comprising (a) Base Case, (b) Case 1, (c) Case 2, and (d) Case 2.

Three additional physical domains are examined:

Case 1: The HTF flows through a pipe with dimensions 80mm×20mm. The HTF is covered by a PCM layer with a thickness of 20 mm, separated by a copper barrier of 2 mm thickness.

Case 2: A concentric pipe with three inner spaces is used. In this configuration, heated water (6.67 mm thickness) flows in the centre pipe and in the outer pipe, while the PCM is located in the middle portion pipe (10 mm thickness), separated by two copper barriers, each with a thickness of 2 mm.

Case 3: In last case 4 concentric pipes has been used, PCM and HTF is taken alternative way. Each PCM is of 6.67 mm width and each HTF is of 5 mm width.

In all cases, from the base to the last one, the volumes of PCM and HTF remain the same. The initial temperature of the PCM and the barrier is 300 K. Paraffin wax (P-66) is used as the PCM, and copper (Cu) is the material for the barrier. The thermo-physical properties of the materials are provided in **Table 1**. This model aims to evaluate and compare the latent heat storage time, heat transfer characteristics, and efficiency of the different configurations involving PCM and HTF under the specified conditions. The governing equations are used to define the heat flow in the PCM and the equations are solved numerically. For the solid-liquid phase change process, the enthalpy-porosity model is used to identify the PCM and fin region. The governing equations are as follows:

Continuity equation: $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial x} = 0$ (1)

Momentum equation:

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \frac{\partial \rho}{\partial x} - \frac{\mu}{K}u + A_{mush}\frac{(1-f)^2}{f^3+\delta}u \quad (2)$$

$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - \frac{\partial \rho}{\partial y} - \frac{\mu}{K}u + A_{mush}\frac{(1-f)^2}{f^3+\delta}v + \rho_{ref}g\beta(T - T_{ref}) \quad (3)$$

Energy equation:

$$\left[(1-\epsilon)(\rho C_p)_{fin} + \epsilon(\rho C_p)_{PCM}\right]\frac{\partial T}{\partial t} + \epsilon\rho_{PCM}\Delta h\frac{\partial f}{\partial t} + (\rho C_p)_{pcm}\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = \lambda_{eff}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \quad (4)$$

$$\begin{cases} f = 1 \; T > T_m \\ f = \frac{T - T_s}{T_m - T_s} \; T_s < T < T_m \\ f = 0 \; T < T_s \end{cases} \quad (5)$$

The total enthalpy is defined as the summation of sensible heat capacity and the latent heat of phase change, which is defined as: H = h + fL and the sensible enthalpy is as follows:

$h = h_{ref} + \int_{T_{ref}}^{T} C_p\, dT$ ; where $h_{ref}$ is the sensible enthalpy of PCM (at $T_{ref}$). 6)

## NUMERICAL TECHNIQUE

For the numerical simulation, computations were conducted in a 2D geometry using the finite volume-based Ansys FLUENT solver. The PCM cavity, sized 80 mm × 40 mm, used a quadrilateral cell mesh structure. A mesh independence test with grid sizes 160×80, 200×100, 240×120, 320×80, and 400×200 determined the 400×200 grid (58,100 nodes, 56,320 elements) as optimal for accuracy and efficiency. A subsequent time independence study with step sizes of 2 s, 1 s, 0.5 s, 0.2 s, and 0.1 s found 1 s to be the most suitable. PCM density and specific heat were piecewise-linear with temperature, based on DSC analysis. The SIMPLE scheme was used for pressure-velocity coupling, and the PRESTO! scheme for the pressure correlation equation, with standard initialization. The optimal 1 s time step with 70 iterations per step ensured convergence and accuracy.

**Table 1** Thermo-physical properties of paraffin wax (P-66) and fin material (copper)

| Properties | P-66 | Copper | Water |
|---|---|---|---|
| Density (*Kg/m³*) | Temperature (K): 301, 327, 350. Density (kg/m³): 828, 745, 702 | 8978 | 965.3 at 363K |
| Specific heat (*J/Kg K*) | Temperature (K): 299, 314, 318, 320, 323, 325, 326, 330, 335, 336, 337, 340, 344. Heat capacity (J/kg·K): 6594, 8871, 10788, 17343, 25800, 18594, 13895, 18718, 55995, 59018, 55129, 10006, 9140 | 381 | 4208 at 363K |
| Thermal Conductivity (*W/m K*) | Temperature (K): 301, 305, 343. Conductivity (W/m K): 0.272, 0.199 | 387.6 | 0.68 at 363K |
| Viscosity (*Kg/m s*) | 0.0252 | - | 0.0003 |
| Thermal expansion factor (*1/K*) | $6.546\times10^{-3}$ | - | |
| Latent Heat (*J/kg*) | $3.2825\times10^{5}$ | - | |
| Solidus temperature (*K*) | 331 | - | |
| Liquidus temperature (*K*) | 340 | - | |

## RESULTS AND DISCUSSIONS

The study reveals that modifying the arrangement of HTF and PCM significantly impacts the rate of melting and overall thermal efficiency. In the base scenario, where HTF and PCM are adjacent, the melting process was slower. Introducing a second HTF layer surrounding the PCM (Case 1) led to a 52.56% reduction in melting time, while the use of three concentric sections (Case 2) achieved an additional 45.08% reduction. These results indicate that expanding the HTF surface area improves heat transfer, though the improvement diminishes after a certain point, as illustrated in **Figure 2** and **Figure 3**.

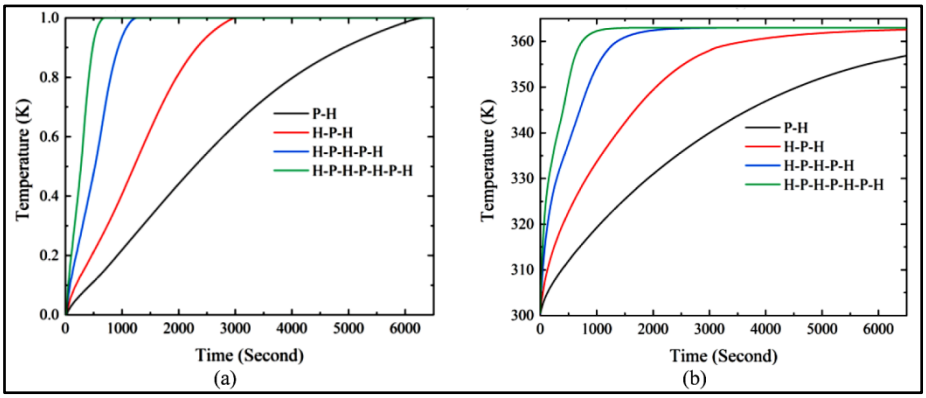


**Figure 2** Comparison of (a) liquid fraction and (b) temperature with (s).

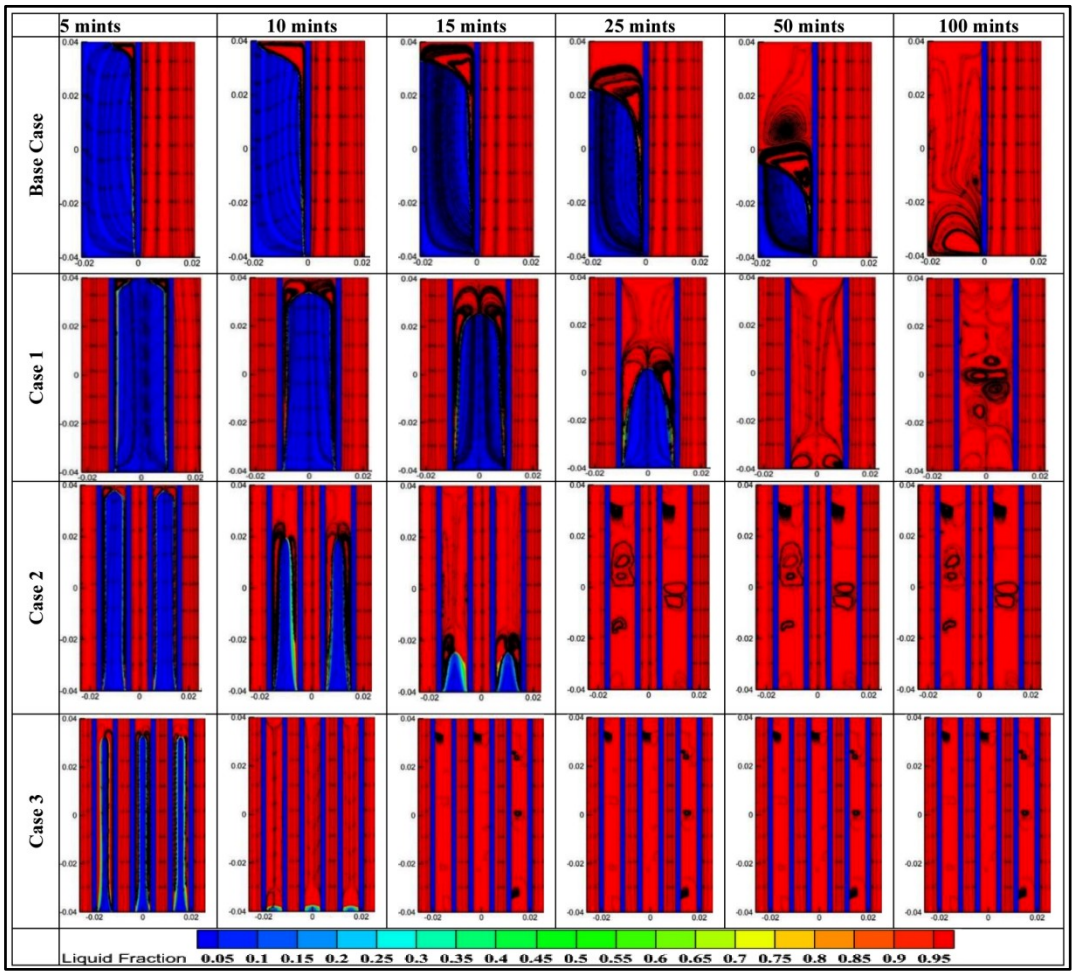


**Figure 4** Liquid fraction contour with streamlines for the various time frames of three different cases with base case.

**Figure 4** showcases the liquid fraction contours for each configuration. In the base configuration, the melting process was slower and less uniform, whereas Case 1 showed quicker melting due to greater HTF contact. Case 2 further enhanced melting speed and uniformity. The best performance was seen in Case 3, where alternating HTF and PCM layers resulted in the most balanced and efficient heat transfer, leading to the fastest melting time.

The temperature contours in **Figure 5** highlight how the distribution of heat changes with each configuration. In the base case, the temperature spread was uneven, resulting in slower melting. Case 1 improved heat distribution, and Case 2 balanced temperature more effectively across the PCM. Case 3 showed the most uniform temperature distribution and the quickest melting process. While increasing HTF-PCM contact area enhances heat transfer, Case 3 provided the optimal setup for large-scale energy storage applications.

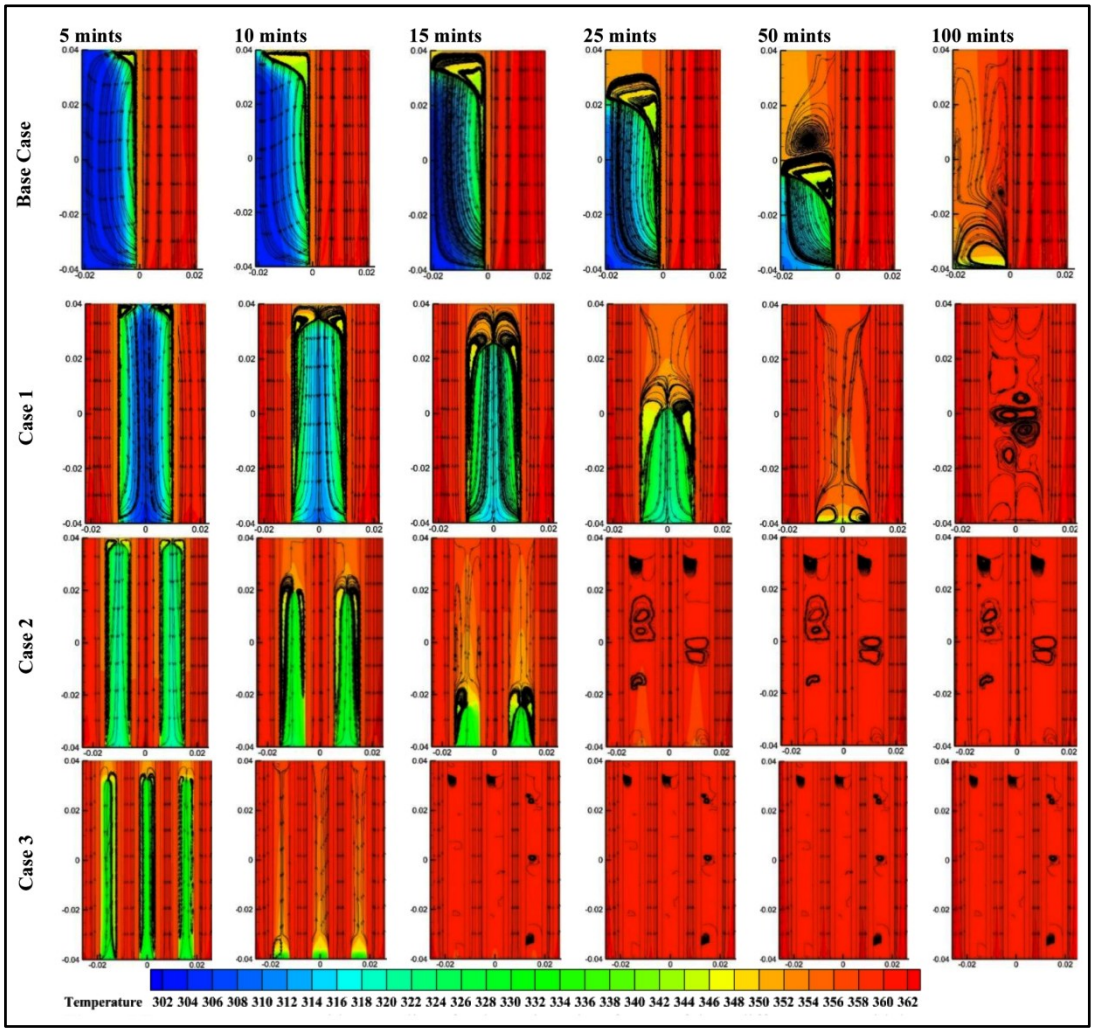


**Figure 5** Temperature contour with streamlines for the various time frames of three different cases with base case.

## CONCLUSION

This study shows that changes in the arrangement of phase change material (PCM) and heat transfer fluid (HTF) can greatly influence the efficiency of energy storage systems by reducing melting time and enhancing thermal performance. Increasing the interaction between HTF and PCM, particularly by dividing them into multiple sections or using alternating layers, resulted in faster heat transfer and improved melting rates. However, the improvement becomes less significant after a certain point, suggesting an optimal configuration. These findings provide important guidance for creating more efficient and compact PCM-based thermal storage systems, with Case 3 standing out as the most effective design for large-scale industrial applications.

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# Power & Energy

## Frontier Technologies in Mobility

187_IEC20145

# Design Innovations and Performance Optimization in Tilting Pad Journal Bearings: A Review

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***Abstract:*** *TPJBs are vital components in high-efficiency machinery, providing superior load support and reduced friction through a hydrodynamic lubrication film. However, challenges such as pad fluttering can lead to increased vibrations and noise, compromising operational efficiency and longevity. This study explores the critical factors influencing TPJB performance, emphasizing the significance of tailored lubrication systems. We highlight the importance of selecting appropriate lubricants based on specific operating conditions—load, speed, and temperature—to prevent fluctuations in film thickness that can accelerate wear. Furthermore, we advocate for adaptive lubrication strategies that dynamically respond to varying operational demands and the implementation of predictive maintenance practices to identify potential failures early. The findings aim to provide engineers and practitioners with practical insights to increase the dependability and functionality of TPJBs. This, in turn, will contribute to the creation of more resilient machinery across diverse industrial applications. By applying these insights, professionals can optimize designs and maintenance practices, ensuring better efficiency and longevity in high-performance systems.*

***Keywords:*** *Tilting Pad Journal Bearings (TPJBs); Pad Fluttering; Lubrication System Design; Friction Reduction*

## INTRODUCTION

Bearings are often the smallest components in machinery, yet their impact on operational efficiency is significant. A bearing failure, despite the relatively low cost of the bearing itself compared to the overall machinery, can lead to substantial downtime and reduced productivity. This highlights the importance of reliable bearing performance for maintaining the smooth operation of industrial processes. Among the various types of bearings used across different applications, these bearins have been a vital option for high efficiency turbines for over a century. TPJBs are a type of sliding contact bearing known for their ability to handle high speeds and loads, commonly employed in applications such as compressors and different types of turbines. Their dynamic stability makes them particularly ideal for high-speed machinery, effectively reducing friction and enhancing load support, which contributes to the overall efficiency and longevity of the equipment. To design and select TPJBs suitable for the specified operating conditions, it is essential to obtain accurate performance characteristics. However, predicting these metrics can be challenging due to the bearings' intricate design, notable increases in oil temperature and chaotic flow within the lubrication film. One critical issue that arises is pad fluttering, an erratic oscillation of the pad shifting back and forth between the pivot point and the journal during shaft rotation, which can result in bearing malfunction. Accurately determining the fluttering characteristics of the upper unloaded pad is essential to prevent failure and facilitate uninterrupted performance of rotating equipment. [1], [2],[3],[4],[5],[6],[7],8]. An important parameter for reducing vibration is oil film thickness. Recent advancements include the development of an electromagnetic sensor equipped with dynamic temperature adjustment, specifically designed for monitoring oil film thickness in tilting pad thrust bearings. This sensor utilizes the eddy current principle to measure the distance to the bearing surface, which directly correlates with oil film thickness. To mitigate the effects of temperature fluctuations on sensor performance, the system adjusts readings based on real-time temperature changes, ensuring consistent accuracy. The calibration process involves setting the sensor against known reference points and making necessary adjustments for temperature-induced deviations. Sensitivity tests confirm that the sensor effectively detects small variations in oil film thickness, while accuracy tests validate its reliability under various conditions. Performance evaluations conducted under various rotational speeds, bearing loads, and oil flow rates demonstrate that the sensor performs reliably across a range of

dynamic conditions, adapting effectively to changes in speed, load, and lubrication. The findings demonstrate that the eddy current sensor with dynamic temperature adjustment is highly efficient for real-time monitoring of oil film thickness in TPJBs, offering significant benefits for the reliable operation and maintenance of rotating machinery. TPJBs exhibit superior stability due to their ability to dynamically adapt the oil-film force distribution, helping maintain an even load distribution that minimizes vibration and wear. Their adaptability makes them particularly suited for high-speed and cryogenic machinery, capable of managing high loads effectively [2], [3], [4], [5], [6]. This literature survey lays the groundwork for a comprehensive review paper, synthesizing existing knowledge and identifying areas where further research is needed to advance the optimization of TPJBs.

## LITERATURE REVIEW

Recent studies on TPJBs have possess advanced the understanding of their responsive characteristics and performance optimization. Seong Heon Yang et al. investigated the vibrating behavior of unloaded surfaces in TPJBs, revealing that increased oil flow stabilizes pads under varying conditions, while higher loads decrease fluttering velocity. This study emphasizes the need for effective load management to mitigate fluttering effects, highlighting the relationship between flutter amplitude and rotor dynamics, which poses risks of mechanical failure due to excessive vibrations [1]. In a related study, Sergei B. Glavatskih introduced an eddy current sensor for real-time measurement of lubricant film thickness and thermal conditions in bearings, enhancing reliability in low-speed applications like hydroelectric power systems. This innovation enables proactive lubrication adjustments, preventing mixed lubrication conditions that could lead to wear and failure, underscoring the integration of advanced monitoring technologies in traditional bearing systems [2]. J.C. Nicholas's foundational work on stiffness and damping coefficients established key analytical frameworks for TPJBs. His research emphasized design modifications, such as increasing pad length and reducing preload, to enhance damping characteristics, which remain relevant for optimizing rotor-dynamic performance. Nicholas's methodologies facilitate efficient simulations in thermo-elasto-hydrodynamic (TEHD) analyses, serving as a reference for ongoing research in journal bearings [3]. T.W. Diamond et al. conducted a comprehensive review of identification methods for fluid film journal bearings, highlighting challenges such as noisy data and the limitations of traditional iso-viscous models. They advocated for advanced modelling techniques, including Heat-Fluid Dynamics (THD) and Heat-Elastic Fluid Dynamics (TEHD) models, to improve predictive accuracy, emphasizing the need for refined methodologies to enhance bearing performance [4]. Huiyu Bai et al. explored the nonlinear dynamics of TPJB-rotor systems, demonstrating that TPJBs outperform conventional bearings due to better oil-film distribution and stability. Their mathematical framework aids in predicting bearing behavior under varying conditions, emphasizing the need to consider nonlinear dynamics for accurate performance analysis [5]. Tianwei Lai et al. focused on gas TPJBs, analysing how varying load directions affect performance. Their findings indicate that understanding local parameters is essential for optimizing bearing designs, especially under changing load conditions [6]. R.G. Kirk reviewed pivot stiffness equations, highlighting the impact of pivot flexibility on bearing performance. His analysis suggests that increased flexibility can reduce damping, leading to vibrations and instability, thus necessitating careful design considerations [7]. The work of Nicholas et al. further examined pad motion's influence on stiffness and damping, concluding that top unloaded pads significantly affect damping, while preload adjustments optimize performance [8]. Despite these advancements, several gaps remain. There is a need for comprehensive experimental validation across a broader range of conditions, particularly at high speeds and loads. Moreover, few studies address environmental impacts and the integration of advanced monitoring technologies for predictive maintenance. Further research into nonlinear dynamics and interdisciplinary approaches could foster innovations in TPJB design, leading to improved performance and durability. In summary, the literature on TPJBs reveals significant advancements but also highlights critical areas for future research, particularly in experimental validation, environmental assessments, and advanced monitoring techniques. Addressing these gaps will be essential for developing robust designs and optimizing operational strategies in various industrial applications.

## EXPERIMENTAL ANALYSIS

The oscillation behaviors of the upper surfaces in (TPJB) are evaluated using a detailed analysis of electrical signals from an accelerometer mounted on these pads. This analysis employs a signal analyser to determine fluttering frequencies, amplitudes, and the incipient velocity at which fluttering initiates under varying experimental conditions

[1]. The accelerometer's electrical outputs are transformed into velocity components using a key feature within the analyser, facilitating a comprehensive assessment of pad behavior. This measurement process is efficient, as it employs a pressure monitoring device and a position measurement sensor on the journal, ensuring real time data collection without time delays [2]. This multi-faceted testing approach allows for a robust investigation of pad fluttering phenomena across different shaft speeds, bearing loads, and oil flow rates, with multiple repetitions to ensure the reproducibility and accuracy of the results.

This comprehensive approach aims to elucidate the dynamics of pad fluttering in TPJBs, contributing valuable insights for optimizing performance and stability in rotor-bearing systems.

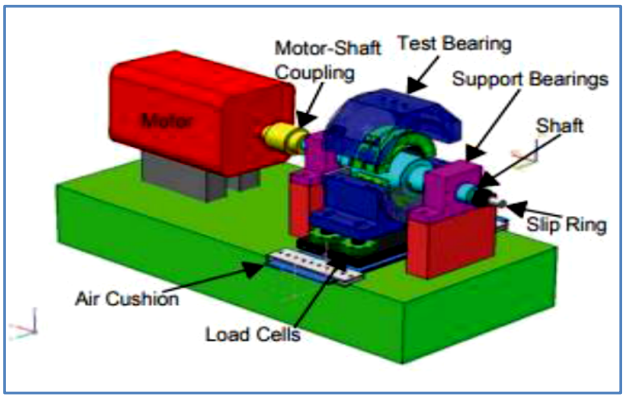



**Figure 3** Testing Setup

**Table 1** shows physical characteristics of test bearing for experimentation to investigate pad fluttering

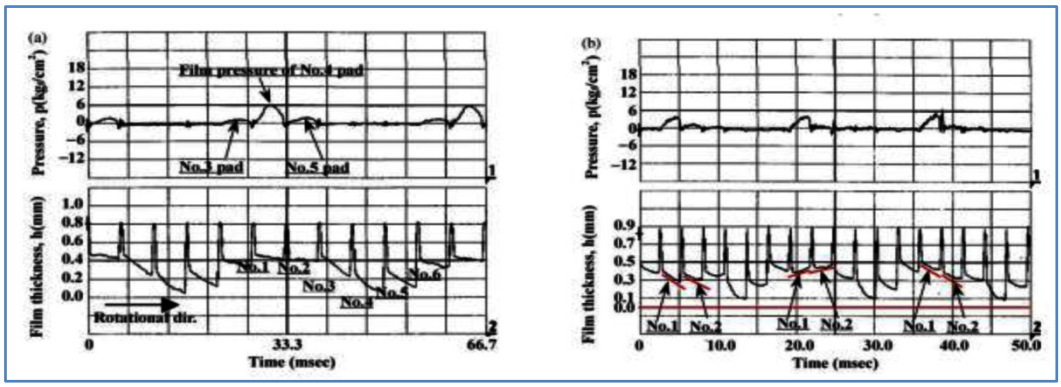
| Sr No | Test Condition | Range |
|---|---|---|
| 1 | Diameter | 300 mm |
| 2 | Length | 150mm |
| 3 | Radial Clearance | 0.460 mm |
| 4 | Number of surfaces | 6 |
| 5 | pad surface curvature | $54^0$ |

## RESULT AND DISCUSSION

This study focuses on the vibration characteristics of the upper surfaces in a TPJB system, specifically investigating the impacts of shaft speed, bearing load, and oil flow rate. As shaft speed increases, distinct sub-synchronous vibration frequencies emerge, differentiating these from synchronous self-excited vibrations. Importantly, while fluttering frequencies remain stable, the amplitude of fluttering increases progressively with higher shaft speeds. The investigation reveals that increased bearing loads lower the onset of fluttering velocity, whereas higher shaft speeds trigger fluttering primarily due to elevated oil supply rates and decreased loads. This indicates that pad fluttering significantly elevates vibrations within the rotor-bearing system. Mitigating fluttering could thus enhance dynamic stability and reduce these vibrations. However, the findings also suggest that merely increasing oil flow rates may not completely eliminate fluttering, indicating a technical limit to this approach. Further studies are needed to explore modifications in pad shape, preload effectiveness and various design parameters.

**Figure 4(a)** and **Figure 4(b)** peripheral profile of the lubrication pressure and lubrication thickness at different load and speed. The experiments utilized a six-pad TPJB system, varying oil flow rates, shaft speeds, and bearing loads. **Figure 4(a)** shows the peripheral profile of the lubrication pressure and lubrication thickness at a shaft speed of 1800 RPM, oil supply of 70 L/min, and load of 10 kN. Here, the film pressure is predominantly supported by the bottom pad, indicating stable lubrication without observable fluttering, crucial for preventing vibrations and ensuring efficient rotor performance. Conversely, Figure 4(b) displays data at 3600 RPM, where the upper pads exhibit continuous oscillation, indicative of fluttering. This behavior, with a fluttering frequency approximately half that of

the rotational frequency, suggests sub-synchronous vibrations that can negatively impact system stability.




## CONCLUSIONS

This review highlights the ongoing efforts to improve the functionality of hydrodynamic TPJB through diverse optimization strategies. By examining critical factors such as pad geometry, lubrication conditions, operating speeds and material properties, the study underscores the intricate interplay that influences bearing efficiency. A key focus on lubrication reveals the trade-offs between oil viscosity and supply pressure, emphasizing the need for a nuanced approach to achieve optimal performance. As research in this field continues to evolve, the insights gained promise to drive innovations in rotating machinery, leading to reduced energy consumption, minimized downtime, and enhanced reliability. This work acts as a useful reference for directing future research and advancing the optimization of these essential components in industrial applications.

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# Power & Energy

# Power System Stability, Reliability and Flexibility

21_IEC75354

# Power System Flexibility — a Key Enabler for the Energy Transition

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***Abstract:*** *Power systems around the world are undergoing significant change, driven particularly by the increasing availability of low-cost variable renewable energy (VRE), the deployment of distributed energy resources (DER), advances in digitalisation and growing opportunities for electrification. Power systems are designed and operated to efficiently manage variability and uncertainty in electricity demand and resource availability. VRE increases this inherent variability and uncertainty, and thus increases the need for flexibility. Systems with significant variability and uncertainty require flexible generators that can rapidly change output, operate efficiently at lower outputs, and operate for short durations. This flexibility in turn can reduce the need to curtail (decrease the output of) solar and wind generation; improve investor confidence in VRE and reduce environmental impacts by increasing system efficiency and maximizing the utilization of VRE. Flexibility has to be harnessed in all sectors of the power system, from power generation to stronger transmission and distribution systems, storage and more flexible demand.*

***Keywords:*** *Power System Flexibility; Energy Storage; Renewable Energy; Global Warming; Energy Transition*

## INTRODUCTION

Energy is at the heart of the climate challenge – and key to the solution. Humans have been using fossil fuels for over 150 years and, as their use increased, so did the release of the greenhouse gases when these fuels are burnt. These greenhouse gases trap the heat in the atmosphere causing the temperature of the Earth to rise [1]. This global warming is one symptom of climate change that has seen a rise in extreme weather events, shifting wildlife habitats and populations, rising sea levels and other impacts.

Currently, around 80% of global energy and 66% of electrical generation are supplied from fossil fuels, contributing approximately 60% of the greenhouse gas (GHG) emissions responsible for climate change. The science is clear: to avoid the worst impacts of climate change, emissions need to be reduced by almost half by 2030 and reach net-zero by 2050. To achieve this, we need to end our reliance on fossil fuels and invest in alternative sources of energy that are clean, accessible, affordable, sustainable, and reliable. Many of the proposed plans for confronting the climate crisis stress the imperative of decreasing emissions by transitioning to 100% “clean” or “renewable” sources of energy. Because renewable energy sources don’t emit greenhouse gases such as carbon dioxide, they do not contribute to global warming.

The cost of renewable energy sources has fallen dramatically, leading to a beneficial and accelerated global build-out and making renewables the most competitive source of energy sector in some parts of the world. The energy sector is undergoing a profound and complex transformation as the shift to renewable energy gathers momentum. Transitioning the electricity system to deal with an increasing share of renewables and different ways of operating is challenging, but it presents many opportunities to help businesses manage their energy costs, as well as capture new sources of growth.

Flexibility has become a common by-word for the energy transition. According to the International Energy Agency, the flexibility of a power system refers to "the extent to which a power system can modify electricity production or consumption in response to variability, expected or otherwise" [2]. Power system flexibility spans from more flexible generation to stronger transmission and distribution systems, more storage and more flexible demand.

## POWER SYSTEM FLEXIBILITY

### A. Variability and Uncertainty of Demand

All power systems have some inherent level of flexibility - designed to balance supply and demand at all times. Variability and uncertainty are not new to power systems because loads change over time and in sometimes unpredictable ways, and conventional resources fail. Conventional generations are the major source of power system flexibility.

Traditionally, power systems did not have any VRE - therefore designed to deal with non-VRE related variability and uncertainty. Main source of variability in conventional power systems is electricity demand, including both intra-day and seasonal variability. Main source of uncertainty is the loss of one or more of the largest in feeds (i. e., generators or transmission lines).

Conventional power systems generally incorporate a least-cost mix of controllable generation assets with desirable techno-economic characteristics to balance varying demand at all times. Base load units - able to generate large amounts of energy at relatively low operational costs. Typical base load units include coal, biomass and nuclear power plants, mostly using steam turbines to generate electricity. Peaking generators - designed for flexible operation with rapid start-up and fast ramping capabilities and low min. operational level. Peaking units are usually gas turbines (open-cycle) and internal combustion engines. Modern combined-cycle gas turbines and reservoir type hydropower units are considered intermediate generators, as they can be used to provide either base or peak load.

Increasing share of VRE in the mix - introduces addl. levels of variability and uncertainty into the so-called net load [3]. As shown in **Figure 1** at low VRE deployment levels, very little difference exists between the net load and the load (demand). As VRE integration increases, the shape of the net load changes - increasingly noticeable differences appear between the two. When load is increasing and VRE generation is decreasing – this requires conventional generators to respond at a faster rate than traditional requirements to compensate for lost supply from VRE.

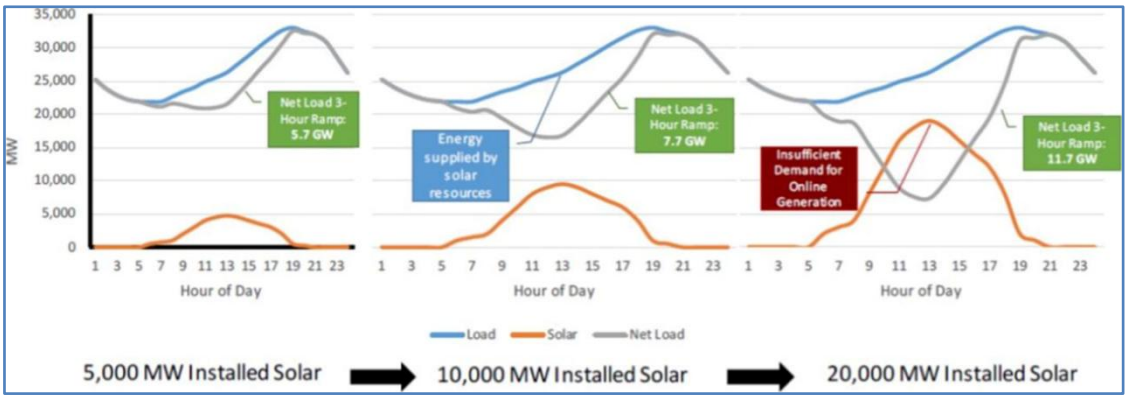


**Figure 1** Change in net load due to different levels of VRE (solar) deployment

Therefore, coal based power plants, originally designed to be base loaded, will increasingly need to operate on a load following or cyclic basis. They need to cycle on and off and ramp up and down to part load more frequently, more rapidly and more cost-effectively. Most existing coal-fired power plants were designed for sustained operation at or near full load to maximize efficiency, reliability and revenues. Depending on plant type and design, these plants can adjust output within a fixed range in response to plant or market conditions. The need for flexibility is shifting their mission profile in three ways:

1) more frequent shutdowns when market or grid conditions warrant.

2) more aggressive ramp rates (rate of output change) and

3) lower desired minimum sustainable load, which provides a wider operating range and hence, enhanced usefulness.

**Figure 2** illustrates the dimensions of flexible power plant operation [4].

Increasingly, coal-fired power plants are being asked to make the transition to one or more of these duty cycles:

- Two-shifting in which the plant is started up and shut down once a day.
- Double two-shifting in which the plant is started up and shut down twice a day.
- Load-following in which the plant operates for more than 48 hours at a time, but varies output as demand changes.
- On-load cycling in which, for example, the plant operates at base load during the day and then ramps down to minimum stable generation overnight.

It can lead to fatigue and creep on components, which may result in higher capital and operational costs, increased forced outage rates and reduced lifetime.

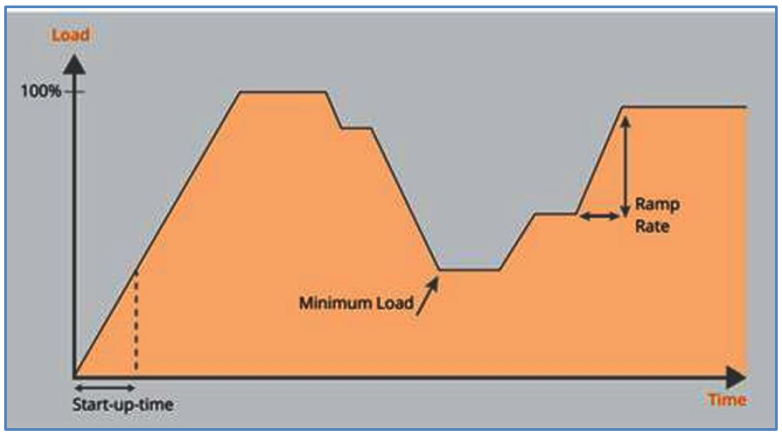


**Figure 2** Dimensions of flexible power plant operation

Cycling and ramping results in degraded performance and higher emissions (viz. $CO_2$, NOx, $SO_2$) over time.

With an increasing penetration of VRE, these challenges are only expected to increase in the future. Plants not designed for these operating modes can lead to more component failures, unplanned outages, increased heat rate, decreased revenue, and staff scheduling and training challenges [5]. At the same time, constraints on cycling operation can be imposed by new or upgraded emission control systems such as selective catalytic reduction [SCR] and flue gas desulfurization [FGD]. Compounding these challenges, many existing flexible coal-fired power plants are being retired as a result of their age or difficulty in meeting new emissions requirements. These include small drum units with high design margins and fewer emission controls, which allow flexibility.

**B. Solutions**

Various alternatives to address the challenge have been explored. These include Scheduling, Energy storage, Demand response etc,

**Scheduling**

Coal-based plants take a considerable amount of time to start up. Daily start/stop operation of the entire fleet is not feasible, technically as well as financially. The entire days scheduling of a coal-based unit needs to be done based on the forecasted value of the maximum evening load on the unit during the day. The units that are scheduled to operate on a given day would be expected to run at low loads when high solar power is available and ramp up gradually when solar generation reduces while the overall power demand increases.

**Energy Storage Systems**

Energy storage plays an important role in balancing grid supply and demand when integrated with renewable energy.

Deployment of energy storage technologies also enables renewable energy time-shift and renewables capacity firming. Flexible power from pumped and battery storage systems should be used along with two-shift operations of old and small coal-fired plants.

**Demand Response**

Demand response is a set of strategies aimed at aligning electricity consumption with available supply. It encourages users to adjust their consumption during periods of peak demand in response to price signals or other incentives. For example, time-of-using charging involves charging customers different rates for energy usage depending on the time of the day. The goal is to incentivize consumers to shift their electricity consumption to peak-off hours when demand is lower.

## CONCLUSION

Climate change mitigation policies require dramatically increased levels of electricity produced from variable renewable sources. Ambitious targets on decarbonization present the need for massive integration of VRE in power systems in India. Flexibility is a prized quality of power systems with increasing levels of VRE generation. Flexibility reduces curtailment and lower curtailment means reduced system operating costs and lower CO2 emissions. Until large scale energy storage systems evolve, India will have a greater demand for thermal plant flexibility in the coming years. Gigawatt-scale tenders for energy storage to support transmission networks and support solar PV integration has been announced by GOI in Feb. 22. Addressing the expanding variability in supply and demand requires harnessing both existing and emerging tools for flexibility.

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40_IEC52519

# Analysis and Risk Assessment of Fault Induced Delayed Voltage Recovery Events and its Interplay with Load Nature

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***Abstract:*** *Load growth and its nature have direct impact on power system and with the increased temperature and humidity, concentration of air conditioning load has significantly increased near city and urban areas. Such drastic increase of Ac loads which are mainly single-phase induction motors have increased the risk of FIDVR event in recent years. Nature of load growth and its changing behaviour in past few years have been analysed. This paper showcase root cause analysis of the real event occurred in eastern region and explains the phenomena of FIDVR in details along with mitigating measures and way forward in long term at planning stage and short term in operational horizon.*

***Keywords:*** *Fault Induced Delayed Voltage Recovery (FIDVR); Battery Energy Storage System (BESS); Air Conditioner (AC)*

## INTRODUCTION

LOAD composition has changed substantially from past few years. In the last few years with the changing environmental conditions, rising temperature, humidity have significantly impacted the load nature, especially space cooling loads. The penetration of Space cooling loads, air conditioning loads have significantly increased which have adversely impacted the system security.

Nowadays, fault induced delayed voltage recovery (FIDVR) events seem to occur more frequently since the density of induction motors is increasing with continuing market penetration of low-inertia air conditioning (A/C) loads which are not equipped with compressor under voltage protection. In the past, 25% of the distribution system load was motor load; however, in recent years, induction motors constitute a major portion of power system loads as high as 70%.

These events generally occurs where large percentage of single-phase AC loads are there. These events generally occur in peak summer, in and around capital cities where AC load concentration is in high amount. Event is generally induced by faults in the transmission system of such areas which results into reduction of voltages of distribution level up to a point which results into stalling of AC loads which is mostly single-phase induction motor. Huge reactive power is drawn by these stalled motors leading to suppressed voltage until thermal overload relay cuts off the Ac units.

Time of the day is also one important factor where if fault near a city occurs at the peak demand time when AC load concentration is high if the same fault at same location occurs at the time when AC load is minimal at night hours the event will not occur.

The more the percentage penetration of AC load, the more is the probability of FIDVR event impacting a large area as it creates cascading event, and a large area will be impacted.

FIDVR events involving a large area will have very detrimental effects on Grid frequency and stability which even may cause cascading leading to partial or total blackout situations which is explained in subsequent sections via detailed real case study of a major state capital metro city of India.

Detailed analysis of this event, root cause analysis along with remedial measure in long term and short term are also discussed.

## ANALYSIS OF LOAD GROWTH AND ITS NATURE LEADING TO INCREASED PROBABILITY OF FIDVR EVENTS

Kolkata load is Predominant with summer beating AC loads (Single phase induction motor) Domestic plus commercial around 66%, leading to high concentration of Single-phase induction motor or AC load 38.9 near city. If we see load categorization in terms of annual energy consumption it is (Domestic-48%, Commercial-18%, Industrial -22% and others -12%)) while the same in terms of peak demand and actual megawatt will be much more.

With Rise in temperature & humidity year on year, and GDP growth AC loads have increased in the city gradually to a very high level that any line fault around the city during peak summer condition may lead to stalling of Acs leading to FIDVR event. After analysing the temperature trend as shown in **Figure 1** in recent years, it is observed that maximum temperature has increased significantly since 2020. The rise in temperature is around 5 degrees. This increase of temperature is one of the driving factors for large amount of AC installation.

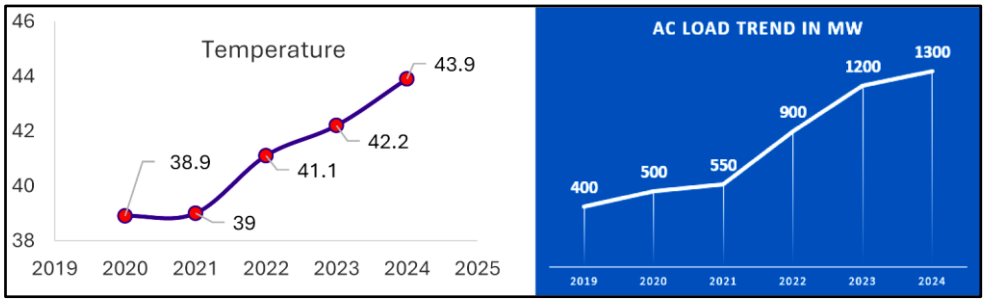



**Figure 1** Trend of Maximum temperature and Air conditioning load growth of city for last 5 years.

With increase of actual temperature by 5 degrees in recent years, real feel temperature got pushed further in range of 50-60 degrees. This temperature range leads to high discomfort and is directly proportional to AC load growth. In the similar pattern of temperature rise, AC load also increases with a high CAGR of 40-50% between 2021-2023. It was also reported that total 1.5 lacs AC units were sold from March to April -2024 within 45 days.

Impact of Covid in Year 2020 and Amphan Cyclone and Impact of YASH cyclone in summer 2021, and Asani Cyclone and Nor-wester in summer 2022 kept demand depressed for 2020-2021,2022. From 2020 to 2022 the rate of increase of average demand was low around 70 MW per year as can be seen from linear fit slope. From 2022 onwards sharp increase in average demand observed with High slope of 273 MW per year in the summer months which posed various challenges in meeting this huge jump in demand while the resources and feeding points remained same.

### Impact of Temperature and Humidity Over City Load

Due to the geographical location of Kolkata in Tropical regional with vicinity of 100kM from coast, high humidity is normally observed in Summer & Monsoon season. Humidity has natural capacity to hold the heat for longer time. For all these reasons, real feel temperature becomes very high compared to actual temperature for any area where humidity is high.

As shown in **Figure 3** the comparison of two days temperature and humidity on D-2 actual temperature was lower than D-1 but humidity on D-2 was higher than D-1 day which has led to higher real feel temperature on D-2 as shown in **Figure 4** and so the demand on D-2 was also higher because large number of Airconditioning units were switched on.

Higher real feel temperature increases the discomfort and leads to more requirements of cooling mainly Air-conditioning. It can be observed that real feel temperature reached as high as 55 degrees on any typical hot & humid

day in summer season. It can be observed that demand remains on higher side for a day with higher real feel temperature. If real feel temperature remains within 40 degrees, the demand becomes 200-250 MW less than the demand at the real feel temperature of 55 degrees. Demand variation is almost 10% of the peak demand.

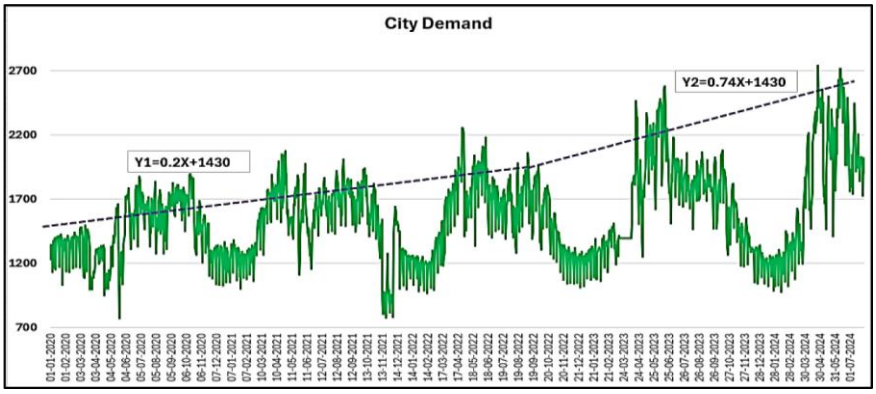



**Figure 2** Trend of Demand for Last five years

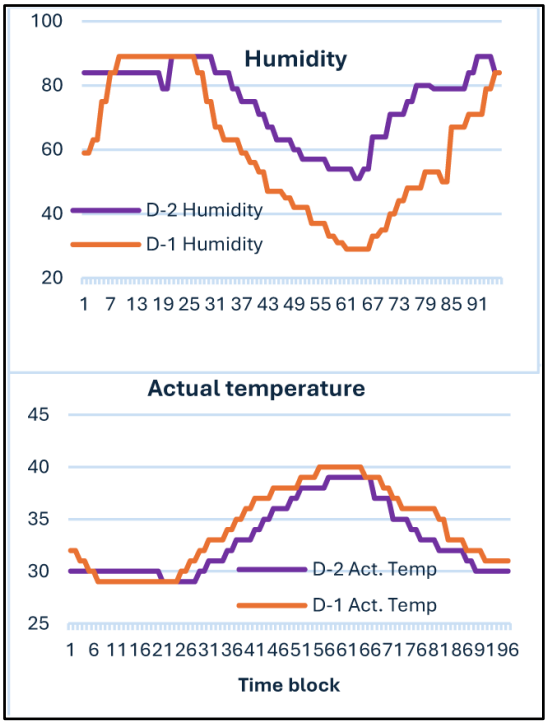



**Figure 3** Comparison of actual temperature and Humidity of two consecutive summer days.

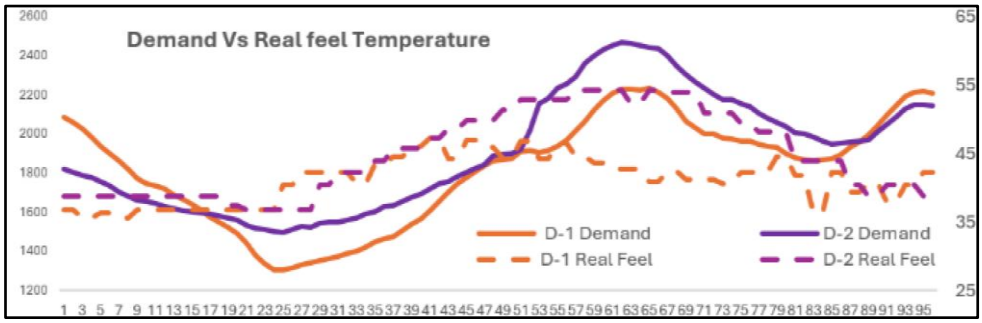
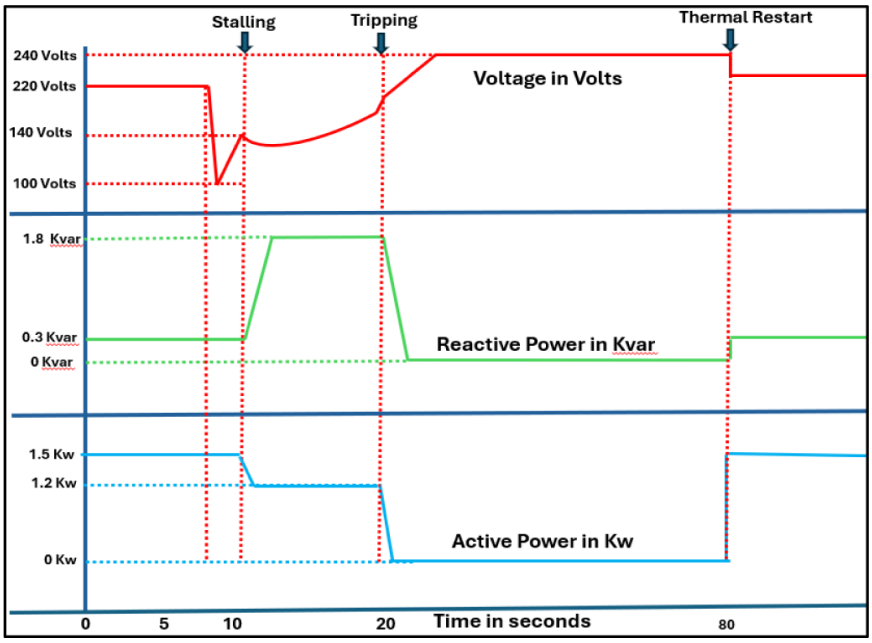



**Figure 4** City demand vs Real feel temperature comparison

## FIDVR PHENOMENON DETAILS AND STALLING OF SINGLE-PHASE INDUCTION MOTOR ACS

Behaviour of a 1.5 Kw residential air conditioner during stalling and post stalling is depicted in figure below. If any fault occurs and at some point, at Transmission level, and at distribution level if voltage reaches up to a value which leads to stalling of Single-phase induction motors.




Air conditioning compressors is driven by Single phase induction motors which are having constant torque characteristics that stall when the system voltage dips to some lower values during the fault/Event conditions.

The inertia of single-phase motors used in residential air conditioning is very small (0.03-0.05 seconds). This causes rapid deceleration of the AC motors during the fault events in which the voltage is suppressed. Therefore, these motors are highly susceptible to stalling even for the faults that are cleared in as low as 5 cycles. Motor generally stalls at around voltage below 0.75 Pu [1].

These types of motors draw a large amount of reactive power from the grid during stalling, motor draw 5-6 times their steady state current. This might lead to voltage collapse and cascading events in the system. Once they are stalled and are drawing huge current, thermal overload protection trips the motors during stalling. Once the motors trips, voltage started to recover in a stepwise sequential manner. Thermal overload may take from 2 to 25 seconds to operate [2]. After the tripping of Ac, they automatically get connected after thermal restart time which varies from 50 seconds to several minutes.

It can be seen from above plot that Active consumption was 1.5 Kw and reactive was 0.3 Kvar and when voltage dropped due to fault at distribution level up to 140 volts (64%) for more than 5 cycles it got stalled and reactive power increased 6 times up to 1.8Kvar while active power reduced to 1.2 Kw as it is now acting as constant admittance load and as voltage is reduced so active power will also reduced as it is proportional to voltage square. With such large amount of current drawl AC will be tripped via thermal protection and active and reactive both will become zero , and voltage recovered then after a minute of thermal restart time it will again be reconnected automatically.

Three-phase induction motors generally do not stall because they have a local control circuitry and motor contactors drop out between 55-65% of the nominal voltage. These motors generally stall at around 50% voltage. Therefore, it is very likely that the contactors drop out before the motor stalling phenomenon. Also, the inertia of these 3 phase induction motor ranges from 0.1 to 1 Seconds [3].

(a) **Results and CASE Study**

Refer **Figure 5** of FIDVR event occurred on 26th April 2024 at 15:27:42 Hrs observed at 220 KV level via PMU.

Plot Description

Point-1: Fault in the transmission line in the vicinity of the city, resulting to dip in voltage. Fault occurred at the instant of peak summer when City was meeting its all-time high demand.

Point-2: Fault got cleared via protective relay and line tripping but by that time voltages at distribution level were also low and Air conditioners stalled and resulted into suppressed voltage even though the fault was cleared as it was drawing high reactive power under stalled condition. This resulted into islanding of the city. Islanding logic is if the voltage at the grid side is below 80% for more than 2 seconds it will be islanded.

Point-3: Recovery of voltage as Thermal overload protection of individual AC units started tripping the motors. Thermal overload may take from 2 to 25 seconds to operate, and at many places it is based on IDMT characteristic.

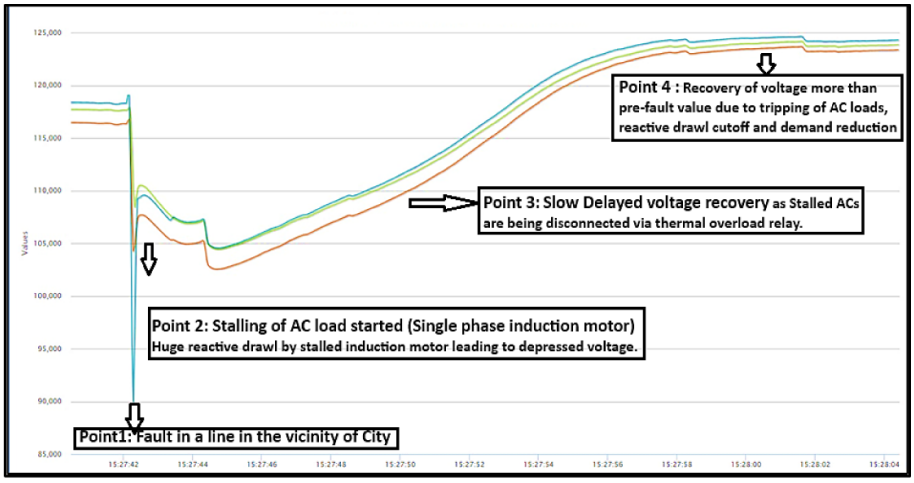



**Figure 5** FIDVR as observed via PMU

Point-4: When all the stalled motors got isolated motors got tripped this resulted into the voltage recovery of more than the pre fault value as significant portion of demand is also lost resulting into reduced line loading and, excess reactive power injection in the system.

(b) **Active and Reactive Power Response of a Radial Load Point**

As can be seen from below **Figure 6** that Blue line (Positive sequence current drawn by load) plotted at primary axis, the Current drawn by load point is increasing in steps indicating sequential stalling of Air conditioners (single phase induction motor loads), in similar way Orange curve which is reactive drawl by load plotted at secondary axis can also be seen to be increased five folds, initially it was drawing only 50 Mvar which has increased up to 250 Mvar.

After few seconds reactive drawl started to decrease gradually as thermal overload protection started to trip the compressors and positive sequence current drawn also can be seen to be reduced lower than the pre fault value due to demand disconnection via thermal relay tripping. Voltage improvement can be seen directly related with reactive drawl same profile observed.

As can be seen from **Figure 6** green colour is Load active power consumption also plotted at primary axis. Active power consumption initially decreased to some extent then later further drop observed.

It can be seen that with stalling of motors as voltage is depressed so under stalled condition motor load will act as a constant impedance load and its active power consumption will be proportional to square of voltage that is why active

power consumption decreased from 350 MW to 300 MW Initially.

Then later gradually Active power started reducing further indication cut off ACS via thermal overload relays.

**(c) Impact on Demand and Frequency**

**Figure 7** shows the demand and frequency variation of island where orange colour is the demand of island plotted at primary axis while blue colour describes frequency plotted at secondary axis,

It can be seen that with the stalling voltage was depressed and islanding also took place for the city and with stalling also demand reduced due to tripping of AC loads via thermal protection and almost 500 -550 Mw reduction was observed due to tripping of loads which led to sudden high frequency within island up to 51.1 Hz.

Now once the voltage is recovered via thermal protection and AC load disconnection then after the restart time which generally varies from the range of several seconds to minutes these ACS will start to reconnect automatically and demand will be restored within few minutes and frequency will be normalized. After 2 minutes which is the restart time of ACS the AC load reconnection automatically started and gradually load recovered up to the pre-fault value and frequency also started reducing in similar manner.

This over frequency at first instance if have reached to over frequency threshold (Which generally starts from 52 Hz onwards) it would have led to tripping of generators and frequency would have been declined sharply and then automatic reconnection of this load again would have further reduced the frequency and island would have collapsed.

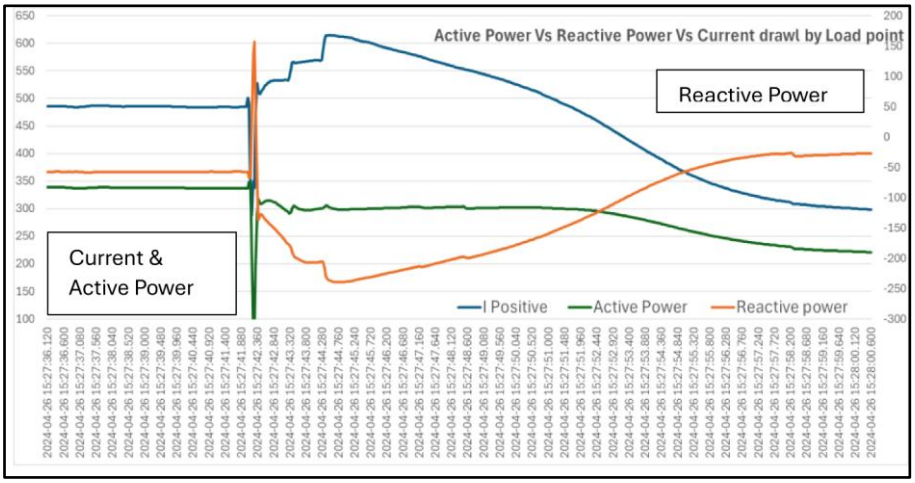



**Figure 6** City Load P & Q drawl with Positive sequence current

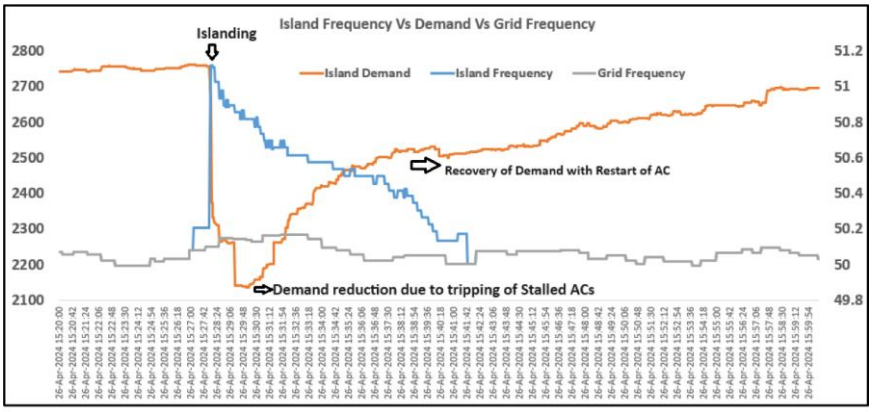



**Figure 7** City demand vs Real feel temperature comparison

## WAY FOREWORD

(a) Planning Stage (Long Term Measures):

Assessment of load growth and load nature and its impact on grid is very crucial starting from the planning stage which is generally missing .The trend of load growth and its nature whether it is dominated by space cooling Air conditioning load , concentration of single phase induction motor & three phase induction motor percentage of power electronic devices needs to be assessed and its impact over the power system also needs to be studied to plan for remedial measures.

If in the planning stage itself with the increased load concentration at a particular pocket or near Capital city if AC load percentage is identified to be near 40-50% then simulation studies with proper load modelling will indicate FIDVR event for different line faults for a delayed clearance fault.

Reactive compensation to be planned accordingly to avoid such events. Installation of suitable FACTS devices such as SVC, STATCOM with proper control to be recommended for installation based on studies in the planning horizon.

Maintaining adequate fault level is also important for a moderate or low fault level node which is feeding such type of loads. This can be done at the planning stage by increasing interconnections to restrict voltage dip for any event to avoid voltages reaching to such low value which can trigger FIDVR event.

Strengthening Low voltage ride through standards for equipment: Distribution code to strengthen and standards for equipment to be streamlined such that Residential Air conditioners or commercial space cooling loads, to be mandated with additional protection where before stalling they will trip the unit which will avoid stalling and voltages will be improved. Ac units with newer inverter technology are less prone to stalling but they should also have protection to trip the units before stalling.

Installation of BESS: Fast responsive battery energy storage systems with proper controls can also mitigate the FIDVR events so sizing and optimal location of BESS can also be chosen near the capital city loads where concentration of load and its nature is projected to cause FIDVR events.

(b) Operational Horizon (Short term Remedial measure):

(1) Under voltage load shedding scheme: Under voltage load shedding scheme can be implemented whereby sensing voltage and before it reaches to a pre-set value which can cause stalling before that it can trip some of the loads to improve the voltages such that voltages always remain above the stalling level. Specific to the case discussed in above sections UVLS will be helpful to mitigate which has been already discussed at regional operational co-ordination committee for implementation.

(2) Special protection schemes: Special Protection Schemes (SPS) may be used as a safety net to confine the area impacted by FIDVR. If a voltage collapse develops near a load centre because of a multi-contingency event, or any large contingency if overloads a portion of network which can cause voltage dips then for such situations based on proper study SPS can be implemented to have some load shedding scheme to avoid overloading and to improve voltage profile.

## CONCLUSION

With increasing space cooling loads, air conditioning units the probability of FIDVR events will be high which can endanger grid security as discussed in the paper hence proper assessment of load nature and future projection of these loads mostly areas dominated by single phase induction motor, AC loads needs to be done. Proper modelling of these loads and simulation to be done even starting from the planning stage so that suitable measure such as installation of SVC, STATCOM , BESS, strong interconnections can also be planned accordingly with load growth to avoid such instances. Proper regulatory standards at distribution and equipment level should also come in the policy for future smooth integration of such loads.

Places where already these phenomena have been observed or started, as a short-term measure SPS scheme or UVLS scheme to be implemented with detailed study of load modelling which can be further complemented by planning long term measures as discussed.

Even with recent technological changes the penetration of power electronics loads, and its impact needs to be assessed from now onwards so that in future further such event can be avoided by proper planning.

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131_IEC5848

# Retrofitment of SEALGUARD ASSEMBLY in WAGON TIPPLER for Reliable Operation of Movable Side Beam in Wagon Tippler: A Case Study of NTPC Kudgi

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***Abstract:*** *NTPC Kudgi has 3 × 800 MW coal units that get coal from diversified sources. coal is transported from more than 1500 kms of coal mines. Coal comes in different sizes up to 200 mm and above. This coal is unloaded at wagon tipplers, crushed at Ring granulator and after getting crushed it is sent for direct bunker feeding or stacking / reclaiming. Being a non-pit head plant coal unloading healthiness is very much critical. Any failure of tippling equipments may stop functioning of the plant which may cause heavy loss in terms of demurrage and power generation. Coal unloading depends upon different equipment like wagon tippler , apron feeder , Side arm Charger , Dribble Conveyor, flap gates, downloading conveyors etc. Due to several reasons like rake bunching, sick wagons, over heaped wagons, multiple tippling requirements problems in downstream conveyors etc Wagon tipplers are always in a state of high duty operation and there is very less room for any breakdown maintenance. From last three years rake movements increased and coal unloading at KUDGI has been increased from 22.26 lac MT (FY 2018) on annual level to 43.5 lac MT (by Sept 2023). Wagon tipplers at KUDGI are M/s TRF make and it was widely mentioned by OEM that to improve cycle time there is need of wagon tippler guide rod greasing frequently. Due to this WT system was becoming unavailable again and again and require top and bottom guide rod greasing round the clock irrespective of any weather condition. It has both operational and safety hazard including maintenance cost. It causes enhancement of wagon unloading time. In absence of guide rod greasing side beam of WT does not forward fully and top – bottom portion are not inline and not touching wagons body properly. As per RDSO there shall be metal to metal contact between the side support beam and the side stanchions of the wagon. Any lag in contact will cause multiple problems like PU pad falling. Refixation of wagon PU pads cause tippling time over-run and finally cost us in form of demurrage. To attend this problem various checking was done like equal pressure (forward–retard condition) at all guide rods, guide rod alignment, guide rod hardware intactness. To overcome the problem one Sealgaurd assembly was designed in-situ to take care of all the Dust and contamination entry while in operation.*

*This system is equipped with perfectly sealed Stainless steel bellows from all sides. They restrict the entry of any foreign Particles and dust during the operation. In addition to this, the graphite Embedded bushes are fixed in bracket portion which takes care of sliding friction and lubrication. 3D model of sealguard assembly was made at site and bill of materials were decided with a local vendor. Same was installed in WT-2 during its overhauling on 30th Sept 23. After its installation and completion of three months ONLY ONE DAY greasing was done as a precautionary step. Now guiderod greasing requirement in WT-2 has been totally nullified and performance of this retrofitment has been also recognised by CHP OPERATION DEPARTMENT. Guiderod assembly has multiple advantages like Wagon Tippling Cycle Time Reduction , Electrical module fuses safeguarding (as multiple time isolations and normalisation cause damage to fuse), enhancement of workman's safety (as even in case of night or rain guiderod greasing was to be done to make system available), Reduction or elimination of persistent problem of repetitive pu pad, spring etc falling and will avoid any problems with Indian Railways.*

***Keywords:*** *Sealguard Assembly; Wagon Unloading*

156_IEC39801

# A Comparative Study of Various FACTS Devices used in Modern Power Systems for Efficient and Reliable Power Transmission

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***Abstract:*** *Over the last few decades, power demand has surged, yet power generation and transmission capacity haven't kept pace. This imbalance strains utilities, pushing them to max capacity, risking Voltage instability and network failures globally. Flexible Alternating Current Transmission System (FACTS) devices offer a solution by enhancing network stability and load handling. To address these challenges, FACTS devices can be a crucial choice for enhancing the stability and loadability of the transmission network. This article provides a comprehensive review FACTS controllers, detailing types, operations, and control features, crucial and power flow capability for power system engineers and researchers. Ultimately, this study hopes to serve as a valuable resource for anyone seeking to improve the stability and efficiency of power transmission.*

***Keywords:*** *FACTS, TCSC, SSSC, SVC, STATCOM, UPFC*

## INTRODUCTION

The demand for electricity and market activities have placed significant strain on power systems. Across the globe, the electricity supply industry is experiencing a significant shift, as a once predictable business is now facing ongoing expansion and increasing demand for energy consumption. As a result, electrical power utilities are under pressure to provide high-quality electricity, making this issue increasingly important in power systems. To address this challenge, power electronics technology has introduced a new solution called Flexible AC Transmission Systems (FACTS). Developed by N. Hingorani in 1988, FACTS implements power electronics devices and methods to control various features like active and reactive voltages, power flow etc. in the sending end side of the transmission network. As modern power electronics technology continues to evolve, numerous advanced FACTS devices have been introduced. Overall, the introduction of FACTS has been critical in enhancing the quality of electrical power in power systems, as electricity demand and market activities continue to stress power grids around the world. [1]

FACTS devices can be broadly classified into three categories based on their connection mode in power systems. Power system compensators serve as pivotal tools aimed at enhancing power system performance. These compensators primarily fall into two categories: shunt devices and series devices. Shunt devices establish a parallel connection with the line, tasked with overseeing voltage regulation and managing of reactive power flow. Prominent among these shunt devices are the Static VAr Compensator (SVC) and the Static Synchronous Compensator (STATCOM).

Conversely, series devices are integrated into the transmission line in a series connection, pivotal for managing active power flow, enhancing transient stability, and suppressing power oscillations. Leading examples of series devices include the Thyristor Controlled Series Capacitor (TCSC), the Thyristor Controlled Phase Shifting Transformer (TCPST), and the Static Synchronous Series Compensator (SSSC). The Unified Power Flow Controller (UPFC) represents a potent FACTS apparatus, skilfully integrating the functionalities of shunt and series devices. It serves as a potent tool for optimizing power flow allocation and enhancing the stability of power systems. A significant stride was achieved with China's inaugural UPFC demonstration project, featuring autonomous intellectual property rights. This landmark initiative commenced in Nanjing on December 11, 2021, further solidifying the practical foundation for UPFC operational principles. Additionally, an upcoming UPFC demonstration project is scheduled to take place in Suzhou. [2]

FACTS stands for Flexible AC Transmission Systems, constituting an array of power electronics-driven and static controllers employed to enhance the manageability and augment the power transmission capability of AC

transmission systems. A FACTS controller denotes power converter-based or static apparatus that governs one or more facets within an AC transmission system. According to the IEEE's definition:

"FACTS embodies components of alternating current transmission systems, integrating power electronics-centric and static controllers to amplify controllability and amplify power transmission capacity."

The IEEE articulates the FACTS controller as:

FACTS controllers embody power electronics-oriented devices and other static mechanisms, orchestrating one or more dimensions of an AC transmission system. The central distinction between FACTS and a FACTS controller lies in FACTS being a collective assembly of controllers, while a FACTS controller is an individual controller. FACTS controllers can be harnessed independently or combined to supervise one or more interconnected system variables. FACTS technology stands as an invaluable asset for power system operators. It assumes a multifaceted role in enhancing power system performance, encompassing:

- Enhancement of power transmission capacity in transmission lines
- Refinement of the voltage profile in transmission lines
- Mitigation of power losses along transmission lines
- Augmentation of power system stability
- Dampening of power oscillations
- Governance of reactive power flow

FACTS technology remains an ever-evolving field, continually unveiling fresh applications. Its potential to revolutionize power system operations underscores its promising nature.

## COMPARISON BETWEEN VARIOUS FACTS DEVICES

TCSC, SSSC, SVC, STATCOM, UPFC and IPFC are the most common FACTS devices and each has its own advantages and applications. For example, thyristor-controlled series capacitor (TCSC) devices can improve power transfer, reduce power oscillations, and improve stability[15]. Static synchronous series compensators (SSSC) can be used to control power transmission, increase power transfer capacity and improve power dissipation. Similarly, static var compensator (SVC) devices also support voltage stabilization and reactive power compensation. To summarize how these devices compare, some comparisons are listed in **Tables 1** and **2**. [5][16]

**Table 1** Comparison between Facts Controllers [5]

| S. No. | Control Attributes | FACTS Controllers | | | | |
|---|---|---|---|---|---|---|
| | | TCSC | SSSC | SVC | UPFC | STATCOM |
| 1 | Power flow control | Yes | Yes | No | Yes | No |
| 2 | Voltage profile improvement | No | No | Yes | Yes | Yes |
| 3 | Line commutated | Yes | No | Yes | No | No |
| 4 | Forced commutated | No | Yes | No | Yes | Yes |
| 5 | Voltage source converter | No | Yes | No | Yes | Yes |
| 6 | Current source converter | Yes | Yes | Yes | No | Yes |
| 7 | Transient and dynamic converter | Yes | Yes | Yes | Yes | No |
| 8 | Damping oscillation | Yes | Yes | Yes | Yes | Yes |
| 9 | Fault current limiting | Yes | No | No | Yes | No |
| 10 | Voltage stability | Yes | Yes | Yes | Yes | Yes |

**Table 2** Problems and their Corrective Measures in the Power System Network [16]

| S. No. | Problems | Associated FACTS Device | Corrective Measures to be Taken |
|---|---|---|---|
| 1 | Parallel line load sharing | SSSC, UPFC, TCSC | Series reactance has to be adjusted |
| 2 | Post-fault power flow sharing | SSSC, UPFC, TCSC | Network reorganization is necessary |
| 3 | Power flow direction reversal | UPFC, SSSC | Phase angle has to be adjusted |
| 4 | Low voltage at heavy loads | STATCOM, SVC | Reactive power is supplied |
| 5 | High voltage at low loads | STATCOM, SVC | Reactive power is taken out |
| 6 | High voltage following at outage | STATCOM, SVC | Absorb reactive power and reduce overloading |
| 7 | Low voltage following at outage | STATCOM, SVC | Reactive power is supplied and overloading is reduced |
| 8 | Transmission circuit overload | SSSC, UPFC, TCSC | Reduce overload |
| 9 | Tripping of Parallel circuits | SSSC, UPFC, TCSC | Limit circuit loading |

## CONCLUSION

This article reviews various FACTS devices and compares their advantages. The need to improve power transmission reliability and performance has led to the development and use of FACTS devices, and over the next decade FACTS controllers are likely to transform the power transmission system, providing reliability, efficiency and better control. These devices use electric current to control the flow of electricity and improve the stability and quality of electrical power. TCSC (Thyristor Controlled Series Capacitor), SSSC (Static Synchronous Series Compensator), SVC (Static Var Compensator), STATCOM (Static Synchronous Compensator), UPFC (Unified Power Flow Controller) and IPFC (Interline Power Flow Control) are commonly used FACTS electronic products. [14]

TCSC devices are often used for power management and security improvements due to their low cost and ease of use. UPFC devices, on the other hand, are complex and expensive, but have many functions such as power control, power flow, and power oscillation damping. Therefore, a comprehensive comparison of the quality and application of these FACTS devices is important for electrical engineers and researchers. In this article, we present two tables comparing the quality and use of these devices, which can help in choosing the most suitable FACTS device for a particular electrical application.

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168_IEC67924

# An Effective Configuration Approach by Reverse Delete Algorithm based on Graph Theory

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***Abstract**: Graph theory application based topological modifications have been possible to reconfigure a mashed network to radial network by operating sensationalizing switches. Benefits of main meshed distribution networks, which include reduced short circuit current, shorter total conductors, and improved fault tolerance, the advantages of the radial networks. Due to its lower power losses an optimum radial network may run more effectively. It is one kind of challenging task to identify the optional redial reconfigure network, Reverse Delete minimum spanning tree algorithm successfully identify the optimum solution with minimum time. This paper successfully implemented the proposed algorithm on mesh network and converted to a radial network topology; and given multiple solutions if faults (single transmission line fault or double line fault) occur in different locations. Two different case studies have been examined on IEEE 14 bus system and IEEE 33 bus system to show the effectiveness of the proposed method. Simulation case study has been made in MATLAB and PSAT software.*

***Keywords:** Graph Theory; Reverse Delete Algorithm; Spanning Tree; Mesh Network; Radial Distribution Network*

## INTRODUCTION

The development of an ideal radial network layout is a complex task. To address this challenge, the Reverse Delete Minimum Spanning Tree (RD-MST) algorithm is explored for its quick discovery of efficient radial network configurations due to its superior time complexity (O((E*(V+E)) + E log E)) where E is the number of edges and V is the number of vertices. compared to Kruskal's and Prim's algorithms. Converting the IEEE 14 bus network from a meshed to a radial configuration[1,4] using this approach demonstrates the potential for optimizing power distribution.

The study investigates the convergence of graph theory, power distribution, and fault management. It explores network reconfiguration towards radial typologies to enhance efficiency, minimize losses, and boost fault tolerance. By developing and evaluating our proposed algorithm on the IEEE 14 bus mesh network and IEEE 33 bus network has been used. The main aim of the proposed approach is that it can be select the optimum MST formation using connected the correct switches to minimize power loss and power system stability. Another aim is to change the minimum switch of the network at faulty condition to reconfigure the operating stages.

## MATHEMATICAL FORMULATION

In this proposed work network configuration can be done by reverse delete algorithm [2] by converting mesh networks to a radial network which is subject to the following objective functions.

### A. Objective Functions

1) Power Balance Constraint

When we convert a mesh network to a radial network, we need to maintain the balance between active and reactive power.

The power balance constraint can be described as follows:

$$\left|\sum_{j\in V_Z}(P_{Gi}-P_{Li})\right| < d \qquad (1)$$

$$\left|\sum_{j\in V_Z}(Q_{Gi}-Q_{Li})\right| < d \qquad (2)$$

where $P_{Gi}$ and $Q_i$ are the injected active and reactive power of the $i^{th}$ bus and $P_{Lj}$ and $Q_{Lj}$ are the drawn active and reactive power of the load from the jth bus, respectively. VZ is a set containing all the buses of the network, Z. Here, P and Q denote the capacity of the active and reactive power, respectively, and d defines error limit for active and reactive power balance of a network.

2) Voltage Constraint

During configuration of a network in power system it's crucial to determine the voltage constraints for maintaining stable operation. These constraints are determined to ensure that at different nodes or buses voltage levels do not exceed the predefined limits.

3) Feeder Capacity Constraint

In power system feeder capacity constraints define the limitations on the maximum amount of power which can be carried by a feeder line according to its design and specifications. During configuration of network, it is essential to contemplate these constraints to avoid overload situation.

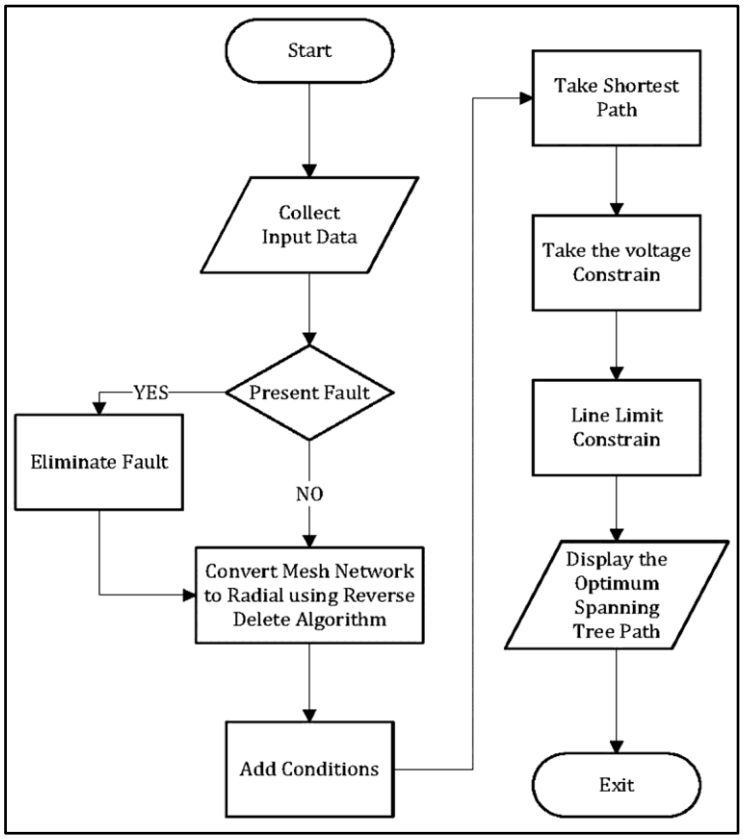


**Figure 1** Flowchart of the working principle

**B. Switching Table**

A switching table in power systems is a comprehensive plan or document that outlines the necessary sequence and

configuration of switchgear operations during the restoration or reconfiguration of an electric power system. It details the specific switches, breakers, and other control devices that need to be manipulated to reroute or restore the flow of electrical power in the event of a fault, outage, or planned maintenance. The switching table of our system is mentioned in **Table I**, in which bus number 1 and bus number 2 are connected to switch S1, similarly bus number 1 and 5 are connected to switch S2 and so on.

**Table I** Total switch allocation

| From Bus | To Bus | Switch numbers | From Bus | To Bus | Switch numbers | From Bus | To Bus | Switch numbers |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | S1 | 4 | 7 | S8 | 7 | 9 | S15 |
| 1 | 5 | S2 | 4 | 9 | S9 | 9 | 10 | S16 |
| 2 | 3 | S3 | 5 | 6 | S10 | 9 | 14 | S17 |
| 2 | 4 | S4 | 6 | 11 | S11 | 10 | 11 | S18 |
| 2 | 5 | S5 | 6 | 12 | S12 | 12 | 13 | S19 |
| 3 | 4 | S6 | 6 | 13 | S13 | 13 | 14 | S20 |
| 4 | 5 | S7 | 7 | 8 | S14 | | | |

The overview of the whole paper has been represented in the flowchart in **Figure 1**.

## RESULT AND IMPLEMENTATION

The IEEE 14 [3] bus system is shown in **Figure 3**. The data given in the following tables is on 100MVA base. The minimum and maximum limits of voltage magnitude and phase angle are 0.95p.u. to 1.05p.u. and -45◦ to +45◦ respectively.

### A. Case Study

The IEEE 14 bus system was examined through a case study wherein all switches were initially closed. Utilizing the reverse delete algorithm, a new network was derived by selectively opening switches. This process aimed to attain an optimal radial configuration for the system. The algorithm's iterative approach of removing edges from the existing network while maintaining radial structure contributed to achieving an efficient and effective system layout. The resultant configuration signifies a refined network design that ensures enhanced operational resilience and functionality within the IEEE 14 bus system.

1) Case 1: Without Fault Situation

The analysis conducted on the Distribution Load Flow focused on evaluating the L-Index, representing voltage stability, and the Active Power Loss (P Loss) and Reactive Power Loss (Q Loss). The obtained values of 0.9816, 0.4301 p.u., and 1.2882 p.u. respectively, portray crucial insights into the system's operational efficiency.

2) Case 2: With Fault Situation

The analysis conducted on the Distribution Load Flow focused on evaluating the L-Index, representing voltage stability, and the Active Power Loss (P Loss) and Reactive Power Loss (Q Loss).

a) Case 2.1: Single fault situation

To assess the impact of a single fault, each bus or node was subjected to a fault condition, and the resultant configuration with open switches was analyzed, recording the corresponding L-Index, P Loss, and Q Loss in **Table 2**. illustrates the relationship between Fault Bus Number and the observed values of L-Index, P Loss, and Q Loss are 0.9547 p.u., 0.2039 p.u., 0.6401 p.u. respectively. The optimum values obtained from the above method respectively. The following Sectionalizing switches are disconnected S2, S4, S6, S9, S10, S19, S20 and rest of the switches remained connected in these circumstances the L-Index value is 0.9547.

**Table 2** Overall analysis report with single fault condition

| Fault Bus Numbers | Switches that are open | LINDEX | P loss | Q loss |
|---|---|---|---|---|
| 2-3 | S2, S3, S4, S9, S10, S19, S20 | 0.9816 | 0.4301 | 1.2882 |
| 2-4 | S2, S3, S4, S9, S10, S19, S20 | 0.9816 | 0.4301 | 1.2882 |
| 3-4 | S2, S4, S6, S9, S10, S19, S20 | 0.9547 | 0.2039 | 0.6401 |
| 2-5 | S2, S3, S5, S9, S10,19, S20 | 0.9951 | 0.3805 | 1.1273 |
| 1-5 | S2, S3, S4, S9.S10.S19, S20 | 0.9816 | 0.4301 | 1.2882 |
| 1-2 | S1, S3, S4, S9, S10, S19, S20 | 0.9937 | 0.3203 | 1.1689 |
| 9-14 | S2, S3, S4, S9, S10, S17, S19 | 0.9795 | 0.4397 | 1.3079 |
| 9-10 | S2, S3, S4, S9, S19, S20 | 0.9897 | 0.4194 | 1.1968 |
| 6-11 | S2, S3, S4, S9, S11, S19, S20 | 0.9799 | 0.4413 | 1.3033 |
| 6-13 | S2, S3, S4, S9, S10, S13, S20 | 0.9810 | 0.4315 | 1.2951 |
| 6-12 | S2, S3, S4, S9, S10, S12, S20 | 0.9838 | 0.4243 | 1.2668 |
| 13-14 | S2, S3, S4, S9, S10, S19, S20 | 0.9816 | 0.4301 | 1.2882 |

b) Case 2.2: Double fault situation

In this case the fault is created in 2 connections 6-12 & 2-3 for which the following sectional switches are disconnected S2, S3, S4, S9, S10, S12, S20. After using the proposed method, the obtained L-Index, P Loss & Q Loss values are 0.9838p.u., 0.4243 p.u. and 1.1273 p.u. respectively.

**Table 3** Overall analysis report with double fault condition

| Fault Bus Numbers | Switches that are open | LINDEX | P loss | Q Loss |
|---|---|---|---|---|
| 2-3, 2-5 | S2, S3, S5, S9, S10, S19, S20 | 0.9951 | 0.3805 | 1.1273 |
| 6-12, 2-3 | S2, S3, S4, S9, S10, S12, S20 | 0.9838 | 0.4243 | 1.2668 |

c) Case 2.3: Triple fault situation

In this case the fault is created in 2 connections 10-11, 7-9 & 3-4 for which the following sectional switches are disconnected S2, S3, S4, S9, S10, S12, S20. After using the proposed method, the obtained L-Index, P Loss & Q Loss values are 0.9515 p.u., 0.2273 p.u. and 0.6208 p.u. respectively.

**Table 4** Overall analysis report with triple fault condition

| Fault Bus Numbers | Switches that are open | LINDEX | P loss | Q loss |
|---|---|---|---|---|
| 2-3, 2-5, 12-13 | S2, S3, S5, S9, S10, S19, S20 | 0.9951 | 0.3805 | 1.1273 |
| 10-11, 7-9, 3-4 | S2, S4, S6, S9, S15, S18, S19 | 0.9515 | 0.2273 | 0.6208 |

In this section, Case I discusses the analysis of 14 bus mesh network without radial configuration. Case II discusses the comparative fault analysis of Single Fault Configuration, Double Fault Configuration and Triple Fault Configuration which is in radial configuration.

3) Case 3: Comparative Analysis

In this case study the voltage profile and phase angle data are derived from the IEEE 14 bus system data. Different case studies have been considered here like initial network configuration, reconfiguring the initial network to MST network along with single fault, double fault, and triple fault situations.

a) Case 3.1: Voltage analysis

In **Figure 2** the voltage profile of each node before and after fault in different location has been shown in the above mentioned 5 scenarios.

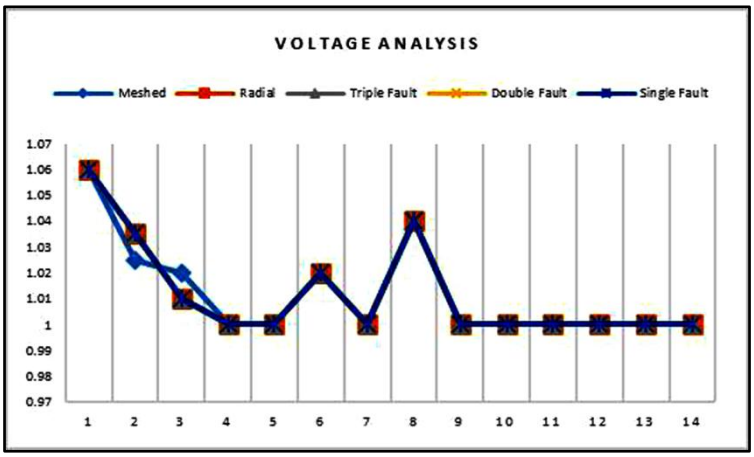


**Figure 2** Voltage Analysis of IEEE 14 Bus System

b) Case 3.2: Phase angle analysis

Similarly in **Figure 3** the phase angle of each node has been shown before and after fault in different location.

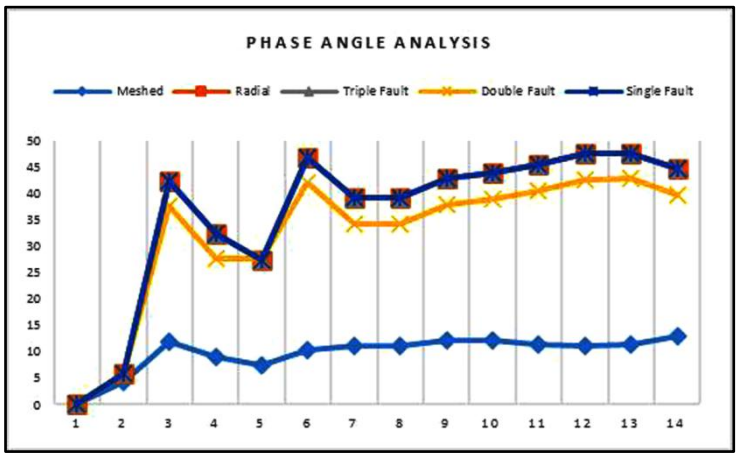


**Figure 3** Phase Angle Analysis of IEEE 14 Bus System

## CONCLUSION

On a network where various fault scenarios were taken into consideration, a network reconfiguration scheme based on the Reverse Delete algorithm has been implemented. With the least amount of loss and maximum load restored in accordance with available resources, the suggested algorithm effectively produced an optimally reconstructed radial network that supplied power via the shortest path. According to the case studies, a power system operator can quickly identify the best reconfiguration as well as restoration plans for emergency power outages with the aid of the recommended technique. A modified IEEE 14 bus system is used to productively evaluate the suggested algorithm, which may also be used to monitor the voltage profile response.

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286_IEC88714

# Modern Concept and Analysis of Power System Stability Improvement by State Estimation and Soft Computing Technique

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***Abstract:*** *The power system stability analysis is vital for the power grid. The Power system stability of an interconnected power system is its ability to return to regular or stable operation after having a specific disturbance. Power system stability analysis is critical to future planning and design of power systems. State estimation plays a vital role in monitoring and controlling modern power systems. The load flow analysis is the aim of state estimation to obtain the best possible values of the bus voltage magnitudes and angles by processing the available network data. Power system stability, theoretical and practical, is essential in the power grid for analysis of reliability and efficiency. So, every power system state must analyze and correct transient faults. Modern approaches to state estimation and soft computing techniques directly apply to the real world. State Estimation involves estimating the current operating conditions of a power system based on available measurements such as voltage, current, power flow, load angle, etc. Advanced estimation techniques include Kalman filtering, extended filtering uses, and recent studies involving soft computing techniques to obtain accurate and real-time information about the system's state. Here, we tested these conditions in an IEEE 30 bus system where all situations are created as a real system grid network. When loads are distributed in distribution lines, balanced supply is hampered, i.e., steady-state supply is hampered, and load flow studies will solve these problems. Here, we first optimized the condition using the Newton-Raphson method, but it is seen that the solution is not optimized, so particle swarm optimization (PSO) and Ant Colony Optimization. Techniques (ACO) are used. These techniques have several benefits: enhanced accuracy, real-time optimization, and robustness[1].*

***Keywords:*** *Power System Stability; State Estimation; Weighted Least Square Method; Particle Swarm Optimization*

## INTRODUCTION

Recent advancements in power system stability improvement emphasize using advanced algorithms and data-driven approaches; Machine learning and artificial intelligence techniques are applied to large datasets and extract valuable conditions for enhancing stability[2]. Overall, the modern concept of improving stability is the contingency analysis. So below flow chart shown why state estimation is important.

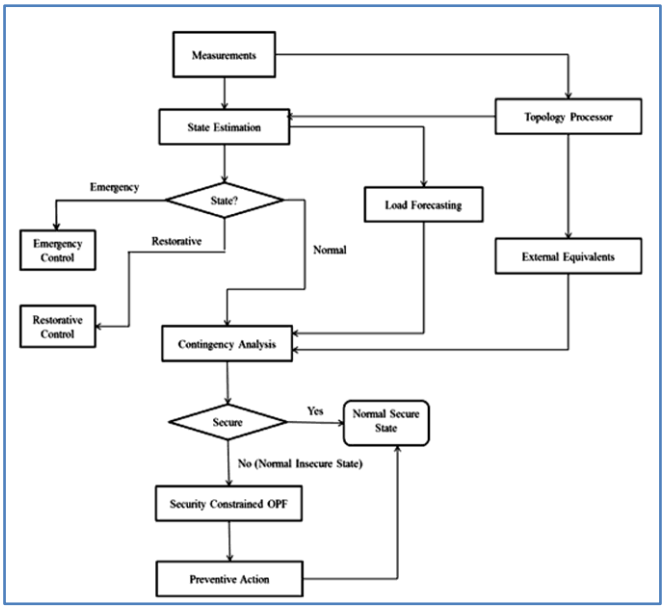



**Figure** Online static security analysis

## THE MEASUREMENT FUNCTIONS

### The Mathematical Analysis

A generalized formulation of the static state estimator using the WLS method utilizes five different types of conventional measurements for estimating the state of the system. The structure of the measurement vector, z, is given below:

$$Z = \begin{bmatrix} P_{inj} \\ Q_{inj} \\ P_{flow} \\ Q_{flow} \\ V_{mag} \end{bmatrix} \qquad (2.1)$$

where $P_{inj}Q_{inj}P_{flow}Q_{flow}$ are the vectors of active and reactive injection measurements and flow measurements, and V is the vector of voltage magnitude measurements. The conventional measurements are related to the states using a set of nonlinear functions as given in (2.2):

$$Z = h(x) + e(x) \qquad (2.2)$$

where x is the state vector that consists of voltage angles and magnitudes of all buses in the network, h is the vector of nonlinear functions relating the measurements and the states, and e is the vector of Gaussian errors. Note that since the conventional measurements are not synchronised like the PMU measurements, the slack bus is set usually as the reference bus. The angle of the reference bus is set at 0, and it is excluded from the state vector. Assuming the network parameters are known, the measurement equations for the five types of conventional measurement are based on the network structure in **Figure 2-3** and are expressed as follows:

• Real and reactive power injection measurements

$$P_i = V_i \sum_{j=1}^{N} V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) \qquad (2.3)$$

$$Q_i = V_i \sum_{j=1}^{N} V_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) \qquad (2.4)$$

• Real and reactive power flow measurements

$$P_{ij} = \frac{V_i^2}{a_{ij}^2}(g_{si} + g_{ij}) - \frac{V_i V_j}{a_{ij}}(g_{ij} \cos\theta_{ij} + b_{ij} \sin\theta_{ij}) \qquad (2.5)$$

$$Q_{ij} = -\frac{V_i^2}{a_{ij}^2}(b_{si} + b_{ij}) - \frac{V_i V_j}{a_{ij}}(g_{ij} \sin\theta_{ij} - b_{ij} \cos\theta_{ij}) \qquad (2.6)$$

$$P_{ji} = V_j^2(g_{sj} + g_{ij}) - \frac{V_j V_i}{a_{ij}}(g_{ij} \cos\theta_{ji} + b_{ij} \sin\theta_{ji}) \qquad (2.7)$$

$$Q_{ji} = -V_j^2(b_{sj} + b_{ij}) - \frac{V_j V_i}{a_{ij}}(g_{ij} \sin\theta_{ji} - b_{ij} \cos\theta_{ji}) \qquad (2.8)$$

• Voltage magnitude measurements

$$V_i = V_i \qquad (2.9)$$

where $G_{ij}$ and $B_{ij}$ are the real and imaginary parts of the $ij^{th}$ element of the network admittance matrix, respectively, gij and $b_{ij}$ are the conductance and susceptance of the transmission line, respectively, $g_{si}$ and $b_{si}$ are the shunt conductance and shunt susceptance of the shunt branch, respectively, and $a_{ij}$ is the tap ratio of the transformer

connecting Bus i and Bus j.

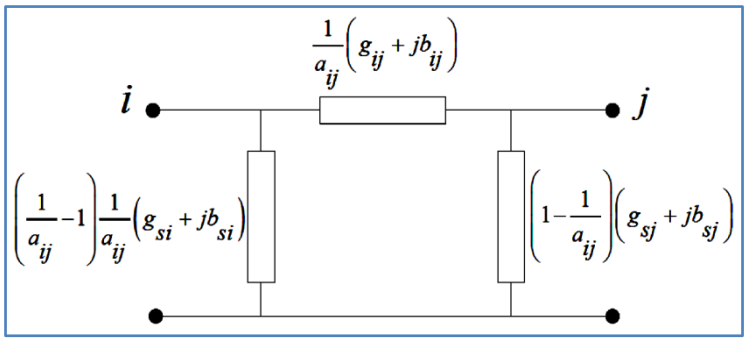



**Figure 2-3** Transmission Line Represented in Pi Equivalent Model

The WLS Objective Function and Its Optimal Solution

According to the MLE theory, the optimal estimate of the state from the measurement **Equation (2.2)** is achieved when the following WLS objective function is minimised:

$$J(\mathbf{x})=\left[\mathbf{z}-\mathbf{h}(\mathbf{x})\right]^{T}\cdot\mathbf{R}^{-1}\cdot\left[\mathbf{z}-\mathbf{h}(\mathbf{x})\right] \qquad (2.10)$$

where R is the covariance matrix of the error vector, e. The minimum of the objective function is found when its first derivative is zero:

$$\frac{\partial J^{T}(\mathbf{x})}{\partial \mathbf{x}}=-2\mathbf{H}^{T}\mathbf{R}^{-1}\cdot\left[\mathbf{z}-\mathbf{h}(\mathbf{x})\right]=\mathbf{0}$$
$$\Rightarrow \mathbf{m}(\mathbf{x})=\mathbf{H}^{T}\mathbf{R}^{-1}\left[\mathbf{z}-\mathbf{h}(\mathbf{x})\right]=\mathbf{0} \qquad (2.11)$$

Where H is the Jacobian matrix of the measurement to state function, h. Since the derived objective function, m(x), is still nonlinear, it has to be iteratively solved using the Newton- Raphson method. The iteration steps are derived as given in (2.12) and (2.13).

$$\mathbf{M}=\frac{\partial \mathbf{m}^{T}(\mathbf{x})}{\partial \mathbf{x}}=-\mathbf{H}^{T}\mathbf{R}^{-1}\mathbf{H} \qquad (2.12)$$

$$\Delta\mathbf{x}^{k}=-\mathbf{M}^{-1}\mathbf{g}\left(\mathbf{x}^{k}\right)=\left(\mathbf{H}^{T}\mathbf{R}^{-1}\mathbf{H}\right)^{-1}\mathbf{H}^{T}\mathbf{R}^{-1}\left[\mathbf{z}-\mathbf{h}(\mathbf{x})\right]$$
$$=\left[\mathbf{G}\left(\mathbf{x}^{k}\right)\right]^{-1}\mathbf{t}^{k} \qquad (2.13)$$

$$\mathbf{G}\left(\mathbf{x}^{k}\right)=\mathbf{H}\left(\mathbf{x}^{k}\right)^{T}\mathbf{R}^{-1}\mathbf{H}\left(\mathbf{x}^{k}\right) \qquad (2.14)$$

$$\mathbf{t}^{k}=\mathbf{H}^{T}\mathbf{R}^{-1}\left[\mathbf{z}^{k}-\mathbf{h}\left(\mathbf{x}^{k}\right)\right] \qquad (2.15)$$

$$\mathbf{G}\left(\mathbf{x}^{k}\right)\Delta\mathbf{x}^{k}=\mathbf{t}^{k} \qquad (2.16)$$

where G($\mathbf{X^k}$) is the Gain Matrix, $\Delta\mathbf{X^k}=\mathbf{X^{k+1}}-\mathbf{X^k}$ is the difference of the state estimate between iterations, and (2.16) is referred to as the Normal Equations. The iteration terminates when $\Delta x_{k+1}$ is below a pre-defined threshold.

The gain matrix can be used for observability analysis of the network, and it is crucial for static state estimation as its inversion is the most computational demanding part. According to [4], the gain matrix has the following properties:

- It is structurally and numerically symmetric.
- It is sparse, yet less sparse compared to H.

- In general it is a non-negative definite matrix, i.e. all of its eigenvalues are non-negative. It is positive definite for fully observable networks.

The sparsity of the gain matrix can be exploited to improve the computational efficiency and reduce the memory requirement. Details of the technique are given in [4].

The Measurement Jacobian Matrix

The measurement Jacobian matrix, H, as defined after (2.11) has the following structure:

$$\mathbf{z} = \begin{bmatrix} \frac{\partial \mathbf{P}_{inj}}{\partial \boldsymbol{\theta}} & \frac{\partial \mathbf{P}_{inj}}{\partial \mathbf{V}} \\ \frac{\partial \mathbf{Q}_{inj}}{\partial \boldsymbol{\theta}} & \frac{\partial \mathbf{Q}_{inj}}{\partial \mathbf{V}} \\ \frac{\partial \mathbf{P}_{flow}}{\partial \boldsymbol{\theta}} & \frac{\partial \mathbf{P}_{flow}}{\partial \mathbf{V}} \\ \frac{\partial \mathbf{Q}_{flow}}{\partial \boldsymbol{\theta}} & \frac{\partial \mathbf{Q}_{flow}}{\partial \mathbf{V}} \\ \mathbf{0} & \frac{\partial \mathbf{V}_{mag}}{\partial \mathbf{V}} \end{bmatrix} \qquad (2.17)$$

Based on the transmission line model shown in **Figure 2-3**, the expressions for each partition are given below:

1. Jacobian elements of the real power injection measurements:

$$\frac{\partial P_i}{\partial \theta_i} = -V_i \sum_{j=1}^{N} V_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) - V_i^2 B_{ii} \qquad (2.18)$$

$$\frac{\partial P_i}{\partial \theta_j} = V_i V_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) \qquad (2.19)$$

$$\frac{\partial P_i}{\partial V_i} = \sum_{j=1}^{N} V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) + V_i G_{ii} \qquad (2.20)$$

$$\frac{\partial P_i}{\partial V_j} = V_i (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) \qquad (2.21)$$

2. Jacobian elements of the reactive power injection measurements:

$$\frac{\partial Q_i}{\partial \theta_i} = V_i \sum_{j=1}^{N} V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) - V_i^2 G_{ii} \qquad (2.22)$$

$$\frac{\partial Q_i}{\partial \theta_j} = -V_i V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) \qquad (2.23)$$

$$\frac{\partial Q_i}{\partial V_i} = \sum_{j=1}^{N} V_j (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) - V_i B_{ii} \qquad (2.24)$$

$$\frac{\partial Q_i}{\partial V_j} = V_i (G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij}) \qquad (2.25)$$

3. Jacobian elements of the active power flow measurements:

$$\frac{\partial P_{ij}}{\partial \theta_i} = -\frac{V_i V_j}{a_{ij}}(-g_{ij}\sin\theta_{ij} + b_{ij}\cos\theta_{ij}) \quad (2.26)$$

$$\frac{\partial P_{ij}}{\partial \theta_j} = -\frac{V_i V_j}{a_{ij}}(g_{ij}\sin\theta_{ij} - b_{ij}\cos\theta_{ij}) \quad (2.27)$$

$$\frac{\partial P_{ij}}{\partial V_i} = 2\frac{V_i}{a_{ij}^2}(g_{si} + g_{ij}) - \frac{V_j}{a_{ij}}(g_{ij}\cos\theta_{ij} + b_{ij}\sin\theta_{ij}) \quad (2.28)$$

$$\frac{\partial P_{ij}}{\partial V_j} = -\frac{V_i}{a_{ij}}(g_{ij}\cos\theta_{ij} + b_{ij}\sin\theta_{ij}) \quad (2.29)$$

4. Jacobian elements of the reactive power flow measurements:

$$\frac{\partial Q_{ij}}{\partial \theta_i} = -\frac{V_i V_j}{a_{ij}}(g_{ij}\cos\theta_{ij} + b_{ij}\sin\theta_{ij}) \quad (2.30)$$

$$\frac{\partial Q_{ij}}{\partial \theta_j} = \frac{V_i V_j}{a_{ij}}(g_{ij}\cos\theta_{ij} + b_{ij}\sin\theta_{ij}) \quad (2.31)$$

$$\frac{\partial Q_{ij}}{\partial V_i} = -2\frac{V_i}{a_{ij}^2}(b_{si} + b_{ij}) - \frac{V_j}{a_{ij}}(g_{ij}\sin\theta_{ij} - b_{ij}\cos\theta_{ij}) \quad (2.32)$$

$$\frac{\partial Q_{ij}}{\partial V_j} = -\frac{V_i}{a_{ij}}(g_{ij}\sin\theta_{ij} - b_{ij}\cos\theta_{ij}) \quad (2.33)$$

5. Jacobian elements of the voltage magnitude measurements:

$$\frac{\partial V_i}{\partial V_i} = 1 \quad (2.34)$$

$$\frac{\partial V_i}{\partial \theta_i} = \frac{\partial V_i}{\partial \theta_j} = \frac{\partial V_i}{\partial V_j} = 0 \quad (2.35)$$

The WLS State Estimation Algorithm

Based on the network model and the mathematical models given in the previous sub-sections, the algorithm for WLS state estimation is outlined as follows [4]:

1. Start iterations, set the iteration index k = 0.
2. Initialize the state vector $X^k$ typically as a flat start (all voltage angles equal to 0, and all voltage magnitudes equal to 1).
3. Formulate the Jacobian matrix, H, according to (2.17) to (2.35).
4. Calculate the gain matrix, $G(X^k)$, using (2.14).
5. Calculate the estimated measurements based on $X^k$,, $h(X^k)$, according to (2.1) to (2.9).
6. Calculate the right hand side **tk** using (2.15).
7. Decompose $G(X^k)$ and solve for $\Delta X^k$ using (2.13).
8. Test for convergence, max $(|\Delta X^k|) \leq \varepsilon$ ?
9. If Step 8 is not satisfied, update $X^{k+1} = X^k + \Delta X^k$, k = k + 1, and go to Step 3. Else stop and output the state estimate.

So, online monitoring using state estimation techniques is vital for security analysis. But output result is not the upto the mark so when we changed our algorithm with other optimisation techniques PSO,ANT colony or Machine

learning then we see that our output functions are nearer to the Threshold value. Here we are discussing a part of our hybrid algorithm which is different and optimised the target values without hampering normal operations. Our algorithm is based on PSO and WLS method (HPSOWLS).

Overall, the modern concept of power system stability improvement involves the integration of state estimation and soft computing techniques to achieve robust, real-time optimization of grid stability, ensuring reliable and efficient operation in the face of diverse challenges and disturbances. The relationship between stability and state estimation optimization in power systems is fundamental for guaranteeing electrical grids' reliable and efficient operation. Now, we discussed how stability and state estimation optimization are related[3][4].

State estimation process provide us real time information about PS network operating conditions, including voltages, currents and power flows. Accurate state estimation enables better understanding and analysis of the system's stability characteristics, findings the operators' issues and take preventive or corrective actions to maintained stability. In our research is a bridge between in complete work done by previous researchers' researchers with new concept. We are mainly focused on mainly below mentioned points for taken corrective actions.

- Modern concept of State estimation for enhancing Steady state and dynamic stability Analysis.
- State estimation for stability Assessment
- Feedback control
- Optimisation of parameters.

New Innovative Methodology

Our methodology based on hybrid techniques of hardware and software combination and optimisation are tested by HPSWSE (Hybrid Particle Swarm Weighted State Estimation); PSO is a computational techniques that uses a population of particles to find optimal solution to a problem, its inspired by the collective behaviour of social animals such as birds, fish or ant work together to find a solution but simply finding solution of social animals is very difficult if any one is out of their folk then it is very difficult to identified that correct path which others are followed or to find the displaced or divert flock will creates problems to main paths and a quartic disbalanced problems can occurred which is very difficult to identifying displaced path or disturbance of main floks, if they getting the solution or optimise their path, it is required more time to find shortest path or mitigrationg their problems. Whereas WLS (Weighted least Squared) method is comparative better then PSO as it is statisticle methods where errors are updated automatically from a threshold value how much is diverted from original value.

$$J(\mathbf{x}) = \left[\mathbf{z} - \mathbf{h}(\mathbf{x})\right]^T \cdot \mathbf{R}^{-1} \cdot \left[\mathbf{z} - \mathbf{h}(\mathbf{x})\right] \qquad (2.35)$$

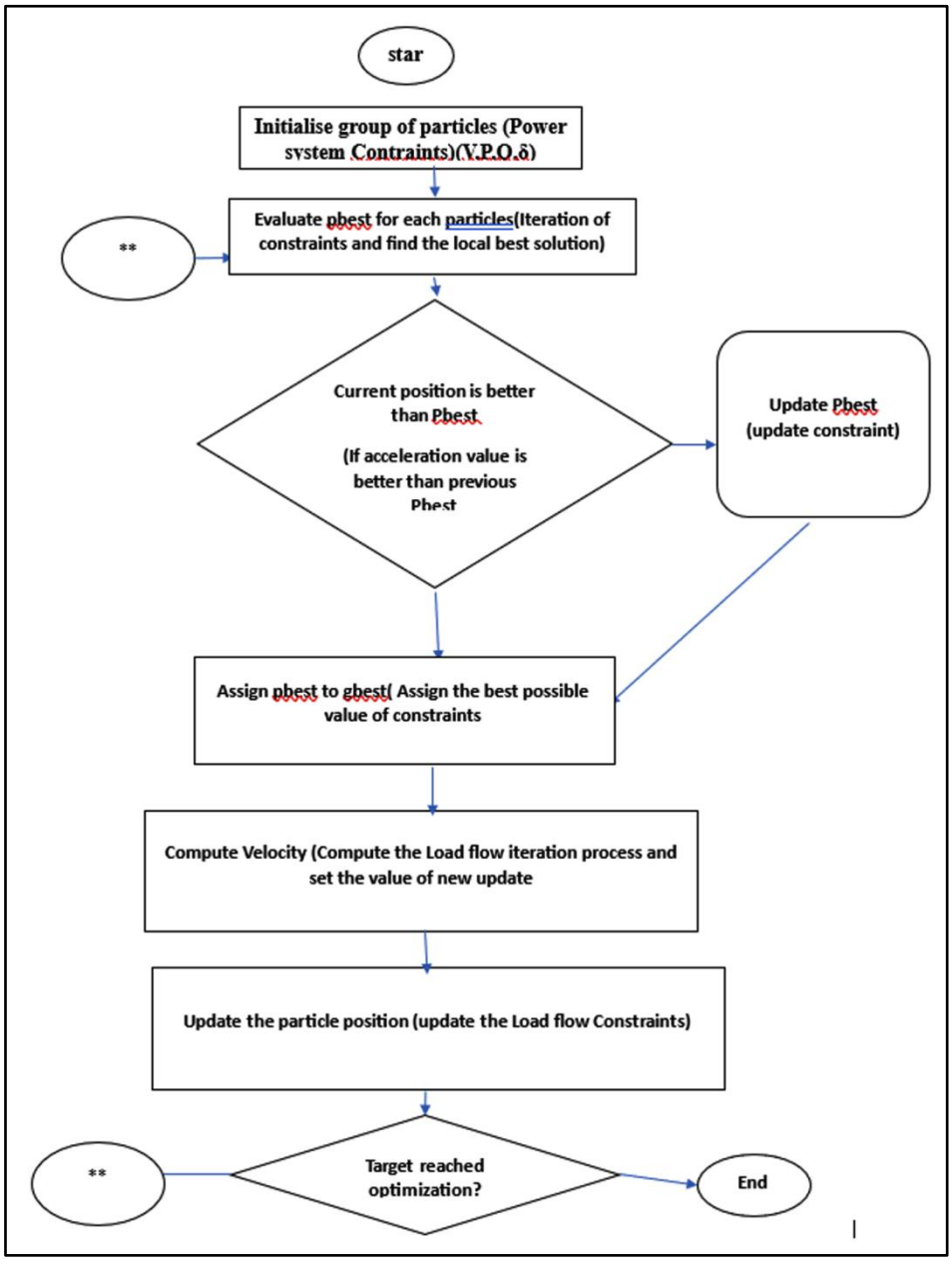
So here we are mixing two algorithm and find a most suitable logic

General flow of algorithm is changed in few steps if any social flock is diverted from his path then error path is calculated then find local best solution and after that they are trying to find the Global best solution by updating each state errors to achieve finally global best solution. So algorithm has been changed to[6][7]

1. Initialization of xi(Pi),Vi(Voltage),iteration, pbest, gbest. Etc
2. Generate random variables (particles)(P)
3. For each particle (i)
4. Calculate Fitness function by variance calculation and WLS by **Equation 2.35**
5. Update Pbest and gbest.
6. End for
7. While iteration
8. For each particle(i)
9. Update Vi, Xi.
10. If Xi> limit then Xi=limit
11. Calculate fitness function fi

12. Update pbest ,gbest
13. Minimise Standard Error by Standard devision
14. Calculate deviation of gbest
15. If div < gbest acc then stop
16. Otherwise continuing solution process

Modern approaches to optimizing power system stability through state estimation and soft computing techniques involve the integration of advanced algorithms and methodologies to enhance the reliability and efficiency of electrical grids[9][10]




Here's an overview of our optimization techniques:

1.**Network Formulation** — As our grid network is mixing of generation transmission and distribution network. Here we are taking IEEE standard bus data, Load data for formulation of Bus network.

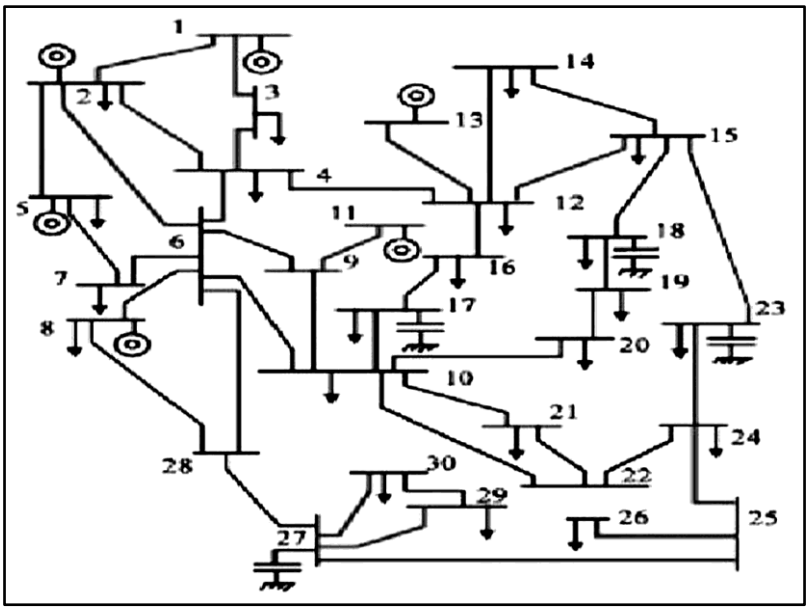



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Figure IEEE39 bus system. Our model is tested in ETAP and Mat-Lab simulation in below techniques. Extended Kalman Filter(EKF),Particle Swarm Optimization(PSO) and Sequential Monte Carlo(SMC) with non linear system models. It optimizes the performance of state estimation algorithams by tuning parameters and improving convergence speed and with less no of iteration system will be optimize and online monitoring will be continuing though system will fall small signal disturbance.

Simulation & Result Analysis

By integrating these modern optimization techniques with state estimation and soft computing approaches, power system operators can improve electrical grids' stability, reliability, and efficiency in the face of dynamic operating conditions and uncertainties. Modern approaches to optimizing power system stability through state estimation techniques involve using advanced algorithms and methodologies to accurately estimate the system's operating state.

With modern state estimation techniques, power system operators can obtain accurate and timely information about the operating state of the grid, enabling effective monitoring, control, and optimization of power system stability. Optimization techniques are essential for ensuring power systems' efficient, reliable, and sustainable operation in the face of increasing complexity, uncertainty, and environmental challenges. They provide decisionmakers with valuable tools for managing resources, improving stability, and meeting diverse operational and regulatory Objectives.

By delving into these aspects, researchers and practitioners can comprehensively understand state estimation techniques in power systems and their role in ensuring electrical grids' reliability, stability, and efficiency IEEE bus data analysis is crucial for various power system analysis and operation aspects. For System Planning and Design, Load Flow Analysis, Fault Analysis and Protection Coordination, Transient Stability Assessment, Voltage Stability Analysis, Optimal Operation and Control, and ensuring reliable and efficient grid operation, Grid Resilience and Reliability. Our Test System is an IEEE 30 bus system. We tested our model in ETAP software and analysed the dynamic stability condition in different contingency conditions. We also found network validation and optimization of output results (Voltage, power flow, frequency, torque angle). The figure below shows how we implement our concept in a natural system.

IEEE 33 Bus System Load Flow Analysis for Power System State Estimation

Case 1: The standard data are in **Table 1** (Bus Data & Cable Data) and **Table 2** (Load Data).

**Table 1** IEEE bus data (Input Data)

| bus data | | cable data | | | | | | |
|---|---|---|---|---|---|---|---|---|
| bus no | nominal voltage | cable | from | to | resistance | reactance | length | ohm per |
| 1 | 11 | 1 | 1 | 2 | 0.0922 | 0.0477 | 1000 m | 100 m |
| 2 | 11 | 2 | 2 | 3 | 0.493 | 0.2511 | 2000 m | 100 m |
| 3 | 11 | 3 | 3 | 4 | 0.366 | 0.1864 | 1000 m | 100 m |
| 4 | 11 | 4 | 4 | 5 | 0.3811 | 0.1941 | 2000 m | 100 m |
| 5 | 11 | 5 | 5 | 6 | 0.819 | 0.707 | 1000 m | 100 m |
| 6 | 11 | 6 | 6 | 7 | 0.1872 | 0.6188 | 1000 m | 100 m |
| 7 | 11 | 7 | 7 | 8 | 1.7114 | 1.2351 | 1000 m | 100 m |
| 8 | 11 | 8 | 8 | 9 | 1.03 | 0.74 | 1000 m | 100 m |
| 9 | 11 | 9 | 9 | 10 | 1.04 | 0.74 | 2000 m | 100 m |
| 10 | 11 | 10 | 10 | 11 | 0.1966 | 0.065 | 2000 m | 100 m |
| 11 | 11 | 11 | 11 | 12 | 0.3744 | 0.1238 | 1000 m | 100 m |
| 12 | 11 | 12 | 12 | 13 | 1.468 | 1.155 | 1000 m | 100 m |
| 13 | 11 | 13 | 13 | 14 | 0.5416 | 0.7129 | 3000 m | 100 m |
| 14 | 11 | 14 | 14 | 15 | 0.591 | 0.526 | 3000 m | 100 m |
| 15 | 11 | 15 | 15 | 16 | 0.7463 | 0.545 | 2000 m | 100 m |
| 16 | 11 | 16 | 16 | 17 | 1.289 | 1.721 | 2000 m | 100 m |
| 17 | 11 | 17 | 17 | 18 | 0.732 | 0.574 | 1000 m | 100 m |
| 18 | 11 | 18 | 2 | 19 | 0.164 | 0.1565 | 1000 m | 100 m |
| 19 | 11 | 19 | 19 | 20 | 1.5042 | 1.3554 | 3000 m | 100 m |
| 20 | 11 | 20 | 20 | 21 | 0.4095 | 0.4784 | 3000 m | 100 m |
| 21 | 11 | 21 | 21 | 22 | 0.7089 | 0.9373 | 2000 m | 100 m |
| 22 | 11 | 22 | 3 | 23 | 0.4512 | 0.3083 | 2000 m | 100 m |
| 23 | 11 | 23 | 23 | 24 | 0.898 | 0.7091 | 1000 m | 100 m |
| 24 | 11 | 24 | 24 | 25 | 0.896 | 0.7011 | 1000 m | 100 m |
| 25 | 11 | 25 | 6 | 26 | 0.203 | 0.1034 | 3000 m | 100 m |
| 26 | 11 | 26 | 26 | 27 | 0.2842 | 0.1447 | 3000 m | 100 m |
| 27 | 11 | 27 | 27 | 28 | 1.059 | 0.9337 | 2000 m | 100 m |
| 28 | 11 | 28 | 28 | 29 | 0.8042 | 0.7006 | 2000 m | 100 m |
| 29 | 11 | 29 | 29 | 30 | 0.5075 | 0.2585 | 1000 m | 100 m |
| 30 | 11 | 30 | 30 | 31 | 0.9744 | 0.963 | 1000 m | 100 m |
| 31 | 11 | 31 | 31 | 32 | 0.3105 | 0.3619 | 3000 m | 100 m |
| 32 | 11 | 32 | 32 | 33 | 0.341 | 0.5302 | 3000 m | 100 m |

**Table 2** IEEE Load data (Input Data)

| LOAD DATA | | | |
|---|---|---|---|
| SERIAL NO | BUS ID | ACTIVE POWER (KW) | REACTIVE POWER (KVAR) |
| 1 | 2 | 100 | 60 |
| 2 | 3 | 90 | 40 |
| 3 | 4 | 120 | 80 |
| 4 | 5 | 60 | 30 |
| 5 | 6 | 60 | 20 |
| 6 | 7 | 200 | 100 |
| 7 | 8 | 200 | 100 |
| 8 | 9 | 60 | 20 |
| 9 | 10 | 60 | 20 |
| 10 | 11 | 45 | 30 |
| 11 | 12 | 60 | 35 |
| 12 | 13 | 60 | 35 |
| 13 | 14 | 120 | 80 |
| 14 | 15 | 60 | 10 |
| 15 | 16 | 60 | 20 |
| 16 | 17 | 60 | 20 |
| 17 | 18 | 90 | 40 |
| 18 | 19 | 90 | 40 |
| 19 | 20 | 90 | 40 |
| 20 | 21 | 90 | 40 |
| 21 | 22 | 90 | 40 |
| 22 | 23 | 90 | 50 |
| 23 | 24 | 420 | 200 |
| 24 | 25 | 420 | 200 |
| 25 | 26 | 60 | 25 |
| 26 | 27 | 60 | 25 |
| 27 | 28 | 60 | 20 |
| 28 | 29 | 120 | 70 |
| 29 | 30 | 200 | 600 |
| 30 | 31 | 150 | 70 |
| 31 | 32 | 210 | 100 |
| total | | 3655 | 2260 |
| square root sum = | | | 4297.281117 |

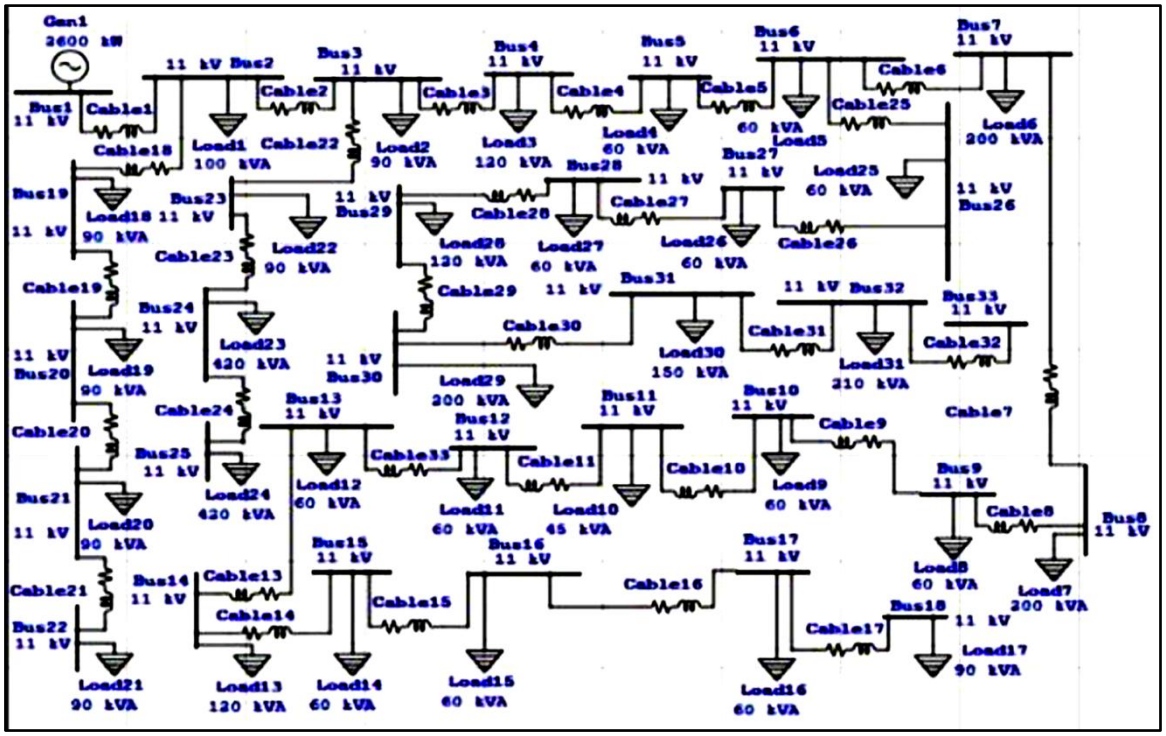



**Figure 1** shows the Test system of IEEE -30 bus Test System

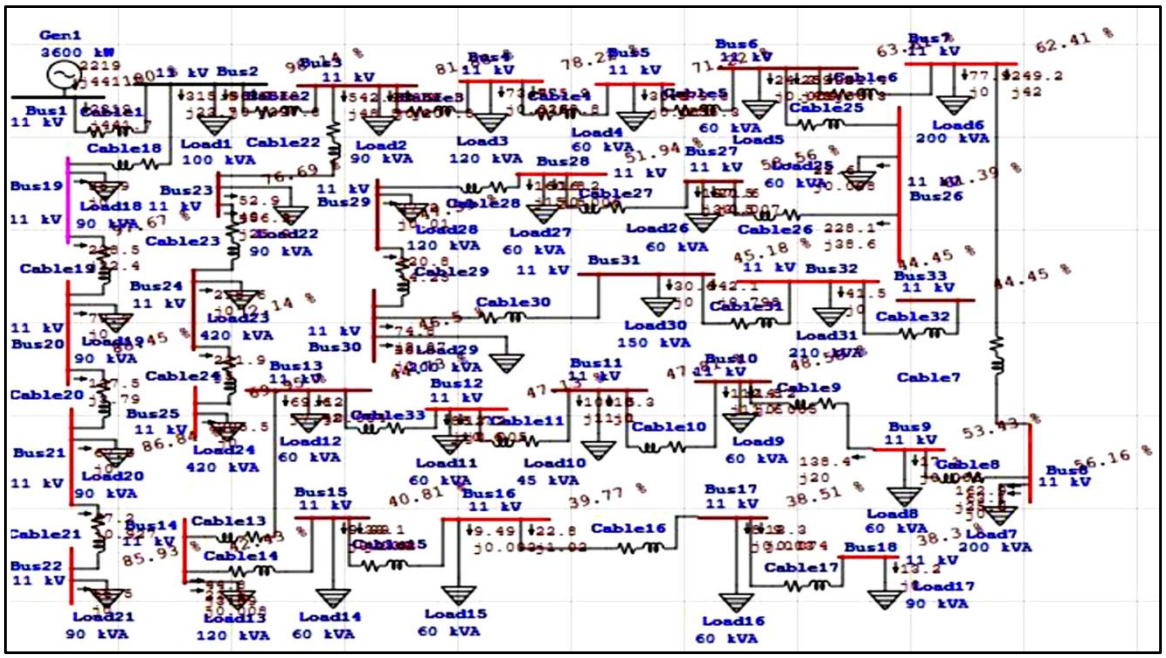



**Figure 2** shows the Test system of IEEE-30 bus Test System

**Out Put Data Table:** Simulation Result (Optimization)

**Table 3**

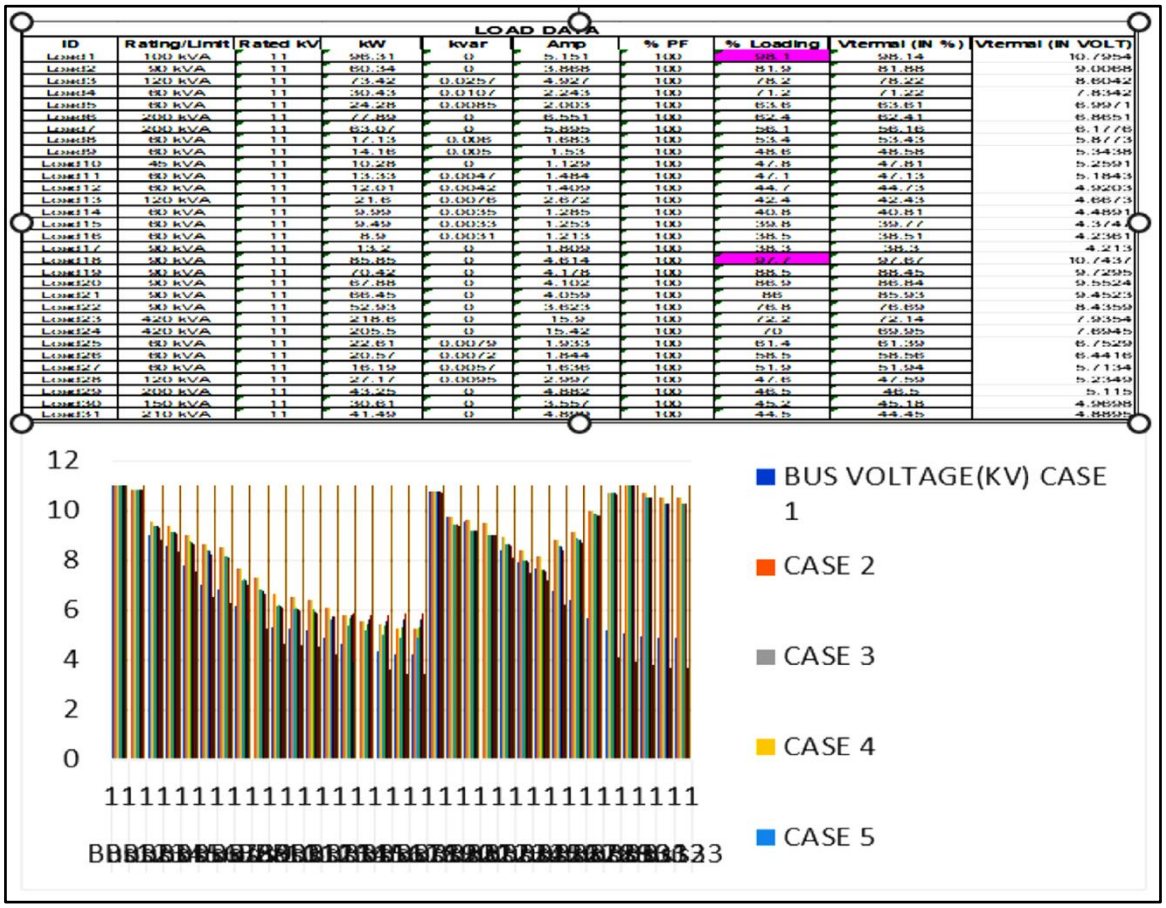
| | LOSSES | |
|---|---|---|
| BRANCH ID | KW | KVAR |
| Cable1 | 39.00387 | 20.17879 |
| Cable2 | 277.8233 | 141.5039 |
| Cable18 | 1.411217 | 1.34668 |
| Cable3 | 37.42652 | 19.06094 |
| Cable22 | 33.04747 | 22.58097 |
| Cable4 | 65.65523 | 33.43921 |
| Cable5 | 64.90204 | 56.02655 |
| Cable6 | 4.31907 | 14.27693 |
| Cable25 | 8.591664 | 4.376247 |
| Cable7 | 23.18948 | 16.73561 |
| Cable8 | 7.335847 | 5.270415 |
| Cable9 | 11.78096 | 8.382604 |
| Cable10 | 1.76113 | 0.582266 |
| Cable11 | 1.382888 | 0.457269 |
| Cable33 | 4.075274 | 3.206363 |
| Cable13 | 3.289071 | 4.329355 |
| Cable14 | 1.638498 | 1.458291 |
| Cable15 | 0.815718 | 0.595694 |
| Cable16 | 0.703219 | 0.938898 |
| Cable17 | 0.071656 | 0.056189 |
| Cable19 | 20.60944 | 18.57069 |
| Cable20 | 2.454693 | 2.867704 |
| Cable21 | 0.70079 | 0.926578 |
| Cable23 | 26.42884 | 20.86937 |
| Cable24 | 6.391227 | 5.000992 |
| Cable26 | 10.00407 | 5.093555 |
| Cable27 | 20.4849 | 18.06114 |
| Cable28 | 12.86 | 11.20333 |
| Cable29 | 2.705976 | 1.378315 |
| Cable30 | 2.087925 | 2.063497 |
| Cable31 | 0.669942 | 0.780843 |
| Total | 693.6219 | 441.6192 |

**Table 4**

| BUS VOLTAGE | | | |
|---|---|---|---|
| Bus ID | Nominal kV | Voltage (in %) | voltage(in KV) |
| Bus1 | 11 | 100 | 11 |
| Bus2 | 11 | 98.14 | 10.7954 |
| Bus3 | 11 | 81.88 | 9.0068 |
| Bus4 | 11 | 78.22 | 8.6042 |
| Bus5 | 11 | 71.22 | 7.8342 |
| Bus6 | 11 | 63.61 | 6.9971 |
| Bus7 | 11 | 62.41 | 6.8651 |
| Bus8 | 11 | 56.16 | 6.1776 |
| Bus9 | 11 | 53.43 | 5.8773 |
| Bus10 | 11 | 48.58 | 5.3438 |
| Bus11 | 11 | 47.81 | 5.2591 |
| Bus12 | 11 | 47.13 | 5.1843 |
| Bus13 | 11 | 44.73 | 4.9203 |
| Bus14 | 11 | 42.43 | 4.6673 |
| Bus15 | 11 | 40.81 | 4.4891 |
| Bus16 | 11 | 39.77 | 4.3747 |
| Bus17 | 11 | 38.51 | 4.2361 |
| Bus18 | 11 | 38.3 | 4.213 |
| Bus19 | 11 | 97.67 | 10.7437 |
| Bus20 | 11 | 88.45 | 9.7295 |
| Bus21 | 11 | 86.84 | 9.5524 |
| Bus22 | 11 | 85.93 | 9.4523 |
| Bus23 | 11 | 76.69 | 8.4359 |
| Bus24 | 11 | 72.14 | 7.9354 |
| Bus25 | 11 | 69.95 | 7.6945 |
| Bus26 | 11 | 61.39 | 6.7529 |
| Bus27 | 11 | 58.56 | 6.4416 |
| Bus28 | 11 | 51.94 | 5.7134 |
| Bus29 | 11 | 47.59 | 5.2349 |
| Bus30 | 11 | 46.5 | 5.115 |
| Bus31 | 11 | 45.18 | 4.9698 |
| Bus32 | 11 | 44.45 | 4.8895 |
| Bus33 | 11 | 44.45 | 4.8895 |

**Table 5**

| BRANCH DATA | | | | |
|---|---|---|---|---|
| ID | Type | kW Flow | kvar Flow | Amp Flow |
| Cable1 | Cable | 2218.9 | 441.7 | 118.7 |
| Cable2 | Cable | 1767.8 | 397.8 | 96.91 |
| Cable3 | Cable | 886.8 | 207.8 | 58.38 |
| Cable4 | Cable | 775.9 | 188.8 | 53.58 |
| Cable5 | Cable | 679.8 | 155.3 | 51.4 |
| Cable6 | Cable | 331.4 | 56.31 | 27.73 |
| Cable7 | Cable | 249.2 | 42.03 | 21.25 |
| Cable8 | Cable | 162.9 | 25.3 | 15.41 |
| Cable9 | Cable | 138.4 | 20.03 | 13.74 |
| Cable10 | Cable | 112.5 | 11.63 | 12.22 |
| Cable11 | Cable | 100.5 | 11.05 | 11.1 |
| Cable13 | Cable | 69.62 | 7.42 | 8.214 |
| Cable14 | Cable | 44.76 | 3.09 | 5.55 |
| Cable15 | Cable | 33.14 | 1.62 | 4.268 |
| Cable16 | Cable | 22.83 | 1.02 | 3.015 |
| Cable17 | Cable | 13.25 | 0.0739 | 1.806 |
| Cable18 | Cable | 315.8 | 23.71 | 16.94 |
| Cable19 | Cable | 228.5 | 22.36 | 12.34 |
| Cable20 | Cable | 137.5 | 3.79 | 8.161 |
| Cable21 | Cable | 67.15 | 0.927 | 4.059 |
| Cable22 | Cable | 542.9 | 48.45 | 34.94 |
| Cable23 | Cable | 456.9 | 25.87 | 31.32 |
| Cable24 | Cable | 211.9 | 5 | 15.42 |
| Cable25 | Cable | 259.3 | 42.97 | 21.69 |
| Cable26 | Cable | 228.1 | 38.59 | 19.78 |
| Cable27 | Cable | 197.5 | 33.5 | 17.96 |
| Cable28 | Cable | 160.8 | 15.46 | 16.33 |
| Cable29 | Cable | 120.8 | 4.25 | 13.33 |
| Cable30 | Cable | 74.83 | 2.87 | 8.451 |
| Cable31 | Cable | 42.14 | 0.798 | 4.896 |
| Cable32 | Cable | 0 | 0 | 0 |
| Cable33 | Cable | 85.73 | 10.61 | 9.62 |



**Analysis:** Here, we simulated our standard data set, an IEEE 30 bus system, and tested it using NRL, ENRL, WLS, and optimization techniques. We find the best solution among them by analyzing load flow studies, and overall efficiency is above 90%, which makes the system more acceptable.[8]

## RESULT & DISCUSSION

Here, we can first draw the system using the IEEE standard data. Then, put all the generator values, branch resistance & reactance, load active power (KW), AND reactive power (KVAR) as per the IEEE standard data table. After putting all the values of that system, we can run the load flow. After load flow, we can get a branch loss report and all the data sets regarding the bus voltage, active power, reactive power, etc. These data sets show how much loss occurs in which branch, every bus voltage drop after load connection, how much power can be drawn by which loads, etc. After giving the connection to the loads, some voltage drops occurred in each bus. Due to the more KVAR drawn by the system, that side load cannot get proper power (KW). Also, we can't know how loss occurred in which line without analyzing the data set. After analyzing the data set, we can add a capacitor because without estimating the reactive power, if we add a capacitor var, that is not proved as applicable for the system and not economical; it is proved as a waste of money. We can improve that system through techniques like

capacitor optimization, generator optimization, etc. We can do this till the system has all parameter values reach the desired value( voltage, active power, etc).The output result analysis is shown below.

## CONCLUSION & FUTURE SCOPE

Power grids distribute and transmit their power concerning load where we see that, theoretically, the network is stable. Still, it is practically impossible, as concluded from different test cases where system parameters are diverted from standard values due to transient stability. Still, it lasts a few milliseconds or more. If output parameters are deviated more or less (setting limit ), then the system will improve by changing the controlling actions by recursive (backpropagation) error analysis and maintaining ($F(x)_{min} < F(x) > F(x)_{max}$) dynamic stability and system automatically improve every state and maintain system balance.

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# Enhancing Power System Stability, Reliability, and Flexibility: A Comprehensive Approach to Future-Proofing the Grid

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***Abstract:*** *The characteristic features of the modern power systems that are urgently needed for integrating renewable energies, peak loads, and sophisticated distribution networks range from reliability to stability and flexibility. All of them lay the basis for resilient power delivery in light of increasing intermittent renewable energy, distributed generation, and changing load patterns. The paper outlines an integrated approach toward powering systems that can positively enhance these three dimensions, explaining the technical, operational, and regulatory challenges that accompany them.*

*These are frequency, voltage, and rotor angle stability. Each is vulnerable to fast fluctuations and disturbances of energy supply and demand. More specifically, efforts at renewable sources cause troubles for the issues of frequency stability at times with several deviations that affect grid performance. This encompasses grid-forming inverters and DSM as leading-edge technologies promising answers regarding stability maintenance. This is supported by the faster response of a system to any changes in frequency and better control of reactive power and voltages at the system level. The PMU is considered the revolutionizing tool in real-time monitoring of power flows and disturbances in power systems from an increased situational awareness perspective and, thus, enhances the stability of the grid.*

*It is only correct to state that reliability in this paper puts emphasis on resilience against power interruptions and faults. Reliability in the context of power systems can be measured through a key performance index, such as SAIDI and SAIFI, which provide a way of coming up with metrics for ascertaining interruptions' frequency and duration. Paper highlights some of the strategies supporting reliability improvement, such as predictive maintenance, automated fault detection, self-healing networks that all work together with grid analytics and machine learning. They provide optimums in schedules of maintenance, bring down downtime by reducing operational cost, and add pre-event failure handling capability to enhance reliability.*

*Increased sensitivity of future power systems and management of fast, unpredictable changes in supply and demand patterns show the importance of flexibility. The paper discusses the role of ESS, namely batteries, flywheels, and pumped hydro, providing important buffering abilities that are vital for the utilization of operating storage to balance supply-demand mismatches. Demand response mechanisms and dynamic pricing structures increase flexibility in that end-use customers are allowed to adjust usage patterns based on their convenience with regards to grid conditions, thereby lowering the system strain at peak times. Flexible AC transmission systems (FACTS) are also part of the arsenal for optimizing power flow and stabilizing system operations against variable load and generation conditions.*

*The managing of the modern grid, through an integral perspective on stability, reliability, and flexibility, becomes essential. This paper aims to discuss and understand the scope of smart grid technology, which utilizes IoT and digital solutions in collecting real-time data, thereby enabling faster decision-making and more precise control over system behavior. Some key enablers cited for proactive management include machine learning and artificial intelligence; capacity predictive profiles in advance; and potential disturbances identified before they become major issues. Solutions to resilience during extreme weather, grid disruptions, or any other scenario are suggested through local solutions in the form of microgrids and coordinated renewable-storage systems, offering energy security as well as flexibility.*

*This paper showcases stability, reliability, and flexibility measures by synthesizing case studies and applying them practically across different regions, such as California and Germany. Challenges are addressed in regulatory hurdles, cybersecurity concerns, and economic implications with regard to promoting policy support and international collaboration. A sustainable model toward achieving robust performance in power systems against rapid technological advancement and the rising energy demands is proposed through this integrated approach.*

# Power & Energy

# Renewable Energy Technologies

33_IEC20606

# Hybrid Battery Trolley for Reducing Down-Time: Innovative Solution by Augmenting Renewable Energy based Charging Feature

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***Abstract:*** *THCM (Tata Hitachi Construction Machinery Private Limited) has been pro-active to cater to the needs of the customer. The number of NPI (New Product Introduction) has been increasing as the competition in the earth-moving industry is increasing. The construction machinery market demands has been very dynamic, with customer demanding cost effective and reliable product which requires product positioning in the market at right time to capture the market share with shorter development time. A well-executed NPI process can help companies: capture premium pricing, increase market share, increase profit margins and improve customer engagement. Testing and Validation phase constitutes a major part in overall timeline of a NPI model and hence this phase has the most influence in the timeline of the project. In recent times we had been facing frequent delays in the testing timeline. When we tried to list down the sources of delay through Pareto study, we found "movement" as major constraint. Most of the movements are done with the help of "battery trolley" which has daily down-time of around 4 hours. Considering various advancement in technology, our team came up with the proposal of "solar powered charging method" to eliminate conventional method of charging.*

***Keywords:*** *THCM; NPI; MPPT; Ergonomics; Sustainability; Hybrid Technology*

## INTRODUCTION

Testing and validation of NPI models accounts for a major part of the overall timeline of a project. A strict adherence to the timeline will lead us to have a well-executed NPI process. In recent times we have been facing frequent delays in the testing process. These delays will affect the product's positioning in the market at right time and we won't be able to capture the market share. We tried to list down all the possible sources of delays which includes five major areas such as countermeasure finalization, movement related, weather related, manpower related and some unforeseen delays. Based on Pareto study of the factors, movement related delays account for 24% of the cases and can be controlled from our end. The rest of the factors are out of our immediate control and hence "movement" related delays must be our primary concern.

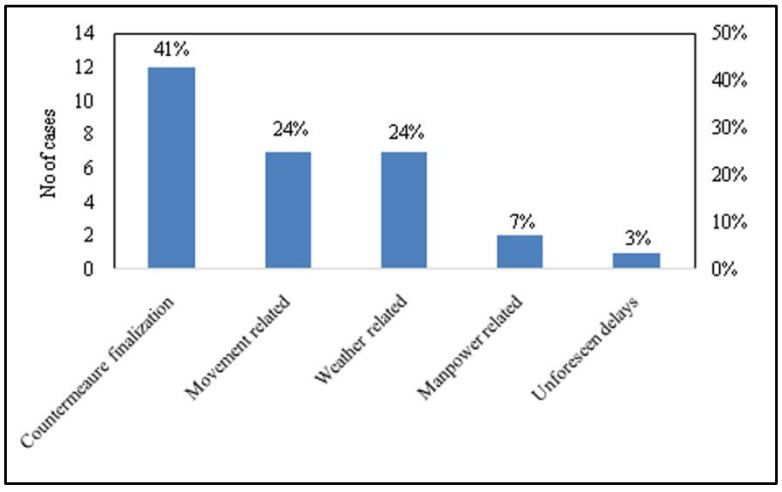


**Figure 1** Factors behind delay in project timeline

Most of the components of NPI prototype and testing apparatus are moved with the help of battery trolley. Daily a battery trolley remains engaged for 5-6 hrs continuously which results in complete discharge of battery and hence a daily downtime of 4 hrs for charging. One way to increase the availability of the trolley is by increasing the numbers which would incur huge investment. Considering various advancements in technology, our team came up with the proposal of "solar powered charging method" to eliminate conventional method of charging. As most of the movement activities occur in open daylight, our battery trolley will get charged during movement itself. We wanted to eliminate the conventional method of charging by augmenting our existing battery trolley with renewable energy sources i.e., solar energy. For this we studied the battery consumption of existing trolley, suitable solar panel and safety devices required in the charging circuit.

## METHODOLOGY

Feasibility study was done which includes battery charging and dis-charging cycle based on the movement. Existing battery trolley uses a drive motor (1.7 kW rating) and battery (289 AH/ 30V rating). Based on the ratings we can calculate the battery drainage time of our battery trolley as shown below.

Maximum energy of the battery = Voltage * AH = 30 * 289 = 8670 Watt-hour (1)

Battery drainage time = Voltage * Capacity/ Motor wattage = 30 * 289/ 1700 = 5.1 hours (2)

**Equation (2)** above shows that complete battery drainage would occur in 5.1 hours. We decided to augment our battery trolley with "solar-based charging" method and hence we would require a solar panel to be mounted on the trolley. Based on the size of our trolley we tried to mount it with 365 W rated solar panel. For extracting maximum output from the solar cell we used MPPT (Maximum Power Point Tracking) controller which would help us in achieving 90% efficiency.

Maximum energy generation by solar panel = Watt * Hour * Efficiency = 365 * 1 * 0.9 = 328 Watt-hour (3)

Total charging time of solar panel = 8670 / 328 = 26.5 hours (4)

The equation 4 tells us that the battery being used in our trolley will be charged in 26.5 hours with the solar panel. This shows us that our idea of augmentation of battery trolley with solar based charging is going to be feasible. In the next step we modified the existing charging circuit as shown below in **Figure 2**.

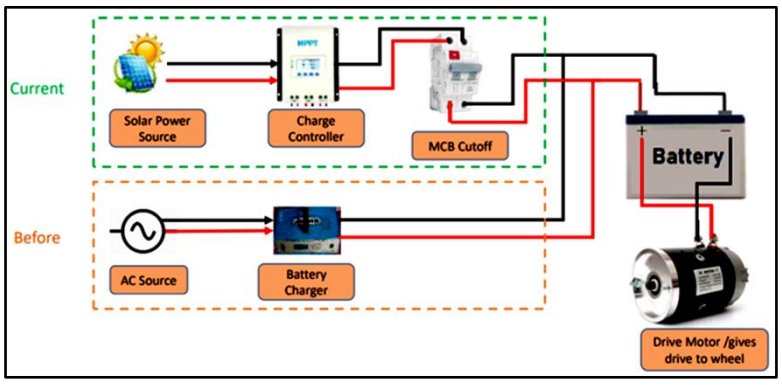


**Figure 2** Circuit diagram of the charging circuit

We implemented the above ideas by preparing suitable brackets for solar panel mounting, incorporating safety check points throughout the system which prevents any damage to both the electrical system and the operator. The mounting of the panel was so modified that no compromise was made with the maneuverability of the battery trolley. Most of the work is done in broad daylight which ensures constant charging while in operation. **Figure 3** below shows the battery discharging cycle after implementation of the idea. On average battery trolley is used typically for about 3 hours and based on the circuit we have designed the downtime of the trolley have been reduced drastically to around 4 hours in a month.

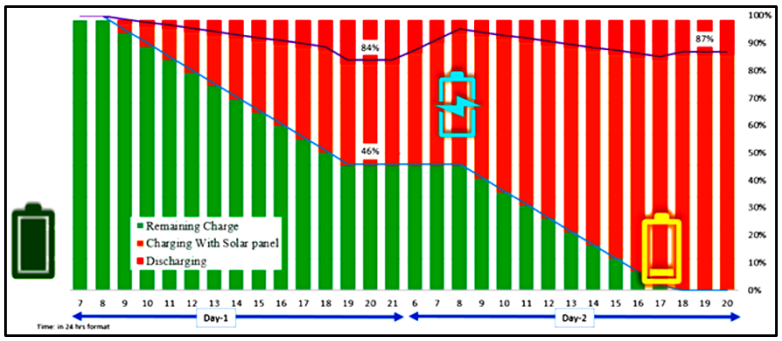


**Figure 3** Battery discharging cycle after augmentation with solar cell

## RESULTS

The trial run of the battery trolley was done, and the effect estimate was studied. We have successfully reduced the downtime of battery trolley from 4 hours in a day to 4 hours in a month by implementing solar power-based charging.

1. We have reduced charging costs by 90% by augmenting renewable energy-based charging.
2. We have reduced the charging time by 90% and hence the availability of the battery trolley has also increased, causing a reduction in delays due to movement.
3. We could reduce our carbon footprint by 3060 kg of $CO_2$ annually.
4. Ergonomics: Solar panel mounted above operator seat works as roof providing comfort to operator in broad daylight especially during summers.

## CONCLUSION AND FUTURE SCOPE

Our technical know-how in implementation of non-conventional based energy systems has improved. We could devise a system which was innovative and at the same time the best economical option to use.

In future we are planning for horizontal deployment across all the battery trolleys being used by THCM which will have a great impact in reduction in carbon footprint and would inculcate GO GREEN initiative across the organization.

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76_IEC2946

# Renewable Energy Sources with Special Effort on Hydropower for Sustainable Development

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***Abstract:*** *Water and Power are the two major inputs for the development of a country. Across the spectrum of electricity generation, water and power remains the only renewable and inexhaustible source of energy, which can be exploited on vast scale at a competitive price. Apart from fast depletion of fossil fuel for non-renewable source of energy, the exploitation of these sources is replete with grave ecological consequences. Renewable energy sources received from solar and wind power backed by storage through batteries supported by advanced technology can reduce emissions globally by 43% by 2030 to stay below 1.5 degrees centigrade, which may reach above pre-industrial temperature level, due to global warming.*

***Keywords:*** *Hydropower; Renewable Energy; Climate Change; Carbon Emission; Global Warming*

## INTRODUCTION

Global warming and climate change is the most debated issue since the climate change impacts have geographical, political, social and economic ramifications. It is also well established that the poorest people/ nation contributes least to the activities leading to the climate change[1]. Unfortunately, they are least equipped with different procedure and measures to deal with the negative impact of climate change. Water and power are fundamental components of our 21 St century life, but they can no longer be considered separately, after water and power experts trying to solve their own problems separately for several decades, more and more of them begin to realize that the two fundamental resources are not independent from each other. In other words, Water is power issue; Power is a water issue.

Renewable energy is a clean and sustainable source of energy, derived from nature and it has potential to provide solutions to the vulnerable energy problems being faced by India.

India has the continuous supply of solar energy which can be harnessed for solar power, tremendous volume of water coming from high hills can provide for hydropower, fast blowing wind provides for wind power, development of tides along costal line offers a source for tidal power, conversion of huge generated waste to biomass provides for biomass energy and presence of hot springs provide for geothermal power.

It is time to make collaborative efforts to extract these naturally gifted sources of energy to meet our long- term energy demands and to ensure sustainable growth of our nation. [1]

## NECESSITY FOR DEVELOPMENT OF RENEWABLE ENERGY

India emitted nearly 929 million tons of $CO_2$ in the last fiscal year from thermal power sector alone, which now accounts for about 60% of the country's power generation. For handling climate change, all consumer section will have to adopt to changes. It may be necessary to recognize the fact that there cannot be exclusive allocations/reservation for single usage but adjustment and prioritization will be required without affecting the economic and sustainability status.

The impact of climate change is to be felt severely in developing countries, especially with agrarian economics. Global warming is likely to reach 1.5 degree Celsius (above pre-industrial levels) between 2030 and 2052, if it continues to increase at the same rate. India remained at the fore front of cop-21 negotiations in Paris in 2015. The path that we take here on will not only determine our well beings, but also that of the generations, who will inhabit our planet after us. Climate justice is about safe-guarding the rights and interests of the poor and marginalized sections of society, who are often the biggest sufferers from the menace of climate change. World leaders of several

countries converged in New Delhi to mark the start of the International Solar Alliance (ISA) in March 2018, so that carbon free energy generation is possible to reduce Global warming.

**Figure 1** Solar panel

OPEC Countries in the list of International Solar Alliance (ISA) potential members include UAE, Saudi Arabia, Venezuela, Libya, Nigeria and Algeria, among others. India also proposed that ISA membership be thrown open to all UN members apart from 121, who are fully or partially between the Tropics of Cancer and Capricorn as initially envisaged by ISA.

ISA, an inter-governmental treaty-based organization was formed by solar-resource rich nations undertake joint efforts to reduce cost of finance and technology and mobilize more than $ 1 trillion investment needed by 2030 for the deployment of at least 1000 GW of solar energy worldwide. The proposal is in fact, in sync with what Prime Minister Modi envisioned, when he gave the call of “one world, one sun, one grid”, while addressing representatives of 40 countries during ISA assembly.

Once the electricity sector is fully decarbonized, essentially two emitting sectors will remain: transportation and agriculture. It will require major technological breakthrough to make zero emission vehicles affordable and profound changes in the farming process.

## HYDRO POWER AS A RENEWABLE-ECOFRIENDLY ALTERNATIVE

Hydropower is cheap, clean and pollution free renewable energy and requires almost negligible energy and requires almost negligible running and maintenance cost. Besides being cheap, renewable and non- polluting hydropower has a stabilizing effect on system operation. It enables optimal utilization of other sources of generation on account of its inherent capability to meet fluctuations of demand and grid stability. Hydropower generation eliminates production and transportation of fuel. This is going to be an important factor in near future on account of technical, practical and financial limitations in augmenting mining and transport facilities of coal. The energy generated through hydropower relies on the water cycle, which is driven by sun, making it a renewable power source, due to which Hydropower is more reliable and affordable source of energy than fossil fuels that are rapidly being depleted.

Although hydropower developments are by and large eco-friendly, large size hydro schemes have come under attack by the environmentalists. Big storage dams have been criticized on account of the deforestation caused by submergence, displacement of population due to submergence and fear of destruction of dams during natural calamities like earthquakes, floods etc. Hydropower does face challenges of difficult topography and complex geotechnical conditions not to overlook the inherent hydrological uncertainties, however with proper planning and dynamic decision, making through efficient use of investigation, instrumentation and analytical solutions, Hydropower project should be judged to make it safe and economically viable.

India’s aim to become a developed country by 2047, it has to cope with the growing energy demands with 24*7 power availability. The focus is on a more efficient exploration and cleaner consumption of energy resources. India’s

Installed capacity has grown from about 1360 MW in 1947 to about 550 GW at present, which is dominated by thermal power. The long-term study for electrical energy requirement until 2029-30 as projected is 831502 MW, which includes Hydro 64 GW, contributing only 8% in comparison to RE sources with 350 GW at 40%, a Battery Energy storage capacity of 34000 MW. Hydropower a clean, green, stable, and reliable source of energy, lends it's advantages as a flexible resource in terms of providing peaking capability, ramping capability, frequency response, part-load operation for maintaining reserves, energy storage capability (Pump Storage Projects).

**Figure 2** Bakhra Dam

As per reassessment studies carried out by Central Electricity Authority during 1978-1987, the hydropower potential in terms of Installed capacity (IC) is estimated at 148701 MW. At present 45400 MW capacity of projects are in operational, 10712 MW capacity of projects are under construction and 45524 MW capacity of projects are at under various stages of development.

In addition to above, 63 pumped storage projects are identified for various stages of development, with a likely capacity of 96524 MW. At present, 9 PSP (4785.6 MW) are under operation, 2 PSP (1080 MW) are under construction, and DPR for one project namely Turga PSP (1000 MW) identified by the West Bengal Government has been concurred by CEA for construction. With the help of pumped storage hydropower plants, it can be possible to even out the flexibility in today's grid due to frequent changes between electricity shortages and surpluses and prevent curtailment of renewable generation.

The Government of India has planned to add about 150000 MW of solar and 85000 MW of wind power into the Grid System by 2030, to reduce carbon emission intensity by 30 to 35 percent by the year 2030 from 2005 level as committed in Intended Nationally Determined contributions (INDC).

**INDIA'S CLEAN ENERGY TRANSITION IS ON TRACK FOR 2070 NET ZERO TARGET**

India aims to achieve net zero emissions by 2070. At the Paris climate summit India pledged to achieve its 40% power capacity from non-fossil sources by 2030. The biggest unnoticed event in 2021 was that the target has been achieved nine years ahead of schedule. This remarkable achievement shows that out of India's total power capacity of 550 GW, the non-fossil share including hydropower has crossed 220 GW.

India's sheer size and its huge scope for growth means that its energy demand is set to grow tremendously compared to any other country in the world in the coming decades. To achieve net zero emissions by 2070, the energy demand of this decade should have to be met by renewable energy sources such as solar and wind power.

The clean energy transition in India is already well underway due to technological developments, steady policy support and a vibrant private sector participation. Sri Gautam Adani is investing $ 50-70 billion in green production

and installation. Sri Mukesh Ambani plans four giant factories worth Rs 60000 crore to produce solar cells, modulus, hydrogen fuel cells and battery grid. Due to favorable global conditions enormous funding for renewable energy is available. The renewable energy sector which was once deemed to be too risky, time consuming and unprofitable are now become the new investment area for trillions of surplus savings created by extraordinary favorable global conditions.

A transition to clean energy is a huge economic opportunity. India is particularly well placed to become a global leader in renewable batteries and green hydrogen. Green hydrogen demand will play a major role in achieving net zero and decarbonizing the hard-to-abate sectors. India could easily create 5 million tones green hydrogen demand, thereby replacing grey hydrogen in the refineries and fertilizer sector. These 5 million tones will result in abatement of 28 million tones as $CO_2$. This green hydrogen economy will grow in such a way, resulting in 400 million tones as $CO_2$ abatement by 2050[2].

## CONCLUSION

Solar Power is now available in India for Rs 4-5 per unit. Other renewables continue to follow the trend. Wind power become competitive with coal around two years ago, and prices have continued to reduce. In 2008, the cost of industrial batteries was $1000 per KWH of energy stored in USA; by 2015, it had fallen to $ 268. Now this may be down to $111. The price drops and related efficiency increase won't stop. These are forming a virtuous cycle: as the price drops, installations double, and as installations double, the price drops. Power usage will keep increasing, so this is a moving target. Taking that into account, solar can potentially provide more power than the world needs in less than 20 years.

So far as hydropower is concerned, hydropower facilities can quickly go from zero power to maximum output. Because hydropower plants can generate power to the grid immediately. In addition to a sustainable fuel source, hydropower efforts produce a number of benefits, such as flood control, irrigation, water supply etc. Impoundment for generation of hydropower creates reservoirs that also offer a variety of recreational opportunities, notably fishing, swimming, boating etc.

When developing technologies like wave, ocean current and tidal in stream energy conversion are taken into account, hydropower's potential become much larger. By capitalizing on its huge potential for sustainable development, the hydropower industry can add jobs from manufacturers to construction workers to plant operations and maintenance.

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79_IEC13616

# Installation and Experimentation of a Vertical Axis Wind Turbine for Domestic Purpose

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***Abstract:*** *Vertical Axis Wind Turbines (VAWTs) are an evolving technology, with ongoing research focusing on improving the design and implementation. VAWTs offer a viable solution for fulfilling small scale energy needs, especially in urban domestic settings. In these scenarios VAWTs show certain advantages over the tradition horizontal axis wind turbines and even more crucially come out as viable alternative to fossil fuel energy generation. Vertical axis wind turbines have some unique advantages, such as their ability to capture wind from any direction and their compact design. However, they also face challenges related to efficiency, scalability, and noise. To gain latest insight into the potential of VAWTs, latest methods and technologies have been compared here, focusing on efficient energy generation. In this work, a hybrid type VAWT has been designed to meet domestic energy requirements. Simulation tools have been used to obtain required turbine performance and ensure effective design. The main goal of this work is to install and run a VAWT which could lead to more sustainable energy solutions.*

***Keywords:*** *VAWT; Renewable Energy; Sustainable Development; Environment; Domestic Energy Need*

## INTRODUCTION

As the effects of climate change become more prominent and affect the daily lives of people more and more, the need for sustainable energy generation has been of the utmost concern. Scientists all over the world are looking for alternative energy sources to fossil fuels to generate sustainable and clean energy [1]. Among others, wind power has presented itself as one of most promising renewable energy sources that can provide clean energy for the masses. Traditional Horizontal Axis Wind Turbines (HAWTs) play a large role in large scale wind energy generation [2]. But they have shown some major disadvantages when it comes to operating in residential areas. HAWTs require lots of open space, and high and consistent wind flow to operate effectively which is not possible in urban settings. Moreover these massive structures require a lot of specialized maintenance and also produce a lot of noise which makes them unfit for domestic electricity generation [3] [4]. In recent times Vertical Axis Wind Turbines (VAWTs) have become increasingly popular for energy generation in domestic settings. VAWTs, as their name implies, have their main rotor shaft vertically aligned as opposed to HAWTs, which have rotor shafts in the horizontal direction. This difference in design makes VAWTs more suitable for wind capture than HAWTs in residential areas, as these places don't have consistent airflow due to buildings and trees. VAWTs also hold the benefits of being more compact, lower noise production and easier and cheaper maintenance over HAWTs. These advantages make VAWTs ideal for domestic electricity generation.

But, VAWTs also have some distinct disadvantages, mainly their lower efficiency than HAWTs [5]. Scientists are working tirelessly to increase the efficiency of energy generation of VAWTs to make them a viable alternative to fossil fuels in urban settings. Several factors need to be considered that affect the efficiency of VAWTs. Some of the primary factors are turbine design, site selection, maintenance etc. In this work, a hybrid Vertical Axis Wind Turbine has been designed, which include aspects of both Darrieus and Savonius wind turbines. The design parameters have been optimized using simulation tools like, and have been optimized for more efficient and reliable energy generation. The designed turbine has been manufactured and tested in a real world setting to maximize energy output in domestic settings.

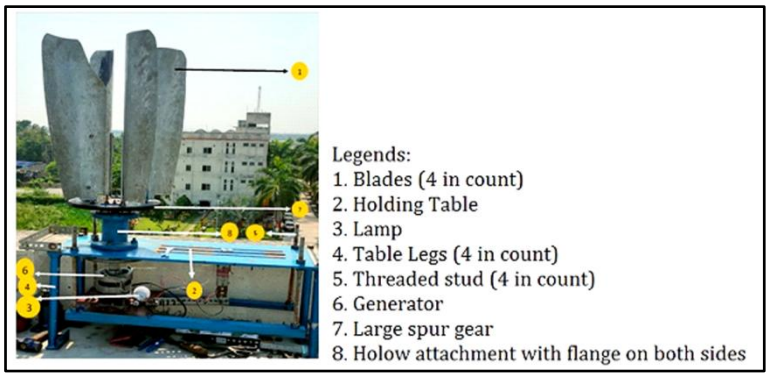


**Figure 1** Various components of installed VAWT

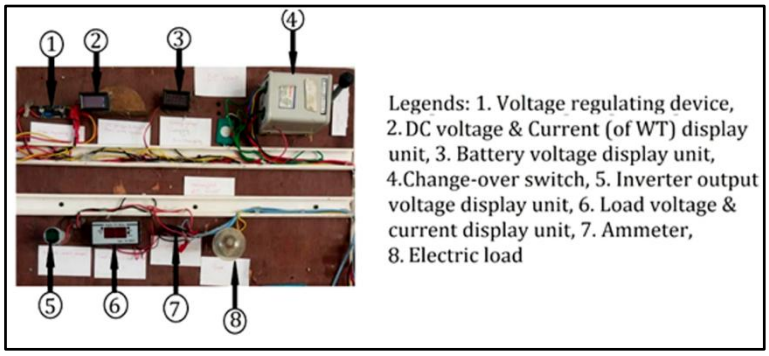


**Figure 2** Various Components of Electrical Circuitry

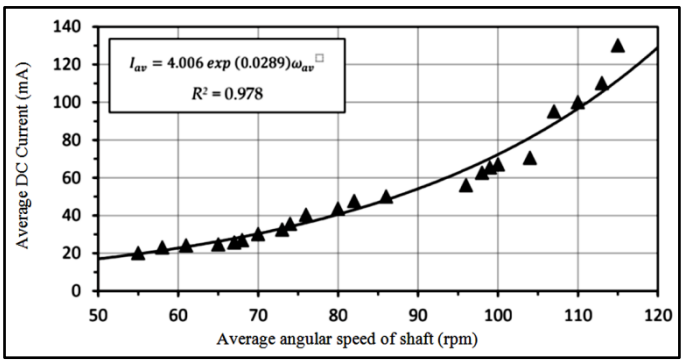


**Figure 3** DC current generation on the basis of angular speed of shaft

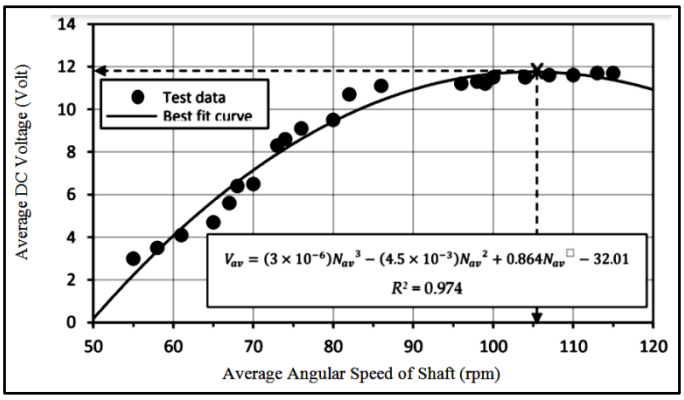


**Figure 4** DC current generation on the basis of angular speed of shaft

**ACKNOWLEDGMENT**

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97_IEC4687

# PV based Security Lighting System of 3 Wheeled Electric Vehicles for Rural Transportation

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***Abstract:*** *The global sales of Electric Vehicles (EVs) have grown significantly, particularly in India, due to rising pollution levels, rising fossil fuel prices, and increased awareness of renewable energy. However, conventional power supply, primarily from coal-based plants, is often used, leading to system instability and increased electricity costs. The Lithium Ion battery (LIB) in EVs has also experienced exponential development and price increase due to increased demand and limited lithium availability. So in reality we are not achieving our original aim of reducing carbon emission due to use of conventional energy sources to charge EVs batteries. Also in recent years more and more research is being carried out on Sodium Ion Battery (SIB) as a replacement of Lithium Ion battery as Sodium is more easily available, low cost with similar electrochemical characteristics as compared to Lithium. This paper gives the complete design and in depth analysis of a Pulse Width Modulation (PWM) based charge controller which has utilized the solar energy by using Photovoltaic Module (PVM) to charge the SIB which can be implemented in small EVs used mainly in suburban and rural areas to provide necessary energy for interior lighting that in turn can reduce the load of the battery supplying energy to the driving motor and thus achieve the aim of using renewable energy to reduce pollution hazards. Moreover, this charger is used to charge SIB so it will reduce the overall cost of the vehicle which in turn will encourage more people to use EVs in rural and suburban areas of our country where most of our country's population lives.*

***Keywords:*** *Solar Energy; PWM, Charge Controller; Sodium Ion Battery*

## INTRODUCTION

India is seeing a huge surge of using small sized EVs specially by the people living in rural and suburban regions for short distance transportation and also there is a huge increase in sales of EV cars in cities as India is going to replace all cars by EVs by 2030 [1]. The process of charging the batteries, which provides electrical power for the EV's motor drive, control circuits, lighting circuits and air conditioning system, is the main interface between the two sections. However, till now we are mostly relying on conventional sources of energy to produce most of the electrical energy and that energy is being used to charge the EVs and the energy provider is burdened more while charging an electric vehicle through the grid, especially when peak demand is present which gives rise to various problems in power system [2]. Moreover, as fossil fuels are used to produce the major part of the electrical energy mainly by thermal power plants, the chances of achieving a greener and safer environment is also reduced. To lessen the adverse effect on the grid, encouraging the use of renewable energy sources for charging is one workable option Elavarasan et al. [3]. It is intended that using various forms of clean energy would also lessen its negative effects on the environment and increase the overall effectiveness of the charging system. As the cost of photovoltaic (PV) modules continues to decline, solar power is being

acknowledged more and more as a competitive energy source to complete the grid [4]. Additionally, the PV system requires very little maintenance in terms of labour and fuel. The use of PVM for EV charging has been made possible by improvements in power converter technologies, battery management procedures, installation methods and standards of design. Moreover, it has very low CO2 emissions and little fuel requirements.

Li-ion batteries (LIBs), which were originally introduced to the market by Sony in the early 1990s, have grown in popularity as portable power sources. Because LIBs are the recommended battery for hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and electric cars (EVs). Because of its low reduction potential (-3.04 Volt) and small weight, lithium is the ideal option for lithium-based battery systems. Lithium may therefore be used to create high-voltage, high-energy density cells. Because of its tiny ionic radius (0.76 Å), lithium ions are also more

diffusible in materials. Li-ion technology has become widely employed in portable electronics products due to these characteristics as well as its higher cycle life and rate capabilities [5].

The main component of LIBs, lithium, is unevenly distributed throughout the crust of the Earth. However, because lithium is not a naturally abundant element, the rising demand for it brought on by these new and extensive applications is predicted to send prices through the roof and have an impact on reserves as well. The current mineable sources of Lithium could only be sustained for a maximum of next six decades at an average annual growth rate of 5%, meaning that the LIBs' implementation will be challenging and extremely expensive [6].

For the past 20 years, Li-ion batteries have dominated the solid state electrochemical literature and the portable electronics sector due to their nearly unparalleled volumetric energy density. Not only will that keep happening, but they are now powering both electric and plug-in hybrid cars. Na and Na-ion batteries are once again being considered as options for medium- and large-scale stationary energy storage due to potential worries about rising lithium costs in the future. This is especially the case given the increased interest in renewable energy sources that require load-levelling and provide intermittent power. Many solid state materials design issues are presented by the SIB industry; in response, various reports of new sodium-ion technologies and electrode materials have emerged in the last few years. So SIB is going to be the obvious choice for EVs in near future [8].

This paper will give the design and cost analysis of a PWM charge controller connected to a PVM to charge a SIB by which has been designed and tested for lighting purpose for small EVs used mainly in rural and sub urban areas.

## DETAILS OF PWM BASED CHARGE CONTROLLER

The PWM based PVM charge controller comprises of the following components like PVM, Charger Controller Circuit, SIB, DC LED bulb, Wires, etc. **Table 1** shows the component list of Solar PWM based charge controller.

**Table 1** Detail Components List of a PWM based SIB charge controller using solar panel system

| Sl no | Name of the components | Specification |
|---|---|---|
| 1 | PV module | 12 Volts, 50WP,<br>Open circuit village($V_{oc}$): 21.8V,<br>Short Circuit current ($I_{SC}$): 3.01Amp. |
| 2 | PWM technology based Solar Charge Controller | 12 Volts, 10 Amp, 6 terminals. |
| 3 | Sodium ion Battery | 12Volt, 14Ah<br>Maximum Current: 2.80A |
| 4 | DC LED lamp | 8W, 12V |
| 5 | Wires | 1.5 Sq mm, Copper wire. |

## PWM BASED SOLAR CHARGE CONTROLLER

The main parts of the PWM based solar charge controller system are namely PWM based Charge Controller & SIB. The Functionality of PWM based Charge Controller & SIB are discussed in this section. The block diagram of the PWM based solar charge controller is given in the **Figure 1**.

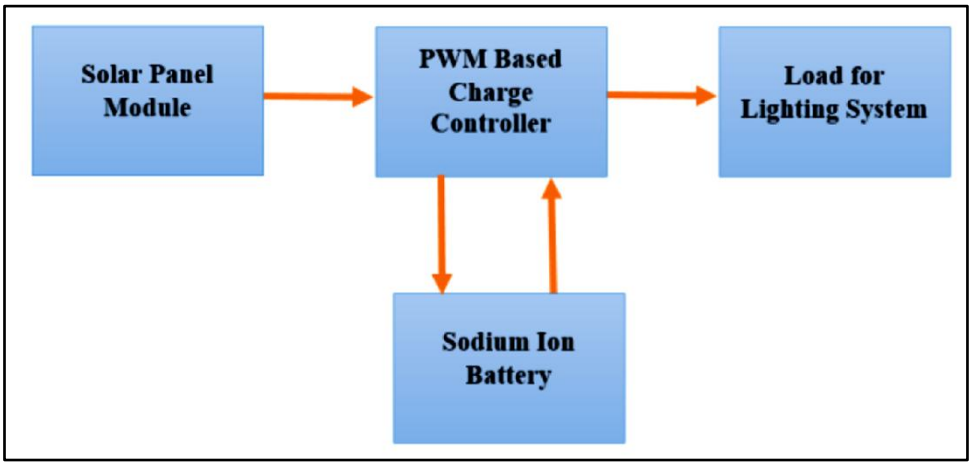


**Figure 1** Block diagram of PWM based PVM Charge Controller system for Lighting Load

The primary function of pulse width modulation (PWM) is to deliver a steady voltage during battery charging, therefore switching the power devices of the solar system controller. PWM is a technique employed by contemporary charge controllers to enable the application of less power to the batteries when they are nearly completely charged. PWM extends the battery's life by enabling full charging while putting less strain on the battery. The PWM controller operates on the principle that a voltage indication indicates the voltage generated by the solar cell. Following this measurement, a voltage controller regulates the voltage; as a result, PVM charges the batteries using this voltage [9]. Among the special advantages of PWM pulsing are —

- The capacity to identify low battery levels and desulfurize batteries.
- Increase the battery's charge acceptance significantly.
- Maximum high average capacity of batteries.
- Balance out batteries that are wandering.
- Minimise gassing and heating of batteries.
- Automatically adapt to the ageing of batteries.
- Self-correct for variations in temperature and voltage in solar systems.

A PWM-based charge controller functions similarly to a switch to link the battery and solar panel. The voltage of the panel and the battery will be almost equal when the switch is closed. As the battery's state of charge increases, the voltage will as well [7].

From the aforesaid figure, it has been shown that the output from the Solar Panel Module is DC. This DC is fed to the PWM based charge controller. This charge controller is charging & controlling the voltage level of SIB module & finally the lighting load is utilizing the energy stored in the battery.

### Functionality of PWM based Charge Controller

PWM charge controllers are among the most often used devices for storing solar energy and transferring it to a backup battery. To store in the battery backup, the solar energy input here has to go through a switching circuit. A battery backup's energy storage capacity determines the oscillator's pulse width, which regulates this switching circuit. The graphic displays the block diagram of the PV Module PWM based charge controller.

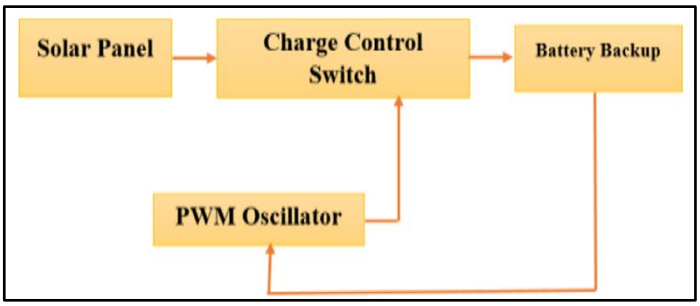


**Figure 2** Block diagram of PWM based charge controller

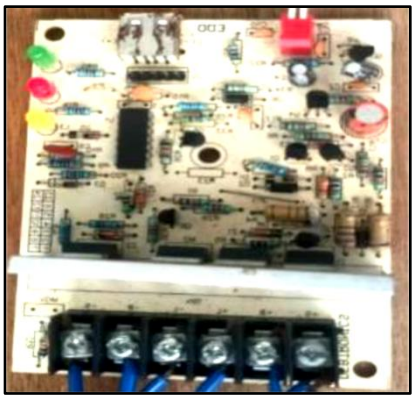

**Figure 3** PWM based charge controller

Pulse width modulation, or PWM, is the most efficient way to achieve constant voltage battery charging. When using PWM control, the solar panel's output current tapers to the battery's level of discharge and recharging requirements.

The solar panel and battery voltages are sensed by the Charge Controller. It determines how to charge the battery and regulate the load current based on these voltages. The difference between the battery voltage and the charge set point voltages determines the charging current amount.

**Functionality of Sodium Ion Battery**

The anode, cathode, electrolyte (no aqueous or aqueous), and separator make up a conventional SIB. The way it works is comparable to LIBs. During charging and discharging in SIBs, the sodium ion is transferred from the positive cathode to the negative anode. The sodium ions from the cathode are taken out and added to the anode during the charging process. During the charging process, electrons are forced from the cathode to the anode via the external circuit. Regarding the discharge procedure, the opposite is true [10].

As price and demand of LIBs is increasing rapidly due to improvement in the EV sector, the need for an alternative of LIBs will be required in near future to meet the demand. Battery based on sodium show great opportunity for energy storage applications due to its high abundance, low cost, and ideal redox potential (-2.71 V versus standard hydrogen electrode which is only 0.3V above the Lithium).The phase stability, transport characteristics, and interphase formation are impacted by the bigger Na+ ions (1.02 Å) in comparison to Li+ ions (0.76 Å).

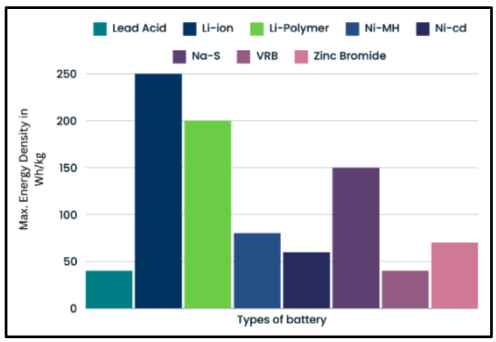


**Figure 4** Graphical representation of comparison of maximum energy density values of various types of batteries

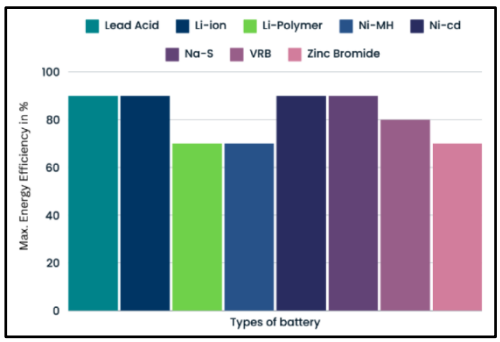


**Figure 5** Graphical representation of comparison of maximum energy efficiency values of various types of batteries

Furthermore, sodium weighs 23 g $mol^{-1}$ compared to 6.9 g $mol^{-1}$ for lithium. So there will never be sufficient energy density in SIBs. But the main factor affecting capacity is the characteristics of the host structures acting as electrodes; the mass of the individual parts and the weight of the cyclable Li or Na account for a very tiny portion of the total

mass. Thus, theoretically moving from LIBs to SIBs should not have any effect on energy density. Furthermore, an alloy reaction between aluminium and lithium is seen below 0.1 V, suggesting that aluminium can be used as a current collector for sodium cell anodes. Because of this, aluminium is a less expensive option than copper for the anode current collector of SIBs. The invention of the high-temperature solid-state sodium ion conductor – sodium β''-alumina ((Na Al11O17) – in the 1960s became a milestone in the field of solid-state sodium ions and electrochemistry as it eventually became the key to development of two batteries that are commercially available-sodium sulphur (Na–S) and ZEBRA (Zero-Emission Battery Research Activities) cells, based on Na-$NiCl_2$. In order to eliminate the possibility of internal short circuits due to dendritic development, both cells run at a high temperature (about 300°C), where sodium and the positive electrodes are melted. Furthermore, the sodium β''-alumina membrane's strong ionic conductivity at the higher temperatures reduces the impedance of the cell [11].

## COST ANALYSIS

The experimental setup shown in **Figure 6**, has been used to analyse the effectiveness of the PWM technique based charge controller that is designed. While testing the system it is seen that the PWM controller is activated when the battery bank is fully charged, allowing as much current as the solar panel or array can provide. As the voltage nears the target, the controller connects and disconnects the battery bank alternatingly, stabilizing the voltage and preventing overcharging, thus ensuring effective charging. On the same way a charge controller detects deep or over-discharge in a battery, isolating it from the circuit to prevent current flow, ensuring battery health. The controller regulates the duty ratio of switches using PWM for steady output voltage, and provides trickle charging, ensuring continuous regulation of charging current. This ensures a steady output voltage and prevents over-use of the battery. So while running the system shown in **Figure 6**, smooth operation of the charge controller was observed and the SIB was charged and discharged effectively without any difficulties.

As this system is designed mainly for interior lighting for small EVs to be used in rural and semi urban areas, it must be cost effective and eco-friendly. The cost details of the components used in the experimental setup is given in **Table 2**.

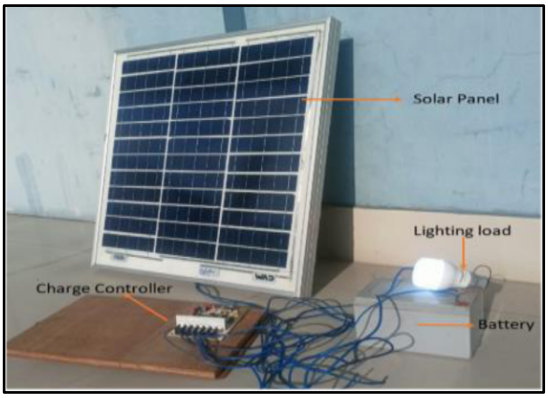


**Figure 6** Experimental Setup

**Table 2** Cost details of the components used in making experimental

| Sl no | Name of the components | Price |
|---|---|---|
| 1 | PV module (1 unit) | 1500/- (INR) |
| 2 | PWM technology based Solar Charge Controller (1 Unit) | 350/- (INR) |
| 3 | Sodium ion Battery (1 unit) | 950/-(INR) |
| 4 | DC LED lamp | 200/-(INR) |
| 5 | Loose Wires | 50/-(INR) |
| Total Cost | | 3050/-(INR) |

As the above mentioned cost is nominal, it suggests that this PWM based charge controller with combination of PVM and SIB turns out to be a cost effective option for small EVs which can be used to cater its indoor lighting circuits and thereby increasing the battery life and charge retention capability of the battery that gives power to the motor drive. It will also reduce the pollution level when implanted in large numbers as this system uses solar energy which is a renewable and eco-friendly energy source.

## CONCLUSION & FUTURE SCOPE

This paper gives a novel approach towards implementing PVM to charge SIBs effectively by using a PWM based charge controller. It has also been shown that this method is cost effective and can be implemented to cater the interior lighting load for small EVs used mainly for short distance transports. In future this approach may be applied to EV cars, buses etc. to energize the interior & exterior lighting circuits and air conditioners so that the system efficiency can be increased and the aim of having eco-friendly environment can be reached.

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139_IEC32699

# Solar Thermal Energy Storage: Emerging Techniques and Technologies

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***Abstract:*** *Solar Thermal Energy Storage (STES) plays a pivotal role in enhancing the efficiency and reliability of solar power systems by enabling the retention and utilization of thermal energy beyond daylight hours. This literature review explores the latest advancements in STES technologies, emphasizing emerging techniques that promise higher energy densities, improved thermal stability, and cost-effectiveness. The review categorizes STES methods into sensible heat storage, latent heat storage, and thermochemical storage, highlighting innovations such as advanced phase change materials (PCMs), novel encapsulation methods, and hybrid storage systems. Methodologies involve a systematic analysis of recent scholarly articles, patents, and industrial reports to assess the performance, scalability, and practical applications of these technologies. Results indicate significant progress in material science and system integration, with several emerging technologies demonstrating enhanced performance metrics compared to traditional methods. The review concludes by identifying key challenges, including material degradation, system complexity, and economic feasibility, while proposing future research directions to address these issues and facilitate the widespread adoption of advanced STES solutions.*

***Keywords:*** *Solar Thermal Energy Storage; Phase Change Materials; Thermochemical Storage; Molten Salts; Energy Efficiency*

## INTRODUCTION

Solar Thermal Energy Storage (STES) is integral to the advancement of solar energy utilization, addressing the intermittent nature of solar power by storing excess thermal energy for later use. Effective STES systems enhance the reliability and efficiency of solar thermal power plants, enabling continuous energy supply and optimizing energy dispatch. Traditional STES methods, such as sensible heat storage using materials like water and rocks, and latent heat storage employing phase change materials (PCMs), have been widely implemented. However, these conventional approaches face limitations in energy density, thermal stability, and scalability. Recent advancements have introduced emerging techniques and technologies aimed at overcoming these challenges, including thermochemical storage, advanced PCMs, and hybrid systems that combine multiple storage mechanisms. This literature review aims to provide a comprehensive analysis of these emerging STES technologies, evaluating their performance, advantages, and potential barriers to implementation.

## METHODOLOGY

A systematic literature review was conducted to gather relevant information on emerging STES techniques and technologies. Databases such as IEEE Xplore, ScienceDirect, and Google Scholar were searched using keywords like "solar thermal energy storage," "phase change materials," "thermochemical storage," and "advanced thermal storage technologies." The selection criteria included publications from the last decade (2013-2023), focusing on

peer-reviewed journal articles, conference papers, patents, and industrial reports. A total of 50 sources were initially identified, from which 30 were selected based on relevance, recency, and contribution to the field. These sources were further analyzed to extract data on various STES methods, their performance metrics, material properties, system designs, and practical applications. Comparative analysis was performed to identify trends, strengths, and weaknesses of different technologies, facilitating a holistic understanding of the current state and future prospects of STES.

## RESULTS

### A. Sensible Heat Storage Enhancements

Sensible heat storage remains a fundamental approach in STES, primarily utilizing materials with high specific heat

capacities such as molten salts and ceramics. Recent advancements focus on enhancing energy density and thermal conductivity. Nanostructured materials and composite media have been developed to improve heat transfer rates and reduce thermal losses. For instance, the integration of nanomaterials with traditional storage media has shown a potential increase in thermal conductivity by up to 30%, thereby accelerating charging and discharging processes [1].

**B. Latent Heat Storage Innovations**

Latent heat storage using PCMs has garnered significant attention due to their ability to store large amounts of energy at constant temperatures. Emerging PCMs include organic compounds like fatty acids and inorganic materials such as salt hydrates. Recent research has concentrated on optimizing PCM encapsulation techniques to prevent leakage and enhance thermal cycling stability. Microencapsulation and macroencapsulation methods have been refined, enabling better integration into solar thermal systems and improving durability over extended use [2][3]. Additionally, composite PCMs incorporating nanoparticles or expanded graphite have demonstrated improved thermal conductivity and structural integrity [4].

**C. Thermochemical Storage Developments**

Thermochemical energy storage (TCES) is emerging as a highly efficient method, offering superior energy density and long-term storage capabilities. TCES systems rely on reversible chemical reactions to store and release thermal energy. Recent advancements include the development of novel reversible reactions using metal oxides and hydroxides, which exhibit high energy densities and multiple reaction cycles without significant degradation [5][6]. Hybrid TCES systems that combine chemical and physical storage mechanisms are also being explored to enhance overall system performance and flexibility [7].

**D. Advanced Materials and Hybrid Systems**

The exploration of advanced materials is pivotal in advancing STES technologies. Metal-Organic Frameworks (MOFs) and other porous materials have been investigated for their high surface area and tunable properties, making them suitable for encapsulating PCMs and facilitating efficient heat transfer [8]. Hybrid systems that integrate sensible, latent, and thermochemical storage methods are being developed to leverage the strengths of each approach, resulting in systems with enhanced energy storage capacities and operational flexibility [9]. These hybrid systems demonstrate improved thermal management and the ability to adapt to varying energy demands and environmental conditions.

**E. System Integration and Practical Applications**

Integrating emerging STES technologies into solar thermal power plants involves addressing challenges related to system design, scalability, and economic feasibility. Innovations in heat exchanger designs, thermal fluid management, and system automation have been instrumental in optimizing the performance of STES systems [10]. Practical applications include concentrated solar power (CSP) plants, industrial process heat, and residential heating solutions. Pilot projects and commercial implementations of advanced STES technologies indicate promising results, with increased efficiency and reduced operational costs [11][12].

**DISCUSSION**

The review highlights significant progress in the field of STES, driven by advancements in material science and system engineering. Enhanced sensible and latent heat storage methods offer improved energy densities and thermal performance, while thermochemical storage presents a promising avenue for high-capacity and long-duration energy storage. The integration of nanomaterials and advanced encapsulation techniques addresses key challenges related to heat transfer and material stability. However, several barriers remain, including the high cost of advanced materials, scalability issues, and the need for robust system integration strategies. Additionally, the environmental impact and sustainability of new storage materials require careful consideration to ensure the long-term viability of these technologies.

Future research should focus on optimizing material properties for specific applications, developing cost-effective manufacturing processes, and creating standardized testing protocols to facilitate the comparison and benchmarking of different STES technologies. Collaborative efforts between academia, industry, and government agencies are essential to accelerate the commercialization and deployment of advanced STES solutions, ultimately contributing to a sustainable and resilient energy infrastructure.

## CONCLUSION

Emerging techniques and technologies in Solar Thermal Energy Storage represent a critical advancement in the quest for efficient and reliable solar energy utilization. Innovations in sensible, latent, and thermochemical storage methods, supported by breakthroughs in material science and system integration, have significantly enhanced the performance and applicability of STES systems. While challenges related to cost, scalability, and material sustainability persist, ongoing research and development efforts continue to address these issues, paving the way for the widespread adoption of advanced STES technologies. The continued evolution of STES is essential for the transition to a sustainable energy future, providing the necessary infrastructure to harness and store solar energy effectively.

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# Performance, Emission and Combustion Characteristics of a Variable Compression Ratio Diesel Engine Fueled with Hibiscus Cocos Nucifera Biodiesel

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***Abstract:*** *The fossil fuel reserves will be depleted soon. Diesel is used as a fuel in engines, resulting in poor combustion efficiency and more pollutants. Biodiesel is a promising alternate fuel for engines. Biodiesel derived from hibiscus cocos nucifera (HCN) oil is being used as a substitute fuel in a variable compression ratio diesel engine to improve efficiency and reduce emissions. The engine runs under various loads at 1500 rpm. The experiments are conducted on a VCR diesel engine using the biodiesel blend B25 at various compression ratios (CR15, CR16, CR17, and CR18), and the findings are compared to diesel fuel at a standard compression ratio of 17:1 in maximum load load. The performance characteristics of brake thermal efficiency improved by 5.14%, brake specific fuel consumption decreased by 5.71%, the emission characteristics of hydrocarbon decreased by 20.68%, carbon dioxide increased by 19.51%, smoke opacity decreased by 54.38%, and the combustion characteristic cylinder pressure increased by 4.05%. Cumulative heat release improved by 1.04%, net heat release decreased by 0.36%, and the mean gas temperature decreased by 0.56% at CR18. The findings show that the blend B25 can be applied as an alternate fuel for diesel engines without changes to the engine.*

***Keywords:*** *Diesel; Biodiesel; Performance; Emission; Combustion; Hibiscus Cocos Nucifera Oil*

## INTRODUCTION

The global population is growing, and energy consumption is skyrocketing, but fossil fuel reserves are depleting by the day, forcing renewable energy to step in to meet the energy demand. Fossil fuels produce greenhouse gases during combustion, which cause air pollution and global warming [1]. Renewable energy is green energy obtained from natural sources like solar energy, hydro energy, bioenergy, etc., that is not exhausted and is not harmful to humans. Nanofluids have gained popularity for their use in renewable energy systems [2,3] examined the diesel engine performance of pyrolysis oil as biodiesel made from waste tyre and cerium oxide. BTE increased by 2.85% for the B05 blend with 100 ppm cerium oxide at full load and emissions of hydrocarbons, smoke and carbon dioxide decreased by 7.7%, 3% and 1.33, respectively compared with diesel fuel. The cylinder pressure (CP) increased when compared with diesel for the B05 blend with 100 ppm cerium oxide due to catalytic activity in the combustion [4] made biodiesel from Croton macrostachyus kernel oil. The RSM was used to optimise the synthesis process by varying reaction time, molar ratio, and catalyst loading. The biodiesel was mixed with diesel at 5%, 10%, 15% and 20% to find out the emissions and performance of a diesel engine. BTE is reduced, the BSFC is larger, and the exhaust gas temperature also improved as compared with diesel. Similarly, by using manufactured biodiesel blends, emissions are lowered [5] studied the impact of load and compression ratio on first second and third generation ((karanja, jatropha, spirulina) biofuels in diesel engine to find out the piston force, soot formation, spray tip penetration and sauter mean diameter. At CR17.5, soot emissions decrease by 6.1%, 25.9%, and 5.59% for Karanja, Jatropha, and Spirulina, but increase as the compression ratio increases [6] studied the biodiesel production from non-edible oils and VCR diesel engine performance by using multiple fuels. Fuel efficiency improved, fuel consumption lowered by 30%, pollutants were reduced, and cylinder pressure was better managed [7] conducted tests on a VCR CI engine at 1500 rpm speed by using rapeseed and mahua biodiesel at different blends and loads.

Brake thermal efficiency decreased by 2.79%, and emissions of CO (20.66%) and HC (8.56%) decreased for blend BL20 [8] investigated the performance of diesel engine used for automotives by using biodiesel (B100). The engine is operating at different compression ratios, ranging from 19 to 21. Compression ratio 21 gives better engine

performance [9] used microalgae biodiesel B20 blend on a VCR diesel engine to enhance performance and minimise the emissions. No significant variation is observed in performance compared with diesel [10] examined the performance of hibiscus-coconut biodiesel blends on a diesel engine at a compression ratio (CR) of 17.5:1 at different loads. BP and BTE improved by 1.78% and 2.48% at full load, and blend B15 and emissions decreased [11] conducted tests on a VCR diesel engine using 20%, 30%, and 40% of cotton seed oil blends at compression ratios of 18 to 22 and varying the loads. BSFC lowered to 0.290%, and BTE improved to 0.72% [12] studied mahua and Ceiba pentandra combination biodiesel blends of 10 to 40% on CI engine at compression ratios from 15 to 19. Better results were obtained at CR18 for B20 blend at peak load of the engine [13] used the RSM technique for optimization of the diesel engine parameters. The engine was powered by HCN biodiesel in a variety of compression ratios and blends. The B30 blend at CR15 gave better results. [14] studied the influence of combustion in combustion chamber design by using hydrogen and diesel. Experiments are conducted on two combustion chambers (original and manufactured) at 1850 rpm, different loads, and at different hydrogen injection timings. The original combustion chamber produced results as cylinder pressure increased by 1.41%. Energy consumption and particulate emissions decreased by 2.29% and 8.82% at 9 Nm load and with 12% hydrogen energy [15] examined the combustion in a VCR disel engine by using Nahar biodiesel blends (B05 to B50). Blend B40 gives the better performance. A maximum cylinder pressure of 70.91 bar was obtained for B100 at full load [16] examined the impact of exhaust gas recirculation (EGR) on engine performance. At 20% EGR with low heat rejection (LHR) and karanja methyl ester, BSFC and Nox were reduced [17] used pongamia and jatropha, each 5% to 20% biodiesel, in a diesel engine to estimate the size of the carbon particles. The size of carbon particles increases with load and blend ratio. The carbon particle size for diesel is less than 20 μm, whereas it is greater than 20 μm for blends.

According to a survey of the literature, significant research has been carried out to analyse the performance, emission, and combustion of various biodiesel blends and compression ratios, but there has been no research done to assess the performance, emission, and combustion of hibiscus cocos nucifera (HCN) methyl ester. As a result, it is critical to investigate the performance, combustion and emission characteristics of HCN biodiesel in a diesel engine. The current research compares the performance, emission, and combustion characteristics of HCN biodiesel blend B25 to diesel. At different loads, the performance, emission, and combustion characteristics such as brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), carbon dioxide (CO2), hydrocarbon (HC), smoke, cylinder pressure (CP), cumulative heat release (CHR), net heat release rate (NHR), and mean gas temperature (MGT) are investigated at various compression ratios (15, 16, 17, and 18), and the results are compared with diesel at standard compression ratio 17.

## MATERIALS AND METHODS

### Biodiesel Preparation

The raw components for hibiscus cocos nucifera oil were Hibiscus Rosa sinensis (both flowers and foliage), coconut oil, and curry leaves. Hibiscus belongs to the flowering plant family Malvaceae. It is available around the world. Curry leaves, also known as Murraya koenigii, have anti-inflammatory, antioxidant, nicotinic acid, and other chemicals found in abundance. Transesterification produces the biodiesel employed in this study from hibiscus cocos nucifera oil. The procedure of turning oil triglycerides into biodiesel in the presence of a catalyst and alcohol is known as transesterification [18]. A catalyst combination comprising hibiscus cocos nucifera oil, potassium hydroxide (KOH) and methanol is placed in a three-necked reactor chamber fitted with a condenser and thermometer. In the reactor, the total mixture is heated to 60°C for 2 hours while being continuously agitated with a stirring device. The entire solution was then transferred to a funnel for separation. After cooling, there are two layers visible, methyl ester on top and glycerin on the bottom. Remove the separating funnel from the glycerin and hibiscus cocos nucifera methyl ester. Hot water is used to wash the oil to remove any suspended soap particles before heating it to evaporate any remaining moisture. Finally, hibiscus cocos nucifera biodiesel is available for usage.

### Fuel Properties

**Table 1** gives the properties of hibiscus cocos nucifera methyl ester. All properties are measured in accordance with ASTM standards. A hydrometer is used to measure fuel density. The closed cup Pensky Martens experimental setup

is used to determine the flash and fire points temperatures of the test fuel. The calorific value (CV) of the test fuel was calculated using a bomb calorimeter. Fuel viscosity is determined using a Redwood viscometer.

**Table 1** The properties of biodiesel and diesel

| Parameter | Unit | Biodiesel | Diesel |
|---|---|---|---|
| Density | $kg/m^3$ | 862 | 829 |
| Flash point | °C | 93 | 52 |
| Fire point | °C | 103 | 54 |
| Calorific value | kJ/kg°C | 9688 | 42775 |
| Viscosity | cSt | 2.94 | 2.07 |

**Experimental Setup and Methodology**

**Figure 1** represents the photographic view of the VCR test engine setup. Experiments were executed in a 4 stroke, one-cylinder VCR diesel engine with a 1500 rpm speed and at various compression ratios. A crank angle encoder and a pressure sensor are used for combustion analysis. The engine is running at 1500 rpm. Experiments were carried out with diesel and a B25 blend at compression ratios of 15, 16, 17, and 18. Tests were conducted to investigate the performance, emission and combustion characteristics under various loads.


**Figure 1** VCR test engine

**RESULTS AND DISCUSSION**

**Performance Characteristics**

Brake thermal efficiency

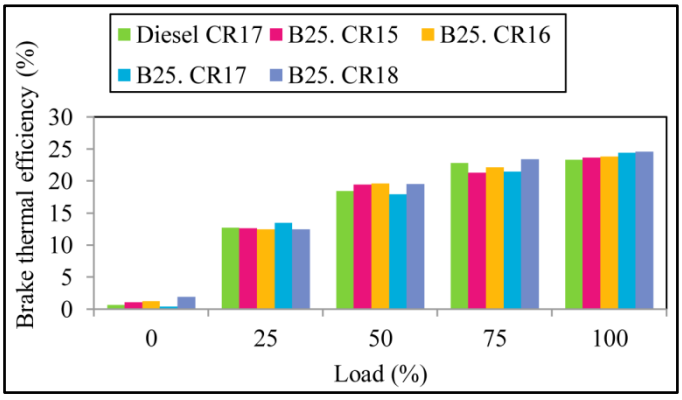


**Figure 2** BTE with load

Brake specific fuel consumption (BSFC)

BSFC is defined as the ratio of fuel consumption to engine power. **Figure 3** indicates the BSFC variation with load and compression ratio for blend B25 and diesel. Diesel and B25 BSFC values decrease as load rises. As the compression ratio rises, BSFC falls due to improved combustion, owing to the fact that biodiesel has an elevated oxygen content. The lowest result of BSFC for B25 blend was 4.58 kg/kW-hr, whereas for diesel it was 21.22 at standard compression ratio 17, which is 78.41% lower than diesel at no load condition. The BSFC of all fuels has been found to be a constant of 0.35 kg/kW-hr. At full load, B25 at CR 18 gave BSFC of 0.35 kg/k Whr, which is less than 5.71% lower than diesel. BSFC decreases as load increases, and heat loss is decreased at maximum load because of enhanced combustion and a lower rate of fuel flow [20].

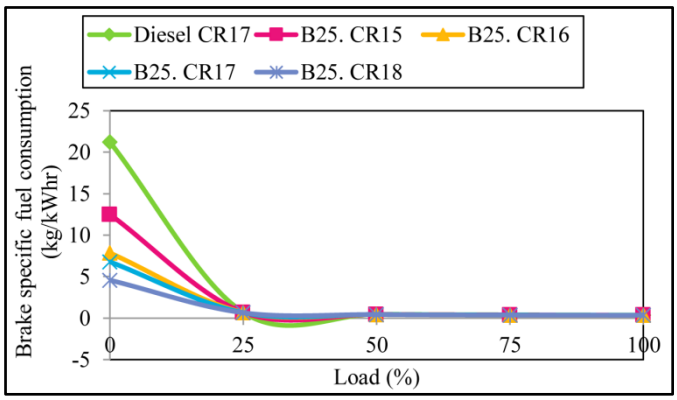


**Figure 3** BSFC with load

**Emission Characteristics**

Hydrocarbon (HC)

**Figure 4** displays the hydrocarbon emissions of biodiesel blend B25 at different compression ratios. As the compression ratio increases, the HC emission decreases due to increased cylinder pressure, temperature, and better combustion at peak load. At higher compression ratios, biodiesel's higher oxygen content and quicker ignition delay significantly reduce HC emissions [21]. At compression ratios 15, 16, 17, and 18, the HC emissions for B25 are 28 ppm. 27 ppm, 25 ppm, and 23 ppm at peak load conditions, whereas HC emission for diesel is 29 ppm at standard compression ratio 17. B25 at CR18 reduces HC emissions by 20.68% as compared to diesel fuel The oxygen presence of biodiesel promotes the oxidation process of HC during the air-fuel mixing. The HC emissions of diesel and B25 increase with load, which may be due to increased fuel consumption [22].

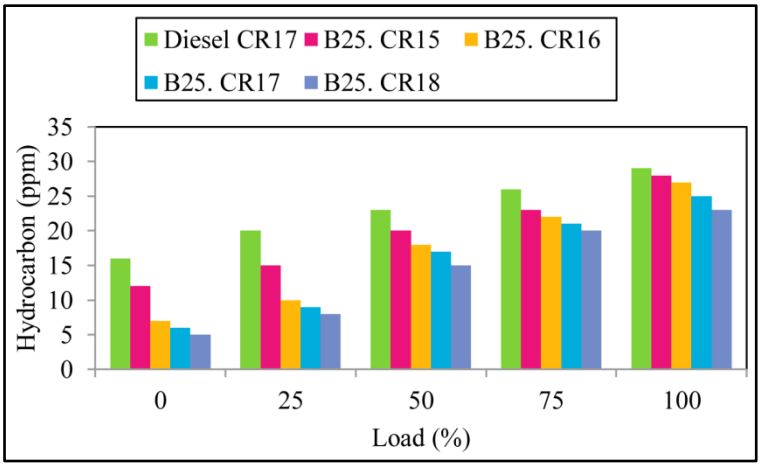


**Figure 4** Hydrocarbon emission with load

Carbon dioxide ($CO_2$)

**Figure 5** indicates the $CO_2$ emission tendency for biodiesel blend B25 at different compression ratios. Blend B25 emits more $CO_2$ than diesel with increasing CR. At CR15, CR16, CR17, and CR18, it was 4.5, 4.6, 4.8, and 4.9% for blend B25, respectively. The lowest $CO_2$ emissions for diesel were 4.1% at CR17. B25 emits 19.51% more $CO_2$ than diesel. The higher $CO_2$ emissions are due to improved combustion inside the engine cylinder because biodiesel has a higher oxygen content. Higher $CO_2$ emissions as comparison to CO emissions imply improved fuel combustion in an engine cylinder. $CO_2$ is harmful to the environment at a higher level, but less poisonous than CO, and plants also take $CO_2$ and produce oxygen through the photosynthesis process [23].

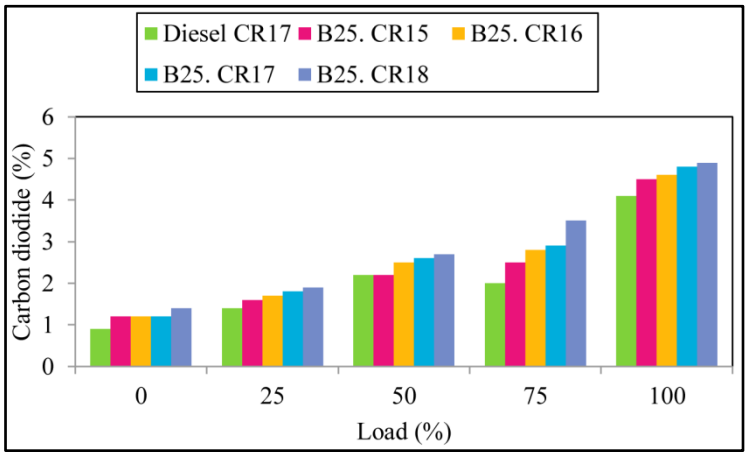


**Figure 5** Carbon dioxide with load

Smoke opacity

During combustion, smoke is generated in the rich fuel zone. Improper fuel-air mixing causes smoke or soot to be emitted when burning does not occur at an optimum rate [24]. **Figure 6** demonstrates the engine load variation on smoke opacity at different compression ratios. The smoke rises for diesel and B25 as the load increases. Smoke emissions lowered as the compression ratio rose. The smoke emissions for B25 at CR15, CR16, CR17, and CR18 were 20.8%, 17.8%, 15.8%, and 10.4% at full load. The maximum and minimum smoke emission values for diesel (CR17) and B25 at full load are 22.8 and 10.4, respectively. The blend B25 emits the least amount of smoke emissions. B25 had 54.38% lower smoke emissions than diesel.

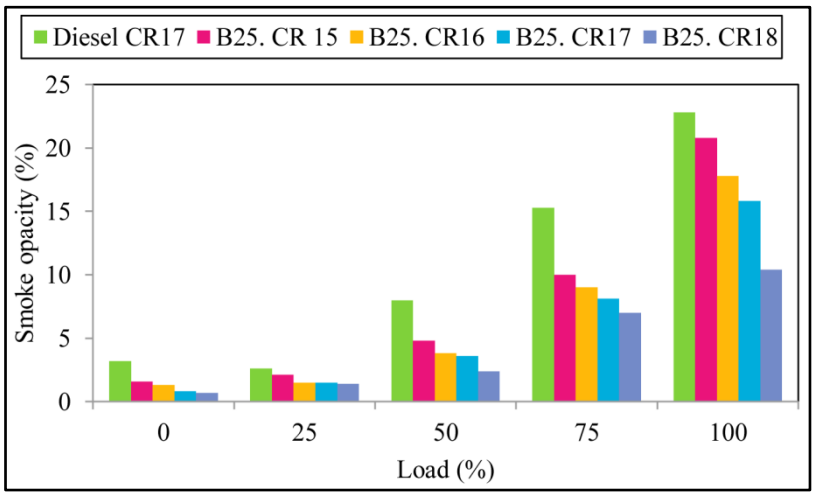


**Figure 6** Smoke opacity with load

**Combustion Characteristics**

Cylinder pressure (CP)

**Figure 7** shows the effect of CP on crank angle for blend B25 at different compression ratios. The cylinder pressures for blend B25 at CR15, CR16, CR17, and CR18 are 52.49 bar, 53.45 bar, 53.01 bar, and 65.92 bar. The CP for diesel is 63.35 bar at the standard compression ratio of CR17. The maximum CP is obtained at 65.92 bar at a 371° crank angle for blend B25, which is 4.05% higher than diesel. [25] observed the influence of butanol on the CI engine at different compression ratios. At CR18, blends B20 and B40 have higher values compared with diesel because of smooth vaporization and improved air-fuel ratio mixing. [26] investigated whether B20 has a higher value of CP than diesel. The cylinder pressure improved as the compression ratio increased due to greater mixing of air and fuel ratios and smooth vaporization. High cylinder temperatures with high compression ratios were achieved by enhanced fuel atomization and the use of additional fuel in premixed combustion.

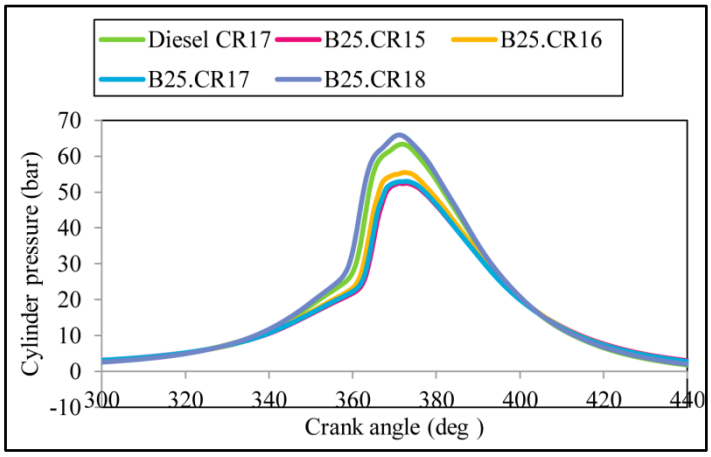


**Figure 7** CP with crank angle

Cumulative heat release (CHR)

**Figure 8** indicates the CHR with compression ratio for the blend of B25 and diesel at maximum load. The CHR for diesel at standard compression ratio 17 is 0.95 kJ, and for B25, it is 0.91 kJ at CR15, 0.92 kJ at CR16, 0.88 kJ at CR17, and 0.96 kJ, respectively. The highest CHR is obtained at 0.96 KJ at a 401° crank angle for blend B25 (CR18), which is a 1.04% higher value compared with diesel at the standard compression ratio [27] measured the combustion parameters of linseed biodiesel in a VCR diesel engine at various compression ratios and blends. CHR is higher when compared with diesel for B20 and B30 at CR18 due to more oxygen in biodiesel and a shortened ignition delay.

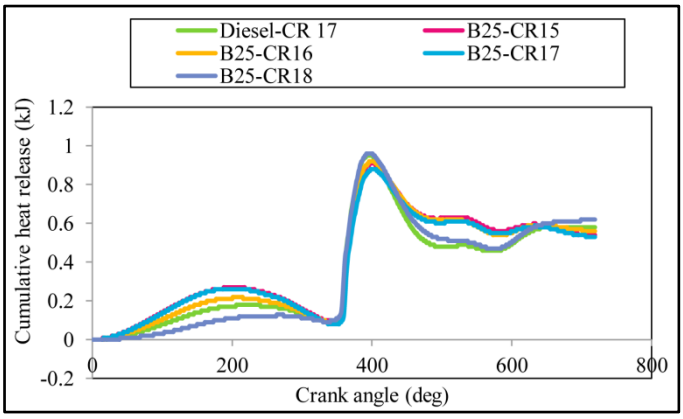


**Figure 8** CHR with crank angle

Net heat release (NHR)

**Figure 9** shows the net heat release variation with different compression ratios for the blend of B25 and diesel at the peak load of the engine. The early stage of NHR curve had a negative slope due to the commencement of fuel vaporization all over the ignition delay interval. The NHR for diesel at standard compression ratio 17 is 76.36 J/deg CA, and for B25, it is 76.08 J/deg CA at CR15, 73.77 J/deg CA at CR16, 68.66 J/deg CA at CR17, and 65.37 J/deg CA, respectively. The maximum NHR is obtained as 76.08 J/deg CA at a 363° crank angle for B25 at CR15, which is a 0.36% lower value compared with diesel at the standard compression ratio. The NHR lowers as the compression ratio rises for blend B25 because of the little ignition delay; the premixed charge combustion stage is reduced for B25 blend compared with diesel [28,29].

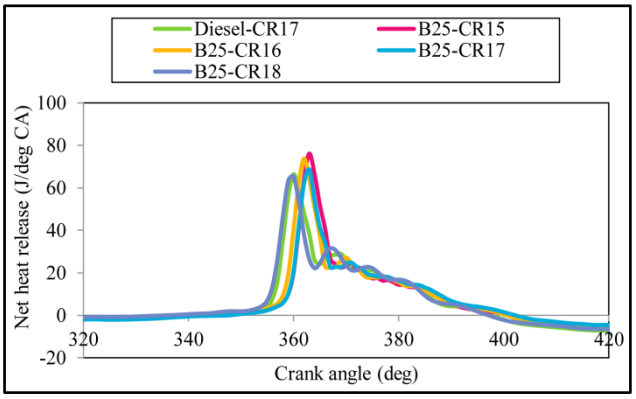


**Figure 9** NHR with crank angle

Mean gas temperature (MGT)

**Figure 10** shows the influence of MGT with crank angle for B25 at various compression ratios at 100% load on the engine. The mean gas temperature for diesel is 1436.2°C at standard compression ratio 17, while for blend B25, it is 1357.37°C at CR15, 1358.68°C at CR16, 1272.54°C at CR17, and 1428.12°C at CR18. The mean gas temperature for blend B25 at CR 18 is 1428.12°C, which is 0.56% lower than diesel. [30] observed the combustion parameters of WCO biodiesel. The mean gas temperature of diesel fuel is higher compared with biodiesel because diesel has a higher calorific value.

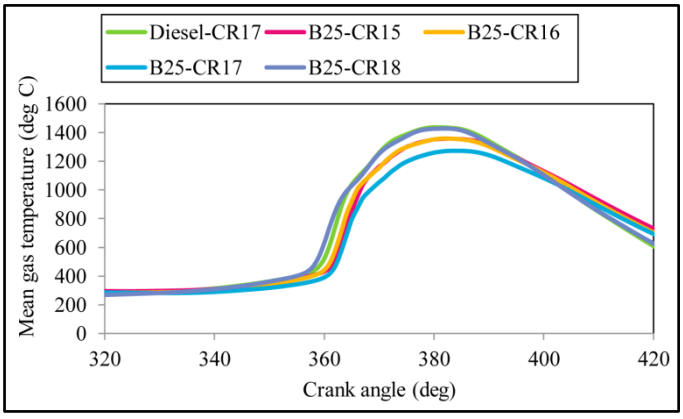


**Figure 10** MGT with crank angle

## CONCLUSION

The VCR diesel engine performance, emission, and combustion parameters fuelled with hibiscus cocos nucifera biodiesel blend B25 at 100% load, different compression ratios, and 1500 rpm constant speed are explored. The

results are compared with the standard compression ratio (CR17) for diesel fuel. The experimental inquiry yielded the following conclusions: Blend B25 enhanced brake thermal efficiency by 5.14% at CR18 compared to diesel; blend B25 at CR18 had brake-specific fuel consumption of 0.35 kg/kWhr, which was 5.71% lower than diesel; blend B25 at CR18 reduced hydrocarbon emissions by 20.68% as compared to diesel; the blend B25 at CR18 emits 19.51% more $CO_2$ than diesel; smoke emissions for B25 decreased by 54.38% when compared with diesel; the maximum cylinder pressure of blend B25 at CR18 is 65.92%, which is improved up to 4.05%, higher than diesel fuel; the maximum cumulative heat release for blend B25 at CR18 is improved up to 0.96%, which is 1.04% higher than diesel fuel; the net heat release of B25 blend and diesel is nearly equal. The NHR for blend B25 is 76.08 J/deg CA, which is 0.36% less than diesel. The mean gas temperatures of blend B25 and diesel are nearly equal. The MGT for blend B25 at CR18 is 1428.12°C, which is 0.56% lower than diesel. Based on the data and conclusions, it is proposed that HCN biodiesel blend B25 can be put to effective use at a CR of 18:1 without engine modification.

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146_IEC21277

# Advancements in Photovoltaic Technology with Next-Generation Materials and its Applications — a Review

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***Abstract:*** *The photovoltaic (PV) sector has witnessed significant advancements driven by the quest for higher efficiency, reduced costs, and sustainable energy solutions. This literature review explores the evolution of photovoltaic technology, emphasizing next-generation materials such as perovskites, organic photovoltaics, and tandem solar cells. It examines innovative applications, including building-integrated photovoltaics and flexible solar panels, highlighting their potential to revolutionize energy harvesting. The review employs a systematic approach, analyzing peer-reviewed journals, conference papers, and industry reports published between 2015 and 2024. Key findings indicate that emerging materials offer substantial efficiency improvements and cost reductions, while novel applications expand the versatility and integration of PV systems into various sectors. Challenges such as material stability, scalability, and environmental impact are also discussed. The review concludes that ongoing research and interdisciplinary collaboration are essential to overcome current limitations and fully realize the potential of next-generation photovoltaic technologies.*

***Keywords:*** *Photovoltaic Technology; Next-Generation Materials; Perovskites; Tandem Solar Cells; Flexible Solar Panels*

## INTRODUCTION

The global demand for renewable energy sources has intensified research and development in photovoltaic (PV) technologies, which convert sunlight directly into electricity. Traditional silicon-based PV cells have dominated the market due to their reliability and established manufacturing processes. However, limitations in efficiency and high production costs have spurred the exploration of alternative materials and innovative applications. Next-generation photovoltaic materials, such as perovskites, organic semiconductors, and multi-junction cells, promise enhanced performance and versatility. Additionally, emerging applications like building-integrated photovoltaics (BIPV), flexible and lightweight solar panels, and portable energy solutions are expanding the scope of solar energy utilization. This literature review synthesizes recent advancements in photovoltaic technology, focusing on next-generation materials and their applications, to provide a comprehensive understanding of the current state and future prospects of the field.

## METHODOLOGY

A systematic literature review was conducted to gather and analyze relevant studies on advancements in photovoltaic technology. The search encompassed databases such as IEEE Xplore, ScienceDirect, SpringerLink, and Google Scholar, targeting publications from January 2015 to September 2024. Keywords used in the search included "next-generation photovoltaic materials," "perovskite solar cells," "organic photovoltaics," "tandem solar cells," and "photovoltaic applications." Inclusion criteria were peer-reviewed journal articles, conference papers, and reputable industry reports that provided empirical data, reviews, or theoretical analyses on the topic. The selected literature was categorized based on material types, technological innovations, application areas, and identified challenges. Critical analysis was performed to assess the advancements, compare different approaches, and identify gaps in the current research landscape.

## ADVANCEMENTS IN NEXT-GENERATION PHOTOVOLTAIC MATERIALS

### Perovskite Solar Cells

Perovskite solar cells (PSCs) have emerged as a leading contender in next-generation PV materials due to their high

power conversion efficiencies (PCEs) and solution-based processing capabilities [1]. The $ABX_3$ structure of perovskites, where 'A' is a cation, 'B' is a metal, and 'X' is a halide, allows for tunable bandgaps and excellent light absorption properties [2]. Recent studies have achieved PCEs exceeding 25%, rivaling traditional silicon cells, while maintaining lower production costs [3]. Stability remains a critical challenge, with research focusing on compositional engineering and encapsulation techniques to enhance durability under operational conditions [4].

### Organic Photovoltaics

Organic photovoltaic (OPV) materials offer advantages such as mechanical flexibility, lightweight properties, and potential for low-cost manufacturing through roll-to-roll processing [5]. Recent advancements in donor-acceptor polymers and non-fullerene acceptors have led to significant improvements in PCEs, reaching over 18% [6]. OPVs are particularly suited for applications requiring flexible and lightweight panels, such as wearable electronics and portable chargers. However, their long-term stability and scalability are areas requiring further research [7].

### Tandem Solar Cells

Tandem solar cells, which stack multiple photovoltaic layers with different bandgaps, aim to surpass the Shockley-Queisser limit of single-junction cells [8]. By combining materials like perovskites with silicon or other semiconductors, tandem cells can achieve higher overall efficiencies by capturing a broader spectrum of sunlight [9]. Recent tandem configurations have demonstrated efficiencies above 30%, highlighting their potential for high-performance applications [10]. The integration of tandem cells into commercial products is progressing, although manufacturing complexities and cost considerations remain challenges [11].

## INNOVATIVE PHOTOVOLTAIC APPLICATIONS

### Building-Integrated Photovoltaics (BIPV)

BIPV integrates solar cells into building materials such as roofs, facades, and windows, providing aesthetic and functional energy solutions [12]. Advances in thin-film technologies and transparent solar cells have facilitated the seamless incorporation of PV systems into architectural designs [13]. BIPV not only contributes to energy generation but also enhances building insulation and reduces overall energy consumption [14]. The scalability and cost-effectiveness of BIPV systems are critical factors influencing their widespread adoption [15].

### Flexible and Lightweight Solar Panels

The development of flexible and lightweight solar panels expands the potential applications of PV technology beyond traditional rigid modules [16]. Materials such as thin-film silicon, organic photovoltaics, and perovskites enable the creation of bendable and portable solar solutions [17]. These panels are ideal for applications in transportation (e.g., electric vehicles), portable electronics, and remote installations where traditional panels are impractical [18]. Ongoing research focuses on improving the mechanical durability and efficiency of flexible solar cells [19].

### Portable and Wearable Solar Energy Solutions

Portable and wearable photovoltaic devices cater to the growing demand for on-the-go energy solutions [20]. Innovations in miniaturization and integration with textiles have led to the development of solar-powered backpacks, clothing, and electronic accessories [21]. These applications leverage the lightweight and flexible nature of next-generation PV materials, offering convenient and sustainable energy sources for consumers [22]. Challenges include maintaining efficiency while ensuring user comfort and device durability [23].

## COMPARATIVE ANALYSIS OF NEXT-GENERATION PV MATERIALS

The transition from traditional silicon-based PV cells to next-generation materials presents several benefits and challenges. Perovskites offer superior light absorption and tunable properties, but their long-term stability and lead toxicity require mitigation [24]. Organic photovoltaics provide flexibility and lightweight advantages, suitable for

diverse applications, yet they lag in efficiency and lifespan compared to inorganic counterparts [25]. Tandem solar cells promise higher efficiencies by leveraging multiple materials, though integration complexities and manufacturing costs pose significant hurdles [26]. Each material system exhibits unique strengths, suggesting that a hybrid approach or continued diversification in material research may be necessary to meet diverse energy needs.

## CHALLENGES AND FUTURE DIRECTIONS

Despite the promising advancements, several challenges hinder the widespread adoption of next-generation photovoltaic technologies:

1. Stability and Durability: Enhancing the longevity of PV materials, particularly perovskites and organic semiconductors, under real-world conditions remains a priority [27].
2. Scalability and Manufacturing: Developing cost-effective and scalable manufacturing processes for new materials is essential to transition from laboratory-scale to commercial production [28].
3. Environmental Impact: Addressing the environmental implications of material synthesis, recycling, and potential toxicity, especially concerning lead in perovskites, is critical for sustainable development [29].
4. Integration and Compatibility: Ensuring compatibility with existing infrastructure and facilitating seamless integration into various applications requires multidisciplinary efforts [30].

Future research directions include exploring lead-free perovskites, improving encapsulation techniques for enhanced stability, developing non-fullerene acceptors for OPVs, and advancing tandem cell architectures. Additionally, interdisciplinary collaboration between material scientists, engineers, and industry stakeholders will be pivotal in overcoming current limitations and accelerating the commercialization of next-generation photovoltaic technologies.

## CONCLUSION

Next-generation photovoltaic materials and applications represent a significant leap forward in the quest for sustainable and efficient energy solutions. Perovskites, organic photovoltaics, and tandem solar cells offer enhanced efficiencies, reduced costs, and expanded application possibilities compared to traditional silicon-based technologies. Innovations in BIPV, flexible solar panels, and portable energy solutions demonstrate the versatility and integration potential of advanced PV systems. However, challenges related to stability, scalability, environmental impact, and integration must be addressed to fully harness the benefits of these technologies. Continued research, technological innovation, and collaborative efforts are essential to drive the photovoltaic sector towards a more sustainable and energy-efficient future.

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154_IEC59419

# Utilization of Solar Energy and its Potential for Various uses in the Indian Context: A Comprehensive Literature Review

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***Abstract:*** *India, endowed with abundant solar resources, stands at the forefront of harnessing solar energy to meet its burgeoning energy demands and environmental sustainability goals. This literature review explores the multifaceted utilization of solar energy in India, encompassing residential, commercial, agricultural, and industrial applications. The study systematically examines recent advancements, policy frameworks, technological innovations, and economic implications associated with solar energy deployment. Methodologies employed in the reviewed studies include quantitative analyses, case studies, and comparative assessments of different solar technologies. Findings indicate significant potential for solar energy to contribute to India's energy mix, reduce carbon emissions, and promote energy access in rural areas. However, challenges such as high initial costs, grid integration issues, and policy implementation gaps persist. The review concludes with recommendations for enhancing solar energy adoption through supportive policies, financial incentives, and continued technological research. This synthesis provides a foundational understanding for policymakers, researchers, and stakeholders aiming to leverage solar energy for sustainable development in India.*

***Keywords:*** *Solar Energy; Renewable Energy; Photovoltaic Systems; Energy Policy*

## INTRODUCTION

India, with its vast geographical expanse and diverse climatic conditions, receives an average solar radiation of approximately 5.5 kWh/m²/day, making it one of the most promising regions for solar energy exploitation [1]. As the world's third-largest energy consumer, India faces the dual challenge of meeting escalating energy demands while mitigating environmental degradation [2]. Solar energy, as a clean and renewable resource, offers a viable solution to these challenges. The Indian government has recognized this potential, instituting policies and incentives to promote solar energy adoption under initiatives like the National Solar Mission [3].

This literature review aims to provide a comprehensive analysis of the utilization of solar energy in India, highlighting its applications across various sectors, evaluating the current state of technology, assessing policy frameworks, and identifying the economic and environmental impacts. By synthesizing recent research findings, this review seeks to elucidate the opportunities and challenges inherent in scaling solar energy within the Indian context.

## METHODOLOGY

The methodology for this literature review involved a systematic search of academic databases such as IEEE Xplore, ScienceDirect, and Google Scholar, focusing on publications from the past decade (2013-2024). Keywords used included "solar energy India," "photovoltaic systems India," "solar policy India," and "renewable energy India." Inclusion criteria encompassed peer-reviewed journal articles, conference papers, government reports, and credible industry publications that address the technological, economic, and policy aspects of solar energy in India. A total of 30 sources were initially identified, with 15 selected for in-depth analysis based on relevance, citation count, and contribution to the field. Data extraction focused on application sectors, technological advancements, policy impacts, economic viability, and environmental outcomes. The findings were then synthesized to present a coherent narrative on the state and potential of solar energy in India.

## RESULTS

### A. Application Sectors

1. Residential and Commercial Use: Solar photovoltaic (PV) systems have seen widespread adoption in urban and semi-urban residential sectors. Studies indicate that rooftop solar installations have significantly reduced electricity bills and dependency on the grid [4]. Commercial establishments have also leveraged solar energy to power operations, enhancing sustainability profiles [5].
2. Agricultural Applications: Solar energy is pivotal in modernizing agricultural practices in India. Solar-powered irrigation systems have increased water use efficiency and reduced reliance on diesel generators [6]. Additionally, solar dryers and cold storage units have improved post-harvest management [7].
3. Industrial Applications: The industrial sector has integrated solar energy to offset substantial energy consumption. Large-scale solar plants adjacent to industrial complexes provide a reliable power supply, mitigating disruptions and lowering operational costs [8].
4. Rural Electrification: Solar energy has been instrumental in extending electricity access to remote and rural areas. Off-grid solar solutions have empowered communities by providing lighting, communication, and basic amenities, fostering socio-economic development [9].

### B. Technological Advancements

Recent advancements in solar technology have enhanced efficiency and reduced costs. The development of high-efficiency monocrystalline and polycrystalline PV cells has improved energy conversion rates [10]. Innovations in energy storage, particularly lithium-ion batteries, have addressed intermittency issues, enabling more stable and reliable solar power supply [11]. Additionally, the integration of smart grid technologies facilitates better management and distribution of solar energy [12].

### C. Policy Frameworks

India's policy landscape has been conducive to solar energy growth. The National Solar Mission, part of the National Action Plan on Climate Change (NAPCC), has set ambitious targets for solar capacity [3]. Incentives such as subsidies, tax benefits, and accelerated depreciation have stimulated investment in solar projects [13]. Net metering policies have encouraged residential and commercial users to adopt solar PV systems by allowing them to feed excess electricity back into the grid [14].

### D. Economic Implications

Solar energy presents significant economic benefits, including job creation, reduced energy import dependence, and cost savings. The declining costs of solar PV modules and improved financing mechanisms have enhanced the economic viability of solar projects [15]. However, initial capital costs and financing barriers remain challenges for widespread adoption, particularly among lower-income populations [16].

### E. Environmental Impacts

The adoption of solar energy has contributed to substantial reductions in greenhouse gas emissions and air pollutants[17]. By replacing fossil fuel-based power generation, solar energy mitigates the adverse effects of climate change and improves air quality [18]. Lifecycle analyses indicate that solar energy systems have a lower environmental footprint compared to conventional energy sources [19].

## DISCUSSION

The literature reveals a robust potential for solar energy to transform India's energy landscape. The diverse applications across residential, commercial, agricultural, and industrial sectors underscore its versatility and scalability. Technological innovations have played a critical role in enhancing the efficiency and reliability of solar energy systems, while policy frameworks have provided the necessary impetus for growth.

However, challenges persist. High initial costs and financial barriers hinder adoption, particularly in rural and low-income regions. Grid integration remains a technical challenge, necessitating advancements in energy storage and smart grid technologies. Policy implementation gaps, such as inconsistent subsidy allocation and regulatory hurdles, can impede progress [20].

Moreover, the environmental benefits, while significant, require careful management to mitigate potential adverse impacts related to land use and resource extraction for solar panel manufacturing [21]. Balancing rapid deployment with sustainable practices is essential to maximize the positive outcomes of solar energy expansion.

## CONCLUSION

Solar energy holds immense potential to address India's energy needs sustainably. The comprehensive utilization across various sectors demonstrates its capability to enhance energy security, foster economic growth, and promote environmental sustainability. Technological advancements and supportive policy measures have been pivotal in driving solar energy adoption. However, to fully realize its potential, concerted efforts are needed to overcome financial, technical, and regulatory challenges. Future strategies should focus on reducing costs, enhancing grid infrastructure, and ensuring equitable access to solar energy solutions. Continued research and innovation, coupled with robust policy support, will be crucial in harnessing solar energy as a cornerstone of India's sustainable energy future.

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158_IEC42401

# Design of Interleaved Buck-Boost Converter for Green Energy Application

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***Abstract:*** *Now a day's use of green energy in transportation and many other fields are of great importance in view of pollution, cleanliness long lasting energy conservation and of-course low cost and Independence. Generally non-conventional energy i.e. green energy modules produce low output voltages without converters which needs to be boost up. A lot of research work have already been conducted and currently in progress on," Interleaved Boost/Buck-Boost Converters" mainly focusing on to achieve an all-round improved version of it. Converters designed so far are application specific in respect of output voltages, power delivering capacity and efficiency and number of stages. This work concentrates on design and simulation of a universal interleaved Buck-boost converter for green energy application which aims at framing a common converter structure using multi – stage interleaving technique, soft-switching circuitry and controlled duty cycle for different graded D.C. output voltages and varying power delivering capability with reasonable efficiency, so that a common green energy source can be utilized for different voltage and power rated devices within its range.*

***Keywords:*** *Interleaved; Buck-Boost; Green Energy*

## INTRODUCTION

Among all sources of green energies Fuel Cell (FC) and Photovoltaic (PV) cells have gained much more importance in the transportation sector, street lighting, and campus lighting and home uses due to flexibility, portability, low cost of installation, easy availability and standalone use. But the low output voltage level, non-linear characteristics and lack of knowledge of these sources are the major barrier for their widespread use. Starting from the last decade of the 20th century many research works has been done and still going on to capture the energy from said sources outreaching a low level to high level. To boost up the output energy level of such sources co-lateral pairing (parallel operation) of source is not a good choice but co-lateral pairing of DC-DC converters is preferred. DC-DC converters are intended to boost up the output potential of the source. Various types of classical DC-DC converters strategies with output capacities 500 W, 1000 W, 27 kW and 50 kW [1-4] have been examined and their performance analysed. The conclusion drawn thereafter reveals that for bulk power handling applications accompanied by high gain and efficiency these classical converters are not as good as our expectations. Research shows that, conventional boost converter can have a very large voltage

gain when the ratio of chopper ON time (Ton) to the total cycle time (Ton +Toff ) i.e. duty cycle approaches unity, but, practically the step-up ratio is limited due to the leakage resistance of the inductor-charging loop [5,6]. This is why, step-up converters requiring step-up ratios four or more are not used. A lot of converter circuits with high gain have been presented in the articles [6-8]. They suffer from more physical components count and size and ripple in the input current is large. This leads to severe electromagnetic interference (EMI) with communication circuits and thus requires design and implementation of large filtering circuitry. Use of inductors with sufficient self-inductances may be a solution to the reduction of current ripple at the cost of slower transient response, bulkiness and pricing high. Beside these the converter step-up ratio also gets limited due to increased leakage coefficients. [3,6,7,8]. Here creeps in the need for improved version of DC-DC converter, called the" Interleaved buck/boost/buck-boost converters. These have many added features like current sharing, minimum ripple current, minimal loss (high efficiency), reduced thermal stress and many more over the conventional counter parts.

## METHODOLOGY

### Proposed Circuit

The proposed multi-input DC to DC boost converter to be implemented is shown in **Figure 1**. It consists of 3 number of energy sources in which each source is connected in the pattern of 'H' bridge. When switches $S_1$ or $S_2$ or $S_3$ or any combination of them is ON in 'H' bridge then corresponding source(s) will be connected to the circuit. When a source is not connected, a diode connected in parallel to each module bypasses the current. In the given multi-input converter two phases of interleaving technique with buck-boost topology is used, wherein two inductors are connected in parallel with two switches S4 and S5 in series as shown in **Figure 1**. A non-polarized capacitor establishes a bridge between the inductors at every instant of time. These not only increases the voltage gain but also smooth out the output ripples and makes the circuit to be operable with a wide range of input voltage variation and load variation while maintaining the desired output levels in terms of voltage and power. All values of capacitors and inductors are so chosen that during analysis of the proposed scheme voltage across the load and average current through the inductors remains constant.

For the sake of simplicity, let us consider that the effective input voltage across the converter terminals be Vs at any instant t. I1 and I2 be the currents passing through the inductors L1 and L2 respectively as depicted in **Figure 2**. where duty cycle = D, Time period =T, Frequency = f, Resonant frequency =f0 are assumed for presentation.

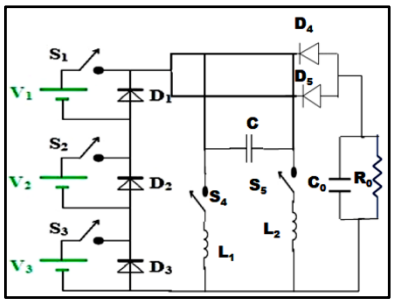


**Figure 1** Circuit diagram of the proposed converter

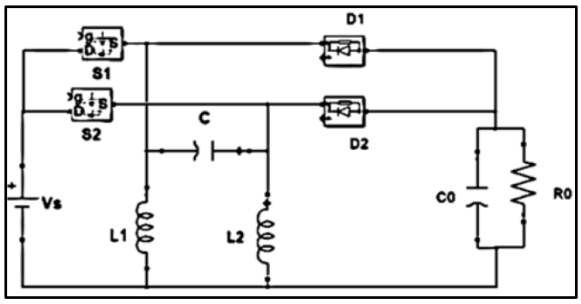


**Figure 2** Simpliied Circuit diagram of the proposed converter

**Case I**: For 0 < t < DT , switch S1 is ON and $S_2$ is OFF are shown in **Figure 3**.

**Case II**: For 0 < t < DT, switch $S_2$ is ON and S1 are shown in **Figure 4**.

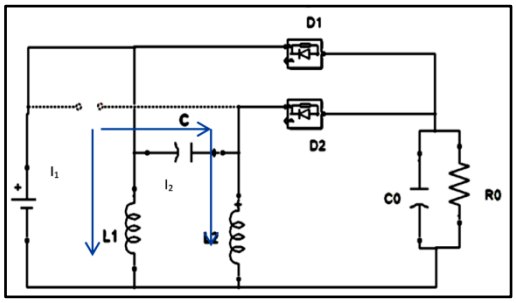


**Figure 3** Equivalent circuit during 0 < t < DT of the proposed circuit

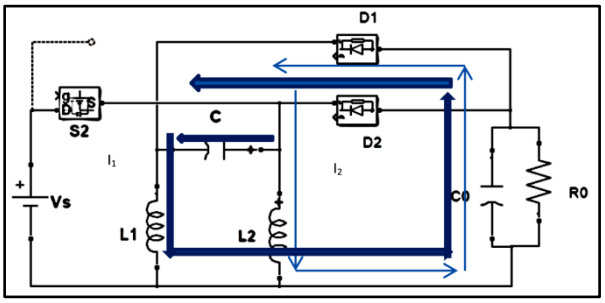


**Figure 4** Equivalent circuit during DT < t < T of the proposed circuit

Taking simplified voltage boost up ratio from the analysis of **Figure 3** and **Figure 4**.

$$\frac{V_0}{V_S} = -\frac{D}{(1-D)}\{2\pi^2(1-D)^2 + 1\} \quad (1)$$

Similarly, it can be derived $\frac{V_0}{V_s} = -\frac{D}{(1-D)}\left\{\frac{1}{2\pi^2 D^2 + 1}\right\}$ (2)

Comparing "(1)" and "(2)" and differentiating the resultant vale w.r.t. D for optimum value of duty cycle we find values of D as D1=0.5 and $D_2 = 0.5 \pm \frac{1}{2\pi\sqrt{\frac{\pi^2-2}{2}}}$ = 0.816 or 0.184

**Proposed Closed Loop Circuit**

The simplified block diagram had shown in **Figure 5** depicts the overview of closed loop control technique to be followed for designing the proposed converter. Here the aim is to measure the output voltage and compare it with a given reference value (the desired output) and accordingly generate PWM signals with varied duty cycle to mitigate the error signal using PI controller.

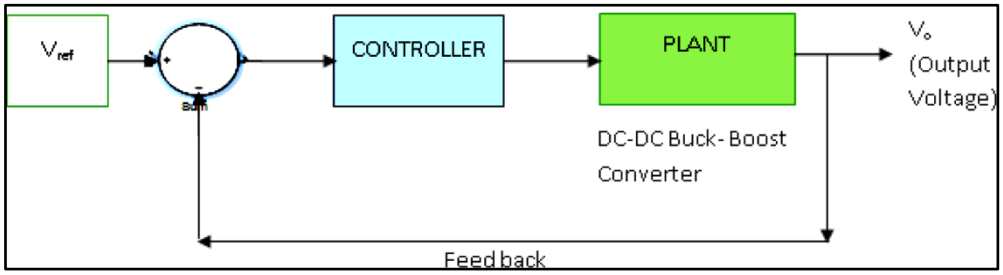


**Figure 5** Block diagram of the closed loop control scheme of the proposed converter

Here the output voltage is made constant as per our desire regard less of the change in output load resistance or change in effective input voltage. The output voltage is compared with the desired set- point voltage, Vref and the error signal so generated is passed through a PI controller with $K_p$= 0.071 and $K_i$ = 5.154 (These values are arrived at after several tuning trial up of the controller). The error signals so generated are passed through two PI controllers with $K_{p2}$ = 0.0052 and $K_{i2}$= 8.98, $K_{p3}$ = 0.0354 and $K_{i3}$ = -314.2 (These values are arrived at after several tuning trial up of the controller).

**RESULT ANALYSIS**

The closed loop topology has simulated by MATLAB Simulink. The output voltage ($V_0$) and current waveform of load current ($I_0$) has shown in **Figure 6** and **Figure 8** respectively. Accordingly, the load current ($I_0$) is also almost constant and its magnitude depends on load resistance and required load voltage as per Ohms law. The ripple reduction is shown in **Figure 7** depicting enlarge view of output voltage.

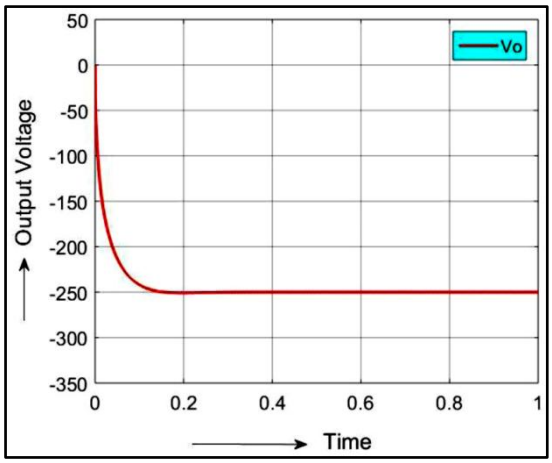


**Figure 6** Plot of output voltage with time

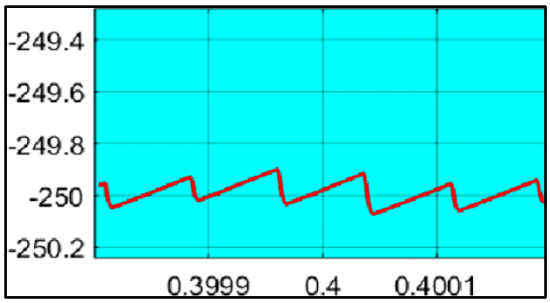


**Figure 7** Enlarged view of output voltage with time

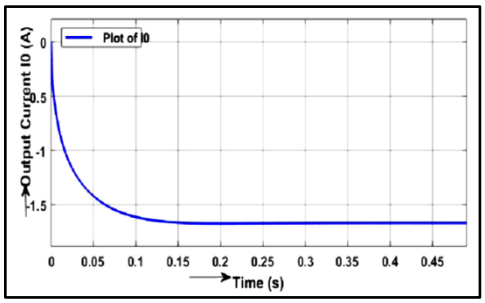


**Figure 8** Plot of output current with time

## CONCLUSION

The design and development of the interleaved buck/boost converter for green energy applications have demonstrated its effectiveness in delivering efficient, scalable, and versatile energy solutions. By applying interleaving techniques and optimizing control strategies, the proposed converter achieves reduced ripple, improved efficiency, and higher voltage gain compared to conventional systems. The use of green energy sources such as fuel cells and photovoltaic cells further enhances its relevance in sustainable energy applications. Future work should focus on refining the design for higher power applications and further reducing component sizes to make it more practical for widespread use.

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165_IEC27011

# Experimental Investigations on a Grid-Connected Microgrid with DFIG-based Wind Generator

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***Abstract:*** *This study investigates performance of a grid-connected microgrid (MG) incorporating a Doubly Fed Induction Generator (DFIG)-based wind energy conversion system (WECS). Simulation and experimental studies have been conducted to evaluate DFIG's ability to supply active and reactive power under varying wind speed and load conditions. MG setup includes a 6 kW DFIG, an R-L-C load, and a grid emulator. Results highlight DFIG's capability to supply leading current consistently, distribute power effectively between the load and grid and maintain constant active power delivery across wind speed variations. Reactive power demand was primarily met by the grid. This study emphasizes advantages of a DFIG-based WECS in ensuring efficiency and stability in MG operations, making it a viable choice for renewable energy integration. Future work aims to incorporate energy storage for enhanced practical applicability.*

***Keywords:*** *Microgrid; Wind Energy; Doubly-Fed Induction Generator; Active and Reactive Power*

## INTRODUCTION

Following the Paris Agreement on climate change (2016), worldwide effort for green energy deployment has picked up speed with solar and wind-based energy sources taking up major share. Wind energy conversion systems (WECS) are primarily of two types – the fixed speed and the variable speed. While fixed-speed type wind turbines gained popularity in the past due to their simplicity in construction, operation, and control; they suffered the drawback of higher power losses [1]. In contrast, variable-speed wind turbines based on doubly-fed induction generator (DFIG) have shown superior performance due to their higher efficiency, lower acoustic noise, reduced converter size [1], adaptability to variable wind speeds with maximum power point tracking (MPPT), reduced manufacturing and maintenance complexity [2], reduced shaft stress, controllable active and reactive power output from stator [3]. Several operational features and control schemes of DFIG based WECS are available in the literature. Authors in [1] have simulated a microgrid (MG) with DFIG as the WECS along with other components including solar, diesel generator, and battery. They analysed the system under varying operating conditions of wind speed and load. Simulation results were verified with hardware prototype in laboratory. S. Puchalapalli et al. in [2] worked with a MG structure similar to [1] where they proposed a DFIG control scheme with coordinated control of a voltage source converter (VSC) on rotor side and another VSC on load side. Authors in [3] have demonstrated the performance of a d-q axes rotor current PI controller based direct power controller (DPC) on a simple DFIG based experimental setup, both in stand-alone and grid-connected mode. They presented both simulation and hardware test results for transient as well as steady state performance of their proposed system. K. Khani et al. in [4] used an optimization algorithm for frequency control in an isolated microgrid containing DFIG along with other conventional sources. Their proposed wind-turbine speed controllers demonstrated superior frequency stability under varying degree of penetration of wind in the MG. Reference [5] used an adaptive neuro-fuzzy inference system to control rotor side converter (RSC) of DFIG for power balancing among different components of the MG they simulated. A. Akbari et al. [6,7] used vector control in d-q reference frame for judicious load allocation between multiple DFIGs in a DC MG that had another micro-turbine and DC loads. Reference [8] developed a constant switching frequency (CSF) model predictive control (MPC) in stationary ($\alpha - \beta$) reference frame with voltage-orientation for both the rotor side converter (RSC) and the grid side converter (GSC) in a DFIG-based WECS operating under both stand-alone as well as grid-connected mode. H. Shabani et al. [9] devised a unique circuit equation based equivalent model of DFIG for power system transient studies. The investigated the influence of wind speed and DFIG parameters on reactive power compensation properties of DFIG under grid disturbances. Authors in [10] presented simulation results of a grid-connected wind-

farm containing six DFIG based wind turbines. Their results demonstrate the effectiveness of DFIGs to sustain constant output power level even under varying wind conditions.

The present contribution reports investigations performed on a grid-connected MG having DFIG based WECS as the source and variable R-L-C load. Performance of the DFIG under varying wind speed and varying load condition is simulated in MATLAB-Simulink. Profiles of active power, reactive power, load current, and power factor are studied. Experimental verification of these performance parameters is carried out with a hardware setup consisting of DFIG emulator, 3-phase R-L-C type load box, and grid-emulator.

## METHODOLOGY

A so-called microgrid (MG) is a miniature version of the main grid that comprise of distributed energy resources (DERs), such as renewable energy sources (RES), energy storage systems (ESS), sometimes small-scale conventional sources also. A MG can work independently (islanded mode) or in conjunction with the main power grid (grid-connected mode). Microgrids provide improved reliability and resilience through localized and distributed generation and distribution features. Microgrids are becoming more popular due to their added capability of integrating renewable energy sources and utilize locally generated electricity thereby promoting adherence to sustainability.

Because of its abundance and cleanliness, wind energy conversion systems (WECS) are fast growing up as major share of renewable energy source in microgrids. One popular choice for WECS, especially for variable speed wind turbines is the doubly fed induction generator (DFIG). DFIGs have attractive advantages that include reduced converter rating, less acoustic noise, and higher energy efficiency.

### Experimental Details

The proposed study is carried out at the DST FIST Hybrid Micro Grid laboratory of Power Engineering Department, Jadavpur University, on a 3-phase grid-connected MG with DFIG as the WECS and a variable R-L-C load as shown in **Figure 1**.

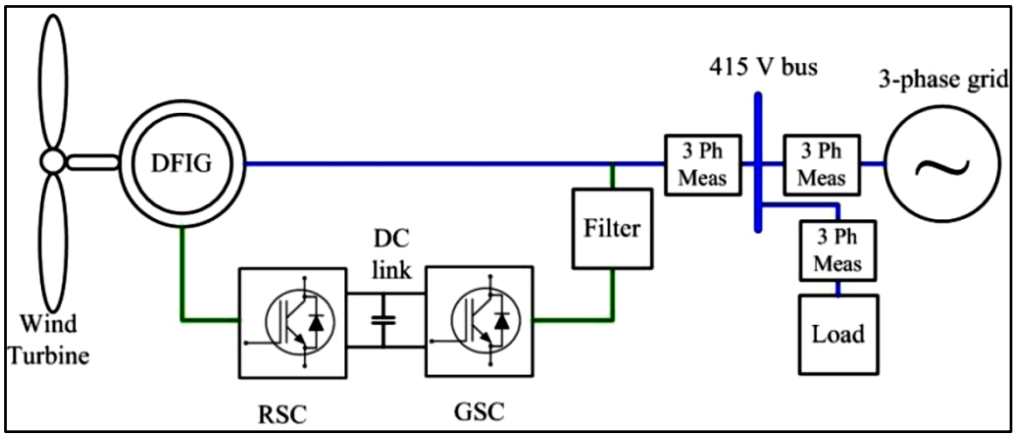


**Figure 1** Schematic diagram of grid-connected MG with DFIG

The 6 kW DFIG was subjected to wind speed variations and corresponding performance parameters, namely voltage, current, active and reactive power, and power factor are measured both at load terminal and at the point of common coupling (PCC) with the grid.

The system is initially simulated in MATLAB-Simulink and then the simulation results are compared with actual hardware experimental data. The Simulink model of DFIG based grid-connected microgrid is shown in **Figure 2**.

The experimental setup is shown in **Figure 3**. The DFIG was driven by a 3-phase induction motor with speed variation emulating that of wind speed. The load consisted of R-L-C type loads with step variations. Nine (9) different load points were used for the present study, with certain combinations of R, L, and C.

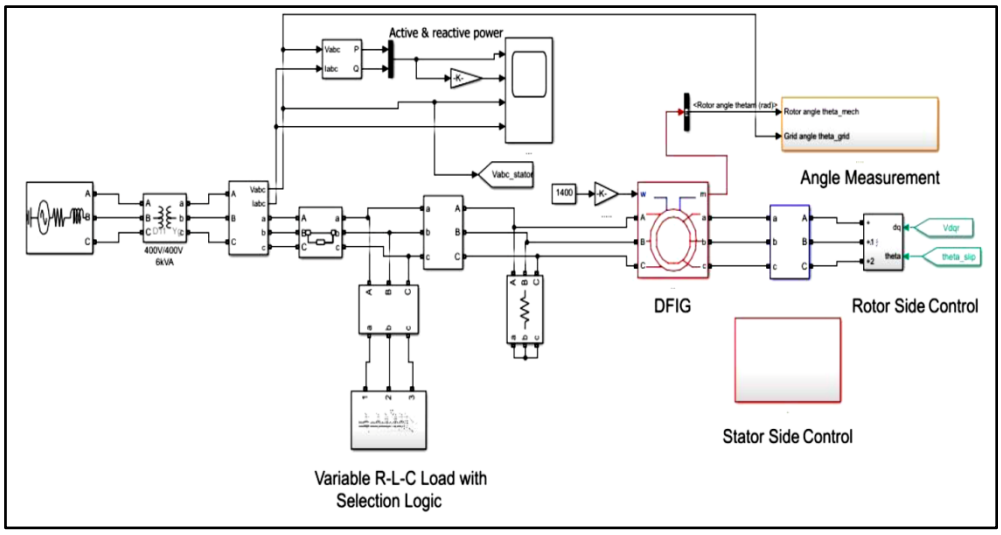


**Figure 2** MATLAB-Simulink model of grid-connected microgrid with DFIG and load

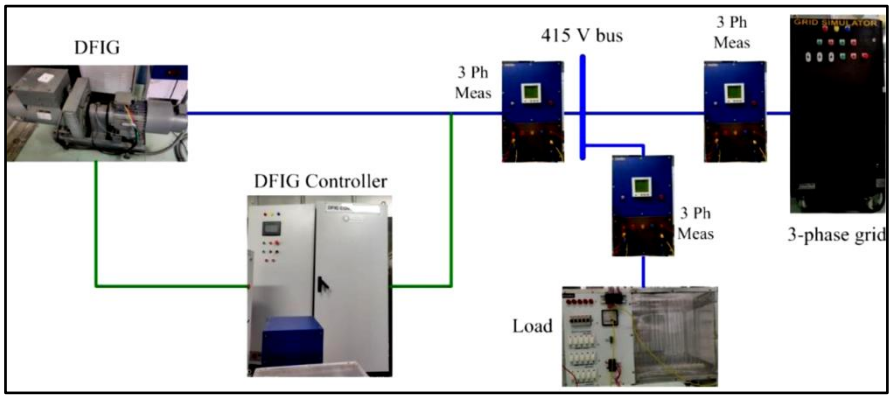


**Figure 3** Experimental arrangement for the grid-connected MG with DFIG, load, and measuring instruments

## RESULTS

### Simulation Results

MALTAB simulation results of active power (P) and reactive power (Q) delivered by the DFIG and how it is shared between the load and grid at varying load demands is shown in **Table 1**.

**Table 1** DFIG output power distribution between load and grid

| Load type | DFIG output terminal | | Load terminal | | Grid terminal | |
|---|---|---|---|---|---|---|
| | P (W) | Q (Var) | P (W) | Q (Var) | P (W) | Q (Var) |
| L1 | 832 | 16 (Lead) | 155 | 290 (Lag) | 680 (To Grid) | 308 (Lag) |
| L2 | 830 | 435 (Lead) | 210 | 450 (Lead) | 630 (To Grid) | 890 (Lead) |
| L3 | 828 | 6 (Lead) | 265 | 520 (Lag) | 568 (To Grid) | 525 (Lag) |
| L4 | 833 | 32 (Lead) | 345 | 80 (Lead) | 485 (To Grid) | 50 (Lead) |
| L5 | 825 | 2 (Lead) | 403 | 0 | 428 (To Grid) | 0 |
| L6 | 835 | 4 (Lead) | 805 | 0 | 30 (To Grid) | 0 |
| L7 | 840 | 45 (Lead) | 1050 | 930 (Lead) | 200 (From Grid) | 890 (Lead) |
| L8 | 780 | 146 (Lead) | 1130 | 600 (Lag) | 350 (From Grid) | 750 (Lag) |
| L9 | 835 | 63 (Lead) | 2700 | 2375 (Lead) | 1850 (From Grid) | 2315 (Lead) |

It is interesting to note form Table I that whatever be the type of load and its power factor, the DFIG always supplies leading current. It is also noted that except for certain power losses, the DFIG output power, be it active or reactive, is perfectly distributed between the load and grid. Any discrepancy in reactive power balance may be attributed to that delivered/consumed by filter placed between DFIG and bus.

It is observed that for loads that demand more active power (L7. L8, and L9), the total load demand is met partially by the DFIG, while the balance power is supplied from the grid. For loads demanding less active power, the DFIG is powerful enough to supply both the load as well as the grid. Reactive power demand of the load is mostly met by the grid, with much less share being drawn from the DFIG. Active power output from the DFIG is found to remain more or less fixed, while variations in active power demand of load is mostly catered by the grid, either by absorbing or by supplying the excess active power.

**Hardware Experiment Results**

Variation of load current, with its active and reactive components with respect to load variations in shown in **Figure 3**. Load power factor is also shown in the same figure for reference. It is observed that as the load power factor reduces, it draws more line current, as expected. At power factor values less than 0.7, there is marked increase in the reactive component of current. Variations in load power is shown in **Figure 4**. It is observed that active power delivered by the DFIG almost remains constant.

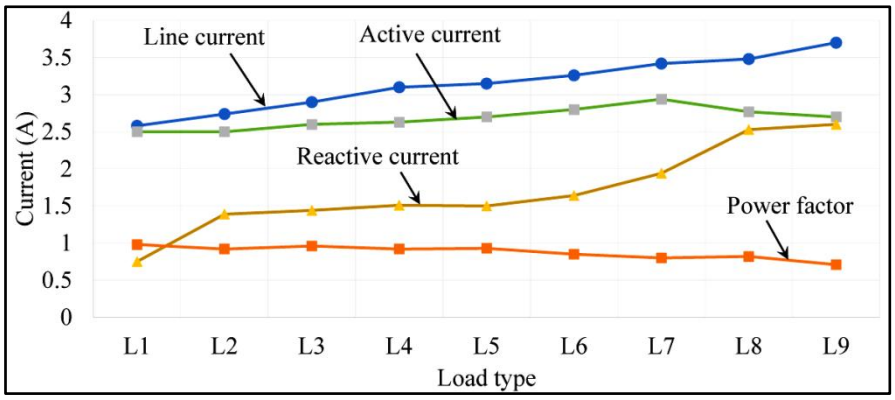


**Figure 3** Load current variations in the MG with DFIG running at a fixed wind speed

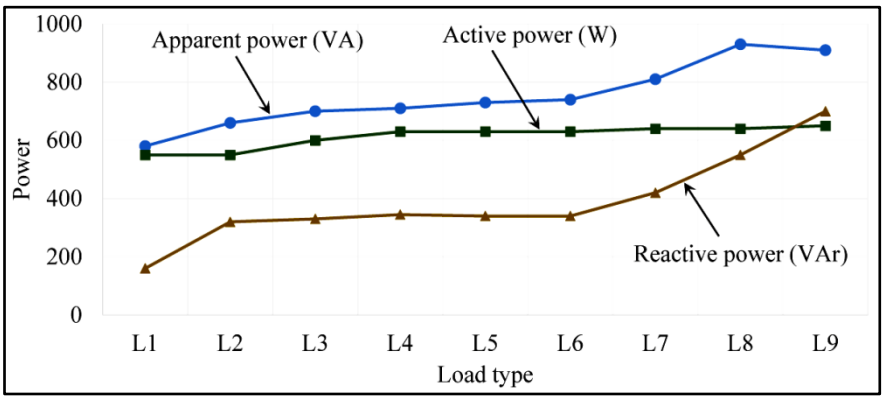


**Figure 4** Load power variations in the MG with DFIG running at a fixed wind speed

In the next phase of the experiments, the wind speed was varied in steps, and the corresponding voltage, current, power and power factor were measured at different load points. Figure 5 shows an excellent demonstration of the capability of DFIG based wind generator systems to deliver almost constant active power to meet the load demand, irrespective of the wind speed. The active power delivered to loads at three different wind speeds of 1100, 1200, and 1300 rpm almost overlap with each other. This is possible due to the negative feedback the machine receives through

GSC and RSC.

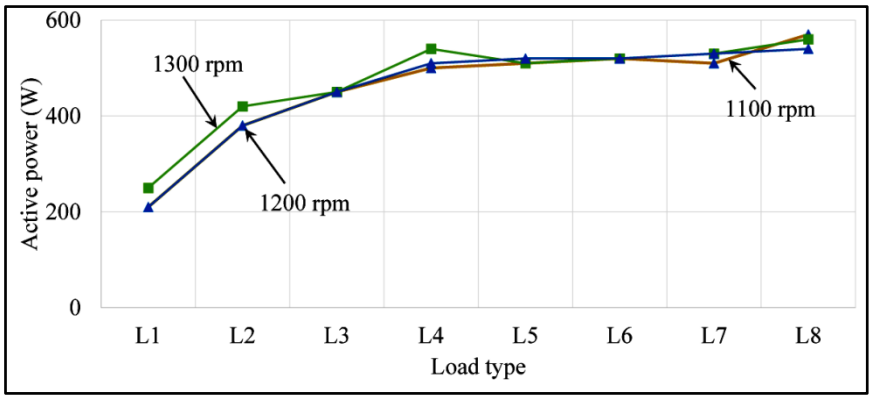


**Figure 5** Active power delivered to load by DFIG while running with different wind speeds

## CONCLUSION

This study reported both simulation and hardware results of an experimental study on a grid-connected microgrid with DFIG based wind energy conversion system. The DFIG was subjected to discreet speed variations, while the load was also varied in steps. Load contained a mixed R-L-C type so as to study the effect of power factor on DFIG operation in a grid-connected microgrid. The following interesting observations could be identified:

- Whatever be the type of load and its power factor, the DFIG always supplies leading current
- DFIG output power, be it active or reactive, is perfectly distributed between the load and grid
- For loads that demand more active power (L7. L8, and L9), the total load demand is met partially by the DFIG, while the balance power is supplied from the grid
- Reactive power demand of the load is mostly met by the grid, with much less share being drawn from the DFIG
- Active power output from the DFIG is found to remain more or less fixed, while variations in active power demand of load is mostly catered by the grid, either by absorbing or by supplying the excess active power
- DFIG based wind generator systems demonstrated capability to deliver almost constant active power to meet the load demand, irrespective of the wind speed

Future work aims at including energy storage system in the microgrid to make the scheme more practically acceptable.

## ACKNOWLEDGMENT

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166_IEC41721

# Suboptimal Robust PD Controller Design of Stewart Platform Manipulator based Dual Axis Solar Tracker System with Semi-Isotropic Tool Center Point

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***Abstract:*** *This paper presents a robust PD controller for a Stewart platform manipulator based dual axis solar tracker system in the joint space taking into account for modeling error and uncertainty in payload inertia. The proposed methodology of finding suboptimal PD controller gains involves the successive use of genetic algorithm (GA) and Levenberg Marquardt algorithm (LM) optimizer, where the set of values of controller gains obtained from the former has been taken as a well-thought-out initial guess for executing the latter. The control scheme utilizes the Stewart platform model to enforce the PD control by means of computed feedforward control, which accounts for nominal leg inertia and friction in all the active and passive joints. Finally, the simulation results pertaining to the performance robustness of the resulting feedforward PD feedback controller are provided through the study of variation of isotropic property of the Stewart platform subjected to step roll demand under wide range of payload inertia variation.*

***Keywords:*** *Stewart Platform: Semi-Isotropy; Computed Feedforward; Simulation Optimization; Robust Control*

## INTRODUCTION

A high-performance dual axis solar tracker system can be designed by using parallel manipulator having significantly high stiffness like that of the Stewart platform manipulator. This would enable one to collect maximum solar energy with consistent tracking accuracy either in the form of light or heat without compromising with the stiffness to external wind gust. However, only the well posed home position of the tracker Tool Center Point (hereinafter TCP) can ensure the least power requirement for driving all the active joints of parallel manipulator. Otherwise, there would be potential degradation in the performance especially in view of control force requirement. The challenge lies in designing the tracker such that it performs agile elevation and azimuth motion of the TCP during actuation (as illustrated in **Figure 1**) and a highly rigid body behavior at static condition. In this work both issues have been separately considered and through performance is analyzed through simulation results.

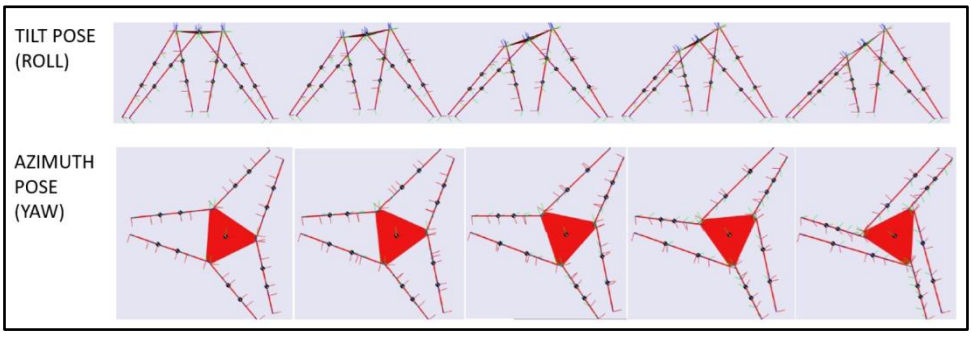


**Figure 1** The SimMechanics simulated poses of the Stewart platform manipulator based solar tracker

**Figure 2** shows the schematic of a Stewart platform, for which the design and performance analysis of the controller has been carried out for pitching and rolling motions. It has a moving platform on the top in the form of a circular disc of radius $r_t$. Its movement could be accomplished by actuating each of its six legs, whose length can be varied by a motor driving a ball type power screw. Besides these two members, each leg has a universal joint at the top and a spherical joint at the bottom. The centers $t^i$ of all the top joints forms a semi-regular hexagon lying on the

circumference of a circle of radius $r_t$. A similar semi-regular hexagon inscribed in a circle of radius $r_b$ is formed by the centers $b^i$ of the bottom joints. The bottom frame is fixed on the ground. At the home position, the centers p and o of the top and bottom circles are located on a vertical line with the smaller sides of the top hexagon being parallel to the longer sides of the bottom hexagon.

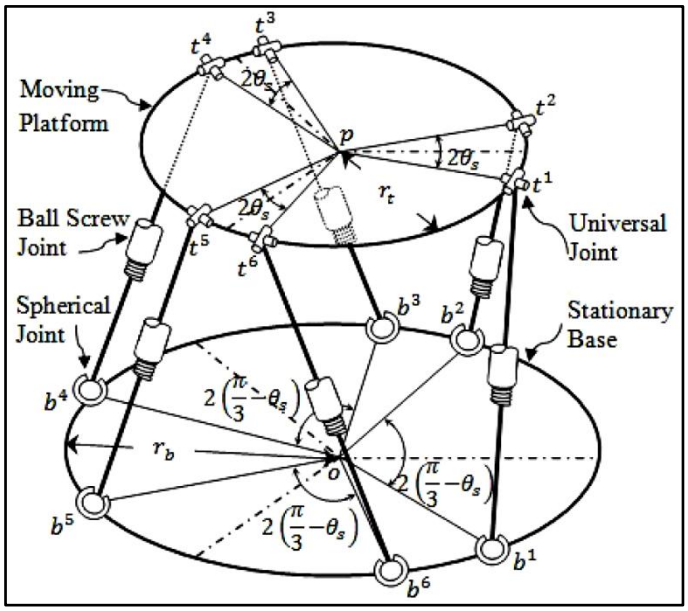


**Figure 2** Schematic diagram of a Stewart platform

**NOTATIONS**

| | | |
|---|---|---|
| $a^{ui}_{(biz)}$ | [scalar] | linear acceleration at actuator upper part about the actuator axis |
| $\mathbf{a}$ | [3×1] | translational acceleration vector m/s$^2$ |
| $b$ | [scalar] | the number of binary digits for GA optimizer |
| $b^i, t^i$ | | $i^{\text{th}}$ bottom and top joint |
| $\mathbf{B}^u_i$ | [3×1] | body force corresponding to $i^{\text{th}}$ leg in Newton |
| $c_i$ | [scalar] | current corresponding to $i^{\text{th}}$ actuator in Amp. |
| $C^{Si}, C^{Ui}$ | [scalar] | spherical joint and universal joint friction coefficients respectively in N.m.rad$^{-1}$s$^{-1}$ |
| $\mathbf{e}(t)$ | [6×1] | error vector in meter |
| $\hat{\mathbf{e}}_{bi}$ | [3×1] | unit vector of $i^{\text{th}}$ leg co-ordinate system with components $\left(\hat{\boldsymbol{i}}_{bi}, \hat{\boldsymbol{j}}_{bi}, \hat{\boldsymbol{k}}_{bi}\right)$ |
| $\hat{\mathbf{e}}_o$ | [3×1] | unit vector of stationary co-ordinate system with components $\left(\hat{i}, \hat{j}, \hat{k}\right)$ |
| $\hat{\mathbf{e}}_p$ | [3×1] | unit vector of moving co-ordinate system with components $\left(\hat{i}_p, \hat{j}_p, \hat{k}_p\right)$ |
| $F$ | [3×1] | force vector at TCP in Newton |
| $F^u_{(biz)}$ | [scalar] | actuator axial forces of $i^{\text{th}}$ limb in Newton |
| $\mathbf{F}^u_{ti}$ | [3×1] | transverse force at the upper part of $i^{\text{th}}$ limb in Newton |
| $G$ | [scalar] | generation number for GA optimizer |
| $i$ | [scalar] | index corresponding to leg, joint and pose number |
| $I^{(.)}_{(biz)}$ | [scalar] | $I^l_{(biz)}$, $I^u_{(biz)}$ and $I^m_{(biz)}$ are the moments of inertia about the screw axis for the lower and upper parts of the screw joint and the motor. |
| $\left(\hat{\boldsymbol{i}}_{bi}, \hat{\boldsymbol{j}}_{bi}, \hat{\boldsymbol{k}}_{bi}\right)$ | [3×1] | unit vectors orthogonal to the axis of $i^{\text{th}}$ limb |

| | | |
|---|---|---|
| $\mathbf{I}^{p}_{(p)}$ | $[3\times3]$ | moment of inertia matrix with diagonal elements $I^{p}_{(px)}$, $I^{p}_{(py)}$ and $I^{p}_{(pz)}$, of the payload in Kg-m$^2$ |
| $J_{ITAE}$ | [scalar] | integral-time-absolute-error performance index |
| $\mathrm{J}(\psi_k)$ | [scalar] | Jacobian matrix for error function with parameters $\psi$ at $k^{\text{th}}$ iteration |
| $J$ | $[6\times6]$ | Jacobian matrix of a kinematic chain |
| $k$ | [scalar] | iteration number for LMGA based optimization |
| $k_{D\max}$, $k_{D\min}$ | [scalar] | derivative control gains of maximum and minimum limiting values respectively |
| $k_{Pi}$, $k_{Di}$ | [scalar] | proportional and derivative gains corresponding to $i^{\text{th}}$ controller |
| $k_{P\max}$, $k_{P\min}$ | [scalar] | proportional control gains of maximum and minimum limiting values respectively |
| $K_t$ | [scalar] | motor torque constant in N.m.A$^{-1}$ |
| $l_c$ | [scalar] | characteristic length in meter |
| $l^a_i$ | [scalar] | instantaneous actuated length of $i^{\text{th}}$ limb in meter |
| $l^l$, $l^u$ | [scalar] | length of the lower part and upper part of each actuator in meter |
| $\boldsymbol{l}_i$ | $[6\times1]$ | length vector of $i^{\text{th}}$ limb |
| $m^l$, $m^u$ | [scalar] | mass of the lower part and upper part of each actuator in Kg |
| $m^p$ | [scalar] | total mass of the payload together with the frame and the disc in Kg. |
| $M$ | $[3\times1]$ | moment vector about TCP |
| $n$ | [scalar] | number of time multiobjective function |
| $N$ | [scalar] | total number of population for GA optimizer |
| $p^b$, $r^b$ | [scalar] | pitch and mean radius of ball screw in meter and meter/rev |
| $(p^x, p^y, p^z)$ | | roll, pitch and yaw axis respectively of moving coordinate system with origin at $p$ |
| $q$ | [scalar] | the number of proportional or derivative gain parameter |
| $r_b$, $r_t$ | [scalar] | radius of the circle on which bottom and top joints are located, meter |
| $\mathbf{R}_{p,o}$, $\mathbf{R}_{bi,o}$ | $[3\times3]$ | rotation matrix corresponding to TCP and $i^{\text{th}}$ leg respectively |
| sgn(.) | [scalar] | signum function |
| $T_f$, $T_s$ | [scalar] | final time for simulation and sampling time interval for simulation solver in sec. respectively |
| $T^{(.)}_i$ | [scalar] | $i^{\text{th}}$ actuator's motor torque in N-m |
| $v^{\text{actd}}_{(bi,z)}$ | [scalar] | $i^{\text{th}}$ desired actuator velocity along actuator axis of the upper part |
| $\mathbf{v}$ | $[3\times1]$ | end-effector translational velocity vector |
| $(x, y, z)$ | [scalar] | Surge, sway and heave in meter in the direction $Ox$, $Oy$, and $Oz$ respectively |
| $\mathbf{x}$, $\mathbf{x}^{\mathbf{d}}$ | $[3\times1]$ | any pose and desired pose vector respectively |
| $\mathbf{x_0}$ | $[3\times1]$ | translational vector of home position of TCP |
| $z_o$ | [scalar] | heave in the direction $Oz$ in meter for pure semi-isotropic configuration |
| $\boldsymbol{\alpha}$ | $[3\times1]$ | angular acceleration vector |
| $\delta$ | $[12\times1]$ | increment in $\psi$ |
| $\theta_{bi(o)}$, $\theta_{ti,p)}$ | [scalar] | angular location in rad of $i^{\text{th}}$ bottom and top joints with respect to $O$ and $p$ respectively |

| | | |
|---|---|---|
| $\boldsymbol{\theta}_{(\cdot)}^{(\cdot)}$ | $[3\times1]$ | rotational pose vector of home position of the TCP |
| $\lambda$ | [scalar] | non-negative damping factor of LM algorithm |
| $\mu^b$ | [scalar] | friction coefficient in ball-screw |
| $(\phi, \beta, \gamma)$ | [scalar] | roll, pitch and yaw orientation of the TCP about $p^x$, $p^y$ and $p^z$ axes respectively |
| $\phi_b, \phi_t$ | [scalar] | half of the angular displacement between each smaller side of bottom and top joints in rad. |
| $\psi$ | $[12\times1]$ | scaled gain vector of $\psi_{PD}$ |
| $\psi_{PD}$ | $[12\times1]$ | PD controller gain vector |
| $\omega_{b\hat{i}(\cdot)}^{(\cdot)}$ | [scalar] | actuator angular velocity about one of the actuator coordinate axis |
| $\boldsymbol{\omega}_{(p)}^{p}$ | $[3\times1]$ | rotational velocity of the moving platform about TCP in moving coordinate system |
| $\boldsymbol{\Theta}(\psi)$ | $[n\times1]$ | time multi-objective vector |
| $\Omega$ | [scalar] | objective function of GA optimizer |

**Subscripts**

| | |
|---|---|
| $bi(o)$ | $i^{\text{th}}$ vector corresponding to point $b^i$ with respect to $O$ |
| $(biz)$ | corresponding to the axis along the $i^{\text{th}}$ actuator |
| $(bix), (biy)$ | corresponding to the axes orthogonal to the $i^{\text{th}}$ actuator axis |
| $p$ | with respect to the TCP location |
| $ti(o)$ | $i^{\text{th}}$ vector corresponding to point $t^i$ with respect to $O$ |
| $ti(o)0$ | at home position corresponding to point $t^i$ with respect to $O$ |
| $ti(p)$ | $i^{\text{th}}$ vector corresponding to point $t^i$ with respect to $p$ |
| 0 | the home position of TCP |

**Superscripts**

| | |
|---|---|
| $(b)$ | feedback value |
| $(d)$ | desired value |
| $(f)$ | feedforward value |
| $l$ | value corresponding to lower part of actuator |
| $u$ | value corresponding to upper part of actuator |

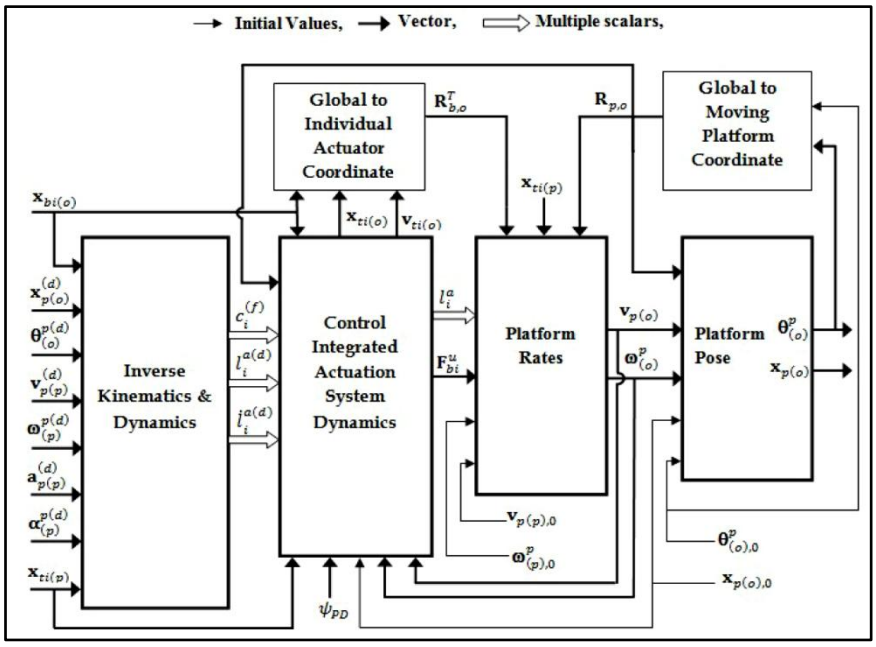


**Figure 3** Solution algorithm for control integrated Stewart platform system with thick arrow, thin arrow and multiple line arrows respectively indicates vectored value, initial value and multiple scalar value

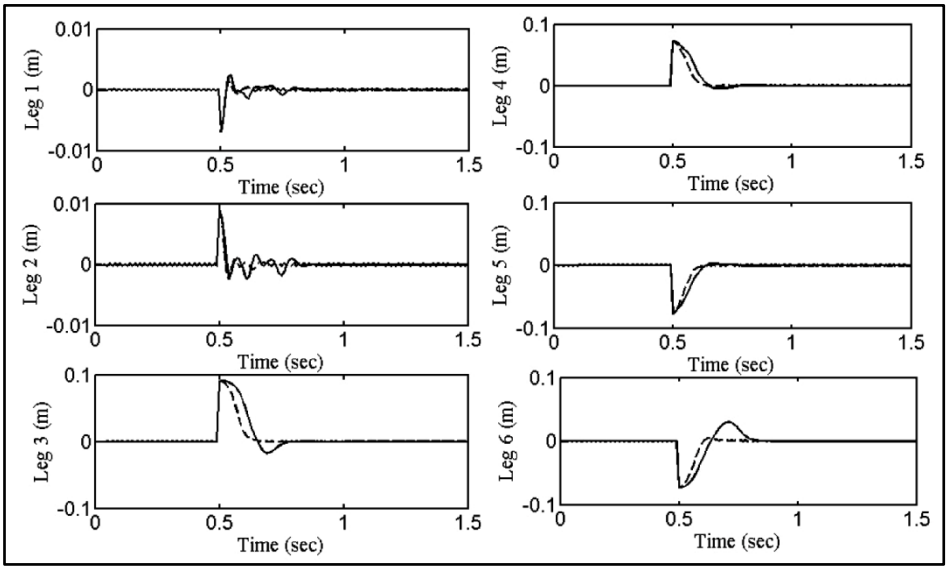


**Figure 4** Comparison of leg length error response for LMGA based PD controller with solid and dotted lines indicating the increase and decrease of inertia respectively

## CONCLUSION

In this paper a robust dual axis tracker system is developed with the parallel manipulator architecture. An optimum semi-isotropic configuration of the architecture is used as a well-posed system at home position. A scheme of computed feedforward-PD feedback control has been designed in joint space considering nominal friction coefficient and leg inertia for the active and passive leg joints of the manipulator. A PD feedback controller gain optimization methodology has been proposed that uses both the GA and LM optimizer where the initial guesses of control parameter for LM optimizer have been taken from more reliable results of GA optimizer. The system performance is analyzed in MATLAB SIMULINK and SIMMECHANICS environment. A significantly less change in the transient response for a step roll demand realized in the study of manipulator subjected to ±40% variation of the pay load

inertia about its nominal values has been a testimony of robustness of the performance.

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203_IEC69302

# A Productive Optimization Strategy for the Relay Coordination Issue

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***Abstract:*** *The strategies used to optimize the calibrating and synchronizing of protective relays so that failed power system can fail correctly in real-time operation which tells you how we could prevent the failures or shutdowns as soon and durability as it requires. Setting up Over Relays (OCRs) for applications using the old fashioned way can be quite complex, because of the different types of protection requirements and load situations that are often met in distribution grids.*

***Keywords:*** *Over-current (OC); Relay Coordination (RC); Particle Swarm Optimization (PSO); Time-Dial Setting (TDS); Coordination Time Interval (CTI)*

## INTRODUCTION

Distribution networks are often set up to accommodate renovations and unique load conditions. Consequently, every OC relay configuration must be tailored accordingly. Additionally, there may be an essential requirement — relay configuration that meets the needs of each possible community setup, depending on the type and location of issues. A key aspect of electrical power systems is relay coordination, which ensures the proper functioning of protective relays during malfunctions or unusual circumstances. This process involves configuring circuit breakers and protective relays so that their time-current characteristics work effectively together, facilitating the rapid isolation of faults. Such meticulous arrangement is vital to reduce the risk of widespread outages and to improve the overall reliability of the electrical distribution system. An optimization plan is crucial to implement every two weeks in order to ensure fast relay response times and effective troubleshooting procedures when required.

The main aim is to prevent interference in a way that maintains the mechanical functioning of the device. Integration of energy systems is a complicated task as optimal coordination is quite hard as these systems are dynamic in nature. Various optimization techniques from advanced machine learning models to classical algorithms are employed to enhance the performance and reliability of relay coordination. Such an approach improves stability, selectivity, and reliability of the protective relay functions since this proposed approach employs complex computations and mathematical expressions to make sure these systems can operate under various conditions. Our intention with this abstract is to illustrate in depth the Relay Coordination Problem and its implications within this context by revealing other issues embedded in the coordination process and the techniques that can be used to address them. Such techniques are imperative in ensuring efficient functioning while distributing electrical energy, thereby contributing to the efficiency of the energy infrastructure.

### Problem Formulation & Constraint Criterion

Illustration of a two-bus radial distribution system may be found in Fig.1 below. There is a systemic flaw k at location F, which is beyond bus B. Relay R2 assumes control of it first since it is the neighboring relay to the issue. If R2 stops operating for whatever reason, R1 takes over after a certain period of time. Relay R1 therefore handles backup protection. Based on the assumption that R2's time of operation has been fixed at 0.1 s, R1's operation time is set plus an additional 0.1 s time delay that is applied to both R1's overshoot time and the operating periods of CB at bus A.

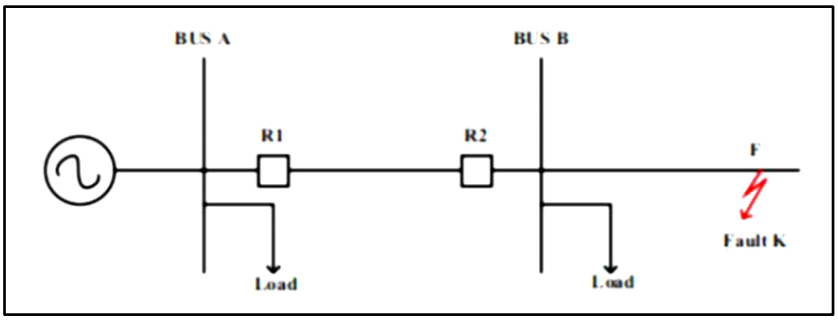


**Figure 1** A system of radial distribution

The distribution network's OC relay coordination may be formulated as an optimization problem. It is represented mathematically as "z," the total time in operation of all equipped relays, for a specific failure point. The following actions should be taken to reduce this to a minimum:

$$Minimize\ z = \sum_{i=1}^{n} W_j \times T_{i_k} \quad (1)$$

where z stands for the problem statement's objective function in this study. Relay number (n) is represented by $T_{ik}$. Operational time of the relay at the problem site (k). The weighting factor is $W_j$. The shortest possible individual operating duration would be approached by reducing the weighted total time of operation of all primary relays. This is one possible application of the weighting factor to achieve the least amount of system shock as a result of the failures. Because the distribution system's short lines have about equal weights and lengths, an issue might arise at any point along the line. As a result, $W_j$ is regarded as 1 ($W_j$ = 1) for every relay. Additionally, it is a coefficient that indicates the probability of a defect occurring. Consequently, there is an equal chance that a defect will develop on each line since the lines have the same length and weight. $W_j$ is often set to 1 due to this equal likelihood. [6, 7, 8]

**Limitations on Operating Time**

The distribution end has a constantly fluctuating load. These little systemic interruptions cause a relay to stall for a few cycles before detecting and documenting a failure condition. The following is a list of restrictions on relay operating time:

$$T_{ikmin} \leq T_{ik} \leq T_{ikmax} \quad (2)$$

Here for the ith relay at position k, where $T_{ikmin}$ and $T_{ikmax}$ represent the lower and higher boundaries, respectively. $T_{ikmin}$ = 0.1 s and $T_{ikmax}$ = 1.1 s are typical values [3]. $T_{ikmax}$ occasionally varies depending on network configuration. This limitation shows that as operating time limits are lowered, relay response times will speed up and TDS will therefore decrease.

**TDS Constraints**

Relay speed is contingent on the appropriate selection of the relay's TDS setting. Its boundaries can be shown as follows:

$$TDS_{imin} \leq TDS \leq TDS_{imax} \quad (3)$$

Where $TDS_{imin}$ and $TDS_{imax}$ is the $i^{th}$ TDS's lower and upper limits, respectively. Normal values for $TDS_{imin}$ = 0.025 and $TDS_{imax}$ = 1.2 in this work are taken into account. [4]

**Coordination Limitation**

When a system malfunction is detected, both the primary and backup relays can act concurrently. Therefore, according to a preset period identified as CTI, the backup relay would only activate once the primary relay fails to avoid false tripping.

As a result, the primary and backup relays' coordination requirements may be mathematically stated as follows:

$T_{bik} - T_{pjk} \geq CTI$ (4)

Where $T_{pjk}$ is the operating time of the primary relay at the same fault k, and $T_{bik}$ is the operating time of the $i^{th}$ backup relay. CTI stands for coordination time interval. The time difference between the primary and backup relays is known as the coordination time interval or CTI. The circuit breaker speed determines the CTI, which can vary from 0.1 to 0.5s.

**Relay Characteristics**

There are many relays available in the OC relay family. The most preferred OC relay is the inverse definite minimum time (IDMT) relay [1,2,3] because of its advanced features. This may be expressed using the equation below.

$$T_{op} = \frac{\beta \times TDS}{(PSM)^{\alpha}-1} = \frac{0.14 \times TDS}{(PSM)^{0.02}-1} \quad (5)$$

in where $T_{op}$ is the relay's operating time and β and α are typical parameters for IDMT relay characteristics. The ratio of the relay's real fault current to its set relay current, or the Plug Setting Multiplier (PSM), is what makes the relay operate. Every time the fault current approaches or exceeds the relay current setting, the TDS modifies the amount of time before the relay activates. The behaviour of **Eq. (6)** is nonlinear, even if sustaining PSM remains constant with a preset pickup current value. It is feasible to convert **Eq. (6)** into a linear equation.

$T_{op} = \alpha_i \times (TDS)$ (6)

Where

$$a_i = \frac{0.14}{(PSM)^{0.02}-1} \quad (7)$$

To get the relay coordination issue's objective function, replace **Eq. (2)** with **Eq. (8)**.

$$Minimize\ z = \sum_{i=1}^{n} a_{ik} \times TDS \quad (8)$$

in which the constant term represents the $i^{th}$ relay at point k is denoted by $a_{ik}$.

**OPTIMIZATION TECHNIQUES**

Across a variety of sectors, optimization techniques are tool which enhances the features and productivity of various matters. These methods are based on the optimization of systems, variations and ways of performing the tasks. Optimization techniques present great potential for impact in several fields ranging from computer science to engineering, finance and logistics. An application of these strategies results in an improvement of the overall performance of the organization, cost minimization, enhancement of productivity, and streamlining of operations.

When applied, the methods assist experts in determining deficiencies and opportunities for improvement among the parts that make up a system. This process does not only perfect the current methods but also fosters the creation of new methods which are specific to the problem at hand. The problems faced by industries are known to be ever changing in nature and the competition is expected to increase which is why these techniques are required.

Performance comparison among algorithms does not imply that there exists at least one particular type of algorithm which is better than every other one. Meta heuristics and its applications have seen tremendous increase over the last few years and have been used onto several concerns.

**Particle Swarm Optimization**

The algorithm commences with a randomly generated population at first. Each single entity on the called particle has

assigned to it the position as well as velocity and then for every particle the corresponding value of the fitness function i.e. the objective function is estimated. In the case of PSO, it is different because there is no mating/crossing-over/mutation of particle into a new one, but some of the best solutions available to each, and all the population are used towards the best. Using a neighbourhood model, the velocity and position for each individual are modified based on the best solution that has been found by their neighbours. This is done until all the convergence is met.

**Genetic Algorithm**

The Genetic Algorithm evaluates the individual based on a fitness function and uses an iterative approach for updating a population of individuals. For creating a new generation some individuals are chosen directly from the previous generation and some are chosen from individuals resulted after performing operations like crossover and mutation. The GA begins with random initialization of a population. The population consists of chromosomes made by a random combination of 1's and 0's also known as genes. After the population is successfully created the next step that comes into the picture is the selection procedure. In the process of selection, we calculate the fitness function corresponding to each individual and then select the individuals with the good fitness function value.

**Simulated Annealing**

Simulated annealing is a stochastic optimization method which is particularly effective on discrete or combinatorial problems. An additional feature is that this approach only requires a point's corresponding function value, i.e. other functional information is unnecessary. Hence, simulated annealing ought certainly to be a candidate solution approach for simulation optimization. The output response of the suggested technique for coordinating a multi-loop-single-end distribution network is displayed in **Figure 1**.

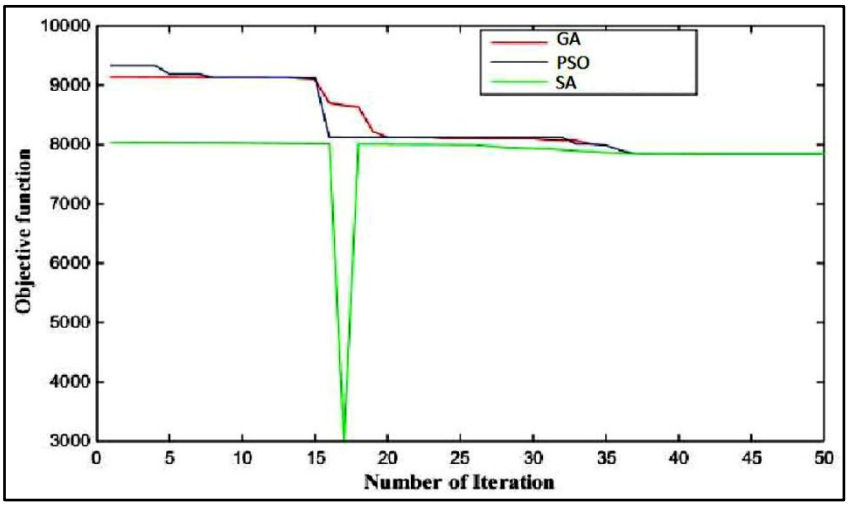


**Figure 1** The convergence of proposed GA,PSO and SA

Among other, GA, PSO and SA are the three most prominent heuristic algorithms that have been examined in depth here and for what purposes perform the best and come closest to the solutions to the problems.

**CONCLUSION**

This domain where mathematical models and algorithms are crucial for relay setting optimization through the use of an optimization framework. Selecting the optimal coordination technique to shorten operating durations, boost selectivity, and enhance system reliability is made simpler using this method. However, it's crucial to understand that there is inherent complexity in both generating and solving these optimization problems. The power system's surroundings are dynamic, with many factors and uncertainties influencing its characteristics. This makes it challenging to maintain an effective relay coordination system that can adapt to changing conditions.

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235_IEC72043

# Model Development and Analysis of a Greenhouse Airconditioning System Coupled with a Desiccant-Coated Heat Exchanger and a Dew Point Indirect Evaporative Cooler

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***Abstract:*** *In hot and humid countries with tropical and subtropical climates, there is a sharp increase in the plea for air conditioning. The conventional vapor compression air-conditioning system consumes high energy as they are incorporated with overcooling and reheating. They are also harmful to the environment. So, alternate cooling technology is essential, as it has energy-saving potential and an eco-friendly nature. A desiccant-coated heat exchanger and Dew point indirect evaporative cooler combined system is a promising technology for greenhouse air-conditioning since both latent heat and sensible heat loads can be handled together. In this paper, a thermal model of a greenhouse is developed. The combined system can supply conditioned air to the greenhouse for the cultivation of strawberries. It is observed that the average greenhouse temperature can be obtained within 26℃ in the daytime on a hot and humid day in July, and the average greenhouse relative humidity can be maintained within 55-70%. The study highlights the need and viability of such systems for cultivating strawberries in tropical and sub-tropical climates that witness scorching and humid weather for a substantial part of the year.*

***Keywords:*** *Greenhouse Air-Conditioning; Dew Point Indirect Evaporative Cooler*

## INTRODUCTION

In the tropical region, 50 to 75% of the total energy consumption is due to air conditioning applications [1]. The conventional vapor compression air-conditioning system consumes high energy, incorporating overcooling and reheating arrangements. They are also harmful to the environment. So, alternate cooling technology, which has energy-saving potential and an eco-friendly nature, is essential. For this reason, many research studies have been reported in the past decade where air conditioning systems powered through renewable energy sources have been used. Also, new technologies that can substitute conventional mechanical air conditioning systems are being studied. The total air conditioning load combines 60% of sensible cooling and 40% of latent heat load related to dehumidification [2].

The latent heat handling capacity is looking for an air conditioning system dehumidification technique with high efficiency. Dehumidification approaches are distributed into two types: condensation and desiccant dehumidification. In condensation type of dehumidification, the air is first cooled down to the dew point temperature of the atmosphere and then condensed so that moisture present in the air can be reduced. So, sensible heat and the latent heat loads are controlled together [3]. In conventional DEC (Direct evaporative cooler), the air stream passes through a wet channel. Thus, the temperature is reduced. But it leads to the higher humidity generation. But, for IEC (Indirect evaporative cooler), the air stream is passed through a dry channel parallel to a wet channel. So direct contact occurs, which results in temperature reduction. No moisture is added further. These two can theoretically reduce the temperature of the process air up to the wet bulb temperature of atmospheric air [5]. In the Dew point indirect evaporative cooler, some portion of cooled process air passes through the wet channel, making further reduction of primary air possible. It can theoretically diminish the temperature of process air up to the dew point temperature of atmospheric air [6].

India is an agricultural country whose significant GDP comes from farming and related sectors [7]. Different kinds of fruits and vegetables are imported as the ambient climatic conditions are unfavorable for their cultivation. Also, owing to the improper storage facilities, there have been huge losses in in-house production. A greenhouse is an inflatable or framed building with a transparent or translucent covering inside, in which the climatic conditions are artificially regulated for the optimum growth of the target plantation [7]. Numerous investigations spotlighted evaluating and enhancing the greenhouse's climate in hot and humid climates. Ghosal et al. [8] developed a

mathematical model of a greenhouse with evaporative cooling. They determined the optimum mass flow rate of water in the study. Ganguly and Ghosh [10] developed and validated the thermal model of a fan-pad ventilated greenhouse. The fan-pad ventilation system limited the effectiveness of evaporative cooling due to the high humidity levels of external air during the monsoon. A Greenhouse cooling system driven by a thermal adsorption refrigeration system was studied by Sultan et al. [11]. They found that the Silica gel was the most effective adsorbent for the application. Banik and Ganguly [12] worked on a distributed- fan-pad-type evaporative cooler enabled with solar desiccation. They worked on a thermal model. The model gave better thermal performance and economic improvement compared to previous works.

Strawberry can be a target plantation inside a greenhouse as it is a good source of many nutrients (160 grams contains the following nutrients: Protein: 1.11 g, Calories: 50 calories, Calcium: 26 milligrams (mg), Iron: 0.67 mg, Potassium: 250 mg, Magnesium: 20 mg, Vitamin C: 97.50 mg besides many more) [9] and has wide demand in the domestic and international market. The maximum yield of strawberries can be achieved when the temperature is around 15°C [9]. The yield decreases when the temperature exceeds 25°C [9]. So, the recommended temperature range is 15 to 25°C. The relative humidity should be 65 to 70 percent for strawberry cultivation to achieve maximum yield and good fruit size [9].

The brief review shows several researchers have worked in greenhouses and related technologies for the last few decades. Most work has been done on developing thermal models of greenhouse systems using different evaporative cooling and ventilation technologies like fan-pad systems, misting, fogging, natural ventilation, etc. Very little work has been reported on greenhouse cooling based on various desiccant-based cooling technologies. At least in the open literature, to the authors' knowledge, a greenhouse system equipped with a desiccant-coated heat exchanger (DCHE) to maintain a conducive climate for flora cultivation is unavailable. Thus, the present study aims to develop a greenhouse model based on a DCHE and Dew point indirect evaporative cooler to provide favourable conditions for cultivating the target plantation-like varieties of strawberries for the climatic conditions prevailing in subtropical zones. A thermal model of the greenhouse is established and compared against a reference study [13] available in the literature. After comparison, the thermal model of the greenhouse was used to analyze its performance for the climatic conditions prevailing in the plains of the Gangetic Bengal on a representative hot and humid day.

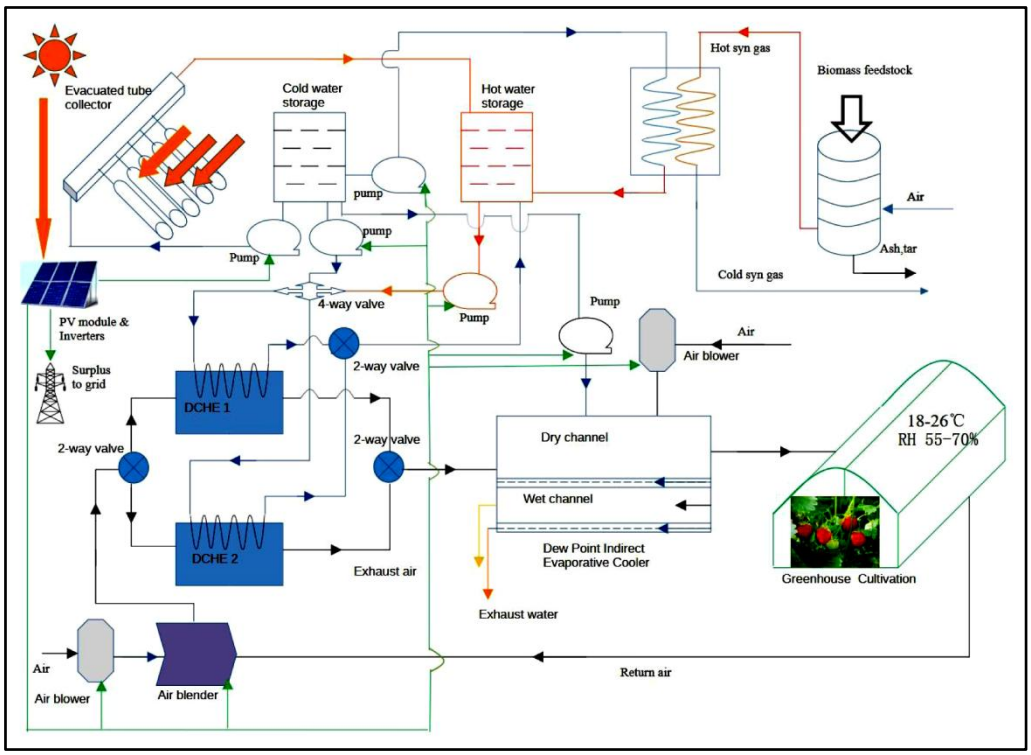


**Figure 1** Schematic diagram of the proposed system

**Figure 1** shows the schematic diagram of the proposed system. The system comprises a Greenhouse, desiccant-coated heat exchanger (DCHE), Dew point indirect-evaporative cooler, Evacuated tube solar collector, and a Biomass Gasifier unit. First, the ambient air is passed to a desiccant-coated heat exchanger using a blower. A DCHE is a heat exchanger whose walls are coated with a desiccant (present case Silica Gel-Lithium Chloride Composite). Cold water is allowed to flow through a duct inside the DCHE. A DCHE removes moisture from the air it passes through using adsorption. The desiccant draws moisture molecules from the air as they travel over the coated surfaces, and thus, its moisture content increases over a period of time. The desiccant material, therefore, needs to be regenerated because it becomes saturated with moisture over time. The desiccant is then regenerated by circulating hot water obtained from an array of evacuated tube solar collectors when solar radiation is present. During the night, when solar radiation is absent, or during cloudy days, when the radiation intensity is lower, a biomass-based heating arrangement is provided as a backup, as shown in **Figure 1**. Therefore, two DCHEs will be the best option for continuous operation (as shown in the figure). One DCHE will undergo dehumidification of air, while the other will undergo regeneration. With the given setup, a continuous flow of dehumidified air can be obtained by periodically switching two desiccant-coated heat exchangers through proper valves. The dehumidified air thus obtained is passed through the dry channel of the dew point indirect evaporative cooler. One wet and one dry channel are in the dew point indirect evaporative cooler. Through the pump and blower the cold water and working air are sent to the wet channel using the pump and the blower, respectively, as shown in the figure. Process air or the outlet air of the desiccant-coated heat exchanger passes through the primary dry channel. The working air cools the primary process air stream of the primary dry channel due to the heat transfer. A portion of the cold air is taken from the primary dry channel and blended with the working air inside the secondary wet channel, further decreasing the process air temperature.

## THERMAL MODEL OF GREENHOUSE

A proposed mathematical model for the greenhouse is presented in this section. The following assumptions are used for the development of the model [12,13]:

(i) Time-independent energy balance equations of the greenhouse are considered.
(ii) The greenhouse-soil system's heat storage or retrieval rate is neglected.
(iii) The entire greenhouse is assumed to be a thermal storage where latent and sensible heat transfer occurs.

The energy balance of the greenhouse can be written as [12]

$$(1 - S)\,\alpha G_0 \tau - K_0 (T_1 - T_{gh}) - \lambda E - H - Q_m \quad (1)$$

In Eq. (1), S, $\alpha$, $G_0$, $\tau$ represent the shading factor, the absorptivity of the greenhouse cover, global solar radiation, and the transmissivity of the greenhouse cover, respectively. $K_0$ represents the overall heat transfer coefficient ($W/m^2K$), $T_1$ and $T_{gh}$ represent ambient temperature, and the average greenhouse temperature in K. $\lambda$ denotes latent heat of vaporization of water (KJ/Kg), E stands for plant canopy transpiration rate ($kg/m^2s$). H describes the total sensible heat accumulated by the greenhouse air, and $Q_m$ represents the heat gain from the greenhouse soil.

In the above equation, H can be calculated as:

$$H = K_S (T_{gh} - T_2) \quad (2)$$

$K_S$ denotes the sensible heat transfer co-efficient($W/m^2K$), and $T_2$ is the inlet cold air to the greenhouse or, as can be said, process air.

$$K_S = \rho_A C_{PA} (ACM) V_g / (60 A_{gf}) \quad (3)$$

Where $\rho_A$ is the density of the process air, the specific heat of dry air at constant pressure is $C_{PA}$. ACM is the air change per minute in the greenhouse, which is assumed to be 1.2 here, as per the reference paper. $V_g$ and $A_{gf}$ are the volume of the greenhouse and greenhouse floor area, respectively.

$$\lambda E = K_l (e_{gh} - e_2) \quad (4)$$

Plant transpiration due to latent load can be determined from Eq. (4).

## RESULTS AND DISCUSSION

Computer Code using Engineering Equation Solver (EES) version 2018 has been developed based on the thermal model discussed in the previous section. The program takes ambient temperature, ambient relative humidity and desiccant property as input and provides greenhouse average temperature, greenhouse relative humidity as output keeping shading factor, absorptivity, transmissivity as constant. Initially the results of our model are compared with a reference study [13] available in the literature. First, absorptivity, shading factor, and transmissivity are taken as 0.7, 0.5, and 0.8 as per the reference model [13]. All other parameters are also taken the same way for model comparison. After the comparison, the model is used to find the greenhouse temperature and relative humidity distribution inside the greenhouse for strawberry cultivation by varying ACM, solar radiation, and ambient temperature. **Figure 2** shows the variation of average greenhouse and ambient temperature for a representative day in July and also compared with the reference model available in literature. It is evident from the figure that with the proposed system, the maximum greenhouse temperature can be restricted within 26°C (at 3 PM), when the corresponding ambient temperature is about 33°C. Thus, it is pretty evident that a substantial temperature reduction is possible using the proposed system even during the monsoon period when the ambient humidity is high. Thus the given system can maintain the greenhouse temperature for the cultivation of strawberry. **Figure 3** shows the ambient and greenhouse relative humidity distribution for the daytime of the day. The relative humidity stays in the range of 55-70% for the entire daylong operation which is suitable for the cultivation of the strawberry plantation in the selected location.

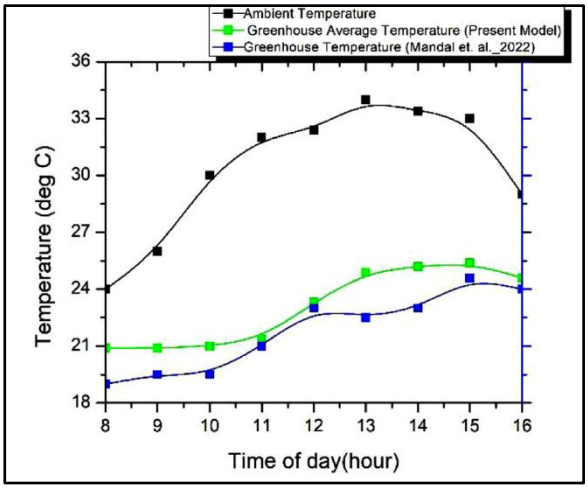


**Figure 2** Ambient and Average Greenhouse temperature comparison with a reference model for a day in July

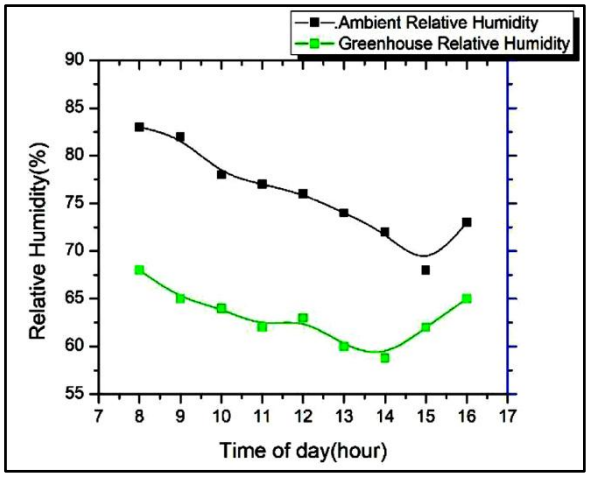


**Figure 3** Ambient and Greenhouse Relative Humidity for a day in July

## CONCLUSION

This paper deals with a novel scheme of a renewable energy-powered desiccant coated heat exchanger and dew point indirect evaporative cooler supported greenhouse for cultivating strawberries in the areas of tropical and sub-tropical climatic zones that witness scorching and humid weather for a substantial part of a calendar year. A thermal model of the greenhouse is developed and analyzed for a representative day in monsoon (July 15) when the relative humidity and ambient temperature levels are very high. The following points are revealed from this study:

(i) It is observed that the average greenhouse temperature can be restricted within 26°C in the daytime on a hot and humid day of July (July 15).
(ii) The average greenhouse relative humidity can be maintained within 55-70% when the corresponding ambient humidity is 70-80%.

(iii) The study thus reinforces the viability of strawberry cultivation in the plains of the Gangetic Bengal in the subtropical climate.

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296_IEC83032

# Waves & Tides — God's Gift for Power GENERATI

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***Abstract:*** *The rapid growth in the entire field of lives of human being is electricity, which is primarily obtained using the once abundant & affordable fossil fuels like coal, oil and gas. The alarming situation is that the once abundant and affordable fuels were depleting rapidly and would soon become expensive to use. The World is rushing towards new source of power at any cost, either it Solar, Wind, bio-energy, etc. Fossil fuel shortages are heightening the need for renewable alternatives like wave and tidal energy generation besides many alternatives these two most important renewable energy sources are yet untouched in many ways by the world.*

*Waves are formed when wind blows over the surface of water and the devices called wave energy converters capture the energy from waves and turned into electricity. Waves have the highest energy density of renewable energy sources. The estimated potential of tidal and wave power in India is 12,455 Megawatts (MW) and 41,300 MW, respectively and in the world it is beyond imagination, wave itself having potential of roughly 29,500 TWh annual power generation as per one estimate. Looking towards Tidal Power about ten to eleven Tidal Projects are generating more than 1000 MW using techniques like, (1)Tidal Barrage,(2)Tidal Stream Generator (3) Dynamic Tidal Power & (4) Tidal Lagoon. Some projects are under planning stage right now having huge potential of tidal power generation.*

*Historically, tide mills have been used both in Europe and America. The earliest occurrences date from the Middle Age or even from Roman Times. Tidal Power/Energy is a form of hydropower that converts the energy obtained from tides into useful forms of power-mainly electricity. In a simple manner we can say that this is the energy harnessed from ocean tides. As Tidal Power draws on the energy inherent in the orbital characteristics of the Earth-Moon system, it makes power generation very predictable, unobtrusive and reliable. In fact it is the only form of power generation that makes use of this Earth-Moon system. A variety of different technologies are under development throughout the world to harness the energy of Tidal waves. Tidal Power makes use of 60+ years of technology development pioneered by the sub-sea oil & gas industry and most recently the amazing development made by the offshore industry in efficient power transmission back to the shore.*

*Looking at India's potential for tidal power generation, we can say that it has a tremendous scope to capture the Tidal Power but due to various financial challenges & high capital cost of Rs 30 to 60 crores per MW power generation something going wrong for this renewable source. Here the challenge comes for engineers of India to show their talent to become a path giver for other countries in this field of Tidal Power Generation. Why we are not putting our efforts to cultivate this technique for the betterment of next generation of Indian people? Why our technocrat's are not eager to develop indigenous, chip & comfortable techniques for tidal power generation, when we are able to reach at Moon. Looking to the present scenario of gap between world's power supply and its demand and less availability of fossil fuels all over the world, one must have to think for development of new renewable energy sources like geo-thermal, wave technology and tidal technologies to fulfil world's endless demand of electricity.*

*To boost such renewable energy sources, Government can provide funding for Research and Development to promote innovation, reduce costs, and improve the efficiency. They can also establish regulations and policies related to such energy, including environmental impact assessments, grid connectivity & permitting processes. Study on Tidal and Wave Energy in India -Survey on Potential and Proposition of Roadmap-conducted by IIT- Chennai in association with Credit Rating Information Services of India Ltd, suggested a roadmap to set up commercial tidal power projects by 2030.*

*The tidal cycle takes place once every twelve hours as a result of the moon's gravitational pull. The difference in water depth between low and high tides is known as potential energy. To harness the full strength of the tidal energy potential, the high tide must be at least five metres higher than the low tide. India is very fortunate for having roughly 20 locations on the earth where the tides are this high. On Gujarat's west coast, the Gulf of Cambay and the Gulf of Kutch have maximum and average tidal ranges of 11 metres and 8 metres, respectively and may capture the Tidal Power Potential about 8000 MW of tidal energy including 8,200 MW in the Gulf of Kambhat & Gulf of Kutch in Gujarat respectively along with 100 MW in Sunder bans in West Bengal.*

*Tidal power have lots of advantages like-Zero Greenhouse Gas Emission, usefulness for long duration about two billion years, predictable and constant, ensure a relatively steady power supply. Though the initial costs are extremely high it has a big*

*advantage of "mostly maintenance free over a life span of about 30-40 years. These Green technologies can boost economic growth, energy security, job creation, and global export. Wave energy can power various establishments such as oil & gas, defence bases, ports & harbours, and islands. It also has potential applications such as sea surveillance, coral reef regeneration, navigational buoys, and desalination. Producing green hydrogen from wave energy can also help reduce greenhouse gas emissions. At present about nine to ten Tidal power generation projects are there which generates about 900 MW using any one technique (1) Tidal Barrage, (2) Tidal Stream Generator (3) Dynamic Tidal Power & (4) Tidal Lagoon. Some projects are under planning stage right now having huge potential of tidal power generation.*

*The renewable power generation sector has the potential to expand, boosting economic growth, lowering carbon footprints, and creating jobs not only along the coasts but also inland along supply networks. Though India is generating power through Solar, Wind and bio-gas but the Tidal Power is challenging all of us. Why we are not putting our efforts to cultivate this technique for the betterment of next generation of Indian people? Why our technocrat's are not eager to develop indigenous, chip & comfortable techniques for tidal power generation, when we are able to reach at Moon. Looking to the present scenario of gap between world's power supply and its demand and less availability of fossil fuels all over the world, one must have to think for development of new renewable energy sources like geo-thermal, wave technology and tidal technologies to fulfil world's endless demand of electricity.*

***Keywords:*** *Renewable Energy; Wave & Tidal Power; Tidal Power Generation; India@2047*

## ADVANTAGES OF TIDAL POWER GENERATION

1. One of biggest advantages of Tidal Power generation is Zero Greenhouse Gas Emission.
2. Tidal Power may be useful for at least 2 billion years, making tidal power as renewable as wind and solar, but the major problem is maintenance over the long term.
3. Unlike solar or wind, the tides are predictable and constant. The tides can be predicted 100s of years into the future and hence we can ensure a relatively steady power supply.
4. The cost of a Tidal Power system is a double-edged sword. The initial costs are extremely high. but, the systems are mostly maintenance free over a life span of about 30-40 years.
5. Barrage system can protect coastal towns and ports from flood, and it can double as a bridge or other connection route, so this facilitates for transportation too.
6. The tidal stream generators are probably the most eco-friendly of all tidal power schemes. They operate at all times. Because tidal stream generators can be designed to work no matter what direction the tide is flowing, they can generate power up to 20 hours per day, making them more practical as a standalone system.
7. Dynamic Tidal Power is not yet tested, but theoretically advantages are many.

## DISADVANTAGES OF TIDAL POWER GENERATION

1. Disruption of the life cycles of certain marine life. They can prevent their movement, can kill wildlife, and can increase silt deposit which can block out sunlight and prevent plants from growing. They can also prevent access to rivers and cut off shipping. They are costly to build and locations are highly limited.
2. Spinning blades of Stream Generators can kill marine wildlife. Their acoustic disturbances can affect migration and other aspects of marine life. They can interfere with shipping channels and are more prone to damage by high waves and rough water than other systems.
3. Dynamic Tidal Power schemes are very costly, are untested yet and more impacts of the system in various things cannot be judged at present.

## CONCLUSION

The Ministry of New and Renewable Energy (MNRE) has taken several steps to fructify Prime Minister Shri Narendra Modi‟s dream of a clean energy future for the 'New India'. The largest renewable capacity expansion programme in the world is being taken up by India. The government is aiming to increase share of clean energy through massive thrust in renewable. Core drivers for development and deployment of new and renewable energy in India have been Energy security, Electricity shortages, Energy Access, Climate change etc. The Government is also planning an active role in promoting the adoption of renewable resources by offering various incentives, which includes-generation based incentives (GBIS). Capital and interest subsidies, Viability gap funding, concessional finance and fiscal incentives. All these leads for better India in field of renewable energy. Tidal energy has the

potential to play a valuable part in the sustainable energy future. Though, there is still a need for re-assessment of Tidal Power potential in India, in terms of scientific evaluation and strategic planning, but the experience gained from pilot projects will decide the future course of action for the development of Tidal Energy programme in India. Let us hope that in coming decade, India will also be in list of those countries which are generating Tidal Power in hundreds of Mega Watts. In my full length paper, I will focus on the various technologies of Wave & Tidal Power Generation and the future prospects of India. By developing such renewable source of energy India can became on the top of the world with economy of 5 Trillion $ bench mark. I hope Hon'ble Prime Minister Vision of 'Atma-Nirbhar Bharat' dream will be fulfilled in the year 2047, which may makes glorious future with a tag of 'Developed Country-India'. Jai-Hind.

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# Optimizing Mesh Geometry and Orientation for Fog Harvesting in Cooling Towers

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***Abstract:*** *Freshwater scarcity is one of the most egregious challenges facing society today. Cooling towers (CT) in thermal power plants are heavily implicated with industrial water losses, as they spew large quantities of water as fog droplets, from the CT cell. Fog harvesting meshes have offered a promising solution to capture a portion of this lost water. A fraction of the drift loss can be recovered by strategically placing optimally engineered meshes near the CT exits, reducing the CT water footprint. The key factors that influence the efficiency of fog harvesting include the mesh's shade coefficient, fibre diameter, and the mesh-inclination relative to the oncoming fog. This study aims to experimentally determine the optimal mesh characteristics for maximizing fog collection in a lab-scale fog tower that replicates actual cooling tower exit conditions.*

***Keywords:*** *Fog Harvesting; Cooling Tower; Mesh Optimization; Collection Efficiency; Shade Coefficient; Mesh Inclination*

## INTRODUCTION

Freshwater scarcity is one of the most pressing concerns of the developed world [1, 2]. United Nations puts 'clean water and sanitation' under its prominent seventeen Sustainable Development Goals (SDGs), where 'availability' of fresh water resources is highlighted alongside cleanliness and sanitation [3]. Therefore, immediate action towards judicious use of water is the need of the hour. Consumption from industries, especially in process-cooling, constitutes a major portion of this usage. In recent years, there has been an enhanced propensity towards the capture of fog emitting from cooling tower (CT) exit [4, 5, 6], with promising results. Capture of a mere 1% of fog-water could save up to 9 ton/hr of make-up water in cooling tower in a 500 MW power plant [4]. Metal and polyester meshes are utilized as fog water collectors (FWC) are currently used to capture fog [7] in such settings. These meshes enable fog droplets to impinge and deposit on their fibres. Subsequently, the droplets coalesce with previously deposited liquid, forming larger drops before detaching from the fibres under their own weight. This detachment process is highly influenced by factors such as mesh fibre diameter and mesh orientation relative to the fog flow [8]. A significant aspect of this research focuses on minimizing losses, and increasing the aerodynamic ($\eta_a$, the fraction of water content in the fog stream that may pass through the fog harvester mesh along with the undisturbed fog), deposition ($\eta_{dp}$, the fraction of water captured by the fog harvester mesh) and drainage ($\eta_{dr}$, the fraction of water drained from the fog harvester mesh to the collector) efficiencies. The overall collection efficiency ($\eta_{coll}$) is expressed in terms of these efficiencies as

$$\eta_{coll} = \eta_a \times \eta_{dp} \times \eta_{dr} \quad (1)$$

Collection efficiency from a mesh at a given flow can be maximized by identifying how the individual efficiency terms appearing in **Eq. (1)** vary with the operating conditions [9]. The aerodynamic efficiency ($\eta_a$) is a function of the shade coefficient (SC) of the respective mesh expressed as [10]

$$\eta_a = 1.09\ SC - 1.05\ SC_2 \quad (2)$$

where

$$SC = \frac{area\ covered\ by\ the\ mesh\ element}{total\ area\ of\ the\ mesh} \quad (3)$$

Additionally, the deposition efficiency ($\eta_{dp}$) is expressed as

$$\eta_d = \frac{St}{(\pi/2)+St} \quad (4)$$

Here, the Stokes number (St) characterizes the behaviour of fog particles within the flow, described as

$$St = \frac{2}{9}\frac{\rho_{fog} u}{\mu_{air}}\frac{R_{fog}{}^2}{2r_f} \quad (5)$$

The parameters in **Eq. (5)** include $\rho_{fog}$, which represents the density of the fog, $\mu_{air}$, the kinematic viscosity of air, u, the flow velocity, $r_f$, the radius of the mesh fibres, and $R_{fog}$, the radius of the fog particles. To optimize fog collection, it is essential to optimize the mesh parameters a under specific flow conditions and fog droplet radius. This requires the development of a scaled vertical fog tower (VFT) to simulate realistic fogging conditions, a one would expect at the CT exit. By subjecting the meshes with varying geometrical configurations and surface treatments (wettability) to a controlled fog stream, the efficiency of water collecting meshes has been systematically evaluated. This study aims to identify the optimal geometric parameters and mesh orientation that maximize fog collection under specific flow conditions and fog droplet size, using an in-house developed vertical fog tower (VFT) as an experimental platform. The water collected from different meshes is measured gravimetrically and compared to evaluate performance.

## MATERIALS AND METHODS

The operational fog tunnel (see **Figure 1**) has a cross-section of 20 × 20 $cm^2$, and 2 meters in height and is capable of replicating real-world fog conditions at a cooling tower exit. It generates dense fog using a nozzle spray and four Yuwell402AI ultrasonic nebulizers, delivering a fog loading capacity of approximately 75 $l/m^2/h$, with a bimodal droplet size distribution of 4 to 30 μm [7, 11]. The tower achieves a maximum flow velocity of 5 m/s, aided by four base-mounted draught fans and an induced draught fan near the exit. A honeycomb flow straightener ensures uniform axial flow across 80% of the cross-section (**Figure 1** — inset at bottom left). Flow velocity is measured using a telescopic vane-anemometer (Extech), and a 3-meter flexible aluminum duct exhausts the fog plume. The fog tower's base includes heater banks installed at the base of the tower, that raise air temperature from ambient 25°C to 55°C, controlled by PID controllers to maintain precision within ±1°C. Eight K-type thermocouples monitor temperature, and flow measurement stations are positioned upstream and downstream of the mesh. The thermally insulated walls withstand 55°C and high humidity for 8 hours of continuous operation. The test section holds an 11 cm diameter circular mesh (Figure 1-inset on the right), providing a 314.15 $cm^2$ exposed area, supported by tilting mechanisms. A water-collection port connected to a side-mounted flask and electronic balance ensures precise gravimetric measurements (accuracy: ±0.01 g). Detachable glass panels allow access to the test section. Aluminum meshes from McMaster-Carr, with SC from 0.24 to 0.64, are used (**Figure 2**). The fog tower, in the present case, maintains a flow velocity, u of 1.5 m/s at the anemometer port before the mesh enclosure and injects 3 ± 0.25 L/hr of water as fog.

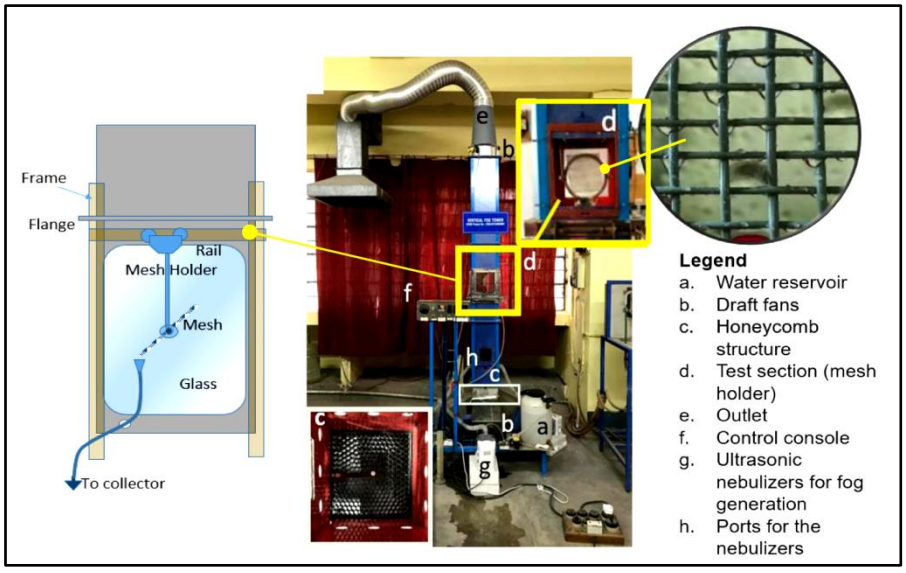
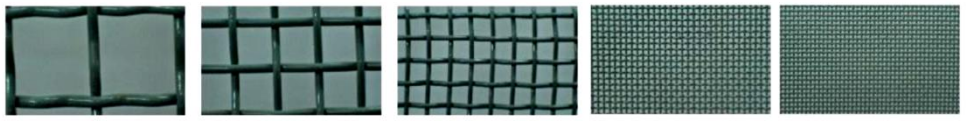


**Figure 1** The operational fog tunnel setup. The insets show the fog collection section (left), the honeycomb flow straightner (bottom left), and the fog harvesting mesh installed at the test section (right).



| Mesh Name | Mesh 1 | Mesh 2 | Mesh 3 | Mesh 4 | Mesh 5 |
|---|---|---|---|---|---|
| ***SC*** (%) | 24 | 44 | 40 | 55 | 64 |
| $f_d$ (mm) | 1.60 | 1.60 | 0.71 | 0.28 | 0.25 |
| **pitch** (mm) | 11.09 | 4.75 | 2.46 | 0.56 | 0.38 |

**Figure 2** Shade Coefficient (SC), fibre diameter ($f_d$), and pitch length of the meshes used in the present study.

The meshes are spray-coated with a commercial primer and rust-proof paint from Asian Paints Pvt Ltd (India), following standard practices for protecting metallic surfaces in high-humidity environments, such as those found in cooling towers, to prevent corrosion [12]. A sessile droplet is observed to have a contact angle of 67° ± 2° on a similarly paint-coated Aluminium flat surface, measured using a goniometer (Holmarc).

Five meshes, shown in **Figure 2**, with shade coefficients (SC) ranging from 24% to 64% and mesh fibre diameters between 0.25 and 1.6 mm were selected for the experiment. The meshes were tested at five tilt angles (5°, 15°, 30°, 45°, and 60°) from the vertical. Hourly water collection data was recorded and averaged over five readings per condition, ensuring statistical relevance. Measurements were taken once the system reached a steady state.

## RESULTS AND DISCUSSIONS

Placing a porous mesh in the path of an oncoming fog stream does not significantly impede airflow but creates enough resistance to capture airborne droplets. The principle behind this fog harvesting method relies on inertial interception, Brownian motion, and, in the case of active filtration, electrostatic deposition of the droplets on the mesh fibres. As the vertically directed fog flow interacts with the mesh, the fibres intercept the fog droplets (see **Figure 1**, right inset). These droplets then accumulate, forming water bridges between adjacent fibres if the mesh pores are sufficiently small. Alternatively, they slide down the fibres under the influence of gravity, collecting in a funnel beneath the mesh. In this study, meshes with varying shade coefficients (SC) and inclination angles were tested to determine the optimal configuration for maximizing fog collection efficiency.

The collection efficiency ($\eta_{coll}$) is calculated as the ratio of the total hourly mass of water collected ($m_{collected}$) to the mass of fog projected ($m_{fog}$), normalized over their respective projected areas. The projected area of the mesh depends on the inclination angle relative to the flow. This is expressed in the equation:

$$\eta_{coll} = \frac{\frac{m_{collected}}{A_{projected\ by\ mesh}}}{\frac{m_{fog}}{A_{duct}}} \qquad (6)$$

The projected area of the mesh depends on the inclination angle relative to the flow, and can be expressed as

$$A_{projected\ by\ mesh} = A_{mesh} \times \sin\theta \qquad (7)$$

**Figure 3** illustrates the collection efficiency of different meshes with varying SC and fibre diameters at different inclination angles (θ). A higher SC implies more material in the mesh and a smaller open area, resulting in better droplet impaction on the mesh fibres. However, as the SC increases beyond 55%, collection efficiency begins to decline, consistent with findings by Rivera et al. [9] and Mukhopadhyay et al. [10]. A lower SC, on the other hand, provides more open space within the mesh, allowing a significant portion of the fog to pass through without being captured.

At SC values above 55%, the mesh becomes too dense, obstructing fog-laden air from flowing through efficiently. Conversely, at lower SC values, the fog passes through without sufficient droplet capture. This relationship aligns with the aerodynamic efficiency ($\eta_\alpha$) described in **Eq. 2**. Further analysis of **Eqs 4** and **5** suggests that, all else being equal, smaller fibre diameters contribute to higher collection efficiency. This trend is reflected in the results for the mesh with an SC of 55% and a fibre diameter ($f_d$) of 0.28 mm, marked in magenta. However, despite a lower $f_d$ of 0.25 mm, a mesh with a higher SC of 64% fails to improve collection efficiency. Thus, both SC and fibre diameter are critical factors in optimizing fog-collecting meshes.

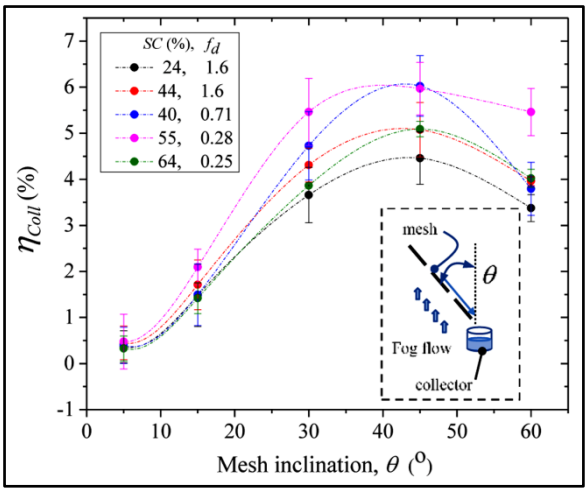



**Figure 3** Collection efficiency of the different fog collecting meshes at different mesh inclination angles. Error bars denote the standard deviation in collection taken over multiple (at least 5) runs

The collection efficiency increases with the inclination angle (from the vertical axis) up to 45°, after which it begins to decline. At higher angles, although gravitational forces cause droplets to roll down faster, the projected area of the mesh decreases, as described in **Eq. 7**, leading to reduced fog collection. Conversely, at lower angles, the larger projected area allows for more fog collection, but weaker gravitational forces cause droplets to fall off the mesh without being effectively captured. Thus, there is a trade-off between these factors, with 45° emerging as the optimal inclination for maximum collection efficiency. Beyond this angle, the fog impacting the mesh cannot be effectively collected, leading to a drop in efficiency.

## CONCLUSIONS

The optimal positioning of a fog-harvesting mesh with fine-tuned properties was tested in a scaled vertical fog tower under realistic flow conditions. A mesh with a 55% shade coefficient and thin fiber diameter demonstrated the highest collection efficiency at a 45° inclination. These results align with existing literature, which identifies maximum aerodynamic efficiency at a 55% shade coefficient and enhanced deposition efficiency with smaller fiber diameters. The 45° inclination was experimentally identified as the optimal angle for effective fog collection. To gain deeper insights into the performance of fog-harvesting meshes, meshes with different surface coatings under varying flow conditions at cooling tower exits will be undertaken. This will help enhance the understanding of optimal mesh configurations for efficient fog harvesting.

## ACKNOWLEDGMENT

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331_IEC35695

# Quantum Dot Solar Cell: Device Modelling and Efficiency Enhancement using CdTe Quantum Dots

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***Abstract:*** *The electrical and optical properties of a novel Quantum Dot solar cell (QDSC) using CdTe quantum dots were explored and simulated using the Silvaco TCAD software (version: 5.26.1.R). A proposed structure of a device comprises the incorporating of cadmium telluride quantum dots in the active layer that consists of Gallium Arsenide (GaAs) supported by the nickel oxide (NiO) hole transport layer and by the zinc oxide electron transport layer. QDSCs can accommodate multiple excitation generation (MEG) which helps in multiple carrier generation for one photon absorbed, which gives them the edge compared to other solar cells. Parameters extracted were power output efficiency of 36.95%, $V_{oc}$ of 1.054 V, $J_{sc}$ of 45.84 mA/cm², and a FF of 76.46%, under simulated illumination of AM1.5g at normal incidence. The structure ensured efficient charge separation, reduced the losses due to recombination, and showed maximum photon absorption for the wavelength range of 300–750 nm. I-V characteristic analysis, absorbance across different wavelengths, along with energy band profile, proved that QDSC was superior in its performance and scalability. This study provided the much-needed insight to design and optimize next-generation solar cells and highlighted the future possibility of QDSCs in advancing renewable energy technologies.*

***Keywords:*** *Multiple Excitation Generation; Quantum Dot; CdTe Q-Dots; Silvaco TCAD; Energy Conversion Efficiency*

## INTRODUCTION

In recent times, to meet the increasing demand of renewable energy, developing high-efficiency solar cells has opened a path to new research and innovation. Among these studies, quantum dot solar cells (QDSCs) have proved itself to be one of the most promising devices, due to their ability to capture a broader spectrum than most solar cells. Compared to other solar cells QDSCs can accommodate multiple excitation generation (MEG) due to being a nano-scalable particle that exhibits quantum confinement effects [1]. In MEG one high-energy photon can produce several electron-hole pairs instead of one. Thus, it increases the output conversion efficiency of the solar cell past the theoretical Shockley-Queisser limit due to this special feature which enables tuneable bandgap. It allows the QDSCs to absorb different wavelengths of light just by altering the size and orientation of the quantum dots[2].

The motivation and the main driving force for this work was to explore the scope of the enhanced efficiency and stability of QDSCs. To achieve and prove our claims we have taken the help of Silvaco TCAD ATLAS simulation mode, where we designed these QDSCs, comprised of multiple layers and regions, each having a specific role in the cell's specific operation. By utilizing the layered approach in active layer with the Q-dots, this worktargets to provide insights into the optimization and designing of next-generation solar cells with the help of TCAD tool.Detailed mesh generation, doping profile and customized material defining and complex computation of solar cell's output efficiency, FF, short circuit current density (Jsc), open circuit voltage (Voc)was performed for analysis and study.

To sum up, this paper presents a study of QDSCs in the Silvaco TCAD tool highlighting its optical activity, efficiency, fill factor, band-gap characteristics and understanding the quantum dot integration in solar cells for enhanced efficiency [3].

## METHODOLOGY

In this particular study of quantum dot solar cells (QDSCs), we simulated our structure using Silvaco TCAD software's (version: 5.26.1.R) with several layers that were designed for effective energy conservation, under some specific condition and model i.e. srh, bipolar, auger, fermi etc. [4]. To allow an easy flow of electrons, the cathode was made of Aluminum (Al). Nickel Oxides (NiO) were chosen as the hole transport layer (HTL) and Gallium

Arsenide (GaAs) was used in the active layer as seen in **Figure 1**.The quantum dots were designed in the dimension of 8nm×10nm×10nm, embedded in the active layers of GaAs to enhance the charge carrier generation through quantum confinement [5]. For the electron transport layer (ETL) we implemented Zinc Oxide (ZnO) and the anode material was set as Indium Tin Oxide (ITO).

To simulate quantum phenomena, a tiny mesh was used, particularly around the quantum wells. To investigate the absorption and charge creation, light with an AM1.5g spectrum model at a 90-degree incidence angle was used to replicate sunshine [6]. Key performances were computed by the program to evaluate the solar cell in both with or without illumination [7].

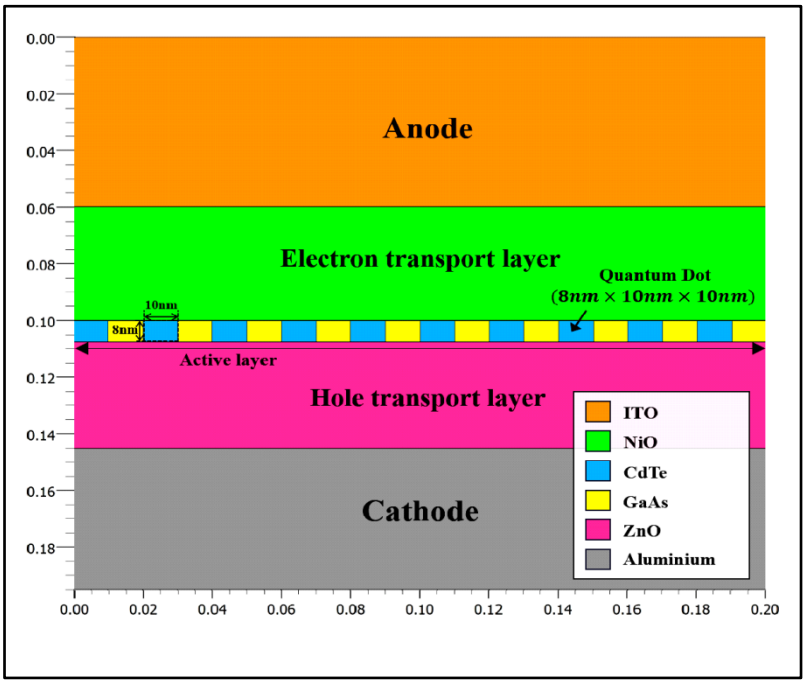


**Figure 1** Cross-sectional design of Quantum Dot Solar Cell

## RESULTS

### Band-gap

The power generation of solar cell mostly depends upon the efficient charge carrier'sseparation and transport, which concerns the used material's energy band structure, more accurately the valance band and conduction band. As shown in **Figure 2(a)**, by selecting Indium Tin Oxide (ITO) and Nickel Oxide (NiO) for distinct band alignment at interfaces, we have created the potential barrier and wells for trapping and directing carriers, reducing recombination and charge separation. The chosen ITO serves as a front contact, due to its conduction band which develops a charge barrier at the ITO/NiO interface, it blocks the electron from reaching the anode and collecting as well as transporting holes to the anode. In the same way, Zinc Oxide (ZnO) have been used in the electron transport layer, which selectively allows electrons to move to the cathode, spearing them to form holes. In our proposed QDSCs the quantum dots of the active layer comprised of Cadmium Telluride (CdTe), which had discrete energy due to quantum confinement, led to increased light absorption and generated electron-hole pairs. The use of Gallium Arsenide (GaAs) was to use its direct bandgap in absorbing light and moving electrons to improve the photocurrent. The alignment of energy levels reduced energy loss and ensured efficient charge collection, leading to a better solar cell performance.

### Optical Wavelength

The Optical wavelength shows the changes in cathode current in accordance with the wavelength. It shows the solar cell most efficiently absorbs the photons at the wavelength of around 300 nm to 750 nm, as depicted in **Figure 2(b)**.

As the wavelength increases towards red and near-infrared the cathode current decreases, due to lower energy photons which ware less effective in exiting and separating the electrons in the electron transport layer.

**I-V Characteristics**

In our study the current-voltage characteristics are crucial for understanding the performance of our proposed Q-Dot solar cell structure. It highlights two sections, the performance of the cell when illuminated in sunlight and the performance in dark condition. Without the presence of light, the current stays zero until 0.8 V, until there was a slight negative current generated at higher bias voltage, due to the minor leakage of inherit recombination process within the cell. Under illumination the current sharply increased and reached 4.58 V, till an anode voltage 0.76 V, with the increasing anode voltage it steadily decreased till 1.2 V showcasing its saturation point.Multiple key parameters had been derived from this I-V characteristics as depicted in **Figure 2(c)**. The maximum voltage our QDSCs can provide without any load was determined by the Voc, which was 1.054 V. On another note, the current density at $J_{sc}$ was 45.84 mA/cm$^2$. The maximum power was attained at 0.94 V anode voltage where it reaches 3.69 × $10^{-12}$ W, which had been referred as $P_{max}$ where the cell performs most efficiently (shown in **Figure 2(d)**). The part of maximum decapitated power could be understood using the power triangle concept too, as its state the relations between $J_{sc}$, Voc and $P_{max}$. The triangular area created by the generated power and the anode voltage also represented the power generated by the QDSCsat any instance.

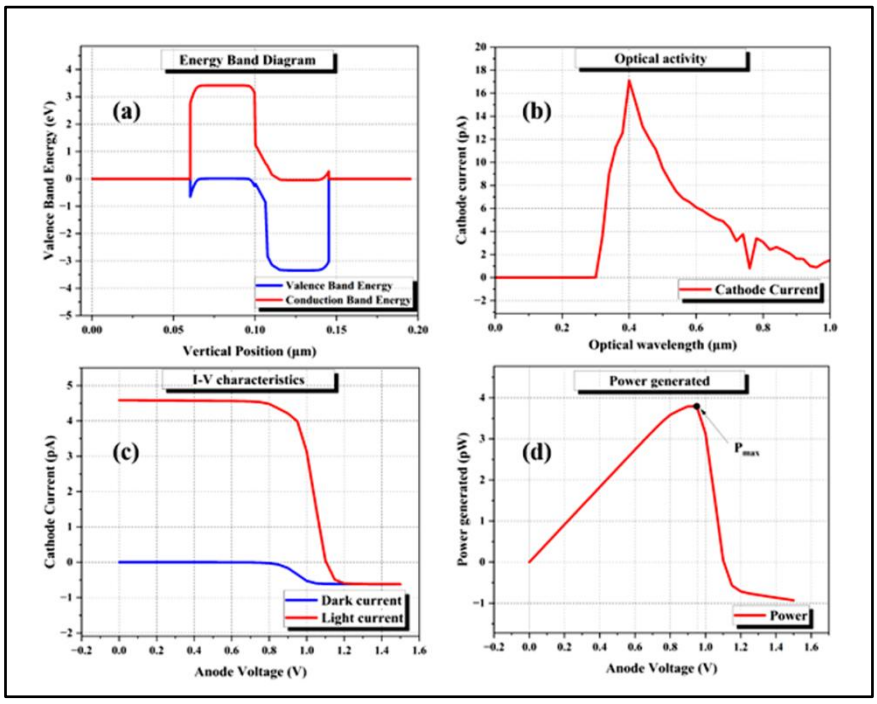


**Figure 2**(a) Energy band-gap diagram across vertical position (b) Optical wavelength (c) I-V characteristics (d) Power generation

The fill factor (FF), that determines how ideal the solar cell I-V characteristics are. It could be defined by the ratio of the maximum power ($P_{max}$) and the product of open circuit voltage ($V_{oc}$) and short circuit current density ($J_{sc}$). Upon calculating with known values of $V_{oc}$, $P_{max}$ and $J_{sc}$ we got the fill factor (FF) 76.46 which indicates how effectively our QDSCs converts the available electrical energy in the given condition. The efficiency (η) of solar cell had been commuted using the ratio of $P_{max}$ and input power ($P_{in}$) in this case as we had taken AM1.5g, the standard sunlight condition would be 0.1W/cm$^2$. With all these values we got our efficiency to be 36.955 which proved to be considerably more efficient than single junction solar cells. With an $V_{oc}$ of 1.054 V, a $J_{sc}$ of 45.84 mA/cm$^2$, a fill factor of 76.46%, and an output efficiency of 36.95%, the quantum dot solar cell exhibits robust performance, to sum up. These numbers demonstrate the cell's capacity for effective energy conversion when it operates close to its maximum power point.

**Table 1** Quantitative results of the proposed Q-dot solar cell model

| Parameters | Values |
|---|---|
| Open Circuit Voltage ($V_{oc}$) | 1.054 V |
| Short Circuit Current Density ($J_{sc}$) | 45.84 mA/cm² |
| Maximum Power Dissipated ($P_{max}$) | $3.69\times10^{-12}$ W |
| Fill Factor (FF) | 76.46 |
| Efficiency (η) | 36.95 % |

## CONCLUSION

In brief, this study illustrates the potential of quantum dot solar cells (QDSCs) as a highly efficient energy-conservative model. The QDSCs could capture a wider spectrum of light, upscaling their performance beyond conventional solar cells utilizing the quantum confinement effect of the CdTe quantum dot. Here the carefully modelled HTL and ETL layer plays a crucial role in separating charge carriers efficiently and minimizing recombination losses [8].

The simulation and study results yielded key parameters such as $V_{oc}$ of 1.054V, $J_{sc}$ of 45.84 mA/cm$^2$ and the FF to be 76.46 as well as the efficiency (η) to be 36.95%. The I-V characteristics revealed optimal power generation at 0.94 V, with a maximum power output ($P_{max}$) of $3.69 \times 10^{-12}$ W.

These results confirm that integrating quantum dots in solar cells works well, paving the way for better energy conversion efficiency while keeping stability & performance high. This study adds to the ongoing effort to develop advanced & cost-effective photovoltaic systems that can address future energy needs.

## ACKNOWLEDGMENT

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334_IEC82704

# Enhancing Sparse Geothermal Gradient Data at Regional Geological Scales using Generative Adversarial Networks

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***Abstract:*** *Geothermal energy is a promising sustainable, low-carbon energy source with significant potential for global heating, cooling, and electricity generation. A critical component in assessing geothermal energy potential is the accurate mapping of geothermal gradients. However, current global geothermal gradient datasets are often sparse, particularly in underexplored regions, limiting comprehensive evaluations. This study leverages Generative Adversarial Networks (GANs), a class of deep learning models, to augment sparse geothermal gradient data in the Puga Valley, Ladakh, India — a region with limited existing geothermal data. By incorporating concentrations of radioactive elements (Uranium-238, Thorium-232, Potassium-40) and petrophysical properties (density, porosity, permeability, thermal conductivity, specific heat capacity) as input features, the developed GAN model generates synthetic geothermal gradient data. The augmented dataset will validate against wellbore measurements, demonstrating improved data density and reliability. The results indicate that GANs can effectively mitigate data scarcity, enhancing the accuracy of regional geothermal assessments and informing more strategic geothermal exploration and development initiatives.*

***Keywords:*** *Renewable Energy; Geothermal Energy; Ladakh India; AI; Temperature Gradient*

## INTRODUCTION

Geothermal energy harnesses the Earth's internal heat for various applications, including electricity generation, district heating, and industrial processes. As a renewable and low-carbon energy source, it plays a vital role in mitigating climate change and reducing dependence on fossil fuels (DiPippo, 2016). The viability of geothermal projects depends on the geothermal gradient—the rate at which temperature increases with depth— which dictates the thermal energy available for extraction. In **Figure 1**, we observe a detailed map of the geothermal provinces of the Indian subcontinent, with a particular emphasis on regions in and around the northern areas of Jammu and Kashmir, India. The color-coded areas in the map represent different ranges of heat flow values, expressed in mW/m². These heat flow values are significant for identifying geothermal activity, where areas with higher heat flow suggest greater geothermal potential. The red regions highlight areas with the highest heat flow values, greater than 180 mW/m², while the progressively lighter shades represent areas with decreasing heat flow values. Additionally, green ellipses mark notable geothermal regions in India, specifically areas with active or potential geothermal reservoirs.

In the context of our study, we have collected data from three significant geological regions: the Kohistan-Ladakh Batholith, Nanga Parbat, and Karakoram Batholith. These regions are marked on the map and are integral to understanding the geothermal characteristics of the broader area under investigation. Specifically, these regions are known for their tectonic and geological complexity, as they are located at the junction of the Eurasian and Indian tectonic plates. The interaction of these plates has contributed to enhanced geothermal gradients and heat flow in the region due to crustal thickening, magmatic intrusions, and radiogenic heat production.

Accurate geothermal gradient mapping is essential for identifying viable geothermal reservoirs and optimizing extraction strategies. The geothermal gradient ($\nabla T$), defined as the rate of temperature increase with respect to depth within the Earth's crust ($\nabla T = dT/dz$), plays a crucial role in geothermal energy extraction. High geothermal gradients are indicative of regions with significant heat flow, which makes them prime candidates for geothermal energy

projects[2]. However, as depicted in Figure 1, geothermal gradient data across various regions are unevenly distributed, particularly in areas such as the Puga Valley in Ladakh, where exploration activities have been limited[3]. The lack of comprehensive data in such regions hinders the development of geothermal resources and delays the evaluation of their potential for energy production.To address these gaps, this study aims to employ Generative Adversarial Networks (GANs) to generate synthetic geothermal gradient data. GANs are an advanced form of deep learning introduced by [4], consisting of two competing neural networks - the generator and the discriminator. These networks work in tandem to produce synthetic data that closely resemble the original dataset. By utilizing GANs, we aim to enhance the sparse geothermal gradient dataset available for the Puga Valley, improving both spatial coverage and accuracy. This approach can revolutionize geothermal exploration by providing a more complete dataset in regions where actual measurements are scarce or difficult to obtain.

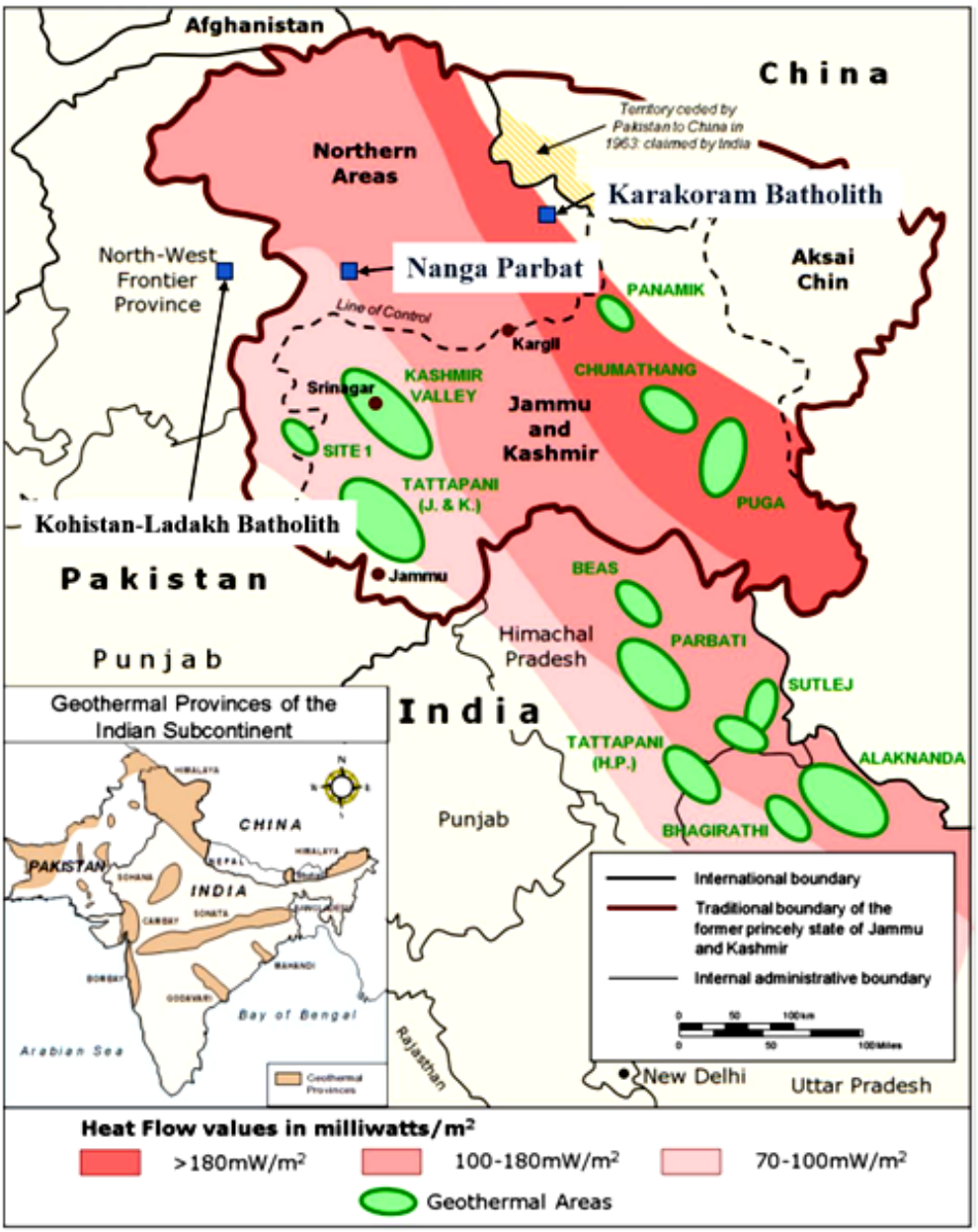


**Figure 1** Geothermal provinces of the Indian subcontinent, highlighting heat flow values across regions and key geothermal areas. The red shaded areas indicate varying levels of heat flow (mW/m²), with the highest values (>180 mW/m²) observed in the northern regions, including Kohistan-Ladakh Batholith, Nanga Parbat, and Karakoram Batholith. Green ellipses mark significant geothermal sites in India.

In geothermal studies, crustal heat originates from two primary sources: radiogenic heat production and mantle-crust heat flow. Radiogenic heat is generated by the radioactive decay of isotopes such as Uranium-238 (U-238), Thorium-232 (Th-232), and Potassium-40 (K-40), while heat flow from the Earth's mantle is influenced by tectonic and magmatic processes. In tectonically active regions such as the Puga Valley and surrounding batholiths, magmatic convection can further enhance heat flow, contributing to the elevated geothermal gradients observed. The data collected from Kohistan-Ladakh Batholith, Nanga Parbat, and Karakoram Batholith provides a foundational basis for this study, and GAN-generated data will augment this foundation by filling in gaps where exploration is lacking [5].By improving the spatial resolution of geothermal gradient data using GANs, this study will not only enhance the geothermal resource assessment in the Puga Valley but also sets a precedent for utilizing machine learning techniques in geothermal exploration globally. This methodology has the potential to overcome the data limitations often encountered in geothermal studies, particularly in remote or politically sensitive regions. In conclusion, enhancing sparse geothermal gradient data through advanced deep learning techniques like GANs represents a transformative approach to geothermal resource evaluation, offering new pathways for energy exploration in previously underexplored or inaccessible areas.

## METHODOLOGY

Geothermal gradient data were sourced from past wellbore studies conducted in the Puga Valley, Ladakh, India. These data were designated for different rocks from three sites: Kohistan-Ladakh Batholith, Nanga Parbat, and Karakoram Batholith. Concentrations of radioactive elements (U-238, Th-232, K-40) were obtained from geological surveys and literature sources [5, 6]. Additionally, petrophysical properties such as density, porosity, permeability, thermal conductivity, and specific heat capacity were integrated from published studies to serve as input features, recognizing their influence on heat transfer within the crust.The data preparation phase involves aggregating relevant features such as latitude, longitude, density, and thermal conductivity from each lithological sample. These features are organized into NumPy arrays and subsequently split into training and testing datasets using an 80-20 ratio. To enhance the neural network's performance, feature scaling is performed using the StandardScaler, standardizing the input features based on the training set statistics.

For the predictive modeling, three separate neural network models are developed using PyTorch, each tailored to predict one of the target variables (eU, eTh, eK). Each model consists of three fully connected layers with ReLU activation functions, enabling the capture of complex nonlinear relationships within the data. The models are trained over 1,000 epochs using the Mean Squared Error (MSE) loss function and optimized with the Adam optimizer, which adjusts learning rates adaptively for efficient convergence. During training, the models iteratively update their weights to minimize the loss, with periodic logging every 100 epochs to monitor progress and ensure effective learning. Upon completion of training, the models are evaluated using the testing dataset to assess their predictive accuracy. A prediction function is implemented to allow for the estimation of elemental concentrations based on new geospatial and lithological inputs. This function applies the same scaling to the input features and utilizes the trained neural networks to generate predictions.

## RESULTS

The dataset, presented in **Table 1**, includes various rock types along with their uranium (eU), thorium (eTh), potassium (eK) concentrations, density, heat production rates, and geographical coordinates. Using the Python-based code developed for this research, we systematically prepared the data by extracting relevant features, normalizing the values, and converting them into a format suitable for neural network analysis.

The prepared data was used to train three separate neural network models, each designed to predict one of the target variables: eU, eTh, and eK. Each model was trained over 1,000 epochs using the Mean Squared Error (MSE) as the loss function and the Adam optimizer to adjust the model parameters. During training, we observed a consistent decrease in the loss values, indicating that the models were effectively learning the relationships within the data. The training process demonstrated that the models could identify patterns in the lithological and geospatial features to predict the elemental concentrations accurately.

**Table 1** Lithological data from Nanga Parbat Massif, Kohistan-Ladakh Batholith, and Karakoram Batholith, including concentrations of uranium (eU), thorium (eTh), potassium (eK), density, heat production rates, and geographical coordinates [5, 7-10]

| Sl. No. | Lithology | eU (ppm) | eTh (ppm) | eK (%) | Density | Heatproducton rate | Coordinates | |
|---|---|---|---|---|---|---|---|---|
| 1 | Nanga Parbat Massif | | | | | | 35°14'15"N | 74°35'20"E |
| a | Gneiss | 8.78 | 30.42 | 3.72 | 2.66 | 4.63921024 | | |
| b | Pegmatite | 8.54 | 12.35 | 4.28 | 2.63 | 3.36143456 | | |
| c | Schist | 2.38 | 9.05 | 1.78 | 2.76 | 1.435752 | | |
| d | Granite | 16.94 | 20.7 | 4.22 | 2.61 | 5.97550104 | | |
| e | Psammite | 0.3 | 1.13 | 0.63 | 2.7 | 0.2144124 | | |
| 2 | Kohistan-Ladakh batholith | | | | | | 35°23'36"N | 73°21'28"E |
| a | Granodiorite | 1.56 | 9.31 | 2.6 | 2.65 | 1.2649192 | | |
| b | Diorite | 1.14 | 6.6 | 2.09 | 2.75 | 0.963105 | | |
| c | Granite | 2.96 | 14.1 | 3.63 | 2.62 | 2.01497912 | | |
| d | Metavolcanics | 0.63 | 2.54 | 1.18 | 2.8 | 0.4649792 | | |
| e | Gneiss | 2.73 | 13.54 | 2.51 | 2.7 | 1.8734436 | | |
| f | Tonalite | 0.25 | 2.95 | 0.65 | 2.8 | 0.341432 | | |
| g | Leucogranite | 2.51 | 12.76 | 3.81 | 2.6 | 1.8153096 | | |
| h | Amphibolite | 0.36 | 2.56 | 1.02 | 2.62 | 0.35449648 | | |
| i | Pegmatite | 1.97 | 7.47 | 3.21 | 2.69 | 1.31940196 | | |
| j | Gabbro | 0.6 | 5.08 | 1.51 | 2.84 | 0.68079344 | | |
| 3 | Karakoram batholith | | | | | | 36°00'00"N | 76°00'00"E |
| a | Gneiss | 4.7 | 16.47 | 3.34 | 2.65 | 2.6110556 | | |
| b | Granite | 15.81 | 61.32 | 3.75 | 2.63 | 8.43021252 | | |
| c | Granodiorite | 5.1 | 19.15 | 3.2 | 2.65 | 2.880868 | | |
| d | Diorite | 2.05 | 10.2 | 2.42 | 2.59 | 1.39988464 | | |
| e | Pegmatite | 9.96 | 9.2 | 4.44 | 2.72 | 3.63996928 | | |
| f | Leucogranite | 12.11 | 10.04 | 3.38 | 2.62 | 4.0021024 | | |
| g | Syenite | 3.71 | 11.87 | 6.92 | 2.58 | 2.3165304 | | |
| h | Schist | 2.29 | 10.38 | 1.97 | 2.7 | 1.4911884 | | |

Currently, we are focusing on validating the performance of these neural network models. This involves testing the models with a separate set of data that was not used during training to evaluate their accuracy and reliability. We are calculating metrics such as the coefficient of determination ($R^2$), Mean Absolute Error (MAE), and Root Mean Squared Error (RMSE) to quantify the models' performance. Additionally, we are using cross-validation techniques to ensure that the models are robust and not overfitting the training data. Early validation results are encouraging, showing that the models perform well on new data. Ongoing validation efforts aim to further improve the models' accuracy and confirm their usefulness for predicting elemental concentrations in geological studies and resource exploration.

## CONCLUSIONS

In this study, we developed neural network models to predict uranium (eU), thorium (eTh), and potassium (eK) concentrations using lithological and location data from three major geological regions: Nanga Parbat Massif, Kohistan-Ladakh Batholith, and Karakoram Batholith. We successfully prepared and processed the data, and trained initial models to understand the relationships between the features and the target elements.Currently, we are working on validating these models to ensure they accurately predict the concentrations. This involves testing the models with new data and measuring their performance using metrics like $R^2$, Mean Absolute Error (MAE), and Root Mean Squared Error (RMSE). While early results are promising, thorough validation is necessary to confirm the models' reliability. Once validation is complete, we expect to present detailed results showing how well the models perform, including charts that compare predicted values to actual measurements. In the future, we plan to expand our dataset with more regions and rock types to improve the models. Additionally, we aim to explore more advanced machine learning techniques and apply our models to real-world geological studies and resource exploration projects. This work will help geoscientists make more accurate predictions about elemental concentrations in different geological settings.

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348_IEC25110

# Performance Enhancement of Rooftop SPV Power Plant by 3C (Continuous Cleaning and Cooling) Process

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***Abstract:*** *Dust deposition over solar PV module is one of a major matter of concern from the prospect of energy conversion from photon energy to electrical energy. Deposited dust particles over a solar PV module create a barrier and refuse to transmit solar irradiation through the glass cover of a module. This optical blockade due to deposited dust particles adds on the additional rise of surface temperature of the module, resulting efficiency drop and affecting power generation from a solar PV power plant. Enhancement of power generation under optimum techno-economic solution is possible by maintaining a scheduled solar PV module cleaning. However, cleaning and cooling make an enormous effect over the generation of a solar PV power plant. An 85 kWp solar PV power plant is identified in eastern India to realize the impact of 3C (continuous cleaning and cooling) process over generation from the solar PV power plant. A remarkable power generation gain is observed due to 3C process under nominal variation of incident solar irradiation and ambient temperature. Cleaning of solar PV modules of a power plant involves noticeable amount of usage of water. To avoid the wastage of water during the 3C process, a water recycling scheme is introduced in the solar PV power plant. This recycles 80% of wasted water to reuse water for further cleaning. This approach reduces water wastage at minimum count with an outstanding generation gain.*

***Keywords:*** *Dust Deposition; Cleaning; Cooling; Power Generation; Module Temperature*

## INTRODUCTION

Dust is an enormous threat for power generation from a solar PV power plant, whether it is suspended in the atmosphere or deposited over the PV module in the field. These dust particles are the foremost reason for variation of incident solar irradiation over the panels. Deposited dust particles over the surface of a solar PV module, allows lessor amount of solar irradiation to reach over the solar cell, as the rests are scattered or absorbed by these deposited dust particles. The amount of these dust particle deposition is completely a location and season specific parameter [1]. It is observed that the maximum dust deposition rate is during summer season followed by winter season for the location Bina, India as realized by pandey et al. [1]. Furthermore, the density of deposited dust particle is fully dependent over the orientation of locality and surroundings. The daily dust deposition rate ranges within 7.5 to 42.1 $mg/m^2$ and vary from 25.8 to 277 $mg/m^2$ within a week. However, for no-precipitation period, dust accumulation reaches to 40 $mg/m^2$/day as experimented by styszko et al. [2]. These dust deposition over the surface of solar PV module affects the performance of the module by losing power generation as experimented by Rao et al. in an indoor experiment with adjustable irradiation level. [3]. Furthermore, several experiments were attempted for further realization of the impact of the deposited dust particles over the power generation of a solar PV power plant [4,5]. This reduces the efficiency of a solar PV power plant by more than 50% [6,7]. This dirtiness of module makes module temperature variation in between 1°C to 9°C which results nearly 0.3% of efficiency variation per each degree of module temperature rise [8].

This phenomenon clearly indicates that the dust particle reduces the generation of SPV plant in two ways, a) by rising the temperature and b) by creating obstacles for light penetration. Hence, cleaning and cooling of a solar PV module enhances the power generation from a solar PV power plant. There are rare attempts of solar PV module cooling in R&D level, [9,10] among which phase change material (PCM) based cooling technology is quite impressive [11]. The energy gain by cooling of solar PV modules may reach to 9.2%, as experimented by Hudișteanu et al. [12]. Furthermore, an efficiency of a solar PV system is compared for continuous cooling, cooling for one hour and noncooling by Sukarno et al. Here, the maximum efficiency of 16.7% by continuous cooling is observed [13]. Experiments are carried out to compare the power generation gain due to cleaning [14,15] and cooling of solar PV

module separately. The result shows the maximum system efficiency reached to 23.6% due to cleaning of module, once in three days and the efficiency reached to 23.9% by cooling of solar PV modules during operation for longer period at Oman [15]. Furthermore, some attempts are made to realize the effect of cleaning and cooling of solar PV modules by water, over the generation of power [16,17]. Elsewhere, cleaning and cooling is attempted by flowing air over the dusty solar PV module surface for varied time duration and observe to be 36.1% of higher power generation for 20 seconds of blowing air by air compressor [18].

Cleaning of solar PV module have a major impact over efficiently power generation from a solar PV power plant. Several cleaning techniques are reviewed by Najim et al. [19]. Mostly, water based solar PV module cleaning is followed everywhere, due to low-cost maintenance. Elsewhere, natural and manual cleaning is compared by smith et al. [20] and effective natural cooling are observed at Portland. However, for frequent rainfall may fulfil the requirement of solar PV module cleaning slightly. But for irregular rainfall forecast for a particular location, manual cleaning of solar PV module is a part of regular maintenance of a solar PV power plant.

This paper includes the realization of the effect for continuous cleaning and cooling (3C) of an existing solar PV power plant at eastern India, having a hot and humid weather condition. A semi-automated cleaning system with waste water harvesting technique implemented at this site, which is elaborated in further sections.

## DESCRIPTION OF AN EXISTING SOLAR PV POWER PLANT THAT IS CONSIDERED UNDER EXPERIMENTATION

Experiments of this work are carried out over an existing 85kWp, shade top solar PV power plant at saltlake, West Bengal, India. The geographical location of the power plant is 22°35’13’’N, 88°24’18” E shown in **Figure 1**. The solar PV modules are mounted over tin shed, having area coverage of 750 sqm, tilted at an angle of 5˚ and facing towards south-east at -58° azimuth angle. There are 156 modules rated at 545Wp each, are distributed over the shed and feeding to two numbers of 50kVA solar on-grid inverter. Each inverter comprises 4 strings, among which two strings are linked with 20 nos. of series connected modules and the other two are with 19 nos. of series connected modules.

## DESCRIPTION OF WET CLEANING ARRANGEMENT

A semi auto operated cleaning system is installed in this solar PV power plant. The semi auto indicates that the whole power plant cleaning will be carried out automatically by water sprinkler but a manual operator is required to initiate the cleaning arrangement by switching on or off. However, a weekly cleaning sequence is instructed here by the owner but for research purpose this cleaning sequence initiation and duration varied several times. Photograph during the cleaning process is shown in the **Figure 1**.

**Figure 1** Semi-automated cleaning under progress of the solar PV power plant

In this cleaning arrangement, one sprinkler having pressure range of 3 to 7 bar is allocated for each solar PV module. Based on the water pressure demand for efficiently working of these sprinklers running at 5 bar pressure, and the availability of booster pump, the segregation is analytically calculated and identified. Here, in this case a 2.5HP

booster pump is used for cleaning the modules distributed at 6 different sections and each section at a time. The novelty of this project is reusability of cleaned water repeatedly by avoiding wastage of water due the purpose of solar PV module cleaning. The water recycling scheme is elaborated in the upcoming section.

## IMPLEMENTED WATER RECYCLING SCHEME FOR CLEANING WATER OF SOLAR PV MODULE

After cleaning of solar PV modules, the waste water is collected to a water storage tank. Later the water from this storage tank is allowed to flow towards filtration unit through 1HP surface pump, to filter the used water for reusing this water for module cleaning again. Schematic of the water circulation system blocks are shown the **Figure 2**.

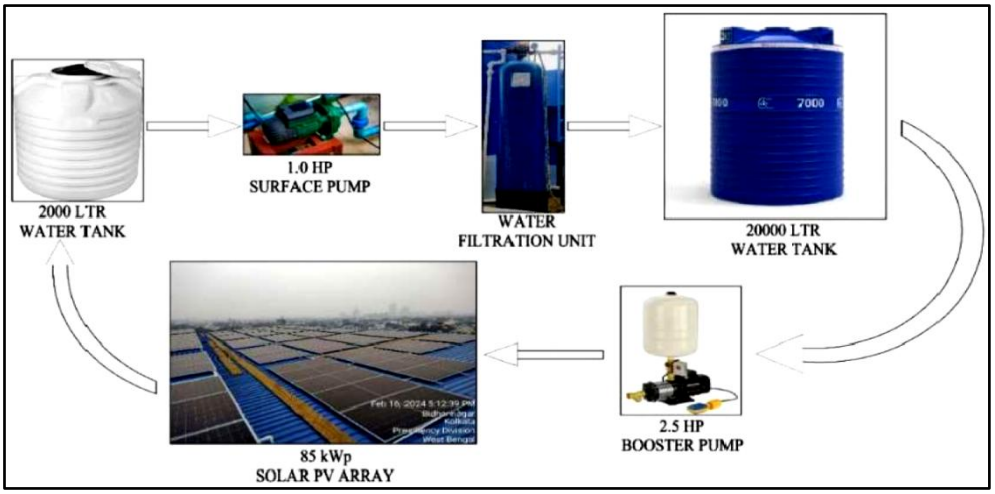


**Figure 2** Cleaning-water recycling system for 85kWp solar PV power plant

The filtration unit consists of treated media sand, graded gravels, anthracite and green sand, installed at different stages of the filtration unit. Here, only particle component removal is attempted is this filtration process to avoid the presence the micro particles in the water during reusing for cleaning of solar PV modules. 80% of the water used for initial cleaning is reused for solar PV module cleaning in second time. Here, in this scheme, the rain water is diverted to the installed soak pit to cater excess load of rain water during rainy season.

## EXPERIMENTATION

Experiments are carried out to realize the impression of semi-automated cleaning with water as cleaning material and effect of cooling, during the water circulation over the power generation of an existing solar PV power plant. Though, the power plant generally follows a significant cleaning schedule that already mention in section-3 due to commercial constraints. Here, a continuous cleaning is activated for the duration of half an hour under incident solar irradiation variation from 700 to 900 W/m$^2$. Cleaning is continued to run from 11:45 to 12:15. The date of experiment was 15th April, 2024. The weather parameters like module temperature, ambient temperature, wind velocity and incident solar irradiation are noted over the whole day using the existing remote monitoring unit installed at the site. Correspondingly, the power generation data are noted to compare the impact of weather parameters over power generation of the power plant. The results are elaborated in the further sections.

## DATA ANALYSIS AND RESULTS

### Impact of Cleaning

Here a noticeable impression of cleaning is observed. During the period of cleaning process, power generation changes from 61.4 kW to 65.2 kW whereas irradiation varies from 870W/m$^2$ to 898 W/m$^2$ as shown in the **Figure 3(a)**. This clearly indicates the power generation improvement due to a nominal irradiation fluctuation. However, just next to the cleaning completion, it is seen that the irradiation does not have a noticeable fluctuation, whereas the power generation drops at higher slope than the irradiation drops. This actually refers to an involvement of the

module temperature impact. Therefore, the variation of temperature during this time period is presented in the later section.

**Impact of Cooling**

The impact of module temperature due to the effect of cooling is remarkable as realized. As realized in the **Figure 3(b)**, during the period of cleaning, a drastic module temperature drops from 62.4°C to 51.8°C is observed. Though, the solar irradiation variation occurs of 28 W/m$^2$ and the ambient temperature drops from 31°C to 29.8°C. Therefore, the clear impact cooling due to continuous cleaning is realized here. The effect of continuous cleaning and cooling adds a gain in generation of 1.5% during this period. Hence, continuous cleaning and cooling (3C) process behaves as a catalyst that enhances the power generation of a solar PV power plant.

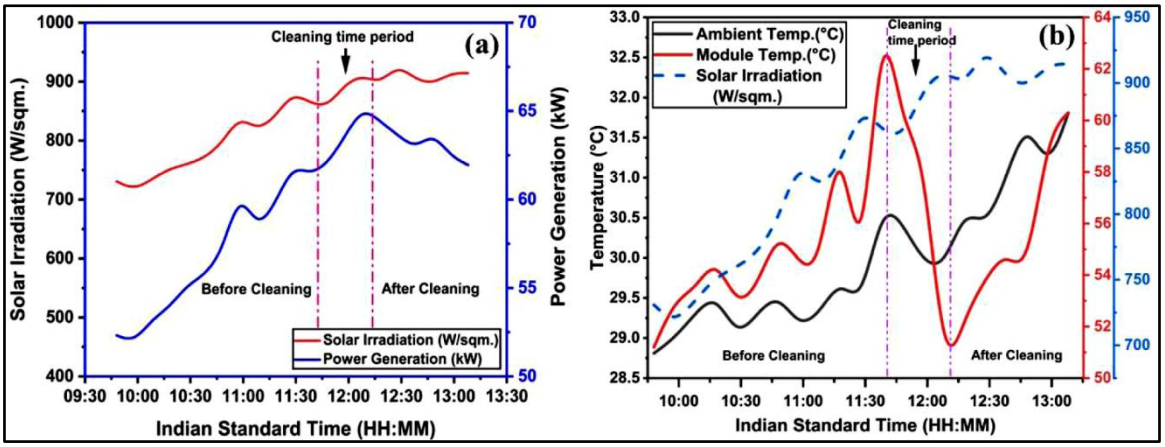


**Figure 3** Power generation impact over SPV plant (85kWp) due to a) Cleaning, b) Cooling

## CONCLUSION

Several environmental factors cause power generation hampering from a solar PV power plant. Dust deposition over solar PV module is the major parameter, that hampers power generation by hindering the solar irradiation as well as increasing the module temperature. Removing of deposited dust particle is the only solution to get optimum power generation. Hence, the easiest as well as the cheapest process of dust removal is cleaning with water. The water cleaning system for solar PV module provides an extra feature of module cooling, that adds more power generation. Here, in our experiments, the impact of continuous cleaning and cooling in a real field is observed for an existing 85 kWp solar PV power plant, installed upon a shed structure on the roof of west Bengal joint entrance board, head office, saltlake. The continuous cleaning and cooling (3C) for the period of 11:45 to 12:15 shows a remarkable gain in power generation. This generation gain of 3.8 kW during the incident solar irradiation variation of 28W/m$^2$ only. Correspondingly, the module temperature variation observed to be 10.6°C, whereas the ambient temperature varies 1.2°C only. The current scenario over cleaning of solar PV module involves huge amount of water for cleaning of those modules. Hence, to avoid the wastage of water, a waste water harvesting system is introduced into this site to avoid the wastage of water after cleaning of those module.

## ACKNOWLEDGMENT

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366_IEC83017

# Decarbonizing Transportation: The Potential of Solar-Powered EV Charging for a Cleaner Future

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***Abstract:*** *The urgent need to reduce Green House Gas (GHG) emissions in the transportation sector, which relies heavily on fossil fuels, underscores the transition to Electric Vehicles (EVs) as a viable solution to achieve climate goals. This paper evaluates the environmental impact of a 30 kW solar-powered DC fast EV charging station and its potential to contribute to a sustainable transport system. It explores the carbon emission savings from such a station, with a 30 kWp solar PV plant estimated to generate approximately 38.325 MWh annually, offsetting nearly 36.8 tons of $CO_2$ emissions annually. In addition to reducing grid dependency, the shift to solar energy for EV charging supports energy resilience and peak demand management. The avoided emissions from Internal Combustion Engine (ICE) vehicles amplify these savings, with around 4.16 tons of $CO_2$ avoided per 100 EV trips replacing ICE trips of 250 km each. This model demonstrates a scalable solution for cleaner transportation, combining solar energy and EVs to significantly reduce carbon footprint. By establishing a renewable infrastructure for EV charging, the transportation sector can advance toward carbon neutrality, aligning with global sustainability objectives and promoting a greener future.*

***Keywords:*** *Electric Vehicles; Carbon Emission; Solar Powered EV Charging*

## INTRODUCTION

The rising emissions of Green House Gases (GHGs) from fossil fuel combustion highlight the urgent need for sustainable climate policies. The International Energy Agency (IEA) proposed a scenario to limit global temperature increase to 1.5°C by 2050, coinciding with a projected global population of about 9.8 billion and an estimated 2 billion road vehicles in use.[1]. Over 90% of the global transport sector relies on oil, consuming 49% of total production. In 2009, it accounted for about a quarter of energy-related GHG emissions and is the fastest-growing energy-consuming sector. Thus, electrifying road vehicles is crucial for addressing these environmental challenges [2-6].

According to a comprehensive report from the International Energy Agency (IEA), the transportation sector is a critical area contributing to global carbon emissions. In the year 2021, it was found that greenhouse gas emissions originating from transportation represented approximately 25% of the total carbon emissions associated with global energy consumption. Among the various modes of transportation, road transportation was identified as the largest contributor, accounting for a substantial 76.1% of all transportation-related emissions [7]. This stark figure highlights the urgent need for strategies and policies aimed at reducing emissions from road transport and transitioning to more sustainable transportation alternatives [8-9].

The global stock of Electric Vehicles (EVs) exceeded 10 million by the end of 2020, reflecting over a decade of growth. However, concerns persist about their ability to reduce carbon emissions from transportation as global warming remains a critical issue [10-12]. Studies comparing the lifecycle carbon emissions of EVs and traditional Internal Combustion Engine Vehicles (ICEVs) show that the batteries significantly influence emissions [13-15]. Battery production is energy-intensive, leading to higher emissions during manufacturing compared to ICEVs. The carbon emissions of EVs during use largely depend on the electricity source. Charging with clean energy, like wind and solar, results in much lower emissions than ICEVs. Conversely, if charged with coal-fired electricity, EV emissions can surpass those of ICEVs.

A significant portion of carbon emissions from EVs comes from their production, accounting for about 46% of total

emissions, compared to 26% for traditional ICE vehicles. Manufacturing a single EV emits nearly four tonnes of CO2, underscoring the environmental impact of this phase. To reduce these emissions and move toward carbon neutrality, implementing a solar-powered charging infrastructure is essential.

This paper focuses on vehicle recharging and shows how infrastructural change such as the integration of renewable energy for charging EVs can make EVs more environmentally friendly and promote carbon neutrality in the transportation sector. The contributions of the present work are as follows:

(i) A comparative analysis has been conducted on carbon emissions for both electric vehicles (EVs) and internal combustion engine (ICE) vehicles, covering the entire lifecycle from manufacturing to operation.
(ii) The study evaluates the effectiveness of renewable charging stations compared to coal-based charging stations.
(iii) Emission calculations have been performed for fuel consumption in conventional vehicles.
(iv) The analysis includes carbon savings for EV charging scenarios: utilizing coal-based charging, solar-powered charging without grid backup, and solar charging with 5% grid backup.
(v) A comparison of carbon savings has been made across various EV charging methods and ICE vehicles.

## COMPARISON OF DIFFERENT PHASES OF REFUELLING OF EVS AND ICE VEHICLES

The initial phase of manufacturing either an electric vehicle (EV) or an internal combustion engine (ICE) vehicle involves the production of a chassis that utilizes a combination of aluminium and steel, resulting in consistent emissions within this segment. The variability in emissions primarily arises during the production of batteries for EVs, whereas for ICE vehicles, the fluctuations during their life cycle. So, we can compare EV and ICE based on the following-

- Production of fuel for internal combustion vehicles (ICVs).
- Manufacturing batteries for electric vehicles (EVs).
- Performance and efficiency metrics of ICVs.
- Performance and efficiency metrics of EVs.

### Production of Fuel for Internal Combustion Vehicles (ICVs):

To purify or refine one litre of gasoline, 1.06 kWh of energy is needed. The estimated $CO_2$ emission for burning 1 litre of diesel fuel is 2.68 kg, while for petrol, it is approximately 2.31 kg. LPG emits around 1.51 kg per litre.

### Manufacturing Batteries for Electric Vehicles (EVs):

The average value of $CO_2$ emission is 177 kg $CO_2$/kWh power. So, for the 30.2kWh battery pack (Indian Standard) total emission is around 5.3 metric tons of $CO_2$. A bigger battery will emit more $CO_2$, for instance, a 60kWh battery emits more than 10 metric tonnes of $CO_2$, and 100kWh emits 17 metric tonnes of $CO_2$.

### Performance and Efficiency Metrics of ICVs:

The overall efficiency of an Internal Combustion Vehicle (ICV) is approximately 25%. This implies that out of 100 kWh of power, only 25 kWh is effectively utilized. Such a significant power loss in ICVs largely stems from the numerous mechanical components that slide or move within the engine. Mechanical losses account for about 20% of the total energy consumed, contributing to the overall inefficiency.

### Performance and Efficiency Metrics of EVs:

Electric vehicles generally have an efficiency of about 70%, meaning that from 100 kWh of electricity, 70 kWh can be used for power. This efficiency exceeds traditional internal combustion vehicles, but gasoline has a much higher energy density. Gasoline provides over 12 kWh of energy per kg, while lithium batteries offer around 240 Wh per kg, making battery packs large and heavy.

As the carbon emission for an EV exceeds ICE-based vehicle due to carbon emission during battery manufacturing and battery charging from the grid, a solar-powered EV battery charging station can convert the EV to Green Vehicles (GV).

## COMPOSITION OF A CONVENTIONAL GRID-CONNECTED DC FAST EV CHARGING STATION

In India, the lowest-capacity direct current (DC) fast chargers for four-wheel vehicles usually operate between 10 to 15 kilowatts and conform to the GB/T (Bharat DC 001) standard. These chargers are ideal for smaller electric vehicles (EVs) and are commonly found in public and semi-public areas. They offer cost-effective DC fast charging solutions, particularly for urban and fleet applications where quick charging is crucial. A 30 kW DC fast charger is regarded as the minimum requirement to meet the growing demand for efficient charging.

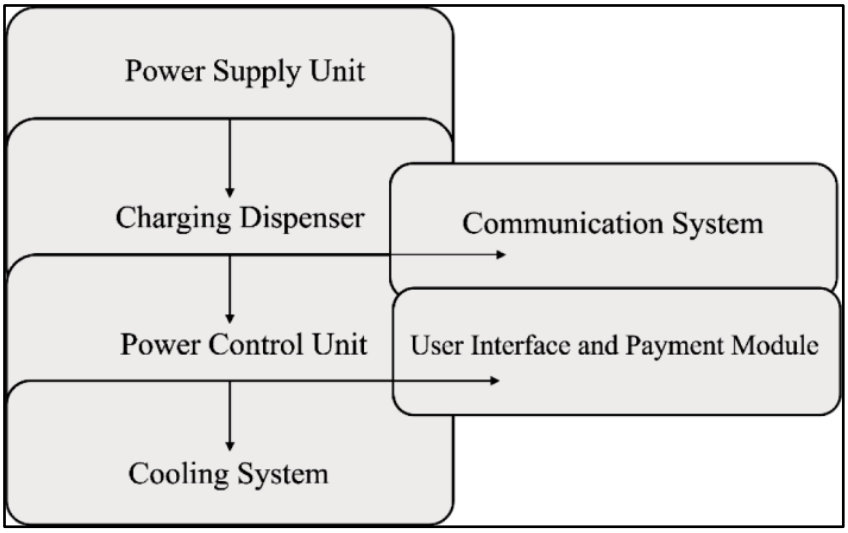


**Figure 1** Block diagram of the components of a conventional grid-connected DC fast EV charging station

Switching from a grid-connected EV charging station to a solar-powered one has multiple advantages, including:

(a) Reduced Operational Costs: Solar power can reduce electricity costs, particularly in areas with high solar irradiance. A solar PV system lowers reliance on grid electricity, resulting in long-term savings despite the initial investment. Transitioning to a solar EV charging station can cut operational costs by about 70-75% over its lifetime, after recovering the initial setup costs.

(b) Energy Independence and Reliability: A solar-powered system offers greater energy resilience by reducing reliance on the grid. It can also ensure uninterrupted charging during grid outages, which is valuable in regions with unstable power supply.

(c) Environmental Benefits: Solar energy is renewable and produces no direct emissions. Replacing grid-based electricity with solar reduces the carbon footprint of EV charging, supporting cleaner transportation and aiding in global emissions reduction efforts.

(d) Peak Demand Management: Solar energy generation aligns well with peak sunlight hours, which typically coincide with peak electricity demand. This setup can alleviate stress on the grid, reducing peak demand charges and supporting grid stability.

## CARBON EMISSIONS SAVINGS FROM A SOLAR-POWERED 30KW DC FAST EV CHARGING STATION

EV battery capacities commonly range from around 30 kWh (for smaller EVs), with an average midsize EV battery around 50-60kWh. On a single charge, an EV can cover 200-350km, depending on the battery size, vehicle efficiency, and driving conditions.

**Estimate Annual Energy Production**

The energy output of a solar PV plant is influenced by factors such as location, solar insolation (the intensity of sunlight), system efficiency, and losses. For a 30 kWp solar PV system, assuming an average solar insolation of 3.5 kWh/m$^2$ per day and 365 days in a year, the annual energy generation can be estimated as approximately 38,325 kWh or 38.325 MWh.

**$CO_2$ Savings per kWh**

The national average emission factor is around 0.96 [considering the average value between 0.82-1.1 kg $CO_2$ per kWh generated by conventional power plants (mostly coal-based)].

**Calculate $CO_2$ Savings**

For a 30 kWp solar PV plant generating approximately 38,325 kWh annually and assuming an emission factor of 0.96 kg $CO_2$ per kWh (typical for India's grid), the savings in $CO_2$ emissions would be approximately 36.8 tons of $CO_2$ saved per year.

**Avoided ICE Vehicle Emissions**

For a roughly 250 km journey (standard range of EVs available in the Indian market), an internal combustion engine (ICE) vehicle typically uses about 18 litres of petrol. Around 2.31 kg of $CO_2$ is released per litre when petrol is burned. $CO_2$ emissions per journey equals 18 litres × 2.31 kg $CO_2$/litre = 41.58 kilogram $CO_2$.

These emissions can be prevented by taking EVs on the same route rather than ICE cars.

Depending on the number of trips made, additional $CO_2$ savings can accumulate. For example:

- 100 such trips per year would save 4.158 tons of $CO_2$.
- 200 trips per year would save 8.316 tons of $CO_2$. [The detailed data for savings of carbon emission from a solar-powered charging station is provided in **Table 1**]

**Table 1** Net carbon savings from EVs including solar-powered EV charging station

| Number of Trips | $CO_2$ Savings from Solar PV (tons/year) | $CO_2$ Emissions from Grid Backup (5%) (tons/year) | $CO_2$ Savings from Avoided ICE (tons/year) | Gross $CO_2$ Savings (tons/year) | Net $CO_2$ Savings (tons/year) |
|---|---|---|---|---|---|
| 100Trips | 36.8 | 1.84 | 4.158 | **40.958** | **39.118** |
| 200Trips | 36.8 | 1.84 | 8.316 | **45.116** | **43.276** |

**CONCLUSION**

This study highlights the environmental benefits of transitioning to solar-powered DC fast EV charging stations in India, addressing rising transportation emissions. A 30kW solar charging station generates about 38.325 MWh annually, offsetting around 36.8 tons of $CO_2$ emissions compared to coal-reliant grid electricity. Further emission reductions occur with the replacement of internal combustion engine vehicles by EVs, saving approximately 41.58 kg of $CO_2$ per 250 km journey. With 100 EV trips per year, this leads to an annual $CO_2$ reduction of 4.158 tons, totalling over 40 tons of $CO_2$ savings from a single charging station.

This model highlights the impact of solar-powered EV charging stations in creating a low-carbon transportation system and reducing fossil fuel dependence. By enhancing energy independence and aiding peak load management, these stations support global climate goals, including the aim to limit temperature rises to below 1.5°C. As electric vehicle adoption grows and renewable technologies advance, solar charging stations will be essential to sustainable urban planning and the transition to clean energy in transportation.

**ACKNOWLEDGMENT**

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# Power & Energy

# Smart Energy Utilization Technologies

13_IEC00013A

# Adaptive Intensity Control and Fault Detection in Smart Street Lighting

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***Abstract:*** *In this research, the authors introduce an intelligent street lighting system aimed at reducing total electrical energy consumption. The system functions by deactivating all streetlights during daytime and adjusting their brightness to 50% at night. It further modulates illumination based on the detection of vehicles and pedestrians, utilizing an Arduino-based Smart Intensity Monitoring (SIM) module installed in each light. This method significantly decreases unnecessary energy use, leading to lower energy production costs and reduced greenhouse gas emissions. Additionally, the system can pinpoint malfunctioning lights through their designated pole numbers, with this data being updated at a central cloud-based monitoring station.*

***Keywords:*** *Smart Street Light; Fault Detection; Arduino; IR Module; Energy*

## INTRODUCTION

With the advent of Industry 4.0, which marks the fourth industrial revolution, there have been significant strides in digitalization and industrial automation. This era has introduced new technologies such as artificial intelligence (AI), machine learning (ML), cloud connectivity, and the Internet of Things (IoT), which are now prevalent in various commercial sectors. IoT, in particular, has transformed everyday life by securely linking numerous devices to the internet through multiple data collection points. The data collected can be analyzed to implement various control measures. A practical application of IoT is in the management of street lighting. Traditionally, streetlights are controlled by timers that turn them on and off at set times, a system that fails to account for seasonal and climatic changes affecting daylight hours. Furthermore, streetlights often remain fully illuminated even when not needed, leading to excessive energy use, higher electricity demand, and increased greenhouse gas emissions. Traditional systems also struggle with issues like undetected non-functional bulbs, which can result in public complaints or road hazards. The proposed research introduces an innovative method for autonomously managing street light illumination. This involves integrating a Smart Intensity Monitoring (SIM) module into each street light pole. The SIM module's primary role is to detect the presence of pedestrians and vehicles, adjusting the light intensity accordingly. It brightens the lights when activity is detected and dims or turns them off when no activity is present. The module also tailors the light intensity based on vehicle speed: increasing brightness for fast-moving vehicles and reducing it for slower or stationary ones. This adaptive approach optimizes lighting while reducing energy consumption. Consequently, it lowers energy production costs and greenhouse gas emissions. Moreover, the system enhances maintenance by automatically identifying non-functioning lights. Each pole is assigned a unique identifier, and any issues are promptly reported to a central cloud-based monitoring station. This automated fault detection ensures timely repairs and helps maintain the reliability and efficiency of the street lighting network. In summary, the proposed system offers energy savings, reduced operational expenses, and supports environmental sustainability by minimizing the carbon footprint associated with street lighting.

## MATERIALS AND METHODS

### A. System Overview

**Figure 1** shows an overview of the proposed system. The working mechanism can be categorized into three primary phases.

Operation during daytime:

- Energy Conservation: During the daytime, all streetlights in the specified area remain in off condition to

conserve energy. This is achieved through the use of analog light-dependent resistors (LDRs) strategically placed to monitor ambient light levels.

- Sunlight Detection: These LDRs are sensitive to the presence of sunlight. When sunlight is detected, the resistance of the LDRs decreases, generating a signal that is sent to the Arduino microcontroller. The Arduino processes this signal and ensures that the streetlights remain off, thereby preventing unnecessary energy consumption during daylight hours.

Operation during night time with dynamic lighting adjustment:

- Sunset Detection: As the sun sets and the level of ambient light decreases, the resistance of the LDRs increases. This change in resistance is detected by the Arduino, which interprets it as an indication that it is time to activate the streetlights.
- Initial Illumination: Upon receiving the signal from the LDRs, the Arduino turns on all the streetlights in the area, setting them to an initial luminous intensity of 50%. This baseline illumination ensures that the area is adequately lit without excessive energy use.
- Detection of presence and dynamic lighting adjustment: In order to enhance efficiency and safety, the system employs infrared (IR) sensor modules installed midway between each pair of streetlight posts. These IR sensors continuously monitor the area for the presence of human beings and vehicles.
  a) Movement Detection: When a moving object, such as a pedestrian or a vehicle, is detected by the IR sensors, they send a signal to the Arduino. The Arduino then dynamically increases the luminous intensity of the streetlight(s) in the forward direction of the moving object to 100%.
  b) Adaptive Lighting: This dynamic adjustment ensures that the path ahead of the moving object is well-lit, providing clear visibility and enhancing safety. Once the moving object has passed, the streetlights return to their initial 50% luminous intensity, thereby optimizing energy usage without compromising safety.

Fault Detection and Communication:

- SIM Module Integration: Each streetlight post is equipped with a SIM module, for monitoring the operational status of the streetlights.
- Malfunction Detection: The system employs digital LDRs integrated into the SIM modules to monitor whether each streetlight is functioning correctly. If a streetlight fails to turn on as expected, the digital LDR detects this anomaly and sends a signal to the SIM module.
- Communication: The SIM module communicates the fault condition to a PC or tablet or a smart phone system. This real-time communication allows maintenance personnel to be promptly informed of any malfunctions.
- Maintenance Alerts: The system generates alerts and notifications for the maintenance team, enabling them to quickly address and resolve any issues. This proactive maintenance approach ensures the reliability and continuous operation of the streetlighting system, minimizing downtime and enhancing overall system performance.

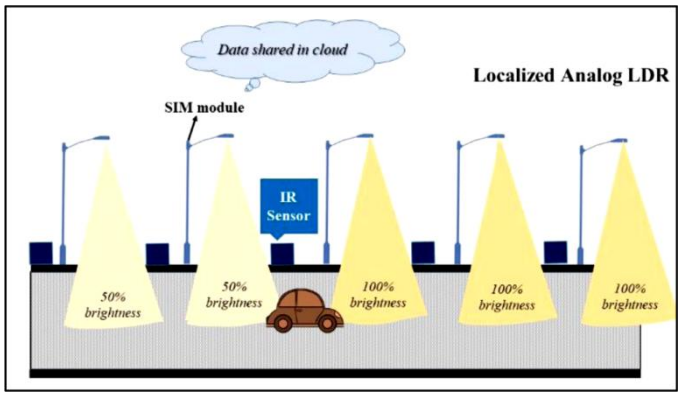


**Figure 1** Overview of the proposed system

The proposed streetlight management system dynamically adjusting lighting levels based on real-time environmental conditions and ensuring timely maintenance through automated fault detection. This innovative approach to street lighting management represents a significant step forward in urban infrastructure development.

**B. Smart Intensity Monitoring (SIM)**

**Figure 2** shows the basic block diagram of a SIM implemented in a smart street light system. The Smart Intensity Monitoring (SIM) device functions as the fundamental framework upon which the proposed street light monitoring system is constructed. This system is an integration of components such as analog and digital light-dependent resistors (LDRs), infrared (IR) sensor modules, Arduino microcontrollers, and ESP Wi-Fi modules. Each of these components plays a pivotal role in ensuring the seamless operation and efficiency of the monitoring system.

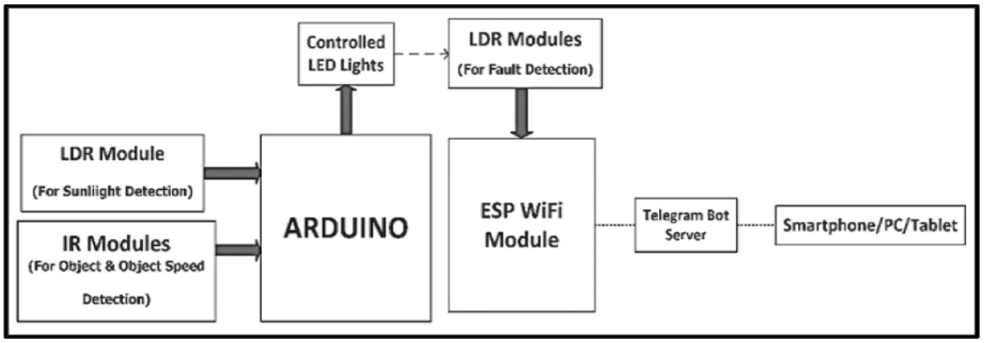


**Figure 2** Block diagram of smart intensity monitoring (SIM) device

Analog LDR modules are strategically placed in an area to continuously monitor the ambient light levels. The primary function of the analog LDR is to detect the presence and intensity of sunlight. When the ambient light falls below a specific threshold, indicative of dusk or cloudy conditions, the LDRs generate a proportional electrical signal. This signal is then sent to the Arduino microcontroller for processing.

The Arduino microcontroller serves as the central processing unit of the system. In this dissertation, the threshold for the analog LDR output is set at a byte value of 500. When the LDR output drops to or below this value, the Arduino microcontroller triggers a signal to activate all the connected street lights. To ensure energy efficiency, the lights are programmed to operate at 50% of their maximum luminous intensity under these conditions. This intermediate level of illumination not only conserves energy but also prolongs the lifespan of the street lights, leading to reduced maintenance costs and enhanced sustainability.

IR sensor modules function independently to identify the presence of people and vehicles, as well as their speed. These sensors are strategically positioned between two street light poles. When an IR sensor detects an object approaching a street light, the Arduino increases the light intensity to its maximum setting. The number of lights illuminated is determined by the speed of the approaching object. For example, if the object's speed is 1.5 or below, only two streetlights ahead are activated. If the object's speed exceeds this threshold, at least three streetlights are turned on. The speed of a moving object is measured by using two infrared sensors set at a fixed distance apart [8]. As the object passes, it triggers the sensors in sequence, allowing the system to record the time intervals between these activations. By dividing the fixed distance between the sensors by the recorded time, the speed of the object is accurately calculated.

Furthermore, the integration of ESP Wi-Fi modules into the system allows for advanced connectivity and remote management capabilities. Through these modules, the street light monitoring system can communicate with a central control server, facilitating real-time monitoring. Fault detection in streetlights is managed using digital Light Dependent Resistor (LDR) modules installed on each light. These LDR modules continuously track the operational status of the lights. If a streetlight fails to operate due to a malfunction, the LDR module identifies the issue and sends an alert to the ESP module. The ESP module receives this alert and forwards a notification to a connected PC or tablet. The notification, which includes the exact location of the faulty streetlight, is sent as text messages via a

Telegram bot [10], ensuring prompt and reliable delivery of alerts. In this way, the centralized control system allows for effective monitoring and adjustment of streetlight performance, ensuring efficient operation throughout the network.

## EXPERIMENTATION

A prototype is built in the laboratory of the electrical engineering department with four streetlights which is shown in **Figure 3**. In the development of the prototype, light emitting diodes (LEDs) are utilized to simulate the functionality of streetlights. In order to facilitate dynamic control and communication within the system, SIM modules are mounted on the poles beneath each streetlight. The integration of SIM modules ensures that the prototype can mimic the intelligent control systems used in modern smart street lighting solutions.

**Figure 3** Prototype Model

The prototype's effectiveness is further tested through the inclusion of three model cars, placed within the layout. By simulating the movement and positioning of cars, the prototype can be evaluated for its ability to adapt street lighting based on traffic conditions, enhancing both safety and energy efficiency. In order to thoroughly examine the system's performance, night time conditions are simulated. This aspect of the testing is crucial, as street lighting systems must be highly effective in low-light scenarios to ensure visibility and safety. The night time simulation allows for a comprehensive evaluation of the prototype's ability to provide adequate illumination and respond to environmental changes during periods of darkness.

## RESULT AND DISCUSSION

In this section the energy consumption is calculated considering 7000 streetlights. The per unit cost of electricity is assumed at Rs.7/ kWh. The following cases are considered.

### A. Existing Conventional Street Light System

**LED streetlight of 180 W rating:**

The electricity consumed by a 180 W LED type streetlight in a single day when kept on for 12 hours at 100% brightness is 2.16 kWh [2]. Hence, the total cost of electricity consumption per day for operating a single 180W LED

streetlight will be as given in **Equation (1)**.

$2.16 \times 7 = 15.12$ INR (1)

Also, the total energy consumed by 7000 numbers of streetlights of the same rating on daily basis will be as given in **Equation (2)**

$2.16 \times 7000 = 15120$ kWh $= 15.12$ MWh (2)

**LED streetlight of 150 W rating:**

Considering LED streetlights of 150W rating, each of its energy consumption for 12 hours per day with 100% brightness is 1.8 kWh. So the daily cost of electricity in such streetlight will be 12.6 INR and the total energy consumption of 7000 numbers of such lights on daily basis will be 12600 kWh or 12.6 MWh.

**LED streetlight of 100 W rating:**

In case of 100W LED streetlight, the energy consumed by one such light for 12 hour duration at 100% brightness is 1.2 kWh. The cost incurred on daily basis by each of such lights for electricity consumption is 8.4 INR. Also, the total energy consumed by 7000 numbers of 100W streetlights on daily basis is 8400 kWh or 8.4 MWh.

**B. Proposed Model**

The proposed model suggests turning on of all the streetlights at 50% of its maximum intensity in the absence of any vehicle or person. If it is assumed that all the street lights are kept turned on at this intensity level for a duration of 6 hours, then the total energy consumed by a single streetlight for 12 hours will be

$$Energy\ Consumption = (6 \times Rated\ Power) + (6 \times Half - rated\ Power) \quad (3)$$

Hence, using **Equation (3)**, the total energy consumption for 180W LED streetlights on daily basis will be $1.62 \times 7000 = 11340$ kWh $= 11.34$ MWh

Similarly, the daily total energy consumption in 150W LED streetlights will be 9.45 MWh and for 100W LED streetlights 6.3 MWh respectively.

The energy consumption can be further improved if the streetlights work with 50% brightness during the midnight hours. Under this condition, it is possible to save 25.66% more electricity as well as money than the existing conventional streetlight system.

**CONCLUSION AND FUTURE SCOPE**

This paper presents an advanced smart street lighting system designed to reduce overall electricity usage. The system boosts efficiency by automatically regulating the operation and brightness of streetlights based on environmental conditions and detected activity.

During the day, the system turns off all streetlights to save energy. At night, the lights are activated at 50% brightness, which can be adjusted depending on real-time conditions. Sunlight levels are monitored using local analog light-dependent resistors (LDRs) that provide data to manage the lighting system.

The system's adaptive lighting feature is achieved through the use of SIM and infrared (IR) modules. IR modules are positioned between streetlights to detect stationary and moving objects, such as pedestrians and vehicles. These modules relay detection information to an Arduino controller, which then adjusts the streetlight brightness to provide appropriate illumination based on current activity.

In case of a streetlight failure, the system uses a digital LDR within the SIM module to identify the issue. It then sends a notification to a PC or tablet, detailing the faulty light's location via a Telegram bot with an ESP module.

Future enhancements could involve integrating artificial intelligence to allow more nuanced adjustments in light intensity based on activity patterns and environmental conditions. Additionally, implementing a cloud-based database could enable real-time monitoring and recording of power consumption and performance metrics for all streetlights. In order to further enhance reliability and sustainability, future developments might include a secondary power source, such as solar panels, to ensure a continuous power supply for the sensors and maintain consistent operation of the street lighting system.

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83_IEC45327

# Case Study on Design and Analysis of Electrical Heat Tracing on Tank Roof Nozzle

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***Abstract:*** *In the present scenario, electrical heat tracing cables are used in a variety of industrial applications to maintain or increase the temperature of pipelines and vessels. The heating element, powered by electricity is physically connected with the pipe. There is a high demand for the heat tracing in the colder nations where the mercury level drops below zero. In one of the Coke Oven by product plant, there are three liquor storage tanks and one cold effluent tank with roof nozzles of varying diameter. As the cold nations experience freezing conditions, electrical heat tracing is essential for process pipes and vessels to maintain the required temperatures. The client had raised a query regarding the efficiency of the proposed electrical heat tracing design and the heat transfer rate on the surface of the tank as the client was apprehensive regarding the tank roof acting like a heat sink. The initial perception of client is to apply insulation over the entire tank. The client also suggested a new design by placing the thermal insulator in between flanges to decrease the heat transfer rate. Considering the process constraints and specific conditions, the heat loss calculations, the steady state thermal analysis and the comparative analysis with the thermal insulator in between flanges and without the thermal insulator has been done using Ansys R14.5. It has been found that as per the process constraints and prevalent conditions both the designs are acceptable and there was a minimum heat transfer rate to the surface of the tank. The temperature attained on the outer surface of the nozzle for the design without the thermal insulator is 80°C whereas the temperature attained on the outer surface of nozzle for the design with the thermal insulator is 47°C. The total heat flux generated is 31617 W/m² on the surface of the nozzle when the thermal insulator is placed in between flanges whereas the total heat flux of 58076 W/m² is generated for the design without thermal insulator. As an outcome of this analysis, the efficiency of the proposed heat tracing could be established and cost due to complete insulation of the entire tank could be avoided.*

191_IEC93788

# Performance Evaluation of Solar PV and Hybrid PV/T Systems: A Step to Enhance System Efficiency

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***Abstract:*** *This paper evaluates the technical viability of a water-based poly-crystalline silicon (PC-Si) solar photovoltaic-thermal (PV/T) hybrid system compared to a conventional PC-Si solar PV system. The hardware setup of both these systems, each of 560 Wp, is installed at NIT Srinagar (34.1217oN, 74.837oE). Analytical models of both these systems are developed using PVsyst software to assess the technical performances. The simulations demonstrate that the hybrid PV/T system operating at 40°C exhibits performance levels similar to those of a conventional PV system at 25°C, underscoring the superior efficiency of hybrid PV/T systems at higher temperatures. The hardware results confirmed the exceptional performance of the hybrid PV/T system, achieving an open-circuit voltage (Voc) of 71.9 V compared to 70.6 V for the conventional PV system. The results reveal that the (Voc) of the solar PV panel diminishes by 0.4409% with every 1°C rise in temperature. The hybrid PV/T system establishes its efficacy by supplying 7.44% more power than a conventional PV system when subjected to the same load. These findings highlight the dominant performance of the hybrid PV/T system compared to conventional PV systems, indicating an optimistic outlook for its application in improving energy efficiency and sustainability in solar energy solutions.*

***Keywords:*** *Solar Photovoltaic (PV); Solar Photovoltaic-Thermal (PV/T); PVsyst Software; Sustainable Development Goal (SDG) 7; Efficiency Improvement*

## INTRODUCTION

The production of energy and its per capita consumption is regarded as an indication of the standard of living in a nation. Depletion of conventional energy resources, along with the imminent threat catalyzed by these resources to climate change and global warming, has already turned the attention towards leveraging solar energy to meet the growing energy demands. India has pledged to install 500 Gigawatt (GW) of renewable energy capacity and reduce greenhouse gas emissions by 45% by 2030. Meeting this commitment involves expediting the adoption of renewable energy to transition away from fossil fuels, aligning with UN Sustainable Development Goal 7 on sustainable energy[1]. To fulfill global obligations, such as achieving net-zero carbon emissions by 2070[2], the Indian government is implementing initiatives like subsidizing solar photovoltaic (PV) systems to promote the use of solar PV, thereby reducing reliance on fossil fuels and lowering the carbon footprint.

However, for PV systems, a limited percentage of the incident solar irradiation is transformed into electrical energy, while a significant amount is lost as heat energy. This heat generation results in elevated module temperatures, consequently diminishing overall efficiency[3].

To improve the electrical efficiency and cost-effectiveness of photovoltaic systems, various innovations have been enacted, including the incorporation of new materials, such as organic compounds and polymers like Perovskite, which represent the third generation of solar cells. Furthermore, implementing thin-film technology in producing solar cells has considerably enhanced the electrical performance of photovoltaic panels[4].

Hybrid photovoltaic thermal (PV/T) systems have garnered significant interest in recent years within the realm of solar technology. The PV/T technologies integrate the functionalities of traditional PV systems with solar thermal systems into a single module, resulting in enhanced efficiency compared to conventional systems. Many authors from different regions around the globe have conducted comparative techno-economic analyses of energy generated from flat-plate water PV/T systems and traditional PV systems. Herrando and Markides [5] conducted a technoeconomic analysis to evaluate hybrid PV/T systems for electricity distribution and hot water provision in a typical residence in London, UK. Their findings indicated that, in terms of primary energy and decarbonization, the PV/T systems presented a notably enhanced alternative compared to traditional PV-only systems but at an increased cost. Studies of

a similar nature regarding PV/T systems, each focused on specific geographical locations, have been conducted by [6,7], and it was determined that the overall practicality and efficiency of both PV and PV/T technologies depend on the geographical location of installation. This inspires the authors to investigate the technical viability of a PV/T system for the specific climatic conditions of NIT Srinagar (Latitude: 34.1217°N, Longitude: 74.837°E).

## STATE OF THE ART

### A. Solar Photovoltaic (PV) System

Orientation

To obtain maximum electrical power output from the PV panel, the global irradiance falling on it should be maximum and loss w.r.t optimum should be minimum. From the simulation, the value of global irradiance on the PV panel is maximum and loss w.r.t optimum is 0.0% when the tilt angle and azimuth angle of the PV panel is 31 degrees & 0.0 degrees respectively at NIT Srinagar location (Latitude: 34.1217°N, Longitude: 74.837°E) as shown by **Figure 1**.

Load Profile

The load which have been operated in simulative environment includes 8 LED lamps of 20 watts each and 2 Televisions of 100 watts each, which accounts for 360 watts. The simulated loads were operated for 7 hours per day.

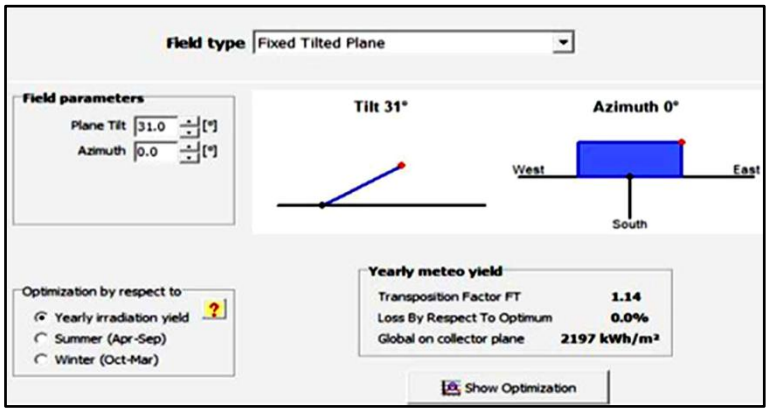


**Figure 1** Orientation of PV module at NIT Srinagar

Panel Selection

The PV panel utilized in the experiment is produced by Son-nenstrom Fabrik – CS Wismar. In this setup, two PV modules were connected in series, and the panel has the following specifications. $P_{nominal}$ = 560 Wp, $V_{mpp\ (35\ degrees)}$ = 60 volts, $V_{mpp\ (20\ degrees)}$ = 64 volts, $V_{oc\ (12\ degrees)}$ = 81 volts, $I_{mpp}$ = 8.9 Amp, $I_{sc}$ = 9.5 Amp.

Inverter Selection

An inverter with an integrated MPPT charge controller has been employed to efficiently convert DC power into AC power. The inverter specifications for the PV system design are as follows: $V_{oc(min)}$ = 45 Volts, $V_{oc(max)}$ = 90 Volts, $V_{oc}$ range for MPPT= 58- 70 volts, Nominal AC power = 500 watt, Maximum efficiency= 93%.

PV Module Losses

Different types of losses that take place in the case of a PV module during the conversion of sunlight into DC electricity for the module under test, estimated at 14.4%, have been shown in **Figure 2**. Out of 14.4% overall loss that occurred on a PV panel, 9.8% loss occurred due to a rise in temperature.

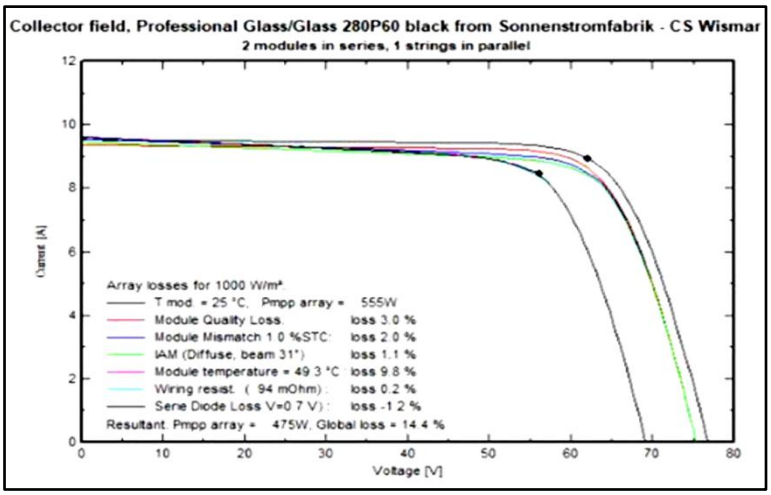


**Figure 2** Effect on losses on performance of PV panel

**B. Solar Photovoltaic-Thermal (PV/T) System**

In the case of conventional PV systems, the increase in temperature above the ambient temperature decreases the open circuit voltage (Voc), thereby reducing the maximum power point voltage ($V_{mpp}$). This further results in a considerable decrease in the maximum power that the PV system can deliver to the load. Due to this reason, the efficiency of conventional PV system is low. To overcome this major drawback, the novel hybrid photovoltaicthermal (PV/T) technology is presented. The PV/T hybrid technology harnesses solar energy by converting some part of it into electrical energy and some part of it into thermal energy. For doing so, a PV/T collector is used. The main components of a solar PV/T system collector are a PV module, Tubes, heat absorbing plate, heat transfer fluid, and storage.

Operating Mechanism

Besides converting some portion of solar energy into electrical energy, a major portion of solar irradiance falling on a PV/T collector is converted into heat energy. In case of PV/T collector since heat absorbing plate is present underneath the panel, this heat energy is absorbed by the heat absorbing plate which is then extracted by the heat transfer fluid flowing through the tubes present underneath the absorber plate. Thus, a major portion of heat is extracted from the PV panel which does not allow excess rise in the cell temperature. Due to this heat dissipation mechanism present in PV/T system, the electrical power output produced by the PV/T collector is more in comparison to the PV module at same ambient temperature and at same insolation level. Moreover, the heat energy extracted by the HTF from the PV panel can be stored by the sensible heat storage system [12]. This thermal energy can also be used to fulfil hot water requirement. Among the PV/T collectors, the most commonly used is the PV/T water collector which uses water as HTF (**Figure 3a**). In case of a PV/T water collector, water tank is used as a sensible heat storage system and is placed on top of the PV/T collector as shown in **Figure 3b**.

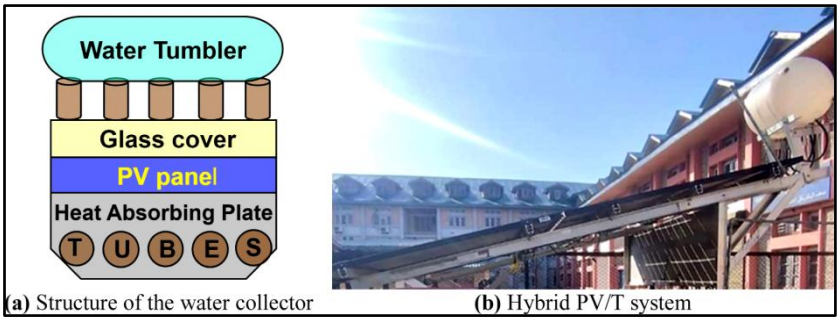


**Figure 3** Solar hybrid PV/T system installed at NIT Srinagar

## METHODOLOGY

The performance of both the presented solar PV systems is evaluated using PVsyst software for the location of NIT Srinagar with weather data obtained from the Meteonorm 7.2 database. This database provides monthly variations in crucial parameters such as temperature, global irradiation, diffused irradiance, and wind, which significantly impact the PV system's performance. Utilizing this data enables a comprehensive analysis of the PV system's performance, allowing for a deeper understanding of its operational dynamics.

Out of these factors, the performance of the PV System is majorly affected by temperature and irradiance, which are highly dynamic and location-specific parameters. With the rise in cell temperature above ambient temperature, the open circuit voltage (Voc) decreases considerably. While the short circuit current ($I_{sc}$) changes logarithmically, resulting in an overall decrease in the output power and efficiency of the PV panel. The electrical power output decreases by 0.3-0.5% for every 1°C rise in the temperature above the ambient temperature [17]. With the increase in solar irradiance, the Isc increases linearly while the Voc increases logarithmically, increasing the electrical power output and efficiency. The temperature of PV cell [18] is given by (1).

$$T_{cell} = T_a + (N_{OCT} - 20)S/80 \quad (1)$$

The temperature-effected DC power [9] is given by (2) and can be calculated as:

$$P_{TDC} = P_{DSTC}\,(1 - C_T\,(T_{cell} - 25)) \quad (2)$$

where: $T_{cell}$ is the temperature of the solar cell, $T_a$ is the ambient temperature, $N_{OCT}$ is the nominal operating cell temperature, S is the insolation level, $P_{TDC}$ is the temperature-assisted DC power, $P_{DSTC}$ is the DC power of the PV module, $C_T$ is the temperature coefficient (%/°C).

## RESULT ANALYSIS

### Simulative Environment

The performance of both the presented solar systems viz. PV and PV/T have been analyzed with solar irradiance of 1000 W/m$^2$ for different ambient temperatures, respectively. The results obtained using PVsyst are documented in **Table 1**. Further, the variation of critical electrical parameters w.r.t temperature for both the presented systems are evaluated using (3).

$$\text{Variation in the parameter as we go from 25℃ to 55℃} = \frac{\text{Parameter(55°C)} - \text{Parameter(25°C)}}{\text{Parameter(25°C)}} \quad (3)$$

It is observed from **Table 1**, that $V_{mpp}$ and $P_{mpp}$ for PV/T system are 63 volts and 560.7 watts respectively at an ambient temperature of 40°C. Further, $V_{mpp}$ and $P_{mpp}$ for PV system are 63 volts and 560.7 watts respectively at the ambient temperature of 25°C. It concludes that the solar PV/T system operated at an ambient temperature of 40°C performs similar to solar PV system operating at an ambient temperature of 25°C. The simulation results also revealed that with each 1°C increase in temperature beyond ambient levels, the open circuit voltage and electrical output of the conventional PV system reduce by 0.42% and 0.39%, respectively.

### Practical Environment (Hardware Implementation)

The electrical and thermal performance of practical solar PV and solar PV/T systems was analyzed under the same external conditions (ambient temperature: 28.3°C, insolation: 517.037 W/m$^2$). The PV panel with specifications as outlined in section II has been used in both PV system and PV/T system. The tumbler placed on top of the PV/T collector, and tubes under the heat-absorbing plate were initially filled with water at a temperature of 23°C. The temperature of water placed inside tubes increased after it absorbed heat from the PV panel, resulting in natural circulation between water present inside tubes and water present inside the tumbler, which was governed by the temperature difference between them. The results obtained after analyzing the performance of both systems have

been documented in **Table 2**, and a comparative analysis has been made between them. The open circuit voltage Voc of PV/T and PV system was recorded to be 71.9 volts and 70.6 volts, respectively, while the average temperature of PV/T and PV panel was 51.1°C and 55.2°C respectively. The experimental results obtained show that the Voc decreases by 0.4409% for every 1°C rise in panel temperature, which highly coincides with the literature survey conducted. Moreover, it was observed that for the same load resistance value in both cases, the power delivered to the load by the PV/T system was greater than that delivered to the load by the PV system. On average, the power delivered by the PV/T system was 7.44% more in comparison to the power delivered by the PV system to the same load for a temperature difference of 4.1°C between solar panel used in PV system and solar panel used in the PV/T system. On the other hand, the temperature of water obtained from the tumbler placed on top of the PV/T collector operating on the thermosiphon principle was raised by 17.1°C i.e. from (23°C to 40.1°C) in a span of 6 hours.

**Table 1** Performance analysis of solar PV and PV/T system in simulative environment

| Ambient Temp (°C) | $V_{mpp}$ (volts) | | $I_{mpp}$ (Amp) | | $P_{mpp}$ (watts) | |
|---|---|---|---|---|---|---|
| | PV | PV/T | PV | PV/T | PV | PV/T |
| 25 | 63 | 67 | 8.9 | 8.9 | 560.7 | 596.3 |
| 30 | 61 | 65 | 8.9 | 8.9 | 542.9 | 578.5 |
| 35 | 60 | 64 | 9 | 8.9 | 540 | 569.6 |
| 40 | 59 | 63 | 9 | 8.9 | 531 | 560.7 |
| 45 | 57 | 61 | 9 | 8.9 | 513 | 542.9 |
| 50 | 56 | 60 | 9 | 9 | 504 | 540 |
| 55 | 55 | 59 | 9 | 9 | 496 | 531 |

**Table 2** Performance analysis of solar PV and PV/T system in practical environment

| Resistance (Ohm) | $V_{load}$ (volts) | | $I_{load}$ (Amp) | | Power (watts) | |
|---|---|---|---|---|---|---|
| | PV | PV/T | PV | PV/T | PV | PV/T |
| Infinite | 70.6 | 71.9 | 0 | 0 | 0 | 0 |
| 25 | 68.3 | 68.8 | 2.6 | 2.8 | 177.58 | 192.64 |
| 23 | 67.8 | 68.3 | 2.7 | 2.9 | 183.06 | 198.07 |
| 20 | 67.0 | 67.6 | 3.2 | 3.3 | 214.4 | 223.08 |
| 17 | 66.1 | 66.8 | 3.6 | 3.8 | 237.96 | 253.84 |
| 14 | 64.1 | 65.9 | 4.4 | 4.7 | 282.04 | 309.73 |

## CONCLUSION

This study offers a detailed comparative analysis of 560Wp conventional PV and hybrid PV/T systems, respectively, focusing on their electrical power efficiency and loss calculations, for the geographical location of NIT Srinagar, Kashmir, India (latitude 34.1217°N, longitude 74.8372°E). The simulations carried out using PVsyst software and weather data from Meteonorm 7.2 database demonstrate that with each 1°C increase in temperature beyond ambient levels, there is a corresponding reduction of 0.39% in the electrical power output of the conventional PV system. On the other hand, the electrical output of the hybrid PV/T system rises by 0.36% for every 1°C decrease in ambient temperature. It is observed that, when subjected to similar operating conditions, the average module temperature of the hybrid PV/T module is 15°C lower than that of the conventional PV module, leading to an enhanced electrical efficiency for the hybrid solar PV/T system. The total losses in the PV module, as obtained in the PVsyst simulation environment, are found to be 14.41%, with temperature being the primary factor at 9.8%. The simulation results are found to be consistent with published literature. Further, experiments conducted under identical external conditions for the hardware setups show that for every 1°C increase in panel temperature, the open-circuit voltage (Voc) reduces by 0.4409%. Experimentally, a temperature difference of 4.1°C between both systems resulted in the hybrid PV/T system producing 7.44% more power than the conventional PV system.

## ACKNOWLEDGMENT

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# Numerical Investigation on Employment of Cavities on Sidewalls of the Microchannel Heat Sink and Parametric Study of the Cavities on the Effect of Performances of the Heat Sink

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***Abstract:*** *Numerical modeling and analysis of flow characteristics and heat transfer performances in a rectangular microchannel with cavities are done in this investigation. Performance of four different cases having cavities on their sidewalls are examined by varying the width and depth of cavity in a rectangular microchannel and comparative study with respect to plain rectangular microchannel has been carried out. Microchannel with cavity exhibits better performance than plain rectangular microchannel in all respect. Furthermore, the microchannel with depth of cavity 50 μm and width of cavity 150 μm shows better performance amongst all. Considered as the optimum channel, this channel exhibits around 10% higher Nusselt number (Nu) and heat transfer enhancement factor (η) than the plain rectangular channel. The formation of suitable vortices inside the cavity which indirectly influences the phenomenon such as enhancement of heat transfer, distributions of fluid velocity, pressure and temperature is found largely dependent on the depth and width of the cavity in the microchannel. Water is taken as working fluid and Silicon is considered as the substrate material in the present study. Knudsen number (Kn) for water under present conditions is less than $10^{-3}$ and so no slip boundary condition is assigned for the surfaces. The range of Reynold's number (Re) taken in the study is around from 150 to 650. The SIMPLEC method is used in the Fluent solver.*

***Keywords:*** *Microchannel Heat Sink; Heat Transfer Enhancement Factor (η); Nusselt Number (Nu); Cavity, Friction Factor (f)*

## INTRODUCTION

Microchannel heat sinks (MCHSs) are the devices to remove heat generated in microelectromechanical system (MEMS) and other electronic devices such as computer processor, micro-chip circuit, sensors, actuators etc. The heat sink is usually made from a high thermal conductivity solid such as silicon or copper with the microchannels fabricated into its surface by either precision machining or micro-fabrication technology. The MCHS contains many parallel microchannels (e.g. 10, 20, 30 numbers) which are also known as fins, having hydraulic diameter less than 0.2 mm and fluid is forced to pass through these channels to take away heat generated from the source. MCHS provides very high surface area to volume ratio, large convective heat transfer coefficient, small mass and volume, and small coolant inventory.

Tuckerman and Pease [1] first explained the concept of MCHSs, in early 1981, by the investigation of high performance forced liquid cooling of planar integrated circuits. They fabricated and tested several high performance water cooled silicon heat sink. They stated that high aspect ratio of the channel reduces the thermal resistance and the heat transfer coefficient is significantly high for the microscopic channel. Xia et al. [2] found the optimum geometric parameters, representing the distance and geometry of the triangular reentrant cavity in a microchannel, by a numerical study. Kuppusamy et al. [3] conducted numerical study in triangular grooved microchannel heat sink (TGMCHS) using nanofluid. Chai et al. [4] performed both experimental and numerical investigations to study the influences of periodic expansion constriction cross sections on pressure drop, heat transfer and thermal resistance in microchannel. In the study of Nu versus Re, they observed that the Nu is significantly increases with the increase of Re for all types of microchannel. Zhai et al. [5] proposed six new micro heat sinks with different types of cavities and ribs and compared their heat transfer performance by evaluating the friction factor and Nu. In the present work, parametric optimization of cavity is the main objective. In this study, the optimum width and optimum depth of cavity in terms of performance parameters are measured. Total four different microchannel heat sink designs are considered

on which the analyses are done. The performance parameters heat transfer enhancement factor (η) and Nu of the above four heat sink designs are evaluated and compared. The hydraulic characteristics and thermal characteristics of the flow through the channels are also assessed.

## DESCRIPTION OF MICROCHANNEL HEAT SINK

The plate size of MCHS numerically studied by Xia et al. (2013) [2] is considered in the present study. The heat sink consists of 10 longitudinal microchannels. The rectangular microchannels with cavity are simulated in the present study. The microchannel without cavity i.e. rectangular plain channel is compared with the results of the studies. Water is flowing through a rectangular micro channel. The overall dimension of plate is: Width =10 mm, Length = 20 mm, Height = 0.35 mm.

### Geometry of the Computational Domain

In this study, a single micro channel out of 10 channels is considered as computational domain. **Figure 1** represents the unit cell (computational domain) of plain rectangular MCHS. **Figure 2** depicts the geometry of a section of single unit microchannel having cavity. Dimensions of unit cell micro channel are given below:

| **Heat Sink computational domain** | **Channel parameter of domain** |
|---|---|
| Length: L= 10 mm | Length: L= 10 mm |
| Width: W = 0.3 mm | Width: $W_c$ = 0.1 mm |
| Height: H = 0.35 mm | Depth: $D_c$ =0.2 mm |

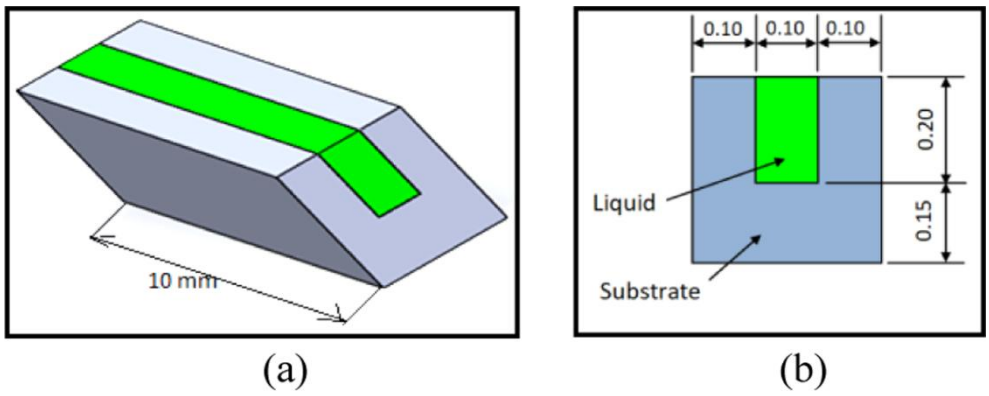


**Figure 1** (a) Computational domain of rectangular channel (b) 2D side view of channel. All dimensions are in mm

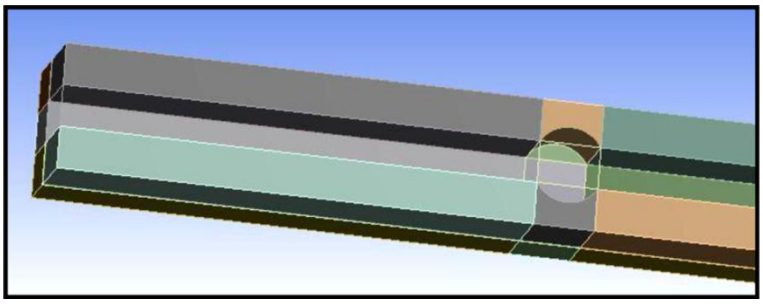

**Figure 2** Section of a micro channel heat sink with cavity

### Meshing of the Computational Model

Hexahedral mesh is used for meshing the geometry with wedge mesh in few zones as shown in **Figure 3** and **Figure 4**. Nodes are created with element size of 0.00001 for the solid and 0.000008 for the fluid domain in all three dimensional coordinates.

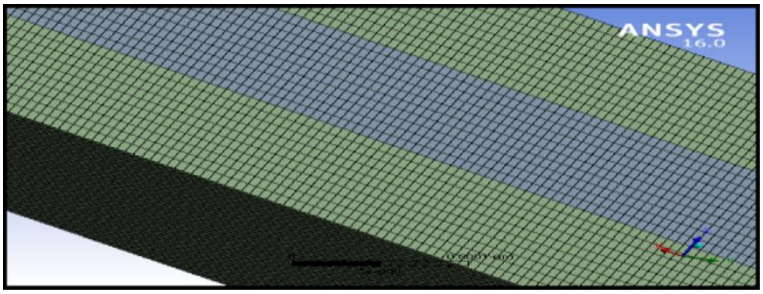


**Figure 3** Meshed model of rectangular channel

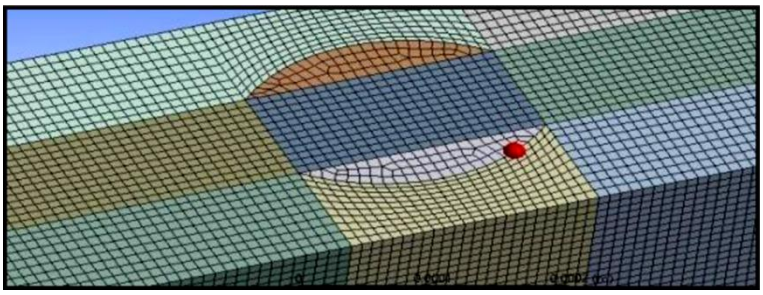

**Figure 4** Meshed model of channel with cavity

## COMPUTATIONAL METHOD

### Solution Method

For the numerical simulation, implicit method is adopted for governing equations discretization; the second order upwind scheme is used for discretizing the convective terms in the momentum and energy conservation equations. The SIMPLEC method is adopted in the Fluent solver.

### Grid Independency Test

To ensure that the present simulation solution is independent of grid size, validation test is carried out on models. As per the simulation results, the relative errors in the validation are tabulated in **Table 1** as below.

**Table 1** % change of Nu and f for different number of grid size

| | Smooth Rectangular MC | | |
|---|---|---|---|
| Number of Cells | 2774400 | 1360416 | 723330 |
| % Error of *Nu* | 0 | 0.545823 | 1.620954 |
| % Error of *f* | 0 | 0.402424 | 1.042008 |

### Validation of Numerical Solution Method

To validate the reliability and accuracy of the present computational model and method, the simple rectangular microchannel with smooth surface is analyzed with Fluent solver and the results are compared with the results of experimental and numerical investigation of Xia et al. [2] carried out on the model of same parameters. The results are in well agreement with Xia et al. [2], with an average deviation of maximum 1.65 % in Nu and thus ensures the reliability and accuracy of the solution results.

## RESULTS AND DISCUSSIONS

In the present investigation, the optimum width and optimum depth of cavity in terms of performance parameters are measured through parametric study of cavity. The analyses are carried out by varying two parameters width ($W_{cav}$)

and depth ($D_{cav}$) of the circular cavity. Firstly, with the constant value of cavity width of 100 µm, depths of cavity taken are 50 µm and 75 µm. In the comparison of the above two microchannel designs, the first case of micro channel heat sink with the value of depth of 50 µm shows better heat transfer enhancement factor (η) and Nu. Then the width is varied with 150 µm and 200 µm taking the optimum cavity depth of 50 µm for the next two microchannel heat sink designs. Thus total four cases of microchannel heat sinks are numerically studied.

The simulations are carried out for the microchannels with four different sizes of cavity at different eight inlet velocities from 0.5 m/s to 4 m/s.

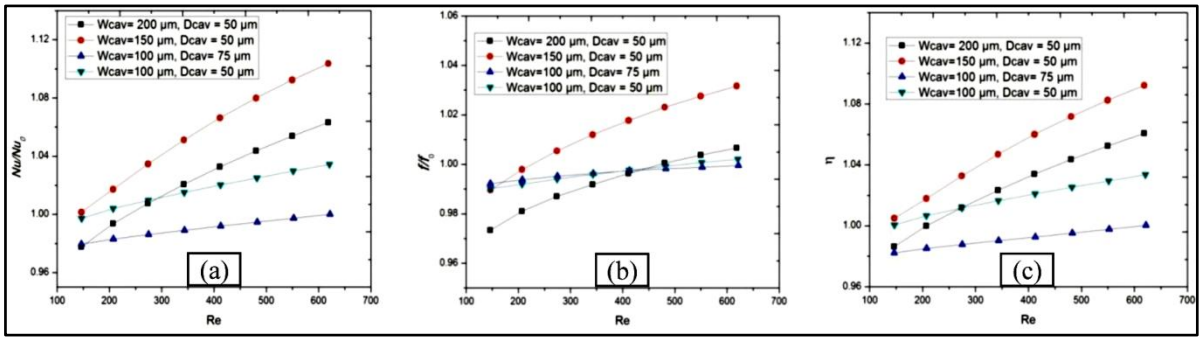


**Figure 5** Comparison of (a) Nusselt number ratio ($Nu/Nu_o$), (b) friction factor ratio ($f/f_o$), (c) heat transfer enhancement factor (η), for microchannels with different cavity parameters at different Re

**Effect of Depth of Cavity**

The microchannel with depth of 50 µm shows better $Nu/Nu_o$ than the channel with depth of 75 µm for the same cavity width of 100 µm. The shape of the vortices formed into the cavity and fluid velocity are the factors which cause rise in $Nu/Nu_o$ for the channel with $D_{cav}$ = 50 µm. In the case of the channel with $D_{cav}$ = 50 µm, the suitable shape and intensity of the vortices introduce the proper mixing of the fluids into the cavity. As a result, convection heat transfer is increased and consequently Nu is increased. At inlet velocity of 4 m/s, η is 1.0335 and 1.0003 for the channel with $D_{cav}$ = 50 µm and $W_{cav}$ = 100 µm and channel with $D_{cav}$ = 75 µm and $W_{cav}$ = 100 µm respectively.

**Effect of Width of Cavity**

Out of 100 µm, 150 µm and 200 µm cavity width, 150 µm gives the best $Nu/Nu_o$ and η. Impressive temperature distribution inside the channel fluid is observed for the channel with $D_{cav}$ = 50 µm and $W_{cav}$ = 150 µm. For this channel, $Nu/Nu_o$ is significantly increased at all Re in comparison to all other channels. The heat transfer enhancement factor (η) is also having the highest value at all Re. The rise in $Nu/Nu_o$ is possible at the cost of higher pressure drop, but the augmentation Nu is more rapid than the increase in friction loss.

**Fluid Flow Characteristics**

Profile figure shows the pressure and velocity distribution of plain channel and channels with different width and depth. Li et al. [6] observed that the static pressure reduces gradually as the water flows along the longitudinal direction of the channel for the cavity channel, which has also been found in the present study.

**Heat Transfer Characteristics**

**Figure 6** shows the temperature distribution in x-direction for plain channel and channel with different width and depth, simulated at inlet velocity of 4 m/s. Impressive temperature distribution inside the channel is observed for the channel with $D_{cav}$ = 50 µm and $W_{cav}$ = 150 µm. In addition to that, the temperature difference between the liquid and substrate is lesser than that of other channels. The average temperature of fluid for this channel is lesser than that of all other microchannels. The lateral mixing disrupts the shear layer separating the bulk flow and the recirculating flow in the reentrant cavity, therefore, leads to heat transfer enhancement without any external forces.

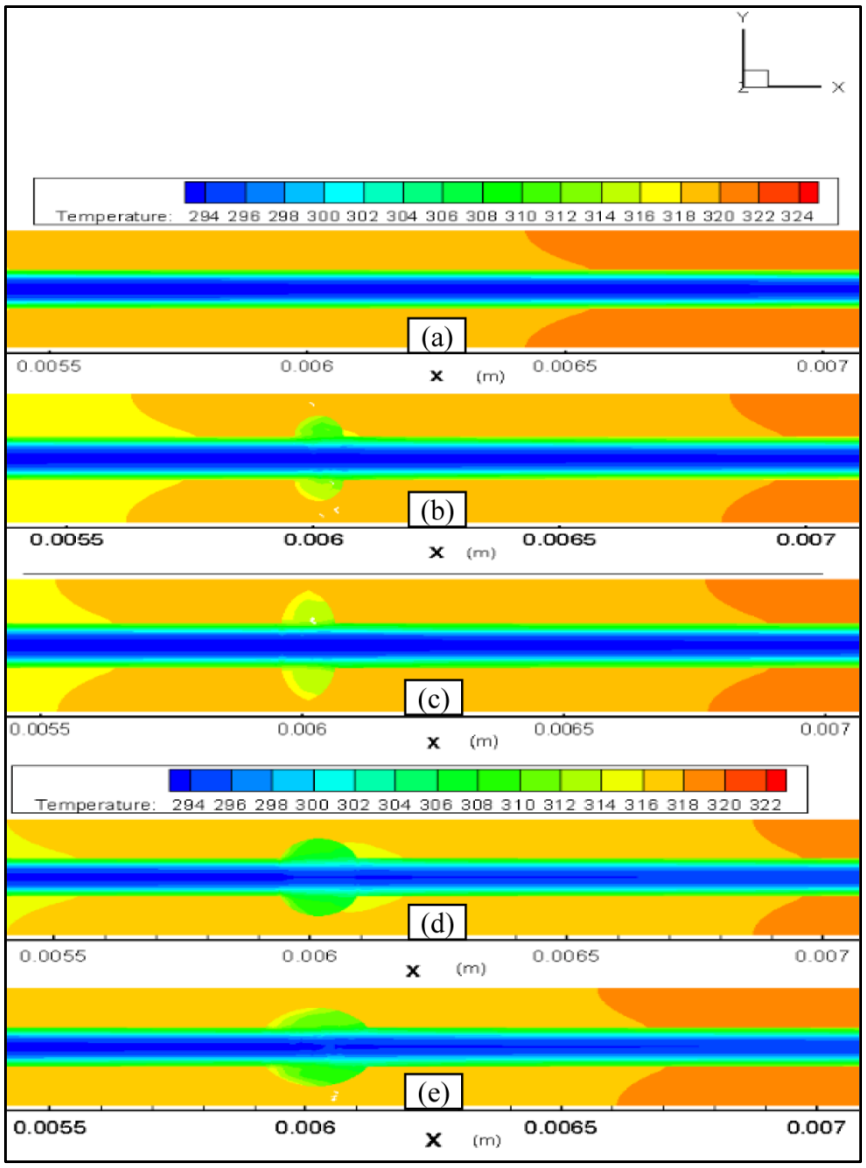


**Figure 6** Temperature distribution in x-direction for (a) Plain channel, (b) channel with $D_{cav}$ = 50 µm and $W_{cav}$ = 100 µm, (c) channel with $D_{cav}$ = 75 µm and $W_{cav}$ = 100 µm, (d) channel with $D_{cav}$ = 50 µm and $W_{cav}$ = 150 µm, (e) channel with $D_{cav}$ = 50 µm and $W_{cav}$ = 200 µm

## CONCLUSIONS

The presence of cavity has accountable influence on the flow characteristics and performance parameters. Parametric analysis of cavity size also exhibits interesting results. In the study of impact of cavity mounted to the channel sidewalls shows that the microchannel with cavity has better result in terms of fluid flow and heat transfer than the plain channel in all cases. It is found that the microchannel with Dcav = 50 µm and Wcav = 150 µm shows better performance than the other channels in terms of better temperature distribution, velocity and pressure profile and is considered to be the optimum channel among all. This optimum channel exhibits around 10% higher Nusselt number (Nu) and heat transfer enhancement factor (η) than the plain rectangular channel. Velocity distribution analysis depicts that the depth of cavity influences the formation of stagnation zones which affects the flow in cavity area. It can be found from pressure distribution analysis that the static pressure reduces gradually as the water flows along the longitudinal direction of the channel for the cavity. It is also found from temperature distribution analysis that the cavity cross-section of the microcannel has significant influence on temperature field, which enables better fluid mixing between the wall and core flow regions.

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275_IEC35585

# Simulation of Bottom Hole Pressure in Managed Pressure Drilling through MATLAB-SIMULINK

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***Abstract:*** *Managed pressure drilling process an adaptive technique to control the bottomhole pressure based upon the changes in the density and the bulk modulus of the fluid in the annulus and the drill string. Mananged Pressure Drilling, commonly known as MPD, is comparatively new technology which is very important for mining process. A mathematical model is used to establish the relationship between the two controls volumes considered in the dynamic system. The amount of variation in the pump pressure, choke pressure, bottomhole pressure and the flow rate with respect to change in density and bulk modulus is determined. The variation in the pressure factors with respect to the variation in the height of the vertical drill bit which influence in swap and surge pressure is calculated. The necessity of maintaining the desired flow rate at each instant is determined through the variation in the bottomhole pressure. The rate of change of pump pressure, choke pressure and flow rate is determined.*

***Keywords:*** *Managed Pressure Drilling; Bottomhole Pressure; Dynamic System; Adaptive Technique; Pressure Determination; MATLAB –SIMULINK*

## INTRODUCTION

In conventional drilling, the drilling fluid used acts as a primary barrier for well control. The bottom-hole pressure is maintained above the formation pressure by simply controlling the density of the drilling. When the drilling fluid gradient tends to exceed the fracture pressure, a casing string has to be run. In case of off-shore drilling the pressure has to be maintained within a small margin as the difference between the pore pressure and the fracture pressure is small. In these cases the conventional drilling operation becomes less feasible as the no of casing points goes on increasing. Managed pressure drilling (MPD) is used to overcome this problem. In MPD, the downhole pressure is kept at the desired level. Managed Pressure Drilling is primarily utilized to drill problem wells that are either impossible or uneconomical to drill with conventional overbalanced drilling methods. The major contributions towards the development of different control systems for MPD dynamic system are reviewed and the research gap is identified. It involves the works on design of various controllers, estimators and automation of drilling processes. Stamnes et al. [1] developed a reduced order observer that adapts to unknown friction and density and estimates the bottom hole pressure in the well during drilling. Alexandrov et al. [2] developed a dynamic algorithm of finite-frequency identification to identify the parameter of managed pressure drilling process. Controller is designed that provides stability of the system and maintains the desired pressure. Hauge, E et.al. [3], addresses control challenges within drilling for the oil and gas industry. J.E.Gravdal et.al. [4] used an unscented Kalman filter to update the friction estimate in both the drill string and the annulus. Breyholtz et al. [5] developed a MPC for regulating BHP in a dual-gradient drilling (DGD) system. Zhou, J et al. [6] developed a nonlinear adaptive observer which uses several delayed observers to get robust estimates of unknown parameters and hence improved state estimates but at the expense of computational load. Based on the literature review, it is concluded that the difference in the densities of the fluid in the drill string and the annulus which is a potential factor in influencing the bottom hole pressure is assumed to be same by all the researchers and similarly the influence of the fluid particles depending upon the geography of the drilling system is also not taken into account. And both these factors have high chances of disturbing the normal drilling system by leading to unusual bottom hole pressure condition thereby leading to the damage of the well. Aligned with this fact the objectives of the current work is to determine the variation of bottomhole pressure with respect to time analysing the system equation and dynamics with MATLAB-SIMULINK modeling so that before implementing actual rig process, engineers have a clear idea on different input and output parameter to optimize the net output of the system.

## MATHEMATICAL MODELLING OF THE SYSTEM

The model only considers fluid phase flow. For modelling purpose the well is divided into two control volumes **Figure 1** shows the two control volumes considered one control volume for the drill string and the one for the annulus. The volumes are connected through the drill bit. The main disturbance that we consider is the vertical motion of the drill string.

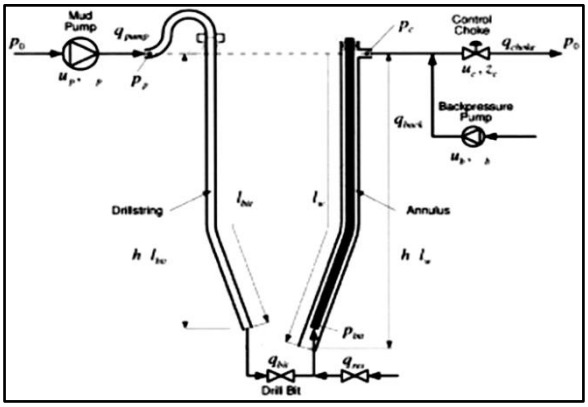


**Figure 1** The drilling system (Stamnes et al (1))

### Mass and Momentum Balance

The pressure dynamics are derived from the mass balance and are

$$\frac{V_d}{\beta_a}\ \dot{P_P} = Q_p - Q_{bit}$$

$$\frac{V_d}{\beta_a}\ \dot{P_c} = Q_{bit} + Q_{back} - Q_{choke} + Q_{res} - \dot{V_a}$$

### Momentum Conservation

The pressure in the whole circuit can be found through momentum co

The pressure at the bit depends on the choke pressure, pressure due to rate of change in $q_{bit}$, friction pressure and hydrostatic pressure, and is given a

$$P_{bit} = \frac{M_a}{M}\ P_P + \frac{M_d}{M}\ P_C + \left(\frac{M_a}{M}\ \rho_{a+}\ \frac{M_d}{M}\ \rho_d\right) g h_{bit} + \left(\frac{M_a}{M}\ F_a - \frac{M_d}{M}\ F_d\right)(q_{bit} + q_{res})^2$$

$$P_{bit} = P_c + M_a \dot{q}_{bit} + F_a(q_{bit}+q_{res})^2 + \rho_a g h_{bit}$$

$$P_{bit} = P_p - M_d \dot{q}_{bit} - F_d(q_{bit})^2 + \rho_d g h_{bit}$$

The $Q_{bit}$ and $P_{bit}$ equations are achieved from the mass and momentum equations by applying it over a control volume. The mathematical model developed helps in drawing block diagram through which the relationship between various factors are determined.

## MATLAB-SIMULINK MODEL

The main control goal of an MPD control system is to keep the pressure at a specified location in the well at a desired set point specified by the operator. This has to be achieved regardless of varying operating conditions like changes of the flow rate from the main pump and the backpressure pumps and disturbances acting on the drilling mud. To design a simulink model for managed pressure drilling a dynamic model for the circulation system is developed as shown in **Figure 2**. In order to obtain the complete system, the models are interlinked through the output variable flow rate ($q_{bit}$) since as discussed earlier in mathematical modeling both the control volumes are connected through the drill bit.

From the three equations obtained, it is clear that the momentum equation is the one which drives the two control mass equations in the drill string and the annulus respectively. The $q_{bit}$ parameter completely controls the entire regulating dynamic system as shown in **Figure 1**.

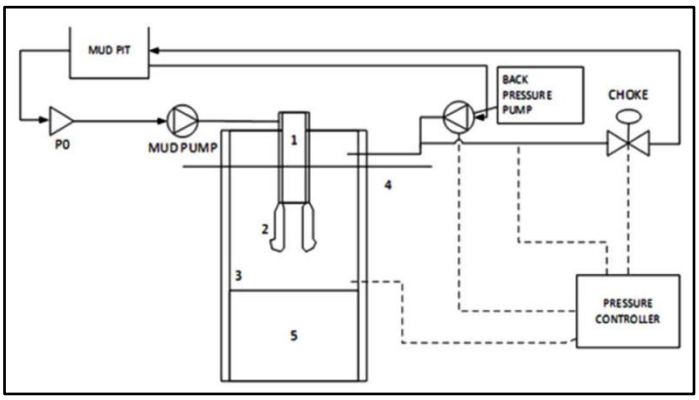


**Figure 2** Dynamic model of circulation system (1-Drill string 2- Drill bit 3-Annulus 4-Sea bed 5-Rock)

**RESULTS AND DISCUSSION**

The density of the fluid particle in the drill string and the annulus will not be same as the fluid in the drill string is only mud whereas in the annulus the formation particle referred as cutting and carvings are transported to the surface through it. And hence the density of the fluid in the annulus goes on increasing. And this is main reason for maintenance of the bottomhole pressure in the well. While performing simulation trails the values of the density in the drill string and the annulus is not same because of the difference in the fluid present in them. Different set of simulation trails were carried out by keeping the density of the fluid in the annulus constant and by varying the density of the fluid in the drill string. Similarly trails were performed by varying the bulk modulus of the fluid in the drill string and the annulus respectively. The values for density are chosen in such a way that the difference between each is not more than 5% of the density of the annulus fluid that is usually set. Hence the results will also have high accuracy. Simulation trails were also carried out by varying the depth of the well ($h_{bit}$) having the initial condition as '0' and having time period as '50'. By varying the density of the fluid in the annulus, the simulation trial is repeated for 3 times and based on those trails the rate of change of pump pressure, choke pressure, the flow rate and the bottomhole pressure are all measured at each time period using matlab simulink and those data are plotted in which results in the following graphs as shown below.

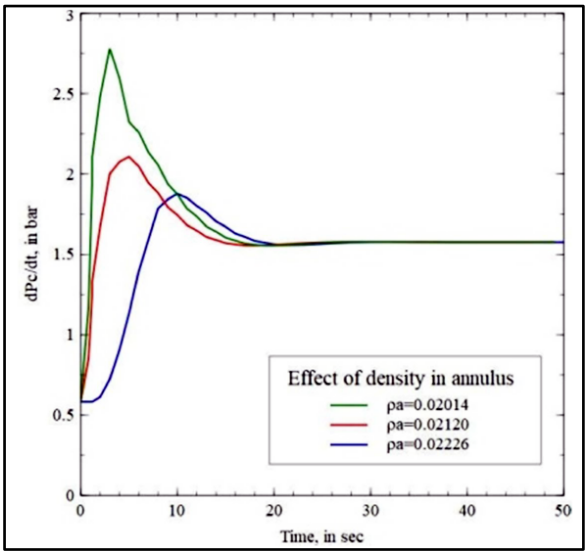


**Figure 3** Step response of rate of change of pump pressure with varying density of the annulus

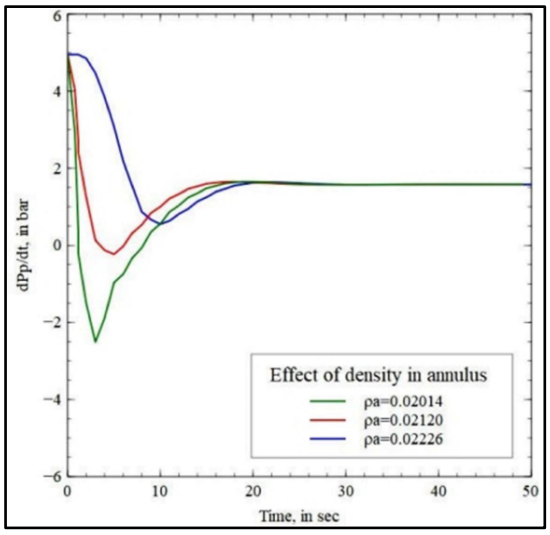


**Figure 4** Step response of rate of change of choke pressure with varying density of the annulus

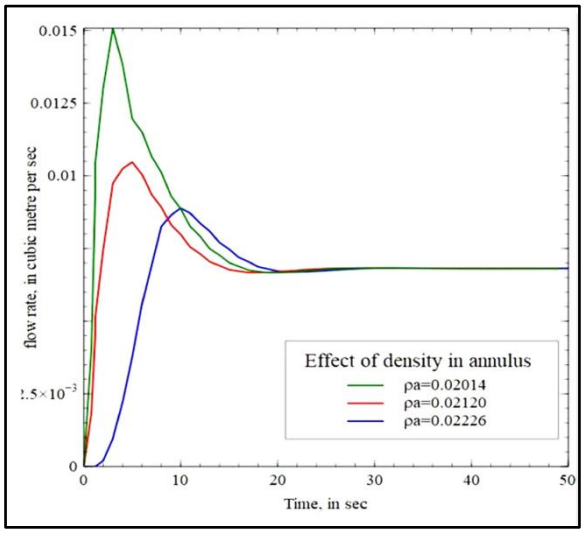


**Figure 5** Step response of flow rate with varying density of the annulus

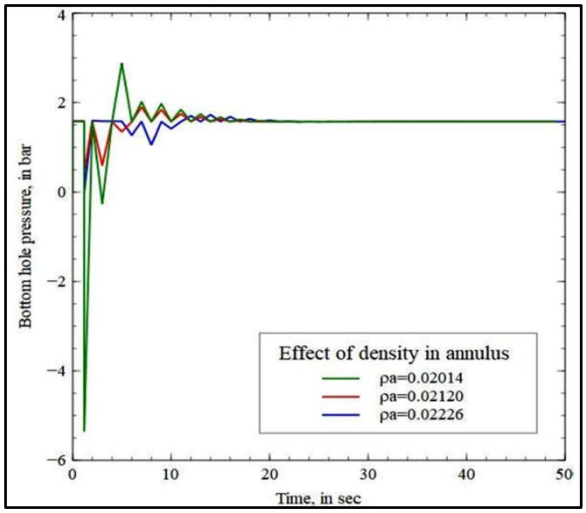


**Figure 6** Step response of bottom hole pressure with varying density of the annulus

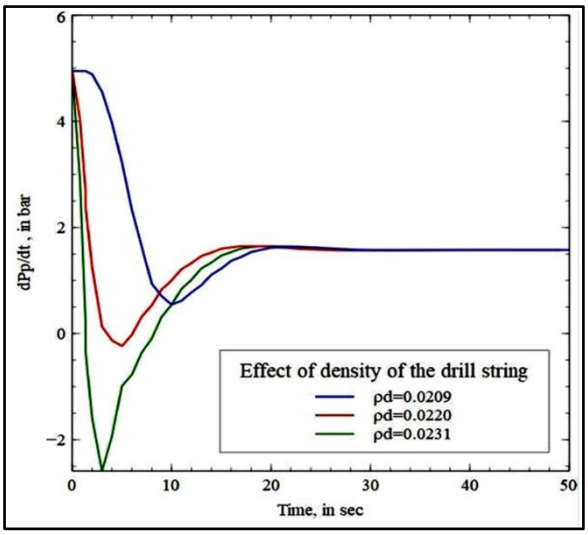


**Figure 7** Step response of rate of change of pump pressure with varying density of the drill string

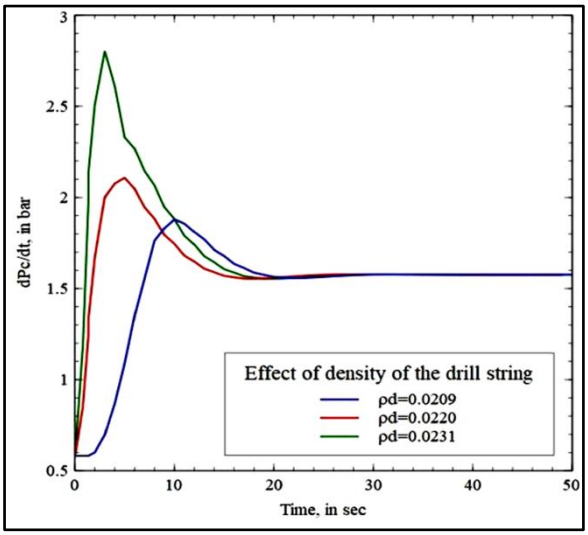


**Figure 8** Step response of rate of change of choke pressure with varying density of the drill string

For the increase in the density of the fluid in the annulus the rate of change of pump pressure decreases as shown in **Figure 3**. As the density of the fluid in the annulus increases, the time taken to reach the lowest peak value goes on increasing and the lowest peak value also increases. With increase in density, the time taken for the response curve to reach and stay within a range about the final value also increases. The rate of change of choke pressure goes on decreasing with respect to time with increase in density of the drilling fluid in the annulus as shown in **Figure 4**. The time taken to reach the first peak of the overshoot increases as the density of the drilling fluid in the annulus increases. The time duration between the first peak of the overshoot and the system reaching steady state value goes on decreasing with increase in density of the drilling fluid in the annulus. The fluctuation in choke pressure decreases with increase in density of the fluid in the annulus. The peak value reached with less density value is very high when compared to that of the high density value of $\rho_a$=0.02226. For the increase in the density of the fluid in the annulus the flow rate decreases as shown in **Figure 5**. The peak value reached for the flow rate with less density value is very high and the fluctuation is tremendous when compared to that of the high density value of $\rho_a$=0.02226. The rate of change of flow rate first decreases and then increases as shown in **Figure 5**. As the density of the fluid in the annulus increases, the time taken to reach the peak value goes on increasing and the peak value also increases. The time duration between the first peak of the overshoot and the system reaching steady state value goes on decreasing with increase in density of the drilling fluid in the annulus. The bottomhole pressure increases and decreases continuously

for a small duration and then it reach the steady state condition where the response curve stays within a range. For the increase in the density of the fluid in the annulus the rate of change of bottomhole pressure increases and the bottomhole pressure increases as shown in **Figure 6**. When the density of the drilling fluid in the annulus is very higher at that instant the fluctuation of the bottomhole pressure is lower as shown in **Figure 6**. With increase in the density of the fluid in the annulus the time required for the response curve to reach and stay within a range about the final value of size specified by absolute percentage of the final value referred as the settling time goes on increasing. With the increase in the density of the fluid in the annulus the bottomhole pressure goes on increasing by a small margin. By varying the density of the fluid in the drill string, the simulation trial is repeated for 3 times and based on those trails the rate of change of pump pressure, choke pressure are all measured at each time period using matlab simulink and those data are plotted. The rate of change of pump pressure goes on increases with the increase in the density of the fluid in the drill string as shown in the **Figure 7**. As the density of the fluid in the drill string increases, the time taken to reach the lowest peak value goes on decreasing and the lowest peak value also increases. With increase in the density of the fluid in the drill string the pump pressure goes on decreasing as shown in **Figure 7**. The choke pressure goes on increasing with respect to time with increase in the density of the drilling fluid in the drill string as shown in **Figure 8**. The time taken to reach the first peak of the overshoot increases as the density of the fluid in the drill string increases. The time duration between the first peak of the overshoot and the system reaching steady state value goes on increasing with increase in density of the drilling fluid in the drill string. For the increase in the density of the fluid in the drill string the rate of change of choke pressure decreases as shown in **Figure 8**. The peak value reached with less density value is very high when compared to that of the high density value of $\rho_d$=0.02310.

## CONCLUSIONS

The simulation results are significant because it doesn't require a projects to get installed to get results. Simulation gives idea of the physics behind every engineering problem. The simulation of the developed mathematical model gives some ideas to the designers and engineers for better design of the rig. The concluding remarks are written below:

1. With increase in the density of the fluid in the annulus the pump pressure increases whereas the choke pressure decreases and the bottomhole pressure increases.
2. With increase in the density of the fluid in the drill string the pump pressure decreases whereas the choke pressure increases and the bottomhole pressure increases marginally.
3. Based on the requirement the parameters which influence the choke pressure such as Qback, Qres, Qchoke are adjusted in order to maintain the bottomhole pressure.
4. The density of the fluid in both the control volume has significant effect on the pressure of the entire system as it directly related with the flow rate of the system whereas the bulk modulus does not affect the system parameters to.

Thus in order to maintain the bottomhole pressure due to increase in the density of the fluid in the annulus, the flow rate is decreased which in turn increases the pump pressure and decreases the choke pressure thereby increasing the bottomhole pressure slightly to achieve a new value where it is held in steady state condition.

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310_IEC66507

# Low-Cost Self-Cleaning System for Efficiency Enhancement of Onboard Smart Nanogrid in Green Transport

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***Abstract:*** *Growing concerns over fossil fuel impact and fuel demand have driven research into renewable energy solutions like solar PV for charging electric vehicles, particularly in remote areas, offering a sustainable alternative for green transportation. However, the accumulation of dust, dirt, and bird droppings on solar panels significantly reduces their performance, especially in regions with high solar irradiance. This paper presents a low-cost automated self-cleaning system designed to enhance the efficiency of onboard solar photovoltaic (PV) panels in green transport, specifically light electric vehicles (LEVs). The proposed system integrates an automated cleaning mechanism with smart sensors to optimize energy capture, ensuring consistent power output. The cleaning process is controlled by a microprocessor that activates the system based on voltage and dust levels detected by sensors. The system operates in both automatic and manual modes, providing flexibility in different environments. Experimental results demonstrate a 14.45% increase in solar energy harvested after cleaning, making the system highly effective and economically viable. The study may also be used to model self-cleaning mechanisms in applications that required solar PV panels.*

***Keywords:*** *Automated Self-Cleaning; Enhanced Efficiency; Light Electric Vehicle; Solar PV*

## INTRODUCTION

The increasing demand for sustainable transportation and the need to mitigate environmental impacts have led to a surge in interest regarding renewable energy solutions. Light Electric Vehicles (LEVs), such as e-rickshaws, represent an eco-friendly alternative to traditional fossil-fuel transportation. However, a significant challenge remains in their dependence on grid-based charging, particularly in remote regions where grid reliability is questionable, such as India's Sundarbans or the pristine beaches of Southeast Asia. This has catalyzed the development of solar-powered charging systems as a sustainable option for LEVs [1].

One major obstacle affecting solar panel performance is soiling, which occurs due to the accumulation of dust, sand, and bird droppings. This problem is exacerbated in sunny, sandy tourist destinations. Soiling, caused by dust, sand, and bird droppings, significantly hampers solar panel performance, particularly in sunny tourist destinations. Research shows that soiling can decrease solar efficiency by 20% to 50%, emphasizing the need for effective cleaning solutions [2][3]. Traditional manual cleaning is labor-intensive and impractical in remote areas. As a result, robotic cleaning systems have been developed, allowing for autonomous operation. While effective, these systems often entail high costs and complex maintenance[4]. Rainwater harvesting has also been explored as a cleaning method, utilizing natural precipitation to remove debris; however, its effectiveness is limited in arid regions. Additionally, aerial cleaning systems employing drones offer flexibility but face logistical challenges and operational costs[4][5]. While various cleaning solutions, including robotic and rainwater systems, have been explored, many are costly or cumbersome to implement. Given these limitations, there is a pressing demand for a low-cost, automated cleaning mechanism.

This research proposes a Low-Cost Automated Self-Cleaning System aimed at improving the efficiency of solar

panels integrated into onboard smart nanogrids for green transport. By automating the cleaning process, this mechanism ensures solar panels maintain optimal performance without manual effort, making it particularly suitable for remote or tourist-heavy locations. The automated design effectively addresses dust and debris issues while remaining economically feasible. The smart nanogrid concept is envisioned as a compact energy network, typically ranging from 500 Wp to 10 kWp, providing power for LEVs and incorporating Distributed Energy Resources (solar PV in this work) and Battery Energy Storage System [6]. This work introduces an automated self-cleaning system within the onboard solar PV nanogrid, maximizing energy capture and extending LEV capabilities. This affordable solution is designed for broad adoption in regions prioritizing both environmental sustainability and costeffectiveness.

## METHODOLOGY

**Figure 1** shows the onboard rooftop Solar PV integrated LEV, the block diagram of the smart nanogrid with the schematic of the proposed automated self-cleaning mechanism, and the control mechanism in the proposed cleaning mechanism inbuilt in a solar-powered e-rickshaw. As seen in **Figure 1**, the cleaning system utilizes a brush and sprayer assembly, controlled by DC stepper motors that receive signals from the micro-controller which in turn processes signals from dust, light, and voltage sensors. The micro-controller triggers the cleaning process when dust levels are high and solar insolation is sufficient. The system operates on a threaded rod mechanism for smooth functioning, with cleaning performed by a lightweight cleaning brush- spray assembly mounted on the pillow bearing that is rotated by the stepper motors. The system offers both manual (Bluetooth-controlled) and automatic modes, where ultrasonic sensors detect edges to guide movement. In manual mode, the user commands the cleaning via Bluetooth. Testing revealed the increase in efficiency that are shown in **Figure 2**, though further improvements are possible [7].

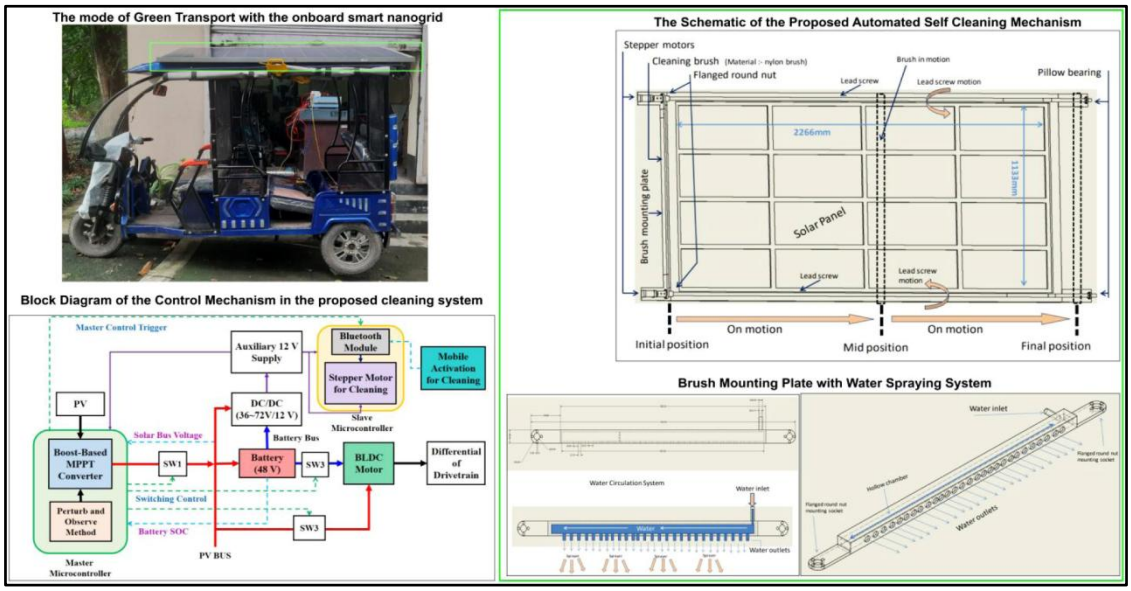


**Figure 1** The schematic of the design and control mechanism inbuilt in the solar powered e-rickshaw

## RESULTS AND DISCUSSIONS

**Figure 2** shows the maximum output current, short-circuit current and the maximum power harvested from the 540 Wp solar module installed in the e-rickshaw before and after the cleaning. The findings indicate there is an increase in the maximum current output, short-circuit current and the maximum output power with the application of the proposed cleaning mechanism. It is also seen that there is an average energy gain of 14.45% over the duration of the day. The data was collected on a bright, sunny day at IIEST, Shibpur, between 07:00 a.m. and 04:00 p.m.

**Table 1** shows the cost of developing the proposed mechanism [8]. Overall, this automated self-cleaning mechanism enhances solar panel efficiency and offers a sustainable, cost-effective solution for improving the performance of

onboard solar PV systems in green transportation.

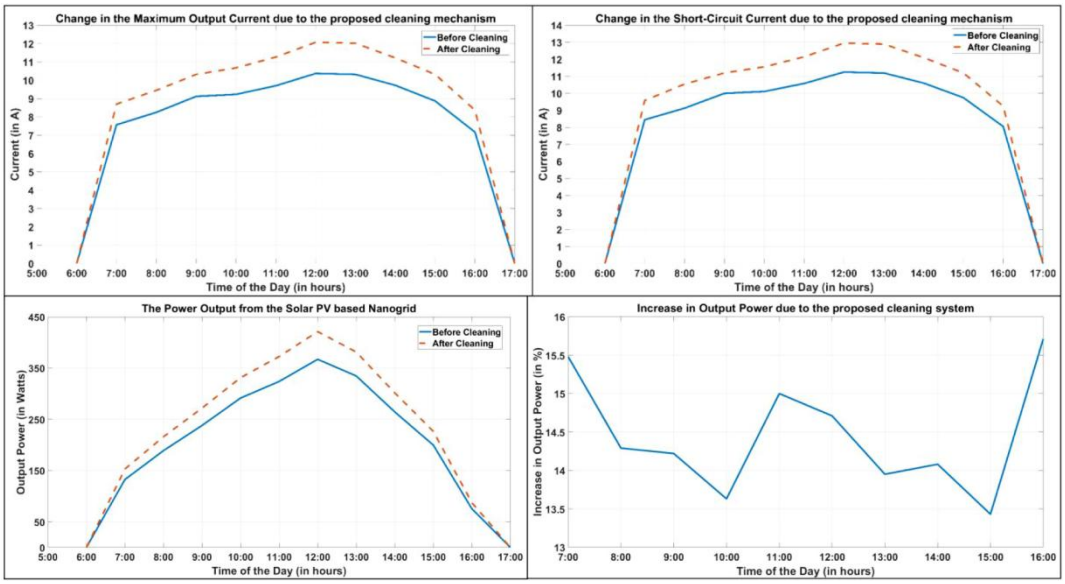


**Figure 2** The change in current and the Efficiency Enhancement in the Green Vehicle due to the proposed cleaning mechanism

**Table 1** Cost of developing the proposed automated self-cleaning mechanism

| Items | Quantity | Cost (in INR) |
|---|---|---|
| Arduino Mega | 1 | 1500.00 |
| Motor Shield (L293D) | 1 | 180.00 |
| Stepper Motor (12V)<br>Nominal Voltage : 4.83V<br>Holding Torque : 4 kg-cm | 2 | 1800.00 |
| Fluid Pump<br>DC Voltage : 3-6V<br>Power Rating : 0.1 kW | 1 | 180.00 |
| Bluetooth Module | 1 | 200.00 |
| Brush and Sprayer | 1 | 1140.00 |
| Expenses for Assembling and Installation | | 5000.00 |
| | Total Amount | 10000.00 |

## CONCLUSION

The development of a low-cost automated self-cleaning system for onboard solar PV panels in green transport significantly enhances energy efficiency. By preventing dust and debris accumulation, the system ensures optimal power generation, extending the operational range of LEVs. The results show a notable 14.45% increase in solar energy output post-cleaning. This affordable and up-gradable solution promotes sustainability while reducing the payback period, making it ideal for widespread adoption in environmentally conscious regions. Future work may explore further optimizations to improve system efficiency and adaptability across varied climatic conditions and also the type of dust deposition.

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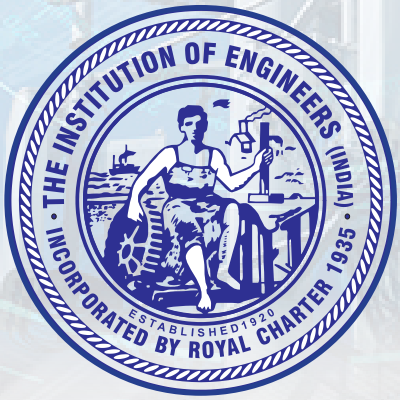


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