The Institution of Engineers (India)

Coimbatore Local Centre, Coimbatore

All India Seminar on

Challenges and Research Opportunities for Electrical Mobility Vehicles in India

on 26- 27 September 2019

PROCEEDINGS

Celebrating Knowledge

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(An Autonomous Institution)

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The IEI, Coimbatore Local Centre was founded in the year of 1965, under the Chairmanship of Dr. G.R. Damodaran, an educationist, who is also the architect of PSG College of Technology. Over the past 54 years the IEI Coimbatore Local Centre has contributed a lot to the engineering community and to the society and has grown to the level of IEI, Local Centre.

The Institution of Engineers (India)

IEI Secretariat

Phone: +91-33-40106207

FAX: +91-33-22238345

Email: sdg@ieindia.org

Contact Us

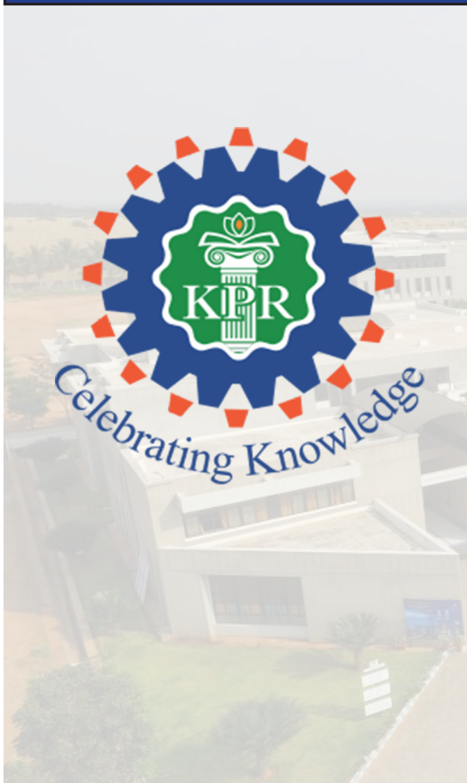
IVRS No: 033-40155400

Address: 8 Gokhale Road, West Bengal, Kolkata-700020

Phone: +91(033)2223-8311/14/15/16

Fax: +91(033)2223-8345

About KPR Institute of Engineering and Technology



KPR Institute of Engineering and Technology (KPRIET), is a new generation engineering college established in the year 2009 by KPR Charities.

KPRIET, approved by AICTE, New Delhi and affiliated to Anna University, Chennai, is dedicated for an unparalleled learning experience. This commitment is best reflected in its vision to become a globally recognized institute for engineering and technology

KPRIET is located on sprawling150 acres of lush green campus with 5.7 lakh sq ft state-of-the-art buildings. Students and staff at KPRIET take great pride in the main features of the institute such as world-class infrastructure, top-flight faculty, well stocked library, high pass percentage, excellent placement record, unique student projects etc.

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Department of Mechanical Engineering offers B.E. Mechanical Engineering with sanctioned intake of 180 students and M.E CAD/CAM Engineering. The department has separate block which includes state-of-the-art laboratories, CAD centre with advanced software and department library. It is a challenging, rewarding and highly respected profession, supporting through its commitment to excellence by experienced and expert faculty members having doctoral degree, outstanding research publications in peer reviewed International/National journals, faculty research presentations at International conferences. An Interactive relationship is maintained between students and staff which enable the students to develop a sound foundation in the stream in a conducive environment.

- **Accredited by NBA**
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Message from Chairman(IEI-CLC)

Dr. P. R. Natarajan

On behalf of the organizing committee of All India Seminar on "Challenges and Research Opportunity for Electric Mobility in India"it is our great pleasure to wish all participants a warm welcome to all India Seminar to be held at KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu on 26th and 27th September 2019.

This All India Seminar is jointly organized by KPR Institute of Engineering and Technology and The Institution of Engineers (India), Coimbatore Local Centre. The academicians and students across nation will be participating in this wonderful event. The chief guest from automobile industry and Eminent academicians will enlighten the gathering with keynote address and invited lectures in relevant areas of their expertise

While preparing this document we feel that much work needs to be done to improve the reach of the Seminar through wider publicity. However many papers either meet or exceed the minimum benchmark and expect that this can improved in the coming years. On behalf of the organizing committee, we would like to acknowledge our gratitude to the joint organizing partner Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu.

Message from Secretary(IEI-CLC)

Dr. H. Rammohan

It gives me great pleasure to congratulate both The Institute of Engineers (India), Coimbatore Local Centre and KPR Institute of Engineering and Technology partnership that has brought the All India Seminar on "Challenges and Research Opportunity for Electric Mobility in India" before us today.

This is also an especially vivid demonstration of IEI and KPRIET Co-operation. Electric Vehicles have tremendous roles to play in the development of country through sustainable growth that M.K Gandhi Dreamt of. The Seminar that has been organized with all efforts to spread knowledge and integrate people all over the countries with alike mind set into the global knowledge arena. It is my hope that this Seminar will help bridge the digital divide by empowering people in Electric mobility.

I thank everyone involved for their leadership, and for this tangible contribution to the All India Seminar on "Challenges and Research Opportunity for Electric Mobility in India".

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Preface

Mobility is going to change rapidly in the coming years as electric vehicles (EV) proliferate, ride sharing continues to grow, and eventually autonomous vehicles (AV) enter urban fleets. This is especially true in cities where new forms of mobility are concentrated and where investment in supporting infrastructure is needed to accommodate this growth. These changes coincide with the evolution towards cleaner, more decentralized and digitalized energy systems and services, and increasing electrification. Today, public- and private-sector stakeholders deploy policy, infrastructure and business models based largely on current patterns of mobility and vehicle ownership. The uptake of privately owned EVs is encouraged, while business models for charging stations vary, as they are deployed or operated by a range of players – public agencies, car manufacturers, energy companies and pure players. Limited interoperability and digitalization of infrastructure can make broad customer engagement challenging. Outside the energy sector, awareness of energy-related issues is low. Mobility integration with electricity system and grid edge technologies is emerging. As a consequence, EV charging could create local constraints and stability problems on power networks and reduce the environmental benefits of electrification.

There is an opportunity to design a different future, and reap both environmental and economic benefits with a call to action around the following three principles to be acted upon:

1.Take a multistake holder and market-specific approach:
First and foremost, a market-specific approach that considers all relevant stakeholders should be applied to new mobility patterns with smarter and cleaner energy systems. Energy, mobility and infrastructure enterprises, along with policy-makers, regulators and urban planners, can collectively define a new paradigm for cities. The paradigm would go beyond today's industry divisions in search of complementary municipal, regional and national policies. The investment and infrastructure to support electric mobility will vary significantly from one place to another, thus any approach needs to be market specific. Local stakeholders should plan for electrification while taking into account local characteristics, especially: urban infrastructure and design, the energy system and the culture and patterns of mobility

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2.Prioritize high-use vehicles.
The focus should be on electrifying fleets, taxis, mobility-as-a-service vehicles and public transport, which will have a greater impact as these represent a higher volume of miles travelled. Although personal-use vehicles will likely remain a significant portion of the vehicle stock for many years, they are on the road less than 5% of the time, representing a low volume of overall miles driven.

3.Deploy critical charging infrastructure today while anticipating the transformation of mobility
To keep pace with growing demand and to address range-anxiety issues, charging infrastructure is needed, especially along highways, at destination points, and close to public transport hubs. To minimize the risk of stranded investments, future mobility and vehicle ownership patterns should be considered, as some current charging locations (i.e. in apartment buildings, at parking meters along city streets) may not be needed in the future. The infrastructure should be deployed in combination with grid edge technologies – such as decentralized generation,

The Future of Energy and Mobility

These recommendations will create value in three dimensions:

– Environment. As the share of miles driven by EVs increases, urban mobility emissions will decrease progressively; electrification combined with a clean energy mix and optimized charging patterns will further reduce emissions, improving air quality and benefiting human health, with a much-decreased ecological footprint.

– Energy. EVs are a relevant decentralized energy resource (DER), providing a new controllable electricity demand, storage capacity and electricity supply when fully integrated with grid edge technologies and smart grids. Smart charging will create more flexibility in the energy system, improving stability and optimizing peak-capacity investments. Fleets of electric and, later, AVs can amplify the potential of smart charging, through the aggregation of multiple vehicles and higher control of load profiles. This will also open the door to broader energy efficiency services.

– Mobility. EVs will become more affordable than vehicles powered by internal combustion engines (ICEs) as the cost of batteries declines. Smart-charging services will reduce charging costs (for example, by charging when energy prices are low, if dynamic pricing is implemented), and new revenue streams for fleet operators, who will be able to provide ancillary services to energy markets. In the future, AVs will also cost significantly less per mile than personal-use ICEs, by as much as 40% and could also reduce congestion and traffic incidents. This report provides recommendations based on case studies and interviews with a wide range of leaders and experts from energy and mobility industries, civil society, academia, city councils and national governments. Working together, public and private stakeholders can adapt these principles to optimally converge mobility and energy, and to enable cities to better meet climate goals, support energy efficiency, foster innovation of services and infrastructure, and generate economic growth, ultimately providing great benefits to citizens.

Bharathwaaj. R
AP/Mech, KPRIET

Papers Presented

S.No	Title of the Paper	Author(s)
1.	Challenges and Opportunities of Electric vehicles in India	Benjamin Franklin Akash Deepanraj Kamalesh
2.	Power Drive Options for Electric Vehicles.	P.V.N.Kutty G.Narashiman N.R.K.Reddy T.Swaminathan
3.	Recent Trends in Electric Vehicles	Magesh Babu D Madhu B Parandhaman B Selvaganapathy T Divakar.K
4.	Energy Autonomous Solar/battery Auto Rickshaw	R Nandhakumar C Palanivel Y Pazhaniyappan R Sandeepkumar C Reswin Jim
5.	Role of electric mobility in a sustainable, and energy- secure future for India	Swathi Sivakumar S Vignesh Rajkumar G. Akash D Ganeshkumar
6.	Wireless Battery Charger Based Charging Station for Eva Vehicle with Pave Inclusion	K Gowrishankar R Dinesh S Mahesh O Kishore
7.	PARKING MANAGEMENT SYSTEM USING WIRELESS SENSOR NETWORK	R Jeevananthan Lakshmipathy Sai Kausik Tariq Aziz
8.	Advanced Redundancy Technology for a Drive System Using In-Wheel Motors	Ajaykumar Abinav P Vinothkumar M.S. Dharmarajan
9.	Globally Cool Vehicles: When Only Electric Will Do	D Abilash S Akash Ganesh Surya Balaji
10.	Energy on Demand	G Chandru Bala Vignesh Chiranjeevi Bala Subramani

Challenges and Opportunities of Electric vehicles in India

Benjamin Franklin[1]*, Akash[2], Deepanraj[3], Kamalesh[4]

Abstract

Over the years, the exploitation and pollution of natural resources have created the need for renewable and environment-friendly products. One of these products is Electric Vehicles. Electric Vehicles are the replacement for petroleum-based vehicles. They are one of the emerging technologies as well as eco-friendly and viable. The replacement of internal combustion engines with electric engines will reduce pollution to a great extent and be profitable to consumers. Many countries around the globe have implemented this technology and are contributing towards amelioration of the environment. We are going to see the opportunities and challenged faced in India over implementing electric vehicles. The electrification of road transport sector can be one of the pathways to reduce dependence on fossil fuel, carbon emissions and vehicular pollution. While there are several technologies like hybrid EV, plug-in hybrid vehicles, all-electric/battery EV and fuel cell vehicles that can help achieve the objectives of the electrification of road transport vehicles. This paper also focuses only on all-electric/battery EV. Electric vehicles (EVs) have advanced significantly this decade, owing in part to decreasing battery costs. Yet EVs remain more costly than Gasoline fuelled vehicles over their useful life. This paper also analyses the additional advances that will be needed, if electric vehicles are to significantly penetrate the passenger vehicle fleet.

Keywords: **Pollution, Electric Vehicle, Eco-Friendly, Lithium Battery.**

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[1] Assistant Professor (Sl.Gr), Department of Mechanical Engineering, Sri Ramakrishna Institute of Technology.

[2,3,4] Student, Department of Mechanical Engineering, Sri Ramakrishna Institute of Technology, Coimbatore.

* Corresponding author email: benjaminfranklin.me@srit.org

Power Drive Options for Electric Vehicles.

P.V.N.Kutty[1], G.Narashiman[2], N.R.K.Reddy[3], T.Swaminathan[4]

Abstract

In this paper, planetary gear arrangement and its advantages when used in electrical vehicle is discussed. The types of electrical motors used in electric vehicles as prime mover are briefed in order to understand the characteristics of drive. Various power train concepts for electric vehicles using planetary gear arrangement are discussed, where different cases will be used in different applications like automatic transmission, hub drive, final drive, etc., and also in types of vehicles like passenger cars, heavy vehicles, off road vehicles with electric drive.

[1]PVN.Kutty, Managing Director, Magtorq Pvt Limited, email-id:pvnk@magtorq.org
[2]G.Narashiman, Manager- Design-MES,Magtorq Pvt Limited, email-d:gnn@magtorqdesign.in
[3]NRK.Reddy,Manager-Design, Magtorq Pvt Limited,email-id:nrk@magtorq.org
[4]Swaminathan T, Design engineer,Magtorq Pvt Limited,email-id:tsn@magtorqdesign.in

Recent Trends in Electric Vehicles

Magesh Babu D[1], Madhu B[2], Parandhaman B[3], Selvaganapathy T[4], Divakar.K[5]

Abstract

Electric vehicles have higher energy efficiency and lower emissions when compared to conventional internal combustion engines. Though they are difficulty in adopting E-vehicles due to the limitations of battery technology, high costs and the lack of recharging infrastructure, with intelligently controlled charging operations it is possible. Over the long term, electric vehicles could represent a sustainable technology path. Electric vehicles as such will not be able to solve all current problems of transportation policy. Yet they may constitute an important component of a larger roadmap for sustainable transportation. This paper delivers a summary of the recent works of E-vehicles. The paper describes the advancement and the comparison of different parts of electric vehicles. The major components in battery technology, charging design, motor, braking and steering are studied and briefly explained. The paper finally demonstrates the E-vehicle model that we designed and fabricated as a conclusion of the papers.

[1,2]Associate Professor, Department of Mechanical Engineering, Velammal Institute of Technology, Chennai
[3]Assistant Professor, Department of Mechanical Engineering, Velammal Institute of Technology, Chennai
[4, 5]Under Graduate, Department of Mechanical Engineering, Velammal Institute of Technology, Chennai
Email: selvamechneer@gmail.com

Energy Autonomous Solar/battery Auto Rickshaw

R Nandhakumar*, C Palanivel*, Y Pazhaniyappan*, R Sandeepkumar*, C Reswin Jim*

Abstract

Auto rickshaws are small, three-wheeled vehicles which are used extensively in many Asian countries for transport of people and goods. The vehicles are small and narrow allowing for easy maneuverability in congested Asian metropolises. In India, auto rickshaws are commonly used as taxis, as they are very inexpensive to operate. Despite the apparent advantages in the vehicle design, auto rickshaws present a huge pollution problem in major Indian cities. This is due to the use of an inefficient engine, typically a 2 or 4 stroke, with almost no pollution control. This paper presents a transportation system based on auto rickshaws that operate in an environmentally friendly way. Existing vehicles are to be replaced by an all-electric counterpart redesigned in a manner which improves the efficiency of the vehicle. In addition, a recharging infrastructure is proposed which will allow for the batteries to be charged using mostly renewable energy sources such as solar power. Thus far, we have looked at the existing vehicle and the environment in which it operates, made a model of the vehicle in ADVISOR software, produced a prototype electric vehicle, and investigated recharging infrastructure requirements and designs. In particular, our proposed recharging infrastructure consists of a central recharging station which supplies distribution points with charged batteries. Since we aim to incorporate renewable energies in the infrastructure, we used HOMER software to design a feasible infrastructure system.

Keywords

battery electric vehicle, auto rickshaw, recharging infrastructure, energy storage, renewable energy

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*Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu India.

Role of electric mobility in a sustainable, and energy- secure future for India

Swathi Sivakumar*, S Vignesh Rajkumar*, G. Akash*, D Ganeshkumar*

Abstract

Within the next decade, a set of four low-carbon technologies – LEDs, solar energy, wind energy, and electric vehicles are set to reconfigure the dynamics of several industries. While India is making significant progress in the first three, we hardly see any electric vehicles on our roads, though the National Electric Mobility Mission Plan (NEMMP-2020) was launched by the Government of India on 9 January 2013 with the aspiration of selling 6–7 million new electric vehicles in 2020 to achieve liquid fuel savings of 2.2–2.5 million tones, along with substantial lowering of vehicular emissions and a decrease in CO_2 emissions. In addition to these vital benefits, acceleration of electric mobility in India will also lead to higher job creation in manufacturing. In this article, key recommendations are proposed to accelerate the progress of electric vehicles as a much-needed move towards a more sustainable and energy-secure future for India and a healthier life for Indians.

Keywords

Battery storage, electric vehicles, energy security, low-carbon economy.

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*Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu India.

Wireless Battery Charger Based Charging Station for Eva Vehicle with Pave Inclusion

K Gowrishankar*, R Dinesh*, S Mahesh*, O Kishore*

Abstract

Abstract: Now a days, we are in situation to create pollution free environment. Per year _60%_ Percentage of pollution was created by vehicle Co2 emission in addition to that, the availability of petroleum product for upcoming years also create problem to our fast lifestyle. So, vehicle manufacture increasing their research and production of Electric vehicle, which is one option to create pollution free environment and to minimize scarcity of petroleum products. Now the charging station is the main problem for Electric vehicle, especially it will create big problem in our India which is under the category of developing country .In this paper we are discussing about charging station of Electric vehicle including PV (photovoltaic panel /solar panel) and wireless battery charger .Here we are using new QDQ (Quad D quadrature)-QDQ coil design which increase the efficiency of power transfer at reasonable misalignment. This QDQ-QDQ structure use 2 sets of -4 adjustment Q coils present inside 1 D coil. The coil design was made using JMEG FEM software to calculate inductive parameter and overall performance calculation from PV to DC Battery storage was checked using MATLAB.

Keywords

EV (Electric vehicle), PV (Photovoltaic), Wireless charging, QDQ (Quad D Quadrature).

*Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu India.

PARKING MANAGEMENT SYSTEM USING WIRELESS SENSOR NETWORK

R Jeevananthan*, Lakshmipathy*, Sai Kausik*, Tariq Aziz*

Abstract

Abstract—In this paper, we conceive and develop a prototype of a car parking management system. The system gives a real-time snapshot of the monitored parking equipped by a Wireless Sensor Network (WSN). The developed application consists of two parts; one embedded in sensor nodes and another one executed at the pc containing interfaces. Moreover, this system enables to develop a Web application which allows the driver to reserve a free place in the parking or to guide him to localize a place using the parking map with all details of the way to reach it.

Keywords

Wireless Sensor Networks; CC2430; SmartRF04EB; ZigBee; J2EE

*Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu India.

Advanced Redundancy Technology for a Drive System Using In-Wheel Motors

Ajaykumar*, Abinav*, P Vinothkumar*, M.S. Dharmarajan*

Abstract

In electric vehicles that use in-wheel motors, the right and left traction forces become unbalanced if a motor malfunctions by motor lock or loss of traction, generating yaw moment. Control methods were designed to reduce this effect by stopping the motor output on the opposite side of the same axle. By using a prototype “Eliica” car, the maximum yaw rate and lateral acceleration were compared for a breakdown of one motor with the results from the “Sensitivity to lateral wind” indicated in Z108-76 of the Japanese Automobile Standards Organization. Under redundancy control, the test results were confirmed to be below the tolerance limits

Keywords

Wheel Motor, Inverter, Control System, Vehicle Stability, Safety

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*Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu India.

Globally Cool Vehicles: When Only Electric Will Do

D Abilash*, S Akash*, Ganesh Surya*, Balaji*

Abstract

Global Warming, Energy Independence and Healthier Air are the driving forces behind the search for alternative-to- gasoline fueled transportation. Though not as widely publicized, congestion worsens these problems by wasting fuel and generating more emissions while waiting for traffic to move. Myers Motors believes that the easiest and fastest way to zero emissions and energy independence at the least total cost for personal transportation will come through pure electric vehicles. Electric vehicles already run on zero total emissions for those getting their power from hydro, solar, nuclear and wind; this will expand to include clean coal, waves and other technologies we haven't heard of yet. Battery technology exists today to power the range requirements on over half the vehicles in America, yet electric vehicles are more talked about than made. Myers Motors' unique method for introducing electric vehicles to the American public focuses on making highway-speed electrics vehicles available at a reasonable price to promote real world ownership.

Keywords

Electric vehicle, fast market entry, Myers Motors, environmental effectiveness

*Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu India.

Energy on Demand

G Chandru*, Bala Vignesh*, Chiranjeevi*, Bala Subramani*

Abstract

The increasing demand and subsequent increasing price of fossil fuels have coupled with concern over global warming to encourage interest in sustainable forms of energy and "greener" transportation. Hybrid vehicles are slowly gaining ground on traditional vehicles, bringing improved fuel efficiency and greater consumer interest in electric vehicles. The availability of mass-produced electric vehicles, however, has remained elusive. Better batteries – or other methods of energy storage appropriate for use in transportation applications – are seen as key technologies for the continued advancement of hybrid and all-electric vehicles. Although simple batteries have been in existence for 200 years, energy storage has never been more at the forefront of vehicle design than it is today.

*Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu India.

Challenges and Opportunities of Electric vehicles in India

Benjamin Franklin[1*], Akash[2], Deepanraj[3], Kamalesh[4]

[1]Assistant Professor (Sl.Gr), Department of Mechanical Engineering, Sri Ramakrishna Institute of Technology.

[2,3,4] Student, Department of Mechanical Engineering, Sri Ramakrishna Institute of Technology, Coimbatore.

* Corresponding author email: benjaminfranklin.me@srit.org

ABSTRACT

Over the years, the exploitation and pollution of natural resources have created the need for renewable and environment-friendly products. One of these products is Electric Vehicles. Electric Vehicles are the replacement for petroleum-based vehicles. They are one of the emerging technologies as well as eco-friendly and viable. The replacement of internal combustion engines with electric engines will reduce pollution to a great extent and be profitable to consumers. Many countries around the globe have implemented this technology and are contributing towards amelioration of the environment. We are going to see the opportunities and challenged faced in India over implementing electric vehicles. The electrification of road transport sector can be one of the pathways to reduce dependence on fossil fuel, carbon emissions and vehicular pollution. While there are several technologies like hybrid EV, plug-in hybrid vehicles, all-electric/battery EV and fuel cell vehicles that can help achieve the objectives of the electrification of road transport vehicles. This paper also focuses only on all-electric/battery EV. Electric vehicles (EVs) have advanced significantly this decade, owing in part to decreasing battery costs. Yet EVs remain more costly than Gasoline fuelled vehicles over their useful life. This paper also analyses the additional advances that will be needed, if electric vehicles are to significantly penetrate the passenger vehicle fleet.

Keywords: **Pollution, Electric Vehicle, Eco-Friendly, Lithium Battery.**

INTRODUCTION

India has been at the forefront of addressing climate change and has emerged as a key player towards achieving global commitment of limiting global warming below 2ºC. In order to achieve this goal, India has laid out clear direction in the Nationally Determined Contributions' (NDC) document submitted to the United Nations Framework Convention on Climate Change (UNFCCC). The document, which now serves as a guidance framework, pledges to reduce emission intensity of India's GDP by 33-35 per cent by 2030 from 2005 level. With a view to achieve this ambitious target, measures should be adopted by all key sectors to reduce emissions. Particularly, the automobile and transport sector which currently constitutes 7.5% of country's total emissions, contributing 142 million tonnes of CO_2. The use of non-renewable and polluting sources for the production of energy has taken environmental pollution to a whole new level. The increasing global warming has an impending need on us to stop the use of non-renewable resources and reduce carbon emissions. Since the industrial age, the atmospheric carbon content is rising. Carbon emissions from vehicles amount for a typical passenger vehicle is 4.7 metric tons per year. The largest human source of carbon emission is from combustion of fossil fuels. The development of electrical engine in vehicles has created a replacement for the internal combustion engines paving way for the Electric Vehicles (EV). EVs have been adopted by many countries since it development creating a positive impact on the environment. We are now going to see the opportunities and challenges impending over implementing electric vehicles in India.

Types of Electric Vehicles:

A. Ground Vehicles

• Battery Electric Vehicles (BEVs)

• Hybrid Electric Vehicles (HEVs)

• Rail borne Electric Vehicles

• Space Rover Vehicles Estimation of MSW Generated Within the City

B. Airborne Vehicles

• Manned & Unmanned Electric Aerial Vehicles

C. Seaborne Vehicles

• Electric Boats

Battery Electric Vehicles (BEVs)

Battery Electric Vehicles are complete electric vehicles that are powered by only electricity and do not include a petrol/diesel engine, fuel storage or exhaust pipe. They use electric motors and motor controllers for propulsion. They do not have an internal combustion engine. They charge the battery through external charging outlet and hence also known as "Plug-in Electric Vehicles (PEVs)". There are various types of BEVs such as electric cars, buses, bikes, scooters, trucks and trains. They even include fewer parts than those used for those vehicles based on internal combustion engines. They even produce fewer noises compared to their counterparts.

Hybrid Electric Vehicles (HEVs)

Hybrid Electric Vehicles are not pure electric vehicles since they use a combination of internal combustion engine and electric propulsion systems. These mainly include cars, buses and trucks. The latest models use technologies focusing on improving efficiencies such as regenerative brakes, which convert kinetic energy of vehicle into electric energy to charge the battery and other systems such as start-stop system, which switches off the engine at idle and restarts when needed to reduce idle emissions and motor-generator. A hybrid electric produces much less emission than those produced by pure gasoline based hybrids improving fuel economy functioning at maximum efficiency. There are also Plug-in Hybrid Vehicles (PHEVs). They even produce fewer noises than pure hybrid vehicles.

Advantages of using Electric Vehicles

A. Cheaper to operate

EVs are cheaper to operate since they have high efficiencies and fuel economies thereby reduce cost for the owner. The electricity to charge an EV is about one third as much per kilometre to purchase fuel for vehicle.

B. Cheaper to maintain

BEVs have less moving parts than those had by conventional combustion engine vehicles. There is less servicing and no expensive systems such as fuel injection and exhaust systems, which are not needed in an EV. PHEVs have petrol engine and need servicing hence costing more than BEVs but they also have an electric propulsion system, which requires less moving parts leading to less depletion of petrol engine parts.

C. Environment Friendly

EVs are less polluting, as they have zero exhaust emissions. If you opt to use renewable energy to charge your EV, you can reduce greenhouse gas emissions even more. Some EVs are made of eco-friendly materials such as the Ford Focus Electric, which is made of recycled and bio based materials and the Nissan Leaf, which is partly made of recycled plastic bottles, old car parts and second hand appliances.

D. Health Benefits

The reduced harmful emissions will lead to better air quality, which is good for our health. EVs are also produce much less noise compared to petrol/diesel-based vehicles.

E. Safer

EVs have a low center of gravity thereby making them less likely to capsize. They also have low risk of fires and explosions. Their body construction gives them more durability hence making them safer during collisions.

Electric Vehicle Timeline

• 1832 – Robert Anderson develops First Crude Electric Vehicle.

• 1890 – William Morrison develops first successful electric vehicle in the USA.

• 1899 – Electric Cars gain popularity

• 1900 – Electric Cars are the trend

• 1901 – The World First Hybrid Electric Car, the “Lohner – Porsche Mixed” is created by Ferdinand Porsche.

• 1908 – The Ford Model T is introduced by Henry Ford .

• 1912 – The Electric Starter is introduced.

• 1920 – 1935 – Decline in electric vehicles due to use of crude Texas Oil as fuel.

• 1960s – Interest in electric vehicles regain as Fuel prices soar.

• 1971 – First Manned Electric Vehicle for the moon, NASA’s Lunar Rover is developed.

• 1973 – Many Automakers explore alternative options to fuel

• 1974 – Sebring Vanguard introduces the ‘Citi Car’.

• 1979 – Interest in Electric Cars fade due to drawbacks

• 1990 – Clean Air Amendment Act is passed.

• 1992 – Energy Policy Act is passed.

• 1996 – General Motors launch EV1.

• 1997 – Toyota produces the first mass produced hybrid, the ‘Prius’.

• 2006 – TESLA announces production of luxury electric cars.

• 2008 – TESLA produces its first electric vehicle, the Roadster with range of 244 miles per charge.

• 2009 – US Energy Department invests in nation-wide charging infrastructure.

• 2010 – General Motors introduce first Plug In Hybrid, the Chevy Volt.

• Nissan introduces LEAF, an all electric, zero emission cars.

• 2012 – TESLA introduces Model S with battery range of 270 miles per charge.

• 2013 – Cost of Electric Vehicle Batteries drop by 50%.

• 2014 – TESLA announces plan to build 'Gigafactory' and double worlds 2014 battery production figures.

• 2016 – BMW Group, Daimler AG, Volkswagen Group with Audi and Porsche along with Ford Motor Company (European Division) agree to build ultra-fast charging sites across Europe by 2020.

• 2017 – Toyota announces sales of 10 million hybrids since production of 'Prius'.

• 2019 – Expected date by which Swedish Automaker Volvo announces to produce only electric and hybrid cars.

• 2020 – China's expectation of 10% of auto imports and production will be only electric vehicles.

• 2025 – Expected date by which Norway and Netherlands plan to ban sales of petrol and diesel cars.

• 2030 – Expected date by which India plans to promote an all-electric car fleet. Also, China expects to limit its carbon emissions, hence affecting sales of petroleum-based cars.

• 2040 – Expected date by which Britain and France announce plans to ban sales of all new petroleum based vehicles.

India's Progress with Implementation of Electric Vehicles

The Government of India has embarked on a mission to create revolution in renewable energy in the country by planning a movement involving transformation to Electric Vehicles by 2030. It is expected to cut its oil purchases by some $60 billion, reducing emissions by 37% and curb demand for road infrastructure within the next 12 years. India currently has around 1.3 billion people with around 21 million vehicles sold annually.

OPPORTUNITIES:

A. Government Initiatives

• In 2015, the Government introduced a scheme called the Faster Adoption and Manufacturing of hybrid and Electric vehicles (FAME) in order to promote electric vehicles.

• In 2015, the National Electric Mobility Mission Plan was drafted to achieve fuel security by expecting to achieve sales of electric and hybrid cars to reach six to seven million by 2020.

• State run firm Energy Efficiency Services Limited (EESL) has appointed the nodal agency to procure around 10,000 electric cars to replace existing government vehicles.

• The Karnataka State Government has approved a policy to promote research and development in electric mobility making it mandatory to have charging points and pods in all major cities of the state.

• The Maharashtra State Government waived off some taxes for Electric Vehicles ever since it became India's First State to have an Electric Mass Mobility System.

• India is obligated to bring down its share of global emissions by 2030 as a signatory to the Paris Climate Agreement.

• The Government plans to setup lithium-ion battery making facility under supervision of Bharat Heavy Electricals Limited (BHEL).

• The Goods and Services Tax (GST) Council has set a tax rate of 12% compared to 28% set for petroleum based vehicles.

B. Battery

• Presently, around 22,000 EV units are being sold, among which around 2000 of them are 4 wheeler vehicles.

• Battery prices have declined from $600 in 2012 to $250 in 2017 and are expected to fall to $100 by 2024 making it cheaper than capital cost of petrol vehicles.

• The storage capability of EV batteries can help with grid balancing

C. Industrial

• Taxi aggregator OLA has launched OLA Electric project aiming to build an electric mobility ecosystem including charging infrastructure and vehicle fleets such as electric cabs, e-rickshaws and much more.

CHALLENGES:

A. Cost of EVs

• The cost of EVs should be reasonable and the EVs produced should hold proper value for money.

B. Efficiency of EVs in India

• The EVs in India on an average provide around 120 km on a full charge in turn making them unsuitable for long drives.

• EVs in India lack speed, which may turn off buyers. The top two India made EVs have speed of 85 km/hr.

C. Demand for EVs

• Increase in demand will help in achieving vision 2030.

• Increase in demand of EVs will lead to increase in requirement for energy and raw materials to for the battery.

D. Vehicle Quality

• Good vehicle quality will lure more customers.

• Better quality vehicles ensure trust among customers.

E. Batteries

• The batteries used by electrics are cars made up of nickel, aluminum, cobalt, graphite and lithium, which are all rare earth materials.

• The availability of these materials is scarce and the amount of these materials available may not be able to produce enough batteries to power the expected amount of electric vehicles to be produced.

• The increasing demand for lithium around the globe given its scarcity on the Earth's surface will make it challenging to meet India's EV requirement.

F. Electricity Generation

• There must be enough electricity generation capacity to meet the increasing demands for charging infrastructure and local consumer utilization.

• There is presently shortage of electricity in many parts of India and a major part of energy generation of the country is still dependent on fossil fuels.

G. Anti – EV Elements

• Anti – EV activists, supposedly fringe elements hired by oil companies or fossil fuel dealers try to thwart growth of EVs. Amsterdam recently witnessed an Anti – EV vandalism case involving damaging of 2 TESLAs.

H. Global Energy Demand

• Any decrease in demand for oil by India and China will have wide geopolitical ramifications as the two countries together account for half of 1% growth in global energy demand in 2016.

I. Land Availability

• Availability of land to setup charging stations in urban areas where land scarcity is present is a difficult task.

• Moreover, a substation nearby is a requirement for a charging station.

Parameters	Diesel Bus	CNG Bus	Electric Bus
Seating capacity	30-40	30-40	30-40
Gross weight	16,200kg	16,000 kg	18,500kg
Cost	INR 35-75 lakhs	INR 35-75 lakhs	INR 2-2.5 Crore
Fuel efficiency	3-4 km/L	2-3 km/kg	0.66 km / kWh
Running cost	INR 12-18/km	INR 13-19/km	INR 10/km
Range	480-560 km	260-390 km	220-250 km
Fuel tank size	160-220 L	720 L	NA
Charging time	NA	NA	4-6hr
Max. power	170-300 BHP	200-250 BHP	180 kW

Source: International Association of Public Transport, 2017

Note: The electric bus considered for comparison is BYD K9, and CNG and Diesel Buses considered were TATA STARBUS

Figure 1: Comparison between Electric, CNG and diesel buses

Financial Challenges:

The financing challenges in the emerging landscape for different stakeholders include:

• Original Equipment Manufacturers (OEMs)

OEMs make large investments in terms of setting up the manufacturing facilities and supporting development of new vehicles in the market. The new paradigm would push OEMs to make additional investments for increased R & D. Given the changes in the businesses, financing mechanisms may have to adapt for the OEMs, and the financiers may need better understanding of the changing risk profiles to evaluate EV manufacturing finance.

• Public transport

As India urbanizes in the new paradigm, the need for public transport would increase multifold. But the public funds available may be restricted to make heavy infrastructure investments, especially in tier 3 and tier 4 towns leading to huge financing gaps. Innovations in financing may be required in bridging this gap along with encouraging private sector participation.

• Personal Vehicles

The personal vehicle segment is poised for a strong growth in India driven by increasing middle class and growing real income. The new paradigm of changing technology of travel may not impact the financing mechanism for the private vehicles as repayments are linked to the repayment capacity of the borrower. However, there may be higher upfront cost to the vehicle owners which may put additional financing constraint to the user.

• Commercial Vehicles

Technology and cost of vehicle would play the biggest role in adoption of the electric mobility paradigm in this sector. The financing of high cost vehicles with lower operational cost would require adaptation to new structures of financing similar to the renewable energy ecosystem for the vehicles especially in the commercial segment as the buyers would like attractive cost per kilometer of operation.

• Energy Service provider

The charging stations installed by energy service providers would be heavily dependent on the number of customers using them. This number may not be substantial at the start of operations. Hence adequate financing support would have to be provided to augment the businesses.

Figure 2: Comparison of operating cost between diesel and electric bus

CONCLUSION

The implementation of EVs in India aims primarily to reduce greenhouse gas emissions and cut oil expenses. The vision 2030 put forth by the Indian Government is an ambitious and difficult task. The Government should make the most out of the opportunities available and find suitable ways to tackle the challenges impending over the implementation of EVs. India's obligation towards many environment friendly agreements has given it a situation where it is prompted to implement vision 2030. Electric Vehicles and the new mobility paradigm are expected to transform the way India moves it goods and people across this large country. It is also expected to reduce carbon emissions and air pollution along with enhancing energy security. It also has the potential of propelling India in the lucrative automotive export market. The Government of India has taken a step forward by taking electric mobility in a mission mode. However, given the challenges in the transition, we have to take a methodical approach in transforming this ecosystem. Identifying the frontrunners is a critical first step towards designing the next steps in promoting electric mobility and gaining experience for moving forward. Focusing on the frontrunners would enable us to create the necessary ecosystem of charging and overcome perception barriers. They would also set the platform for quickly scaling up other segments. The transition to electric mobility would require changes in the business models for Indian industry as well as changes in the usage patterns for the customers. Innovations in finance would be a critical enabling factor in supporting this transition.

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Power Drive Options for Electric Vehicles.

P.V.N.Kutty[1], G.Narashiman[2], N.R.K.Reddy[3], T.Swaminathan[4]

Abstract:

In this paper, planetary gear arrangement and its advantages when used in electrical vehicle is discussed. The types of electrical motors used in electric vehicles as prime mover are briefed in order to understand the characteristics of drive. Various power train concepts for electric vehicles using planetary gear arrangement are discussed, where different cases will be used in different applications like automatic transmission, hub drive, final drive, etc., and also in types of vehicles like passenger cars, heavy vehicles, off road vehicles with electric drive.

I. Introduction

Planetary drives are used as final drive in most of heavy vehicles and off road vehicles, as planetary gear arrangement is compact and can be fitted in the hub. Hub drives are used in large earth moving vehicles because of its rigid housing construction and heavy duty traction motors can be used as drive for this application since it has high starting torque capacity, high efficiency and high power density and importantly it is more compact as well. Planetary gearing system is also utilised in several automatic transmissions of vehicles because of its arrangement itself and various possibilties in gearing arragnement.

II. Planetary gear arrangement

Planetary gear is in-line shaft arrangement and considered to have good advantages over traditional parallel shaft gears. The arragement of planetary gear system is such that, the planet gears (three or more and sometimes less) will mesh around the sun gear and held in a position with a help of planet carrier and bearings inside the planet gears. Internal ring gear to be placed over the planet gears so that all planet gears to mesh with internal ring gear. Internal ring gear completely fixed in most cases and in other cases it will be allowed to rotate. [3]

When the sun rotates, planet rotate about its own axis and since it meshes with fixed ring gear it is forced to revovle around the sun and output can be taken out with the help of carrier. This is simple planetary arrangement. If the ring is allowed to rotate we get two outputs and this is called Differential Planetary. Similiarly there are various arragement like compound planetary.

Because of this arragement, high reduction ratio can be achieved compared to conventional prallel gearings. Since the load is shared by many gears, the gears will be smaller compared to parallel gears.

III. Types of electrical Drive

[1][2]Types of drives for e-vehicle used are,

1. DC Series Motor
2. Brushless DC Motor
3. Permanent Magnet Synchronous Motor (PMSM)
4. Three Phase AC Induction Motors
5. Switched Reluctance Motors (SRM)

1. DC series Motor

DC series motor is simple in construction and has high speed control, therefore used in various applications and low power traction applications. However because its construction contains brushes and rings, it has maintenance problems.

2. Brushless DC Motor

As name suggests, this motor has no brushes and hence its maintenance free. Brushless DC motor possesses traction characteristics such as high starting torque, high efficiency and high power density.

3. Permanent Magnet Synchronous Motor(PMSM)

PMSM (Fig.1) has high traction characteristics like high starting torque, high power density, and high efficiency compared to BLDC and in-par to induction motors. Despite being high in cost, PMSM is preferred for high performance depending applications like passengers cars and heavy duty applications.

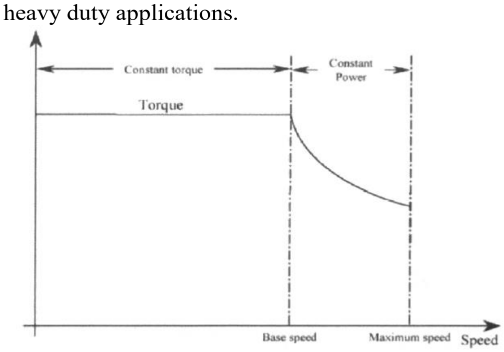

Fig:1 Torque speed characteristics for PMSM

1)PVN.Kutty, Managing Director, Magtorq Pvt Limited, email-id:pvnk@magtorq.org
2)G.Narashiman, Manager- Design-MES,Magtorq Pvt Limited, email-id:gnn@magtorqdesign.in
3)NRK.Reddy, Manager-Design, Magtorq Pvt Limited,email-id:nrk@magtorq.org
4)Swaminathan T, Design engineer,Magtorq Pvt Limited,email-id:tsn@magtorqdesign.in

4. **Three Phase AC Induction Motors**

Three Phase AC Induction motors (Fig.2) is most preferred traction motors for electric vehicle for reliability, robustness, less maintenance and ability to work in hostile environments. However, we need control method to achieve this traction characteristics and main drawback being complex inverter circuit and control of motor is difficult.

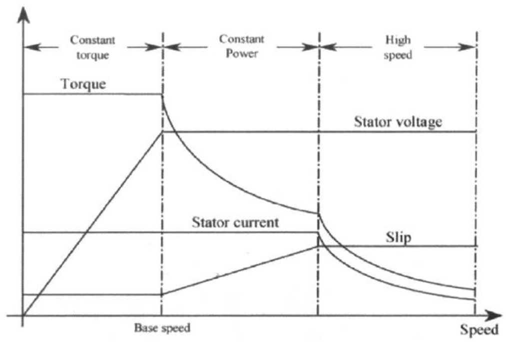

Fig:2 Different characteristics of Induction Motor

5. **Switched Reluctance Motors(SRM)**

SRM is known for its simple and rigid construction with no windings in rotor and no brushes, hence high efficiency. Rotor has no windings or permanent magnet and resulting in less weight leading to less inertia. It has good torque speed characteristics and simple control which makes it suitable for Electric vehicle. However, there are some disadvantages like high noise, high torque ripples. Fig 3 is torque speed characteristics of SRM.

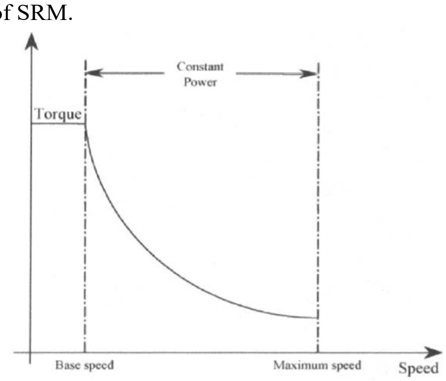

Fig:3 Speed-Torque Characteristics for SRM

6. **Axial Flux Motors**

In this type of motors, permanent magnets are placed in faces of the rotor and it is placed in-front of the stator and flux direction will be axial and there will be two rotors placed on either side of stator to balance the magnetic force. This arrangement makes the motor more compact and power density is high compared to radial flux motors. Efficiency of the axial flux motor is higher than the radial flux motor. Fig 4 shows the torque-speed characteristics of axial flux motors. These advantages making it more ideal for electrical vehicle.

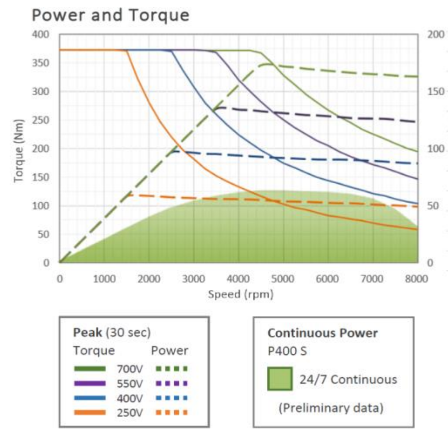

Fig:4 Speed-Torque characteristics of YASA Motors

IV. Regeneration braking as power saving.

As per physics, energy cannot be destroyed. Hence during braking of vehicle every time, kinematic energy is converted into heat energy and will be dissipated. In regenerative braking, during braking electrical motor will act as generator and which causes the vehicle to slow down and as well as generate energy simultaneously. However, main disadvantages are, it works efficiently at certain speeds and unlike conventional fiction brakes; it does not stop effectively in comparison. In case, if the motor fails to slow down the vehicle quickly, the electronic control module applies the conventional friction brakes and stops the vehicle.

V. Planetary gear arrangements and its applications.

Different Planetary gear arrangements and its application in different electric vehicles are discussed.

Arrangement-I

A typical simple planetary gear arrangement shown in Fig.5 is compact and light weight capable of transmitting power from the electric motor to the axle of the vehicle through bevel differential arrangement. Because of planetary gear arrangement, more compact and efficient power transmission can be achieved. This arrangement can be used in commercial vehicles like passenger car, bus etc.,

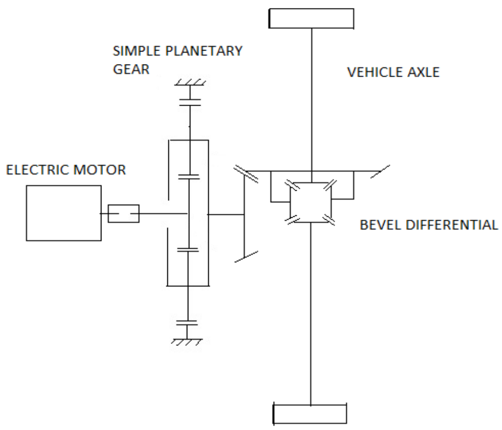

Figure:5 Simple planetary arrangement

Arrangement-II

This Differential arrangement with single input and two output is shown in Fig.6. Here, one output is taken from planet carrier and other output is taken from ring gear of planetary. The ring gear have gear teeth at the outer periphery and it meshes with an output gear ,The gear teeth are chosen to have same speed at the two outputs. Bevel differential as shown in the arrangement -1 is not required as the differential planetary described above is doing the function of speed reduction as well as splitting the power to two wheels.

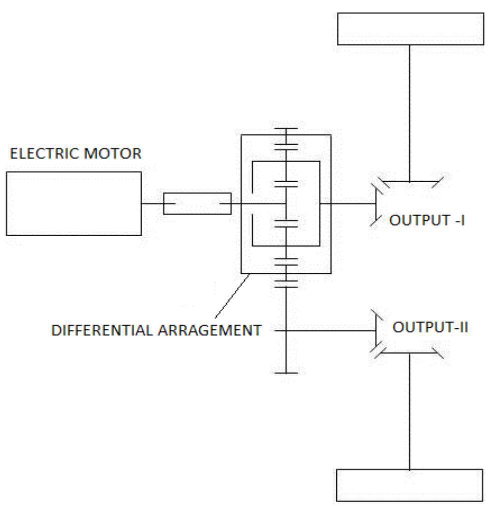

Figure:6 Differential arrangement with one inpit and two output

Arrangement-III

In this Differential planetary gear arrangement, there are two inputs and one output as shown in Fig.7 with two motors at each side. One input is through sun gear and second input is through ring gear and output is planet carrier. Various scenarios possible in this arrangement, such as, Case-1: Ring gear can be locked by braking the input-II with help of external brake, which makes this simple planetary gear arrangement. Case-2 Input is through sun gear and ring gear. Both ring gear and sun gear are driven by two different motors and output is through planet carrier. It increases the output speed with same torque as case-I. Therefore various output speeds can be obtained in this configuration. This arrangement is suitable for for heavy vehicles and earth movers.

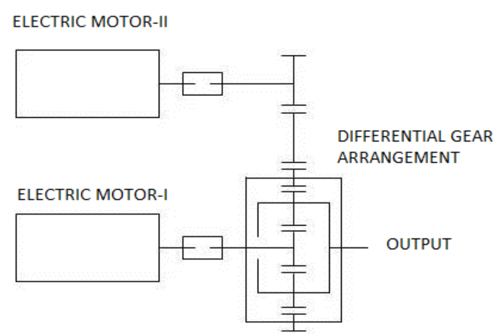

Figure:7 Differential planetary with two input and one output

Arrangement-IV

The Simple planetary gear arrangement with two configurations as shown in in Fig 8 and Fig.9 with input sun gear driven by motor can be used. Either Ring gear or Planet carrier can be used as output depending on the requirement. The different out speeds can be obtained by varying the speed of input motor using variable frequency drive. Since each wheel side is attached with individual gear drive with motor, steering of the vehicle can be done by varying speed of the motors.

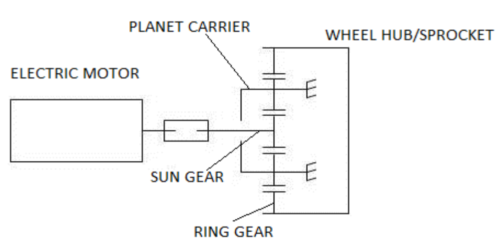

Figure:8 Simple Planetary with carrier fixed and ring rotating

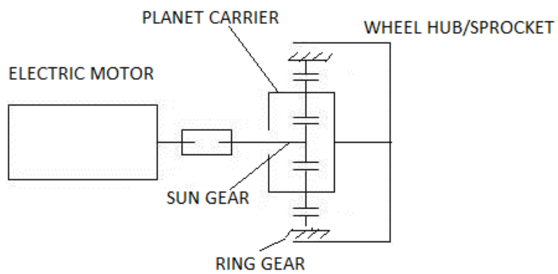

Fig:9 Simple Planetary with ring fixed and carrier rotating

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Recent Trends in Electric Vehicles

Magesh Babu D[1], Madhu B[2], Parandhaman B[3], Selvaganapathy T[4], Divakar.K[5]

[1,2]Associate Professor, Department of Mechanical Engineering, Velammal Institute of Technology, Chennai
[3]Assistant Professor, Department of Mechanical Engineering, Velammal Institute of Technology, Chennai
[4, 5]Under Graduate, Department of Mechanical Engineering, Velammal Institute of Technology, Chennai

Email: selvamechneer@gmail.com

Abstract – Electric vehicles have higher energy efficiency and lower emissions when compared to conventional internal combustion engines. Though they are difficulty in adopting E-vehicles due to the limitations of battery technology, high costs and the lack of recharging infrastructure, with intelligently controlled charging operations it is possible. Over the long term, electric vehicles could represent a sustainable technology path. Electric vehicles as such will not be able to solve all current problems of transportation policy. Yet they may constitute an important component of a larger roadmap for sustainable transportation. This paper delivers a summary of the recent works of E-vehicles. The paper describes the advancement and the comparison of different parts of electric vehicles. The major components in battery technology, charging design, motor, braking and steering are studied and briefly explained. The paper finally demonstrates the E-vehicle model that we designed and fabricated as a conclusion of the papers.

I. INTRODUCTION

Electrical vehicle based on electric propulsion system. No need of internal combustion engine. All the power is based on electricity. The main benefit is the high efficiency in power conversion through its proposition system of electric motor. Recently there has been massive research and growth reported in both academic and industry. Commercial vehicle is also available. Many countries have given incentive to users through lower tax or tax exemption, free parking and free charging facilities.

On the other hand, the hybrid electric vehicle is an alternative. It has been used extensive in the last few years. Nearly all the car manufacturers have at least one model in hybrid electric vehicle. The questions come to us: Which vehicle will dominate the market and which one is suitable for future? This paper is to examine the recent trends in electric vehicle and suggest the future development in the area.

II. Electric Vehicles & Hybrid Electric Vehicles

Hybrid Electric Vehicle has been promoted extensively in the last decade. Nearly each manufacturer has at least one HEV in the market. It is supposed to rescue the battery energy storage problem at that time. Using hybrid vehicle, it allows the electric power can be obtained from engine. The HEV is broadly divided into series hybrid and series hybrid. The engine power of the series hybrid is connected totally to the battery. All the motor power is derived from the battery. For the parallel hybrid, both the engine and motor contribute the propulsion power. The torque is the sum of both motor and engine. The motor is also used as a generator to absorb the power from engine through the transmission. Bothe series or hybrid can absorb power through regeneration during braking or deceleration.

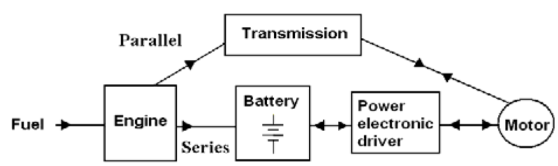

Fig 1: The series or parallel path of an HEV

Nevertheless, HEV still has emission. The introduction of plug-in HEV that solves some of the problem . It accepts the electric power to battery through plug in from the mains. Therefore, when convenient, users may charge the battery using AC from the mains.

III. PARTS IN ELECTRIC VEHICLE

The electric vehicle is rather simple in structure. The key components are the propulsion parts. Fig 2 shows the configuration.The battery is the main energy storage. The battery charger is to convert the electricity from mains to charge the battery .

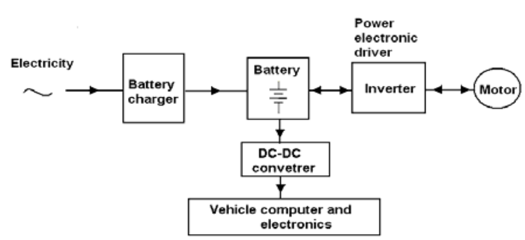

Fig 2: Parts of an Electric Vehicle.

The battery voltage is DC and I is inverted into switched-mode signal through power electronic inverter to drive the motor.The other electronic components in a vehicle can be supplied to the battery through DC-DC converter that step down the voltage from the battery pack to lower voltage such as5V-20V.

IV. MOTORS

There are a number of motors available for electric vehicle: DC motors, Induction motor, DC brushless motor, Permanent magnetic synchronous motor and Switched reluctance motor.

1. DC motors:

It is a classical motor and has been used in motor control for a long time. All the power involved in electromechanical conversion is transferred to the rotor through stationary brushes which are in rubbing contact with the copper segments of the commutator. It requires certain maintenance and has a shorter life time. However, it is suitable for low power application. It has found applications in electric wheel-chair, transporter and micro-car. Today, most of the golf-carts are using DC motors. The power level is less than4kW.

2. Induction motor

It is a very popular AC motors . It also has a large market share in variable speed drive application such as air-conditioning, elevator or escalator. Many of the higher power electric vehicles, for more than 5kW, uses

induction motor. Usually a vector drive is used to provide torque and speed control.

3. DC brushless motor

The conventional DC motor is poor mechanically because the low power winding, the field, is stationary while the main high power winding rotates. The DC brushless motor is "turned inside out. The high power winding is put on the stationary side of the motor and the field excitation is on the rotor using a permanent magnet. The motor has longer life time than the DC motor but is a few times more expensive. Most of the DC motor can be replaced by the brushless motor with suitable driver. Presently, its applications find in low power.

4. Permanent magnetic synchronous motor

The stator is similar to that of an induction motor. The rotor us mounted with permanent magnets. It is equivalent to an induction motor but the air-gap filed is produced by a permanent magnet. The driving voltage is sine wave generated by Pulse Width Modulation(PWM).

5. Switched reluctance motor

It is a variable reluctance machine and its famous recently because of the fault tolerance because each phase is decoupled from other. The power stage is different from other the motor discussed in 2-4. Each phase winding is connected in a fly back circuit style.

V DIRECT DRIVE AND HUB MOTOR

Direct drive reduces the loss in the mechanical units of the drive train. The motor is connected directly to the shaft to reduce needs of transmission, clutch, and gear box. Recently the in-wheel motor is promoted by researcher . The in-wheel motor is to turn the rotor inside out and attached to the wheel's rim and the tire. There is no gear box and drive shaft.
The motor is also called wheel-hub motor. Its main advantage is the independent control of each wheel. Fig 3 shows the 4-wheele drive vehicle. Each of the wheels works any speed and direction. Therefore, the parallel barking can be achieved easily. The Anti-lock braking system can be implemented easily by the technology. It has been shown that it can successfully prevent spinout. The whole vehicle is much simpler in structure.
Many different types of motor can be used for in-wheel motor. The prominent one is the switched-reluctance types. Its phase-winding is independently from each and therefore the fault tolerance is much more advanced that the other. There is no permanent magnetic in the motor, it reduces any interference by permanent field and the fluctuation of the permanent magnetic materials.

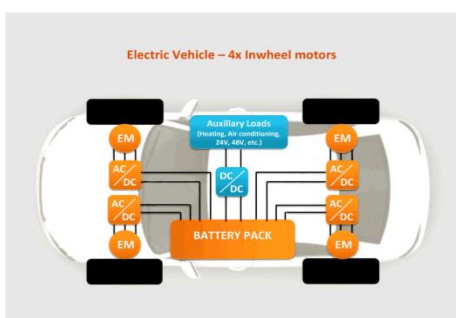

Fig. 3: True 4-wheel drive vehicle.

VI. ENERGY STORAGE

1.Batteries

The battery is the main energy storage in the electric vehicle. The battery in-fact governs the success of the electric vehicle. Recently there are massive works being reported in battery development. The battery such as Li-ion is now being used by new generation of electric vehicle. The danger of the instability of the battery has been studied by many reported. It seems that the $LiFePO_4$ type is preferable because of its chemically stable and inherently safe. Other Li-ion such as $LiCoO_2$, $LiMn_2O4$ and $Li(Ni_{1/3}Mn_{1/3}Co_{1/3})O_2$ may has the thermal and overcharge concern . For low cost solution, the lead-acid battery is still dominant part of the market. The battery has found applications in electric wheel chair, Golf-cart, micro-car and neighborhood town air. The recent RoHS has also stopped the use of NiCdbattery.

All the research is looking towards the fast charging for batteries. MIT reported the technology of a crystal structure that allows 100 times of charging speed than conventional Li-ion battery. Other alternative is to use ultra-capacitor.

2. Ultra-Capacitor

Capacitor is basically a static component. There is no chemical reaction in the components. Its charging and discharging speeds are very fast. However, the energy storage is limited. Its energy storage density is less than 20% of the lead-acid battery. Although the expected ultra-capacitor density will go up in next few years, its total solution for main energy storage is a challenge. The number of cycles and the temperature range is excellent. Table 1 shows the comparison.

Table 1: Comparison of different energy storage unit

	Lead-acid	NiMH	Li-ion	Ultra-capacitor
Energy density Whr/kg	40	70	110	5
Cycle life	500	8,00	1,000	500,000
Working temperature(°C)	-30 ~ +50	-40 ~+50	-40~ +60	-40 ~ +85
Cost $/kWhr	1,000	2,400	5,000	50,000

Therefore, ultra-capacitor is useful for fast speed or transient energy storage. As it allows high current charging, its charging time can be shortened to within a few minutes.

VII. CHARGINGSYSTEMS

1. General charger

The charger needed for the battery system for slow charging or fast charger are both required to handle high power. The H-bridge power converter is needed. The converter is famous for its efficiency and has found application in charger and DC-DC converter.

2. Ultra-capacitor charger

The voltage on the ultra-capacitor various from the full-voltage to zero when its energy storage varies from full to zero. This is different from the battery as its voltage will only varies within 25%. The capacitor voltage is internal point and is not in contact with users. The transformer isolated converter is not necessary. A tapped converter should be used as it will have higher efficiency for power conversion. The efficiency of the power converter is higher than the transformer-isolated version. The structure is simple.

3. Battery management systems

It is also referred as BMS. The battery system is formed by a number of battery ells. They are connected in parallel or series that is according to the design. Each of the cell should be monitoring and regulated. The conditioning monitoring includes the voltage, current and temperature. The measured parameters are used to provide the decision parameter for the system control and protection.

Two parameters are usually provided. They are the state of charge (SoC) and the State of Health (SoH). SoC is like the oil tank meter that provides the battery charging condition. It is measured by the information of voltage and current. The SoH is to record the health or aging condition.

4. Energy management systems

Even for ultra-capacitor system, the energy storage is made by a number of capacitors or in a combination with other energy storage devices such as battery. The same conditioning monitoring and management system will be used.

VIII.CHARGINGNETWORK

1. Charging network

The charging method of EV is controversial because of the uncertainty of the power needed, location and the charging time. The charging time of batteries has been reported to be shorter in the recent development. The lead-acid batteries are restricted by its technology. The charging rate is less than 0.2C and quicker charging rate seriously shortens its life time. Other battery such as Li-ion has recommended charging rate of0.5C.

Usually most of the electric vehicles have an on-board battery charger. A power cable is connected from the vehicle to a charging point. A charging station should provide a number of powerpoints and a suitable transaction program to calculate the tariff.

The power needed for the charging station is not a concern. Usually for private car, a standard charging power is less than 2.8kW. Single-phase power line is used. In average a vehicle is needed to be charged every 3 days. Using Hong Kong as an example, it will only affect the power consumption of less than 2% even all the private cars are charged to EV.

2. Fast charging station

For fast charging, a high current is needed, therefore three-phase power is usually used. The charging station should consider the method to connect the 3-phase socket to users as not all the civilian can handle the use of 3-phase socket system. The following has been discussed:

a. Magnetic contactless charging: There is no metal contact, all the power transfer is through magnetic induction. This reduce the concern when a civilian to handle high power cable and he/she does not need to contact the conductors.

b. High voltage power transfer: The heavy and large 3-phase socket and cable can be reduced in size byhigh voltage connection. The power source is stepped up to high voltage of several kV, and the cable is reduced. There is another step-down converter in the vehicle that reduced the high voltage to suitable lower voltage to charger the battery.

c. Battery rental: This has been suggested from the 1st day of the promotion of EV. All the batteries are not owned by the users but on a rental arrangement. Users go to charging station to swap the batteries to fully-charged ones. The time needed is just a few minutes. The design of the EV should be made for such changes. The vehicle battery charging in the station can also be used for energy storage to ease peak demand through valley supply compensation.

IX. Steering and Braking

1. Skid Steering

Steering is achieved by differentially varying the speeds of the lines of wheels on different sides of the vehicle in order to induce yaw. To satisfy the requirement of the turn radius, the longitudinal slip must be controlled, so a method of slip limitation feedback is used in the simulation. When the vehicle is turning on a slippery surface, because of the drop at the coefficient of road adhesion, the drive wheels may slip. The traction control system reduces the engine torque and brings the slipping wheels into the desirable skid range.

2. Braking and power regeneration

The braking of a vehicle in the past based on mechanical system such as disc brake. The braking method of an EV should be integrated with both mechanical and the electrical braking. In the initial region of the braking pedal, it electrical power regeneration braking should be applied. This is usually for deceleration or going down a slope, the kinetic energy of the vehicle can be returned to the battery. The final region of the braking, mechanical braking is used. This provides a compromise of the energy saving and safety.

Today, we can make motors with high power of regeneration that is in the expenses of the motor size, a compromise between the motor weight, cost, power regeneration efficiency and safety are needed. To increase the region of the power regeneration, the motor should be made with acceptance of the high power design plugging mode which is to provide high reverse torque to stop the vehicle. The motor drive should also be implemented with high frequency decoupling capacitor to absorb the fast transient of the reverse current.

3. Anti-lock braking(ABS)

Conventional ABS is installed in most of the vehicle to prevent skidding and to obtain a stable braking performance. The braking characteristic depends on the wheel slip as well as the road condition. It combines continuous slip changing and discrete valve action which induces discrete hydraulic pressure, PID and finite state machine theory are applied to the anti-lock braking system.

The ABS optimization consists to maximize the tire forces whatever the conditions of the road. Therefore, it must to localize the wheel slip ratio which corresponds to the peak tire road adhesion characteristic. The location and the value of these peak values varies in large range depending on the road, tire and many other different factors, For any rolling conditions, the optimal wheel slip rate, which will be used as control reference to optimize the braking force.

X. Suspension

The developed direct-drive linear motor actuator for the automobile active suspension systems can generate control forces to absorb road shocks rapidly, suppress the roll and pitch motions, and ameliorate both safety and comfort, while maintaining the vehicle at a horizontal level. For conventional passive suspension systems, it is difficult to be achieved, since a soft spring allows for too much movement and a hard spring causes passenger discomfort due to road irregularities. Thus, significant improvement of suspension performance is achieved by the direct-drive linear switched reluctance actuator. Comparing with hydraulic active suspension systems, the developed active suspension system based on the direct-drive linear switched reluctance actuator is simpler since it needs fewer devices and mechanical parts. Due to no hydraulic devices, this is an oil-free system. Furthermore, it can include the energy generation from the suspension. The development includes the design of direct-drive linear switched reluctance actuator, its characterization, and the design of the automobile active suspension system. The converter drive is also needed to develop to match with the linear switched reluctance actuator. The drive is expected to fit the driving pattern of the suspension system and to provide suitable force control, energy generation control and position control.

XI. Electric bike

Recently there are a number of local and overseas companies and institutions have been working on electric vehicle. The development on electronic parts and accessories from propulsion, safety and control has been reported. A Velammal Institute of

Technology has recently reported their EV development. Fig 4 shows the prototype of electric bike we designed and fabricated.

Fig. 4: A prototype of an off road electric bike

XII. CONCLUSION

This paper discusses the recent development in electric vehicle. The paper first describes general structure and discusses the energy storage. It then extends to the future vehicle components. The paper provides an overview of the recent E-bike we designed and fabricated.

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Energy Autonomous Solar/battery Auto Rickshaw

Abstract

Auto rickshaws are small, three-wheeled vehicles which are used extensively in many Asian countries for transport of people and goods. The vehicles are small and narrow allowing for easy maneuverability in congested Asian metropolises. In India, auto rickshaws are commonly used as taxis, as they are very inexpensive to operate. Despite the apparent advantages in the vehicle design, auto rickshaws present a huge pollution problem in major Indian cities. This is due to the use of an inefficient engine, typically a 2 or 4 stroke, with almost no pollution control. This paper presents a transportation system based on auto rickshaws that operate in an environmentally friendly way. Existing vehicles are to be replaced by an all-electric counterpart redesigned in a manner which improves the efficiency of the vehicle. In addition, a recharging infrastructure is proposed which will allow for the batteries to be charged using mostly renewable energy sources such as solar power. Thus far, we have looked at the existing vehicle and the environment in which it operates, made a model of the vehicle in ADVISOR software, produced a prototype electric vehicle, and investigated recharging infrastructure requirements and designs. In particular, our proposed recharging infrastructure consists of a central recharging station which supplies distribution points with charged batteries. Since we aim to incorporate renewable energies in the infrastructure, we used HOMER software to design a feasible infrastructure system.

Keywords

battery electric vehicle, auto rickshaw, recharging infrastructure, energy storage, renewable energy

1. INTRODUCTION

India is home to over 2.5 million auto rickshaws. In recent years, rickshaw companies have come out with alternative models such as Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG) rickshaws to mitigate the pollution problem caused by traditional petrol models [Rajkumar, 1999]. Two main disadvantages exist with incorporating those technologies on the rickshaws: (1) oil is still added to the chamber in the two-stroke configurations, which adds to the pollution, and (2) LPG and CNG are nonrenewable energy sources. The best way to redesign the rickshaw is to make the main power source renewable. One way to do this is to use an energy system that can take advantage of several sources of renewable energy – namely, electricity.

Rickshaws are an ideal candidate for electrification due to the low speeds of the vehicle and a relatively small distance covered in a day. Therefore, we have set out to make auto rickshaws the example of environmental consciousness in India by replacing the existing hydrocarbon-powered vehicles with electric vehicles and recharge the batteries using mostly renewable energy sources.

We began the project by doing research to determine the rickshaw's role in the culture and economy of India, and the political and cultural atmosphere with regard to issues concerning renewable and sustainable technology. The student team made an in-depth market study in the form of over 700 surveys conducted in two different cities of India, the results of which steered further economic and design research. In addition, GPS data was recorded from a number of rickshaws in major Indian cities. With this information collected, we worked to develop a driving cycle of the auto rickshaw in a typical large Indian city – in this case, Delhi. The driving cycle provided performance demand characteristics, which helped us to develop a model of the actual vehicle in ADVISOR software, and to determine the necessary vehicle parts chosen for the prototype vehicle.

We then converted the stock rickshaw to an all-electric vehicle, fitting the vehicle with a data acquisition unit to gather the relevant data. The vehicle model was then altered accordingly so that the simulated values match the actual performance data. The end result is agreement between the simulated and actual results. Once the model validity was confirmed, the relationship between battery technology used and the resulting motor efficiency was studied in order to analyze the effect on vehicle range.

In addition to the work done on developing the vehicle, the recharge infrastructure was considered in great detail. With the help of HOMER software, we developed a range of designs for a large solar and wind powered battery recharge station, with the option of an assisting LPG generator located in the vicinity of Mumbai, India. The method of transporting the batteries to and from the customer was also investigated. We chose to transport the batteries to and from the customer via all-electric converted trucks to further minimize the pollution. A small truck, TATA ACE, was identified as the vehicle of choice for the transport. The effect on the system efficiency of transporting the batteries was also considered in the design of the mother recharging station. The result is a comprehensive vehicle and infrastructure system design, with much future work entailed.

2. DRIVING PATTERN RESEARCH

In the first stage of research, team members investigated the political, economic and technological scene in India today with respect to this vehicle. Surveys helped to identify operator (driver) and passenger demographics, routines and interest in environmentally-friendly transport. This research also isolated what is needed to make the electric rickshaw a success (infrastructure recommendations, technical improvements, political/government support, etc) [Mulhall et al., 2007]. From the surveys, a greater understanding of the economics of the auto-rickshaw operator and the typical usage pattern helped establish the design criteria [Lukic et al., 2007]. In addition to survey data, GPS data was collected to build a driving cycle for the rickshaw. In light of the amount of data collected, we developed two standard

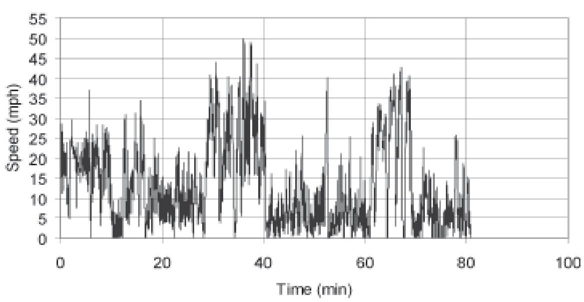

Fig. 2 Standard evening driving cycle

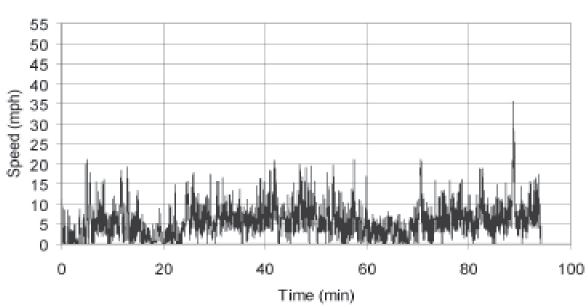

Fig. 1 Standard daytime driving cycle

driving cycles to replicate the entirety of the driving conditions during daytime and evening hours. The procedure used to arrive at these driving cycles is described in detail in [Lukic at al., 2007]. The driving cycles are shown in Figure 1 and Figure 2.

3. VEHICLE ANALYSIS AND ELECTRIC VEHICLE DEVELOPMENT

The electric vehicle prototype considered here reuses the chassis of the existing rickshaw – in particular the very popular Bajaj vehicle (Figure 3). The vehicle parameters are given in Table 1.

Fig. 3 Bajaj Auto Rickshaw

Table 1 Vehicle parameters

Outline (LxWxH)	2.67x1.24x1.69 m
Clearance	0.2 m
Frontal Area	2.09 m2
Coeff. of drag	0.5
Center of veh. mass	0.4 m
Wheel Base	1.07 m
Kerb weight	290 kg
Engine	35 kg
Transmission	15 kg
Battery	10 kg
Tank	10 kg

The existing engine, transmission and differential were removed and replaced by two brushed permanent magnet electric motors. The two motors were installed in parallel to power the rear wheels independently as seen in Figure 4. Four twelve-volt Nautilus Gold deep cycle marine batteries were connected in series providing a total of 48 Volt output to the motors. These batteries were chosen as an inexpensive option which would be

Fig. 4 Two Etek motors mounted on the autorickshaw readily available in India.

Two motors were used because such a setup eliminates the losses in the differential. In addition, the setup allows for the testing of the electronic differential concept [Gair et al., 2004; Perez-Pinal et al., 2007]. The introduction of the electronic differential, where the current is split unevenly between the motors when the vehicle is taking a turn, will make the vehicle more stable when turning, as well as improve the efficiency. At this stage, the motors were given the same current command. In the future, the advantages of implementing the electronic differential will be evaluated.

The all-electric vehicle was constructed and tested. The test results in conjunction with the known vehicle parameters were used to adjust the model in ADVISOR software, which was then used to evaluate the benefit of implementing certain improvements to the vehicle. Such a study was performed to investigate the effect of passenger load, driving pattern and battery chemistry on the range of the vehicle. More information about the modeled batteries is used later in the paper. The results are presented in Figure 5. Note that the solid horizontal lines represent the average of light and heavy traffic, while the vertical lines represent the actual heavy and light traffic range.

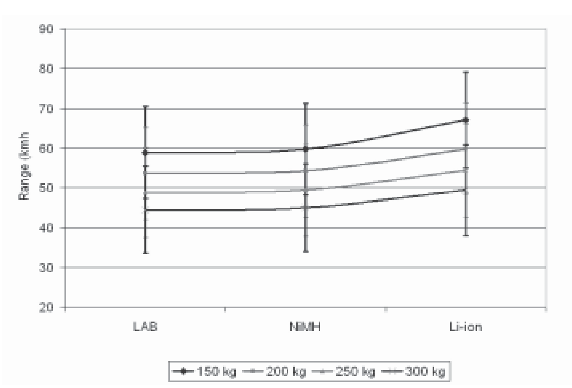

Fig. 5 Summary of the effect of passenger weight on the range with error bars accounting for the variation in range depending on the driving style (daytime or evening)

4. RECHARGING INFRASTRUCTURE REQUIREMENTS

We established several goals for the design of the recharge infrastructure. Firstly, we set goals of the operation: the battery swap process should appear as quick as petrol refueling in the eyes of the rickshaw driver, and should be as efficient and effective as possible. Secondly, the economic goal in designing this system is to maximize the amount of energy to be produced by renewable energy sources, while simultaneously minimizing the time to recover the invested money. Thus we decided to go with a centralized recharging station. The fact that the batteries are charged at a central location allows for easy maintenance by trained staff, thus ensuring longevity of the packs. In addition, the placement of renewable sources at a centralized location ensures these resources will be operated in an efficient manner. Thirdly, we wanted to eliminate the additional stress on the grid; as the electric power grid in India is either weak or non-existent in rural areas, the additional stress for transportation energy is unjustified.

Several options were considered for transferring batteries from the drop-off location to the central station: (1) use of the existing electrical grid (2) construction of a separate electrical distribution grid (3) transport of batteries by trucks. We decided to avoid using the existing electricity grid for various reasons: we aim to (1) insure that the energy used to charge the batteries is clean, (2) add no extra burden on an already weak grid, and (3) add possibilities for remote locations which have no access to the grid. On the other hand, the construction of a separate grid is prohibitively expensive.

Research and investigation into the current petrol (gas), Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG) stations revealed models of the possibilities for the supporting infrastructure for EV auto rickshaws, as well as incorporating solar technology in current and future stations. Based on this research the refueling system is envisioned to operate as shown in Figure 6. Once the batteries are charged, they are transported on trucks to "daughter" stations. These daughters are existing gas stations where the batteries can be stored until the rickshaw driver comes for a replacement. Finally, the charged battery pack is installed into the rick-

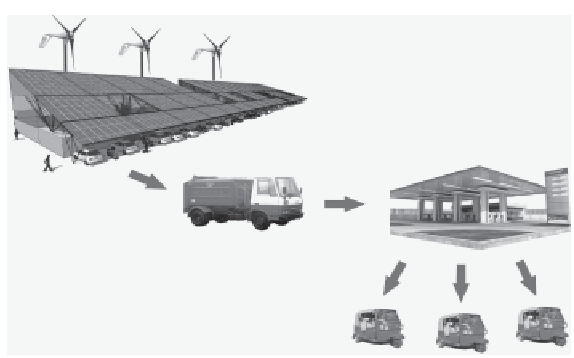

Fig. 6 Recharging infrastructure layout

shaw, while the discharged pack is taken back to the mother recharging station. We used HOMER software to find the most cost effective way of supplying energy to the batteries. In addition, once the layout of the station is known, we calculated the average amount of power produced by renewable energy sources.

For a complete efficiency analysis of the infrastructure design, we deemed it necessary to investigate the trucks used for battery transport. To do this, we determined that the use of all-electric converted trucks is ideal, specifically the TATA ACE trucks shown in Figure 8. Due to the short distances considered, the all-electric option is viable and desirable. In addition, the large number of batteries in use by the trucks can be used for load leveling at the recharging station.

The battery delivery system and the location of the mother and daughter stations are laid out as shown in Figure 7. The issue here is to design a method to service all of the daughter stations. It was shown that regardless of the branch taken by the truck, the truck does not cover more than 10 km going one way. Therefore,

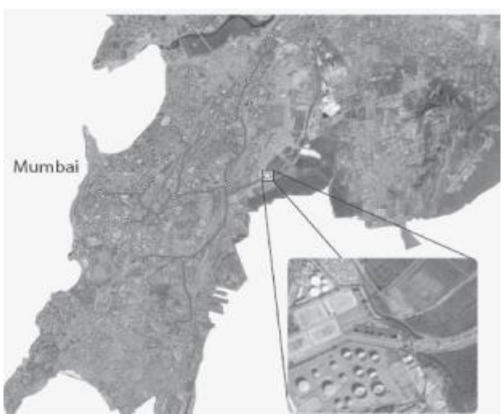

Fig. 7 Proposed locations of mother and daughter stations in Mumbai, India

Table 2 Conventional TATA truck specifications

Parameter	Value
Overall Length	3800 mm
Width	1500 mm
Wheel base	2100 mm
Overall height	1820 mm
Track Front	1300 mm
Track Rear	1320 mm
Min Turning Circle Diameter	8600 mm
Max. GVW	1550 kg
Kerb weight	805 kg

the size of the truck battery pack can be sized accordingly. In addition, the cost of transporting the batteries on a per mile basis can be calculated.

We chose the Tata ACE truck shown in Figure 8 because of its small size and maneuverability. Table 5 shows the specifications of the vehicle. This allows economical trips to one of the daughter stations each time. The truck battery pack needs to be kept small to minimize the "dead weight" that the vehicle is carrying. Based on the layout of the recharging infrastructure, it is apparent that the vehicle only needs to cover a distance of less than 20 km between stops at the mother recharging stations. This results in a goal to size the batteries so that the vehicles can achieve a reasonable range while minimizing the battery pack size. Therefore, the pack size was chosen to be large enough so that the vehicle can cover at least 20 km with a full payload, regardless of the driving conditions (heavy or light traffic). Note that the vehicles will be simulated over the driving cycles developed for the rickshaw. Ideally, GPS information would be collected from trucks used for LPG delivery. However, at this stage the rickshaw driving cycle approximation is an acceptable one.

Fig. 8 TATA ACE truck

Table 3 Electric truck specifications

Parameter	Value
Battery Type	Lead Acid
Pack Capacity	120 Ah
Pack Voltage	100 V
Motor Type	Brushed DC
Motor Peak Power	50kW
Kerb weight (w/o pack)	570 kg
Pack Weight	320 kg
Gross weight with 5 pack load	1700 kg

5. RECHARGING STATION LOAD ESTIMATION

To be able to estimate the operation and optimize the size of the recharging station, the daily energy demand from the station needs to be computed. In this section we try to estimate this load based on some assumptions of how the rickshaws will be operated and how the batteries will be transported.

One parameter which will have a major influence on the energy demand is the battery technology. Based on extensive research, three batteries representative of the three prevalent battery chemistries are considered. Their parameters are shown in Table 4. According to ADVISOR simulations, a battery pack twice the size of that of the rickshaw is sufficient to cover the target distance. This means that a battery pack that has an energy capacity of 12kWh is sufficient for one trip, and the weight of this pack is used as the minimal "dead weight on the truck". The results are summarized in Table 5. Note that the figure for the energy required for each transport is arrived at with the following assumptions:

- Truck travels an average distance of 8km to the daughter station (16km per trip)
- The truck can be loaded up to 1130kg (maximum truck payload)
- Truck is considered to travel 50% of the time in low and 50% of time in high traffic conditions

Note that the average energy required for each transport is most likely overestimated, since the vehicle will mostly be driven in light traffic conditions where less energy is used per mile. At this stage, each mother station will be designed to service a 10 mile radius with 600 vehicles. Based on these the size of the electrical load on the mother station can be approximated. To calculate the load on the power plant certain assumptions about the power plant were made based on the above discussion:

- Average weight load on the vehicle is 200kg
- The vehicle covers an average daily distance of 100km

Table 4 Battery pack specification

Battery Characteristic	Lead-Acid 40kg, 1500Wh, 11L	Ni-MH 11.6kg, 750Wh, 5L	Lithium-ion 1.5kg, 225Wh, 0.6L
Battery Cell Type	Conventional Plates-Based	Prismatic HEV20	Cylindrical
Module Type	12V120Ah	12HEV60Ah	3.6V60Ah
Number of Modules	4	8	28
Nominal Capacity	120Ah	120Ah	120Ah
Nominal Pack Voltage	48V	48V	48V
Total Energy	5.72 kWh	6 kWh	6.2 kWh
Specific Energy	35 Wh/kg	65 Wh/kg	150 Wh/kg
Energy Density	135 Wh/L	150 Wh/L	380 Wh/L
Pack Weight	160 Kg	93 kg	42 kg
Pack Volume	44L	40L	19L
Cost per kW	$ 200	$ 700	$ 1000

Table 5 Energy expended for battery transportation

	LAB	NiMH	Li-ion
Max payload on truck (kg)	1130	1130	1130
Actual payload on truck when fully loaded (kg)	1120	1116	1092
No of packs on truck when fully loaded (kg)	5	10	24
Truck maximum Range high traffic (km)	20.5	21.2	21.5
Truck maximum Range low traffic (km)	36.9	37.4	37.7
Average Range (km)	28.7	29.3	29.6
Average mother-daughter distance (km)	8	8	8
Energy stored in the pack (kW)	11.4	12	12.4
Energy per battery transportation (W)	1672.47	819.113	337.838

Table 6 Total daily energy expenditure by the all-electric rickshaw

	LAB	NiMH	Li-ion
Unit energy expenditure (Wh/km)	111.9	110.7	100.2
Daily distance covered (km/day)	100	100	100
Daily energy expenditure (Wh)	11,194	11,070	10,025
No. of Daily Transports (based on 100km/day)	1.86	1.84	1.67
Transport Energy Expenditure (Wh)	1672	819	337
Daily Transport energy (based on 6kWh pack)	3110	1507	563
Total Daily Energy Expenditure per rickshaw (Wh)	14,304	12577	10588
No. of Rickshaws	600	600	600
Total Load per day	8,582,400	7,546,200	6,352,800
No. of packs in use	1,440	1,265	1,060
"Transmission" efficiency	78.3%	88%	94.6%

- The driving is done half in heavy and half in light driving conditions (average range).

Based on these assumptions, the total daily energy expenditure per rickshaw can be calculated for each of the battery technologies.

The load on the recharging station should be distributed in such a way to match the output of the solar array. At the same time, the amount of energy put into the batteries needs to balance the energy used by the rickshaws and the battery transportation buses within 24 hours. On average, the amount of power produced by the mother station will match the energy used by the auto rickshaws plus the energy needed for transport.

6. MOTHER STATION OPTIMIZATION

As described above, the mother station will have to produce enough energy to power 600 rickshaws as well as to provide the additional energy lost in transportation. Based on the calculations above, we have arrived at the total daily energy requirements for the recharging station as a function of the battery technology used.

As was noted earlier, it was decided that the mother station will not be connected to the grid. Therefore the energy sources have to be sized in such a manner as to ensure that the station will always have enough energy to supply the daily requirements. The mother station topology chosen for investigation is shown in Figure 9. The system was modeled in HOMER software. The software was used to optimize the size of each of the components.

It was decided that the use of both wind and solar energy would be beneficial since the availability of power form these two sources is somewhat complementary. In addition, there is a need for a power source when the availability of the renewables is not sufficient. It was decided to utilize a propane powered generator. Note that other more environmentally friendly options are also possible, such as fuel cells. In this case, a regenerative (reversible) fuel cell will allow the reduction of the size of the battery bank.

6.1 Component models

The wind turbine data was obtained from a 7.5 kW Bergey Windpower turbine assuming turbine height of 25m. The curve is shown in Figure 10. The solar panels are modeled using an efficiency value shown in Figure

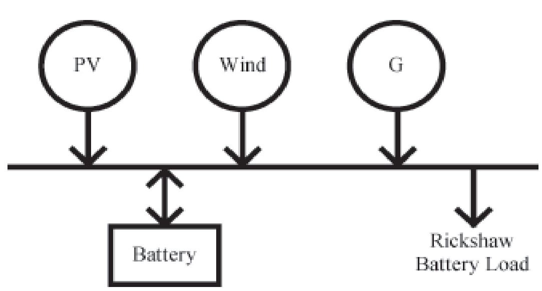

Fig. 9 Mother recharging station architecture

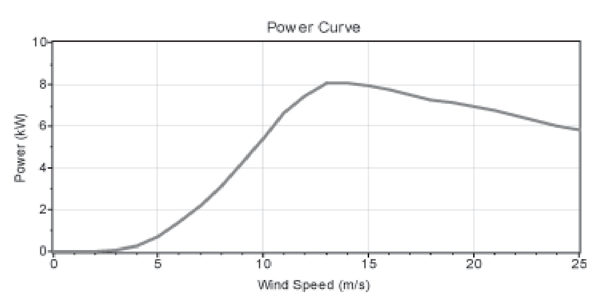

Fig. 10 7.5 kW bergey windpower turbine characteristics

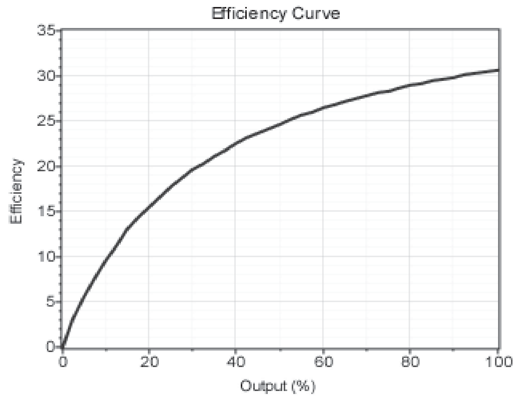

Fig. 11 Solar panel characteristic

11. The efficiency is derived using two simple assumptions:

- A two-axis tracking system is employed ensuring that radiation is perpendicular to the solar panels
- Factors such as soiling of the panels, wiring losses, shading, aging, and temperature-related effects are all lumped into a single derating factor.

6.2 Environmental conditions

To be able to predict the power production of the PV's and the wind turbines, the environmental conditions at the recharging station need to be determined. The average values on a monthly basis for global horizontal radiation and the wind speed at 10m above ground are shown in Figure 12 and Figure 13 respectively. Solar irradiation is straightforward to measure, and is consistent over larger areas. The values used in this study are derived from the information available in HOMER, given the longitude and latitude of Mumbai. Wind speed is much harder to predict, as it is dependent on the precise location, and obstacles present around the chosen location. Therefore the average monthly wind speeds are derived from HOMER. The daily variations are then estimated using data available and the wind speed at 25m can be extrapolated using procedures presented. [Sorensen, 1998].

6.3 Charging station component size optimization

To optimize the size of the recharging station components, the following procedure is used:

(1) Determine the ratio of wind to solar capacity which minimizes the month-to-month renewable energy availability. This number will be computed based on historical resource availability data

(2) Set load profile to match the profile of renewable energy availability and still meat the daily energy demand

(3) Set the size of renewable resources to meet the load during the month when renewable resources are at

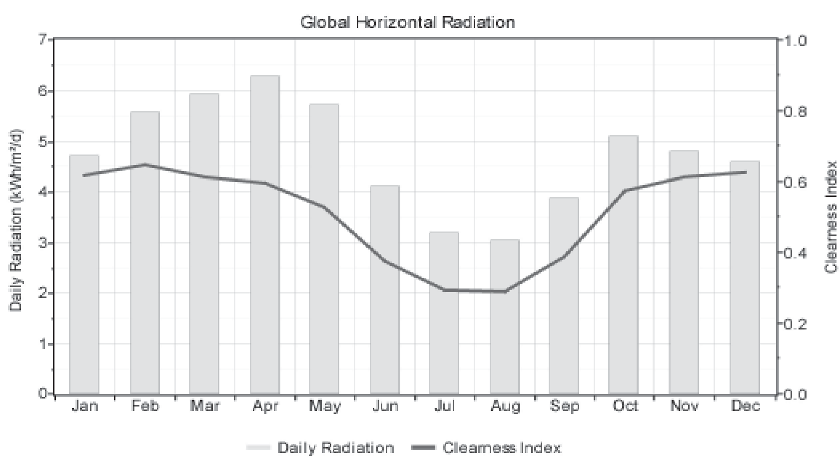

Fig. 12 Average solar irradiation

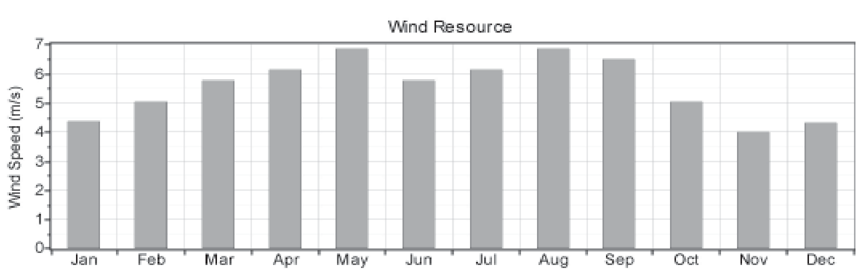

Fig. 13 Average wind speed

their peak

(4) Vary the size of the renewable resources so as to minimize the excess electricity produced.

6.3.1 Determining the ratio of wind to solar capacity

The first task was to determine the relative size of the PV array to the size of the wind turbine. It was decided that the relative size of these two components should be chosen such that their total power output varies as little as possible. It was found that $\frac{P_{PV}}{P_W} = \frac{100}{73}$ gives the least variation on a monthly basis, as shown in Figure 14. Note that the fraction is based on minimizing the variability on a month-to-month basis. There are daily peaks of power produced by renewable resources which would much exceed the daily average. As the load is somewhat flexible in terms of instantaneous power supplied, the load profile can follow the power supplied by the renewable resources. Therefore, the batteries will act as a dynamic load which follows the power supply.

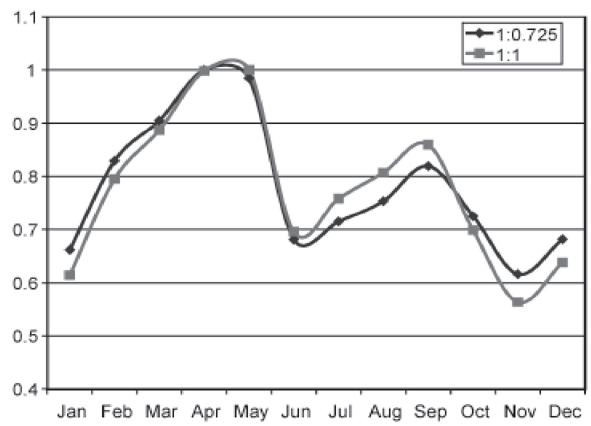

Fig. 14 Minimizing renewable energy fluctuation by optimizing the wind to PV peak power capacity ratio

6.3.2 Determining the load profile

In light of the fact that the load can be made to follow the availability of the renewables, and that the availability of renewable resources can be predicted fairly well for a 24-hour period, we can optimize the operation of the off-grid mother recharging station. The goal is to set the operation of the generator at a fixed value that will ensure that the batteries are fully charged by the end of the 24 hour period. The generator power can then be set using equation (1).

$$\overline{P_{GEN}} = \frac{\int_{24hrs} P_{RENEWABLE} - P_{LOAD}}{T_{RECHARGE}}$$

Results of such a control strategy are presented in Figure 15 for April 1-3 given $T_{RECAHRGE}$ =24hrs. From equation (1) it is apparent that if the renewable production exceeds the amount of energy the load can absorb within a day, some of the produced energy will go to waste.

6.3.3 Sizing the off-grid recharging station

The next step was to determine the actual size of the PV and the wind turbine to maximize the renewable fraction while minimizing excess electricity production due to overcapacity. One method would be to size the renewable resources so that they meet all of the demand during the months of April and May. This would be the maximum size of the renewable resources, as larger renewable resources would produce substantial losses in the months of April and May. At the same time, care should be taken to ensure that just enough power is delivered to the batteries on a per day basis. Therefore,

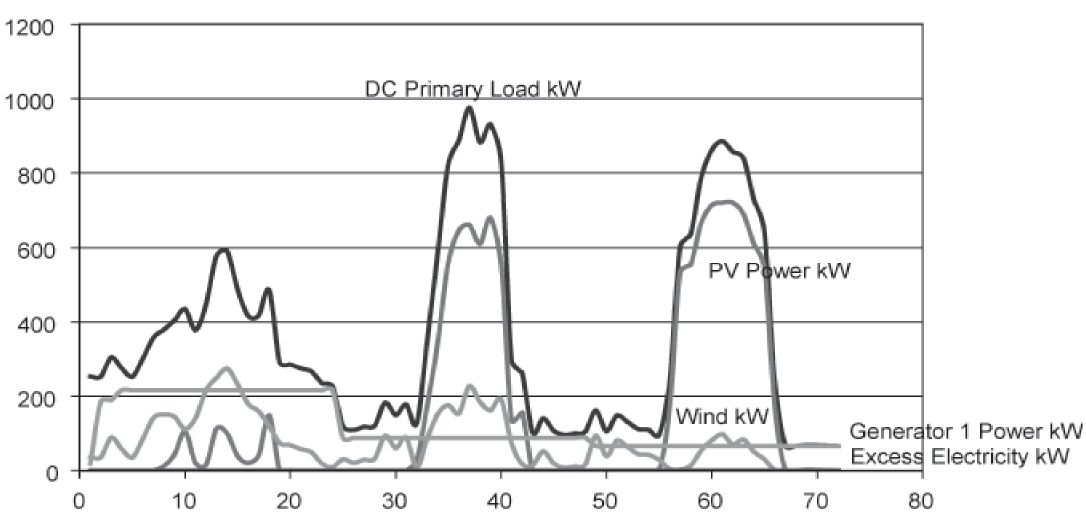

Fig. 15 System operation for April 1-3

Table 7 Case study for sizing the mother station

	Size (kW)			Output (MWh/yr)			Excess		
	PV	Wind	Gen	PV	Wind	Gen	%	MWh	% Renewable
Case 1	600	438	350	1288	1128	896	4.82	159	73.0
Case 2	540	394	350	1159	1031	1053	2.74	89	67.5
Case 3	480	358	350	1030	914	1246	1.11	35	61.0

the generator must be sized to provide sufficient power during November when least renewable power is available. Based on these constraints, three cases are considered in Table 7.

In addition, the size of the additional energy storage is studied. The goal of including the UPS is to minimize the renewable energy that will not be absorbed by the load. From Figure 16 it is apparent that increasing the size of the UPS will not reduce the excess energy produced. The reason is that most of the excess energy production occurs on consecutive days. This means that the load shifting capability of the energy storage system is used only once.

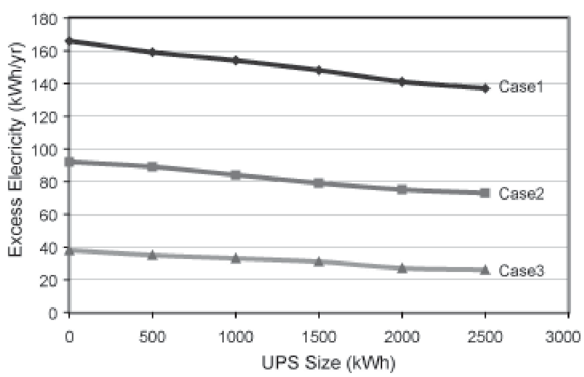

Fig. 16 Effect of the size of the additional energy storage on the excess electricity produced

7. CONCLUSION

In this paper, we have investigated the use of all-electric auto rickshaws for transportation in Asia. The all-electric vehicle was designed and tested, and a model of the vehicle was developed for use in system level simulations. In addition, we presented the operation of the entire transportation infrastructure including an off-grid recharging "mother" station. It was shown that the mother station with 480kW PV, 358kW wind turbine, and 350kW propane generator can power 600 auto rickshaws while producing 61% of its energy using renewable resources. In the future, a grid connected mother station will be investigated.

Acknowledgement

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Role of electric mobility in a sustainable, and energy-secure future for India

Within the next decade, a set of four low-carbon technologies – LEDs, solar energy, wind energy, and electric vehicles are set to reconfigure the dynamics of several industries. While India is making significant progress in the first three, we hardly see any electric vehicles on our roads, though the National Electric Mobility Mission Plan (NEMMP-2020) was launched by the Government of India on 9 January 2013 with the aspiration of selling 6–7 million new electric vehicles in 2020 to achieve liquid fuel savings of 2.2–2.5 million tonnes, along with substantial lowering of vehicular emissions and a decrease in CO_2 emissions. In addition to these vital benefits, acceleration of electric mobility in India will also lead to higher job creation in manufacturing. In this article, key recommendations are proposed to accelerate the progress of electric vehicles as a much-needed move towards a more sustainable and energy-secure future for India and a healthier life for Indians.

Keywords: Battery storage, electric vehicles, energy security, low-carbon economy.

INDIA adopted the 17 Sustainable Development Goals (SDGs) on 25–27 September 2015 and entered into the Paris Agreement on 30 November 2015. The country ratified the Paris Agreement on 2 October 2016 and confirmed its Nationally Determined Contributions (NDCs) for the years 2021–2030 to the United Nations Framework Convention on Climate Change (UNFCCC)[1]. On 3 June 2017, the Prime Minister stated that environment protection is an article of faith and a centuries-old tradition for Indians. The Government of India (GoI) has launched the National Action Plan on Climate Change (NAPCC), comprising eight missions in specific areas, and announced a National Electric Mobility Mission Plan (NEMMP-2020) for promotion of electric vehicles (EVs) as part of the NAPCC[2,3].

India's per capita emission of 1.72 t CO_2 equivalent in 2016 was about 38% of the world average (4.49 t) and approximately one-fourth that of China (6.62 t). In 2015, the power sector was the largest contributor of CO_2 emissions in India, contributing about 50% (1066 Mt (Million tonnes)) of total CO_2 emissions from fuel combustion (2066 Mt), while the road transportation sector ranked third with 237 Mt of CO_2 emissions[4].

Transportation fuels – the Achilles heel in India's energy security

The consumption of petroleum products in India has been growing at a compounded annual growth rate (CAGR) of 4% during the 12th Five-Year Plan (FY12–FY17) to reach a level of 194 Mt in FY17 (ref. 5). In 2016, India was the world's third largest oil consumer with 4.8% of the total crude oil consumption, while holding only 0.3% of the world's proven oil reserves. Production of crude oil in India has declined from 38 Mt in FY12 to 36 Mt in FY17, largely due to the declining output of mature oil fields[5]. As a result, the share of imports in the country's consumption of petroleum products has increased from 75.6% in FY12 to 81.7% in FY17 (ref. 5).

Crude oil consumption in India is expected to increase at a CAGR of 4.4% during the 13th Plan[6]. However, due to the absence of fresh discoveries and exploitation of reserves from mature oilfields, the balance recoverable reserves of crude oil in India have declined from 660 Mt in April 2011 to 604 Mt in April 2017, leaving the country with a reserve/production ratio of 17 years at the current rate of production[5].

India imported 214 Mt of crude oil during FY17 valued at Rs 470,251 crores as against an import of 203 Mt valued at Rs 416,579 crores in FY16 – an increase of 5.46% in quantity terms and 13% in value terms compared to the import of crude oil during 2015–16 (ref. 5). Therefore, the increase in crude oil prices to US$ 60 per barrel[7] after averaging US$ 46–48 per barrel during FY16 and FY17 is a cause for concern, particularly in view of the fact that crude oil imports accounted for 22.6% of the total imports of India in FY17 after reaching an all-time high of 36.6% in FY14 (ref. 5).

While falling crude oil prices have driven the improvements in India's public finances over the past couple of years, a spike in oil price to around US$ 70 per barrel (from the current level of US$ 60) is enough to strain our public finances and increase GoI's fiscal deficit by 0.4% (ref. 8). As India will continue to depend on domestic sources (coal and increasingly renewable sources) for electricity generation, GoI has more control over electricity prices than on those of imported crude oil. It makes compelling economic sense for India to accelerate its move to EVs, rather than be held hostage to external forces controlling the crude oil market. In this regard, the country must study the set of energy policies adopted by China, which is the second largest oil importer in the world (consuming over 13% of the world's total consumption in 2016) and adapt them to suit our own situation.

Further, in May 2017, NITI Aayog and Rocky Mountain Institute recommended several initiatives for India's mobility, energy and environment needs, including offering incentives to EV manufacturers and discouraging privately-owned petrol- and diesel-fuelled vehicles[9]. According to this report, 'India can save 64% of energy demand from the road sector for passenger mobility and 37% of carbon emissions in 2030 through its EV program. This would result in a reduction of 156 Mtoe (million tonne of oil equivalent) in diesel and petrol consumption for that year. At US$ 52/bbl of crude, this would imply a net savings of approximately US$ 60 billion in 2030'. These projected savings exceed Rs 388,000 crores at the current exchange rate.

Electric vehicles – global scenario

UNFCCC has declared that, 'transport contributes almost one-quarter (23%) of the current global energy-related greenhouse gas (GHG) emissions and is growing faster than any other energy end-use sector. GHG emissions from transport are anticipated to rise from today's levels by nearly 20% by 2030 and close to 50% by 2050 unless major action is undertaken'[10]. The Paris Declaration on Electro-Mobility and Climate Change and Call to Action has emphasized the need to ensure that at least 20% of all road transport vehicles globally will be EVs by 2030 (ref. 10). In view of their much wider popularity[11], the scope of this article is limited to battery electric vehicles (BEVs), and plug-in hybrid electric vehicles (PHEVs), which are collectively referrred to as electric vehicles in this article.

While EVs continue to face challenges, they have caught on much faster than was thought likely just a few years ago, due to a potent combination of technological improvements, subsidies, tax breaks, government mandates and environmental awareness[12]. While just 1.1% of all cars sold globally in 2016 were EVs, two million EVs were plying on the world's roads in 2016, out of which 1.2 million were BEVs[11]. While the global EV stock corresponds to just 0.2% of the total number of passenger light vehicles in circulation today, this is projected to increase to 10% in 2030 in the 2° rise scenario[11]. During the first nine months of 2017, global EVs sales (including passenger cars, light trucks and light commercial vehicles) reached 764,000 units, a year-on-year growth of 46% over 2016 (ref. 13). During the last quarter (July–September 2017), BEVs accounted for 66% of EV sales worldwide with PHEVs forming the balance 34% (ref. 13). More importantly, in 2016, the number of publicly accessible charging points reached 320,000 units globally, representing a 72% growth since 2015 (ref. 11).

In 2009, the Clean Energy Ministerial (CEM) established a multi-government policy forum called Electric Vehicles Initiative (EVI) dedicated to accelerating the deployment of EVs worldwide[11]. The EVI has ten member governments (Canada, China, France, Germany, Japan, the Netherlands, Norway, Sweden, the United Kingdom and the United States) with International Energy Agency (IEA) as the coordinator[11]. China and the United States are co-leading EVI, while India is 'also engaged in the EVI's activities'. The EV30@30 campaign launched in 2017 has set the collective aspirational goal for all EVI members of a 30% share for EVs in the total sales of all cars and commercial vehicles in 2030 (ref. 11).

In 2016, China had the largest stock of EVs on the road, with about a third of the global total[11]. China was by far the largest electric car market in 2016, with 336,000 new EVs registered, more than double the number (160,000) registered in the United States[11]. Seventy-five per cent (257,000) of the 336,000 EVs sold in China during 2016 were BEVs, while PHEVs accounted for the balance 25% (ref. 11).

China's overall policies have created several favourable conditions for EV owners/operators. EV subsidies in China are the second most generous in the world after Norway[14]. For an EV with a range of 250 km or more, the total subsidy offered by the Central and City Governments in Beijing amounts to US$ 10,000 per vehicle[15]. Further, in six major cities, including Beijing and Shanghai, electric cars are exempt from license-plate lotteries and high registration fees that apply to cars with internal combustion engines[11]. As a result of these monetary and non-monetary incentives, while EVs accounted for 1.4% of the total number of cars registered in China in 2016, they had a share of 7.3% among all cars registered in Beijing during the same period[11]. After 2020, China will shift away from direct subsidies to the provision of non-monetary incentives, including the expansion of its already extensive public charging infrastructure with 150,000 public charging points[16].

While more than 200 companies (including global majors like Ford, Tesla and Volkswagen) have announced their intention to make EVs in China, some Chinese manufacturers have started selling their EVs globally. In 2016, a Chinese home-grown company, Build Your Dreams (BYD) sold approximately 100,000 EVs compared to

Tesla's sales of 76,000 BEVs[14]. Emboldened by its success in China, BYD (backed by the world's most famous portfolio investor, Warren Buffett), has now tied up with India's Goldstone Infratech to deliver 25 electric buses to Himachal Pradesh for plying on the steep gradients of the Kullu–Manali–Rohtang Pass route, in addition to six electric buses to Mumbai for use within the city[17,18]. As BYD is also the world's largest producer of EVs, it is well-placed to manufacture EVs in India if the business prospects are more conducive.

In the United States, a Federal income tax credit of up to US$ 7500 (Rs 485,000) is allowed for the purchase of a new qualified EV that is placed in service[19]. This amounts to 20% of the purchase cost of the Cheverlot Bolt (about US$ 38,000 or Rs 2,460,000), which was the second largest selling EV in the US during the first 10 months of 2017 (ref. 20). This tax credit (coupled with the proliferation of public charging points) continues to contribute to the popularity of EVs for intra-city commuting in the US, a country reared on internal combustion engine (ICE) vehicles. However, this tax credit will be phased out gradually for each auto company when it crosses the 200,000 mark in cumulative EV sales within the US[19].

The United Kingdom (UK) has approximately 13,000 public charging points spread across 4500 locations to cater to about 115,000 electric cars today[21]. The UK Government has recently committed £400 million (Rs 3450 crores) to increase the number of roadside chargers, and an additional £100 million (Rs 862 crores) to provide up to £4,500 (Rs 388,000) as a grant towards the cost of buying an EV till 2020 (ref. 22).

Despite Tesla's small size (approximately 76,000 cars in 2016 versus Ford's 6.6 million) and massive losses, it is perceived to be a future winner in the auto industry which is facing more change over the next few years than in the past century, thanks to new technologies such as electrification and self-driving systems. Therefore, Tesla has a market value of US$ 57.6 billion, compared with the US$ 48 billion valuation for a century-old auto company like Ford[23]. This is the key factor driving all global auto majors to diversify into EVs.

Electric vehicles – current scenario and way ahead for India

India is the fifth largest market for passenger cars in the world, with more than three million cars sold in FY17 (ref. 24). The country's car market is expected to grow at a CAGR of 9–11% over the next five years to become the third largest car market in the world by 2020 (ref. 24). As early as April 2011, GoI approved the National Mission for Electric Mobility, after which an apex mission structure with a National Council for Electric Mobility and a National Board for Electric Mobility was set up (ref. 25). In January 2013, NEMMP 2020 was unveiled by the then Prime Minister of India[26]. According to NEMMP 2020, '6–7 million units of new vehicle sales of the full range of electric vehicles, along with resultant liquid fuel savings of 2.2–2.5 million tonnes can be achieved in 2020. This will also result in substantial lowering of vehicular emissions and decrease in carbon di-oxide emissions by 1.3% to 1.5% in 2020 as compared to a status quo scenario'[26].

To realize these goals, a scheme entitled, 'Faster adoption and Manufacturing of (hybrid and) electric vehicles in India' or FAME-India scheme was also approved under NEMMP 2020, with a budget of Rs 13,591 crores over a five-year period (FY15–FY19), out of which Rs 12,471 crores was allocated to demand-side initiatives[25]. In June 2014, NEMMP 2020 was included in the National Action Plan for Climate Change (NAPCC), with an overarching aim of shifting road transportation in India towards sustainable development through greater emphasis on national energy security, and the use of renewable sources to mitigate the adverse impact of economic growth on environment and climate change[25]. However, EVs are yet to take off in India due to a variety of reasons, including lack of public charging infrastructure as well as financial and regulatory barriers, though NEMMP 2020 envisaged that, 'savings from the decrease in liquid fossil fuel consumption as a result of shift to electric mobility alone will far exceed the support provided, thereby making this a highly economically viable proposition'[26].

Specifically, under the FAME-India scheme[27,28]:

- The maximum incentive for an electric car is limited to Rs 138,000 which is about 12% of the ex-factory cost of the Mahindra eVerito sedan supplied to EESL recently.
- Between 1 April 2015 and 30 June 2017, out of a total amount of Rs 196.77 crores sanctioned as demand incentives for procuring 145,431 hybrid/EVs, the Ministry of Heavy Industry (MHI), GoI, could incentivize the procurement of only 2446 PHEVs and 1599 BEVs with a total incentive payout of less than Rs 37 crores[29]. The bulk of the incentive payout of Rs 196.77 crores has been used to procure about 96,000 mild-hybrid cars (which cannot be plugged into an electrical system), with an incentive payout of about Rs 125 crores, while Rs 31.4 crores has been used to procure approximately 42,000 low-speed two-wheelers with conventional batteries[29].
- While 25 charging stations have been installed at six different locations in Bengaluru by Mahindra REVA Electric Vehicles Pvt Ltd between August 2015 and June 2017, MHI has sanctioned proposals for installing only 435 charging stations (predominantly in New Delhi) under the FAME-India scheme[30].

The FAME-India scheme was envisaged with four thrust areas, viz. technology development, demand creation, pilot projects and charging infrastructure. However, the creation of charging infrastructure which is critical to facilitate adoption of EVs has been sadly ignored till recently[31]. Public charging infrastructure should therefore be deployed in advance in order to minimize the potential adverse effects of negative driving experiences using EVs. However, India has only 222 public EV charging stations[31] compared with the 150,000 public charging points already installed in China[16]. In 2014, the Lawrence Berkeley Laboratory (LBL), USA, had recommended the installation of 1270 charging points (including three fast DC chargers) at various locations to cater to 10,000 EVs in the NCR[32]. In contrast, it was only on 10 November 2017 that NITI Aayog released a proposal for 135 public charging stations in New Delhi at 55 locations[33]. This shortfall in availability of public charging infrastructure vis-à-vis the number of public charging points required to meet the needs of EV users has hindered the growth of EVs in India according to the roadmap laid out in NEMMP 2020.

In September 2017, MOP-controlled Energy Efficiency Services Limited (EESL) finalized orders for procuring 10,000 electric sedan cars to be used by various GoI departments and companies controlled by them[34]. While only 500 electric cars have been supplied in the first phase, the 9500 cars that will be procured during 2018 may be the game changer for EVs in India. As these 10,000 cars are for captive use by GoI and its companies, and charging stations will be connected to the electricity meter of government buildings, there is no reselling of electricity by non-licensee private companies, which is currently prohibited by the Electricity Act 2003 (ref. 34).

China is playing a lead role in the proliferation of EVs by promoting home-grown companies which have already mass-produced electric cars capable of travelling 200–300 km on a single charge[11]. In contrast, only two Indian auto companies could qualify to supply EVs against the EESL tender[34], which specified a minimum range of 130 km on full charge. Recently, Suzuki has entered into an agreement with Toyota to manufacture and sell electric cars in India by 2020, which will be fitted with Li-ion batteries produced locally in a JV with battery manufacturers, Toshiba and Denso[35].

India's Forum of Electricity Regulators (Forum) has studied the integration of EVs into the distribution grid and stated that EVs will not have a substantial impact on the grid voltages in residential, commercial and mixed feeders[36]. The Forum has recommended that Central Electricity Authority (CEA) notify additional standards for grid connectivity of public charging infrastructure[36]. Further, the use of smart chargers will also facilitate cost-effective renewable energy integration[37].

While NEMMP 2020 was announced by GoI in January 2013, the Electricity Act 2003 does not permit EV charging businesses to resell the electricity without specific licensing arrangements till today[36]. Therefore, the Forum has recommended several statutory interventions to ensure uniformity and harmony of regulations as well as suitable provisions in the rules, tariff policy, grid code, and standards to facilitate the goals of NEMMP 2020 (ref. 36).

If the growth of BEVs attains the trajectory recommended in a recent LBL study, they will constitute 44% of the projected active car stock (89 million) in 2030 (ref. 37). The proliferation of BEVs will reduce CO_2 emissions, in addition to reducing India's import dependence for crude oil while increasing the requirement of electrical energy by 46 TWh, which is only 1.8% of the total electrical energy demand of 2522 TWh projected in 2030 (ref. 37). In the NDC-compliant scenario of India's power sector, BEVs can reduce CO_2 emissions from cars by 40–50%, if their sale increases to 10 million in 2030 from the 2015 level of 20,000 (ref. 37).

Batteries for electric vehicles

As the number of parts in an electric car is approximately two-thirds of that in a petrol/diesel car, the ability to integrate production across several fronts, which is a key strength of conventional automakers, may be less important for electric cars[38]. Batteries form the most critical and single most expensive component of an EV today. Car makers are planning significant growth in EV sales – between 25% and 40% CAGR right up to 2025 (ref. 39). Battery producers are expected to match EV growth rate while responding to growing demand from other areas, i.e. stationary storage. In 2015, battery pack production volumes of over 200,000 packs per year were estimated to cost US$ 200/kWh or less, which was 33% lower than the US$ 300/kWh estimated for production volumes between 10,000 and 30,000 units[11]. Due to economies of scale, the cost of batteries fell by more than half between 2012 and 2016 (ref. 40).

EV batteries will also require a secure and sustainable supply of raw materials, including nickel, cobalt and lithium[38]. Tesla has identified nickel, cobalt, graphite and lithium as the biggest cost drivers of battery cost[41]. The EV sector is projected to consume 24% of total lithium output by 2020, up from approximately 7% in 2015 (ref. 38). To cater to this surge in demand, Goldman Sachs projects the global lithium supply to expand at a CAGR of 12% till 2020 to fuel the demand created by batteries during this period[38].

While the exact composition of the Panasonic/Tesla batteries is not known, typically cobalt represents about 0.22 kg/kWh in nickel–cobalt–aluminum (NCA) batteries used by Tesla, compared to 0.36 kg/kWh for nickel–manganese–cobalt (NMC) batteries adopted by most peers[42]. All major EV battery producers are moving to higher nickel-rich batteries (higher intensity NMCs and

NCAs) due to: (i) superior energy density; (ii) lighter weight for any given battery size; (iii) increased vehicle range and (iv) lower metal cost[39]. An NCA cathode (used in Tesla batteries) is comprised of 80% nickel and 15% cobalt[42]. Li-ion battery cells that contain cobalt have higher energy densities than those without it, which is why cobalt is in great demand by Li-ion battery manufacturers seeking the highest energy capacity in the smallest package[43].

The cascading impact of low-carbon technologies is exemplified by the significant expansion required in the production capacities of lithium, graphite, nickel and cobalt to cater to the rapidly increasing demand for batteries, both for grid-level storage as well as for EVs[38]. Each EV fitted with an NMC battery (~250 kg) is estimated to require approximately 138 kg of copper in addition to 11 kg each of cobalt and nickel[44]. Around 95% of the world's supply of cobalt comes as a by-product of nickel or copper processing, making cobalt supplies largely dependent on the production of these two metals. On the other hand, more than 60% of primary cobalt (electrode) is mined in the strife-torn Democratic Republic of Congo (DRC), which has raised fears among automakers over security of supply[45]. However, this has not stopped Chinese companies from acquiring control of the Tenke Fungurume mine in DRC, one of the largest known cobalt sources[42].

China, with the second largest reserves of lithium, is trying to secure strategic stakes in Australia and Chile, while American mining companies have already acquired mines in Chile in addition to stakes in upcoming lithium projects in Australia[46]. China will continue its efforts to secure cobalt and nickel mines and downstream assets.

Therefore, GoI must start working on securing key raw materials for EV batteries (lithium, nickel and cobalt) in India and/or abroad, since five companies produce 50–60% of the world's nickel and cobalt[39]. As India does not produce primary cobalt or nickel today[47,48], GoI must direct the Geological Survey of India (GSI), Mineral Exploration Corporation (MEC), National Mineral Development Corporation (NMDC) and Coal India Ltd (CIL) to dedicate well-resourced efforts towards proving the currently known resources of lithium, cobalt and nickel as well as the discovery of new reserves. The Council of Scientific and Industrial Research (CSIR), New Delhi must focus its R&D efforts in this direction, and develop cost-effective technologies for recovery of values from these reserves.

Summary and recommendations

Within the next decade, a set of four transformative low-carbon technologies – LEDs, solar energy, wind energy and EVs will reconfigure dynamics in several industries with parallels to other tech-driven developments like shale gas or e-commerce. While India is making significant progress in the first three, there is hardly any progress with regard to EVs.

EVs have a long way to go before reaching deployment scales capable of making a significant dent in the growth of global oil demand and CO_2 emissions, since the global EV stock constitutes just 0.2% of the total number of passenger light-duty vehicles in circulation today[11]. But electric car sales have grown at rates exceeding 40%/annum from 2010 onwards[11,13]. The economic, environmental, health and security-related benefits of replacing diesel/petrol driven vehicles with EVs in India have been documented in a number of studies[9,32,37], along with a listing of the key areas where substantial changes are required in some of our statutes, policies, standards and practices[9].

During December 2017–January 2018, two home-grown Indian automobile companies, Tata Motors and Mahindra & Mahindra have developed and sold a total of 500 electric versions of their popular sedan models (Tigor and Verito respectively) to EESL after testing and certification[49]. The balance 9500 cars will be supplied in 2018. Each of these cars has a range of over 100 km on full charge, which is sufficient for daily commute by most individuals. EESL's order includes the maintenance of these 10,000 EVs by the respective suppliers for five years.

EESL has also procured 200 numbers of 3.3 kW AC chargers (capable of charging an EV in 7 h) from two Indian companies, in addition to 25 numbers of 15 kW DC chargers capable of charging an EV battery in 40 min (ref. 49). While these chargers will be adequate to charge the 500 sedans already supplied, EESL has announced that it will be placing additional orders for EV chargers (which may be as high as 4000 numbers), as the balance of the order of 10,000 EVs is gradually fulfiled. EESL has also decided to place another order for 10,000 EVs next year[50]. On 21 November 2017, GoI also announced the standardized protocols for EV charging infrastructure[51]. This indicates that there is no technological barrier as such to the development of EVs or the critical charging facilities by Indian manufacturers, and that GoI has also developed the confidence required to place bulk orders.

However, in order to broadbase user acceptance of EVs in India, GoI must step up its public infrastructure development (including upgradation of local electricity grids to feed power efficiently to fast-charging stations), fiscal incentives and R&D efforts, to achieve the goal of NEMMP 2020. While NITI Aayog has been tasked with the development of a strategy for clean mobility solutions in a note to the Union Cabinet[52], the following recommendations are proposed to transition towards a low-carbon, greener and more energy-secure economy for India, consonant with NEMMP 2020:

- Range anxiety is a critical factor influencing the decisions of prospective EV owners. Creation of adequate charging infrastructure for EVs will facilitate a significant reduction of tailpipe emissions within the top six cities in India, that are already facing high pollution levels leading to heightened health concerns of their residents. Therefore, GoI should develop business models and enact suitable policies based on international best practice to incentivize the installation of fast charging facilities in all parking lots (public or private) in the top six cities of India to start with.

- To achieve the goals of NEMMP 2020, GoI must amend Electricity Act and Rules, and remove all barriers hindering the private sector from setting up EV charging points. The Forum has recommended statutory interventions to ensure uniformity and harmony of electricity regulations as well as suitable provisions in the electricity rules and tariff policy[36]. GoI must implement these recommendations immediately.
- Introduction of EVs in captive fleets can reduce emissions and operation costs, while raising employee awareness for green technologies. The total number of vehicles used by GoI and its agencies is estimated to be 500,000 (ref. 34). Therefore, GoI should frame a policy to mandate and/or encourage procurement of EVs by Governments/PSUs as well as other authorities on the lines of the declaration by eight EVI countries during COP22 (ref. 53). In case EESL extends its services to State Governments (including its State PSUs) as well as public transport undertakings, this will ensure economies of scale through standardization, and reduce the need for subsidies to proliferate EVs and electric buses while improving the environment in our cities as the existing fleet of diesel-powered buses is progressively replaced and/or replenished. This will also enable the proliferation of EV charging infrastructure in several cities and promote better acceptance by other categories of EV customers (companies, institutions, and individuals).
- EESL must start selling EVs to the public as well with a package of fiscal incentives and maintenance packages to kickstart the electric mobility revolution by giving the Indian auto market sufficient consumer experience to start building a consumer base on a large scale. This strategy will help individual buyers to get access to the optimal technology and attractive commercial terms and conditions already secured by EESL, and therefore facilitate the broader acceptance of EVs according to NEMMP 2020.
- Shared mobility (ride-sharing) is becoming popular in India. Since the financial attractiveness of EVs is directly proportional to their daily usage, GoI must facilitate ride-sharing companies who are deploying EVs in different cities[54], by incentivizing them to install fast-charging infrastructure for EVs that can also be used by the public.
- Governments across the world offer substantial direct and indirect incentives to EVs. Direct incentives include purchase subsidy for EVs and subsidies for installation of public charging stations as well as smart chargers, while indirect benefits include access to reserved lanes and parking spots[11,36]. GoI should replicate such proven strategies starting with the six largest cities having reliable power supply and robust distribution systems.
- While the GST rate of 12% on EVs is significantly lower than that on petrol/diesel cars today[55], the incentives under FAME-India are not sufficient to ensure sales of EVs in India according to NEMMP-2020. Therefore, GoI must enhance and broaden the package of incentives till EV sales in India reach the NEMMP-2020 target of 6–7 million per year.
- GoI has recently declared that there is no proposal under consideration to incentivize manufacturers to set up facilities in India for making lithium-ion batteries[56]. However, GoI must provide attractive fiscal incentives for a limited period to companies investing in such facilities in the country to achieve the goals of NEMMP 2020. These batteries will also enhance the use of renewable energy in remote locations with autonomous micro-grids.
- In an earlier study based on a target of 100% EV sales by 2030, NITI Aayog and Rocky Mountain Institute have estimated that India's cumulative EV battery requirements between 2017 and 2020 will be at least 120 GWh, rising to a cumulative EV battery requirement exceeding 970 GWh between 2021 and 2025 (ref. 9). In their updated study published in November 2017, they have recommended the development of India's EV battery manufacturing industry in three stages, with progressively larger economic value capture at each stage[57].
- In a scenario with 100% EV sales by 2030, India's cumulative battery requirements between 2026 and 2030 will exceed 2410 GWh (ref. 9). Production volume is a key factor in determining the cost of battery packs. Therefore, GoI must take immediate steps to promote the creation of facilities to design and build solar cells/modules and storage systems in quantities commensurate with NEMMP 2020. Manufacturing EV batteries in India will enable Indian automakers to produce EVs at attractive prices and will potentially enable the country to become an export hub for batteries. Domestic manufacturing of batteries at this scale presents an enormous economic opportunity for India[57]. Therefore, GoI should make an effort to implement all enablers required to facilitate the domestic industry to put up advanced battery manufacturing capacities in the country.
- GoI must secure key raw materials for batteries (especially lithium, nickel and cobalt) in India and/or abroad with the same zeal dedicated to acquiring oil and gas fields earlier. GoI must also facilitate research in the recycling and reuse of used Li-ion batteries to

reduce the need for such imported minerals with limited global supplies today.

- GoI-controlled exploration/mining organizations like, Geological Survey of India, Mineral Exploration Corporation, National Mineral Development Corporation, and Central Mine Planning and Design Institute, must be directed to carry out exploration for cobalt and nickel in India, while the Council of Scientific and Industrial Research must set up pilot plants for optimal recovery of values from lithium, cobalt and nickel ores.

Finally, air quality is also a key driver for cities to encourage proliferation of EVs. GoI must therefore facilitate and incentivize the six largest cities of India which have reliable power supply and distribution systems, to proliferate electrification of all road transport as the economic and social benefits of a healthier population are immeasurable. Learnings from these cities can be replicated across the nation in consonance with NEMMP-2020.

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Wireless Battery Charger Based Charging Station For Eva Vehicle With Pave Inclusion

Abstract: Now a days, we are in situation to create pollution free environment. Per year _60%_ Percentage of pollution was created by vehicle Co2 emission in addition to that, the availability of petroleum product for upcoming years also create problem to our fast lifestyle. So, vehicle manufacture increasing their research and production of Electric vehicle, which is one option to create pollution free environment and to minimize scarcity of petroleum products. Now the charging station is the main problem for Electric vehicle, especially it will create big problem in our India which is under the category of developing country .In this paper we are discussing about charging station of Electric vehicle including PV (photovoltaic panel /solar panel) and wireless battery charger .Here we are using new QDQ (Quad D quadrature)-QDQ coil design which increase the efficiency of power transfer at reasonable misalignment. This QDQ-QDQ structure use 2 sets of - 4 adjustment Q coils present inside 1 D coil. The coil design was made using JMEG FEM software to calculate inductive parameter and overall performance calculation from PV to DC Battery storage was checked using MATLAB..

Index Terms**: *EV (Electric vehicle), PV (Photovoltaic), Wireless charging, QDQ (Quad D Quadrature).***

I. INTRODUCTION

Due to increasing greenhouse gas radiation, and scarcity of petroleum products for upcoming years makes vehicle manufactures to find out alternative solution like Electric vehicle, hydrogen car etc. The electric vehicle become famous from 21st century from 2010 to 2016 around 1 million electric vehicles including (cars, vans and trucks) was utilized by consumers. India will also going to be part in upcoming years. In this paper the power levels of battery charging and the infrastructure required for EVs are described[1].But charging station become major problem now a day especially for India which is under the category of developing country. So in this paper we are focusing mainly on charging station for electric vehicle it will be very much help full for India which is under the category of developing country.

As of now, three types of Charging Station are available for this Electric vehicle

TYPE 1: EV charging station –120v AC Plug
TYPE 2: charging Station -240v /280v AC Plug
TYPE 3: DC Fast charger

By considering the worry of electric car owners to find out suitable charging point, High cost and space consideration make us to move Type 4: wireless battery charger. This paper Discuss about charging station for electric vehicle with the combination of PV power and wireless battery charger.

We are now in situation to rectify drawbacks that found in wireless battery charger. Even though many advantages present in this wireless battery charger there are some Disadvantages will also present

1) Charging time
2) Efficiency in performance
3) Misalignment between sender and receiver

In this paper we are using QDQ – QDQ coil structure with LCC -LCC compensation. As compare to many other Basic topologies of compensation methods like primary series-secondary series (SS), parallel-series (PS), primary series-secondary parallel (SP), parallel-parallel (PP) and other high order topologies such as LLC -S, CLC-LC, LCL-LC (L- inductor, C-capacitor and S-series connected capacitor). The LCC-LCC compensation methods has proven to have higher efficiency so in this paper we are using LCC (primary) - LCC (secondary) for achieving higher efficiency. We have introduced new model of coil design QDQ – QDQ structure for reaching high Misalignment tolerance.

In wireless battery charge there is the chance of misalignment between charging coil (primary) and Pick -up coil (secondary). Due to misalignment in power transmission, the coupling coefficient produce between coils and design will reduce. So here we are in the situation to develop a coil design to withstand misalignment between both coils (Primary and secondary). Most of our current wireless charger are design as in circular, Oval and rectangular. From circular coil design we can achieve efficiency but it does not consider about misalignment .when misalignment acquire the output power get reduce. Then oval shape coil design was introduced but it is not helpful to transfer High power. Later DD pad design (2 rectangular coil joins together) was introduced. Its size is much larger than circular pad. But this pad design has good misalignment tolerance in X-Direction but poor in Y-Direction. So, we can't use this method for all direction alignment tolerance issue. In this paper we introduce new form of coil design QDQ (quad D quadrature)-QDQ (quad D quadrature) to perform misalignment tolerance in both X and Y direction.

The overall block diagram and circuit diagram for wireless battery charging station is shown in fig 1 and 2.

Fig.1 Block diagram of wireless battery charger

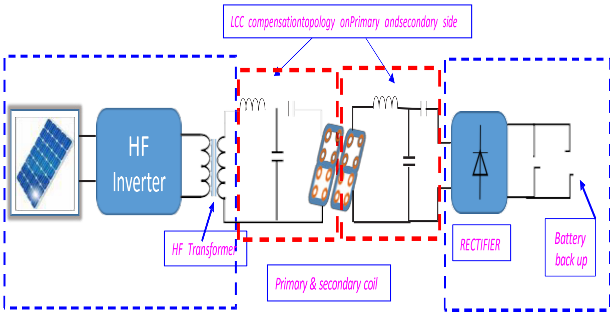
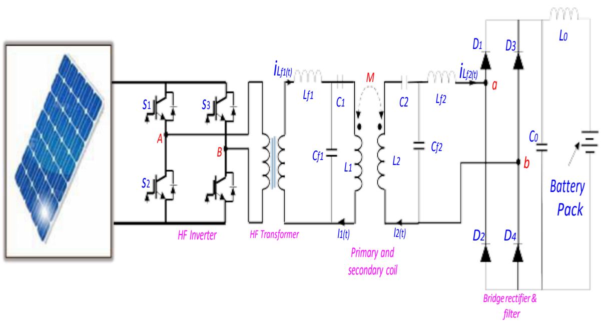


Fig.2 Circuit diagram of wireless battery charger



We are using solar panel from which we can get direct DC. The output from solar panel (DC) is converter into AC by using High Frequency (HF) inverter. The HF inverter Convert DC to High frequency AC whose frequency range is in KHz. High frequency transformer is used in order to transmit constant power across the wireless pads. The air gap between primary and secondary coil is 150mm. Here we are using LCC compensation on SS (series-series) Topology which give higher efficiency as compare to other compensation method. Were Lf1, Cf1, C1 are the compensation devices at primary side and Lf2, CF2, C2 are the compensation devices at secondary side. AC output that fed from secondary coil is converted into DC by using rectifier. The DC output is used to store in battery.

II. Proposed Coil Design

The New coil design is shown in fig 3. As shown in fig each coil has 2 square shaped coils joined together and 8 adjoining circular coil are surrounded by square coil which splitted in two half (4 for 1 side and remaining 4 for another square shaped coil) Both the coils, primary and secondary have same design & diameter. The energy transfer concerning the primary and secondary coils changes with respect to shape and position of the coil .The FEA tool is employed to design verification of the planned structure .Thirdly, in order to discover out the influence of compensated coils with respect to position. An analysis software is employed to model the structure proposed. The circular coil diameter in 10cm and square coil diameter in 30 cm. The simulation results are shown fig 5,6,7,8,9,10,11.

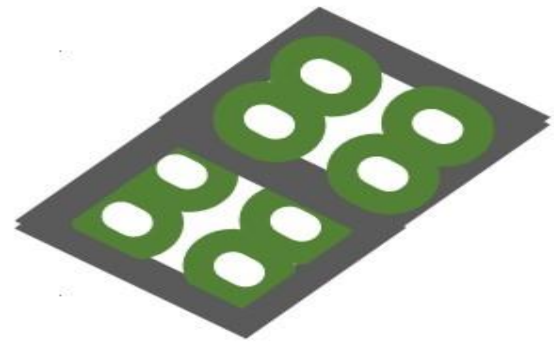


Fig.3 Proposed coil structure

III. Equivalent Circuit of Series-Series Inductive Power Transfer (WPT) System

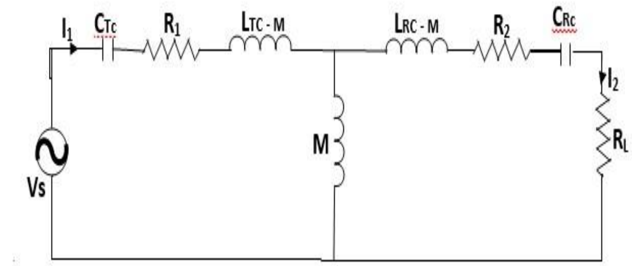


Fig.4 Circuit diagram of WPT system

$$\eta = \frac{Pout}{Pin}$$

Where,

The extent of coupling between charging coil & pick-up side coils is defined by coupling coefficient (K), is given by:

$$K = \frac{M}{\sqrt{LTc + LRc}}$$

The total impedance of the circuit for set parameters can be calculated. as:

$$Zss = \left(R1 + j\left(LTc\omega - \frac{1}{CTc\omega}\right)\right) + \left(\frac{\omega^2 M^2}{R2 + j\left(LRc\omega - \frac{1}{CRc\omega}\right) + RL}\right)$$

The amount of current used from the supply is given by:

$$I1 = \frac{Vs}{Zss}$$

$$I1 = \frac{Vs}{\left(R1 + j\left(LTc\omega - \frac{1}{CTc\omega}\right)\right) + \left(\frac{\omega^2 M^2}{R2 + j\left(LRc\omega - \frac{1}{CRc\omega}\right) + RL}\right)}$$

The power input can be obtained as:

$$Pin = \frac{Vs^2}{\left(R1 + \left(\frac{(2\pi f)^2 M^2}{R2 + RL}\right)\right)}$$

Likewise, the power output can be obtained as below:

$$Pout = \frac{Vs^2 (2\pi f)^2 M^2 RL}{(R_1R_2 + R_1RL + ((2\pi f)^2 M^2))^2}$$

IV. THE STIMULATION RESULTS

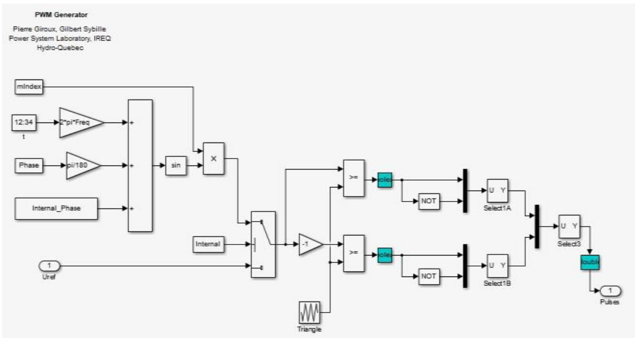


Fig.5 Array simulation diagram

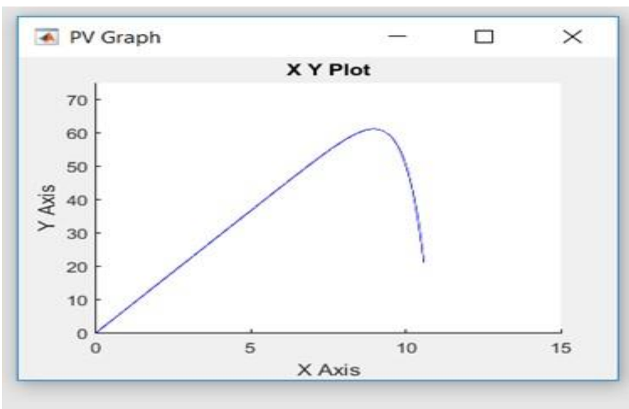


Fig.6 P-V Graph

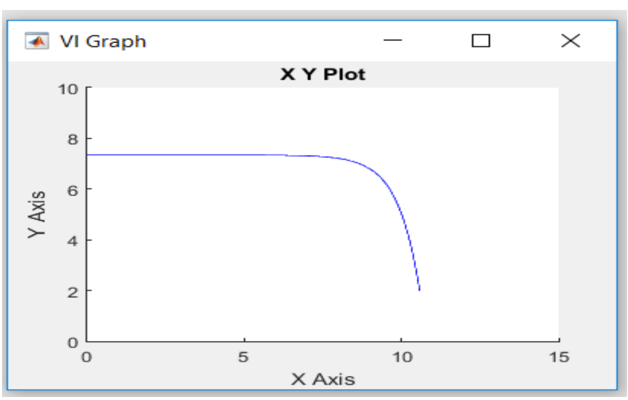


Fig.7 I-V Graph

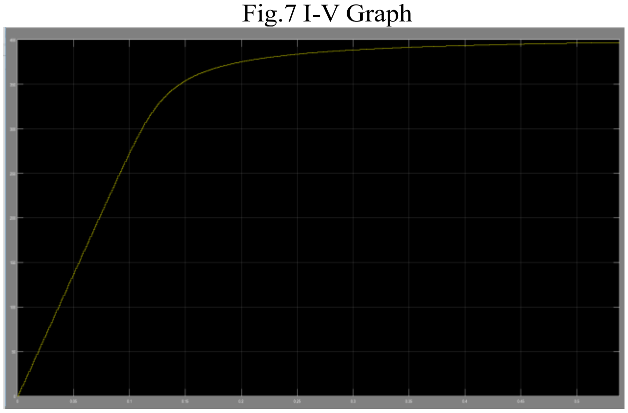


Fig.8 400V PV Array Output

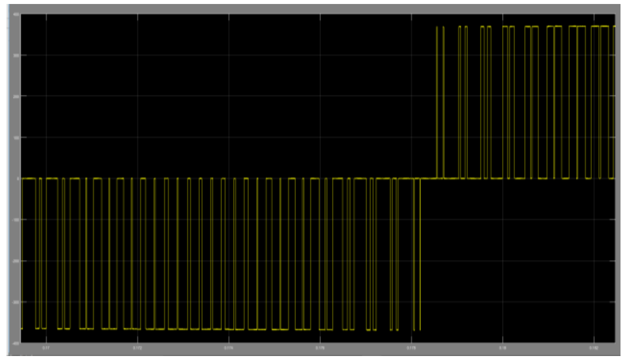


Fig.9 Inverter output voltage

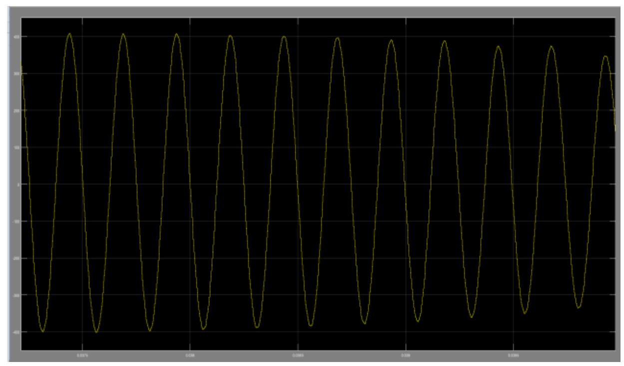


Fig.10 Recoil output voltage

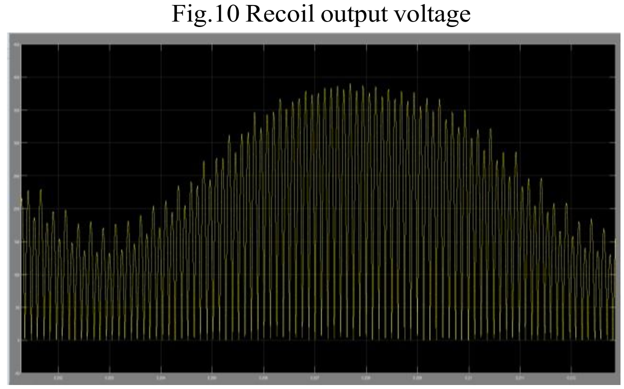


Fig.11 400v rectifier output.

V. RDWARE IMPLEMENTATION

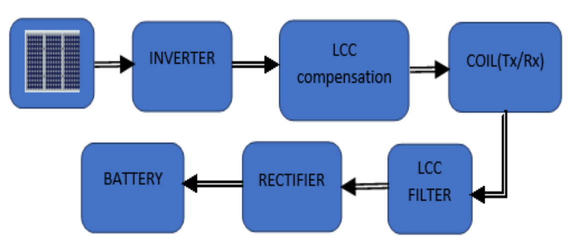


Fig.12 Block diagram of hardware implementation.

This design employs solar panel of a larger photovoltaic system. This installations contains several panels as the amount of power generated is limited in case of solar panels. We are then using switching devices like MOSFET to convert AC to DC (square waves), which is again converted back to DC by the process of rectification by high frequency technique. We are doing this to get compactness and to become economical. We have used IC SG3525. The pin diagram of IC SG3525 is shown in Fig.13.

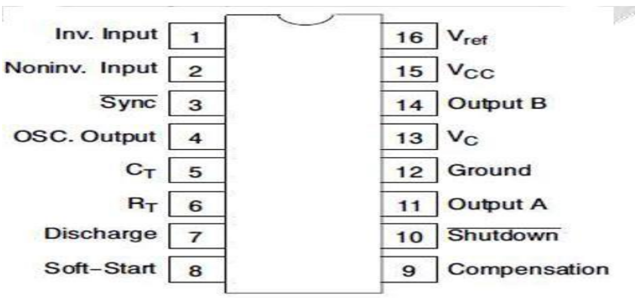


Fig.13 Pin Diagram of IC SG3525.

A. PROPOSED COMPENSATION TOPOLOGY

As an integrated LCC compensation topology comprises of two capacitors and one inductor, forms a structure analogous to an LCL-T network at both the (primary) transmitter and the (secondary) receiver sides. The additional coil (inductor) is integrated with the (transmitter coil or receiver coil) main coil on the identical side. Additional space for inductors are not needed since the additional coil and the main coil can be integrated.

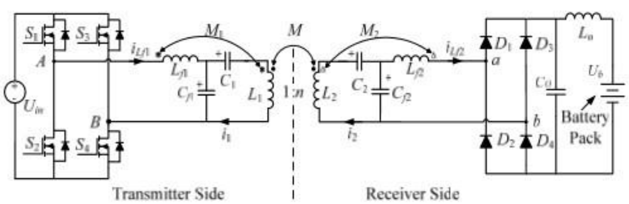


Fig.14 Proposed compensation topology.

In this proposed system the resonant frequency is independent of both load condition and coupling coefficient.

The presence of rectifier converts (AC) alternating current, which periodically reverses direction, to (DC) direct current, which flows only in single direction.

Rectifier are categorized in two namely:

1) Half wave rectifier
2) Full wave rectifier

In half-wave rectifier with single-phase supply, also known as uncontrolled one-pulse midpoint circuit. In this rectifier either the positive or negative half of the AC wave is passed, while the other half is obstructed. Mathematically,

$V_{rms} = V_{peak}/2 \quad V_{dc} = V_{peak}/\pi$

Where:

Vdc, Vav – DC voltage & average output voltage,

Vpeak, the peak value of the phase input voltages,

Vrms (RMS) value of output voltage.

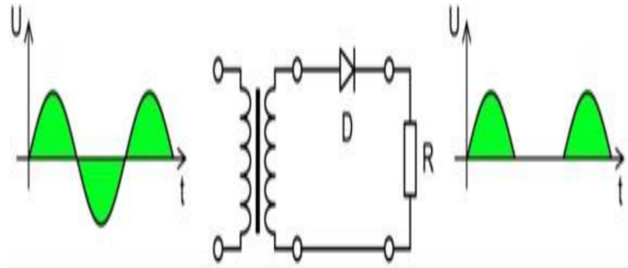


Fig.15 Half wave Rectifier

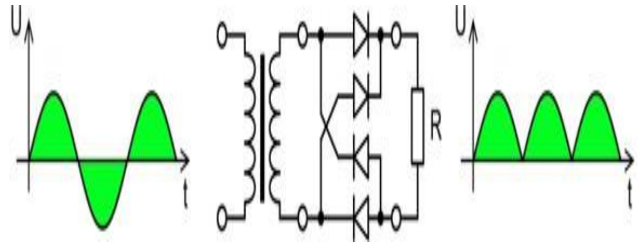


Fig.16 Full wave rectifier

B. BATTERY

An electric battery was incorporated in the system to power the circuit. It involves of one or more electrochemical cells that transform the chemical energy stored into electrical energy. The cells consists a cathode, and anode.

Fig.17 Hardware Assembly.

C. HARDWARE DISCRIPTION (Prototype Description)

The proposed design employs the use of solar panel with a huge photovoltaic system to generate and supply electrical energy. In this project we are using 10w solar panel with maximum output voltage 18 v and current 0.58A.

Fig.18. 10W Solar Panel

D. INVERTER

We then used an Inverter for getting Power from power supply unit. The IRF840 MOSFET switch is used in our Hardware. During the avalanche mode of operation the N-Channel enhancement mode silicon gate power field effect transistor is an advanced power MOSFET tested, designed, and guaranteed to withstand a specified level of energy.

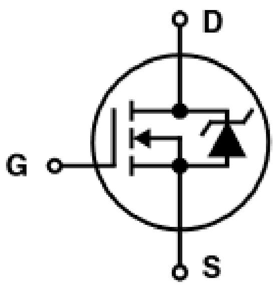


Fig .19. IRF840 symbol

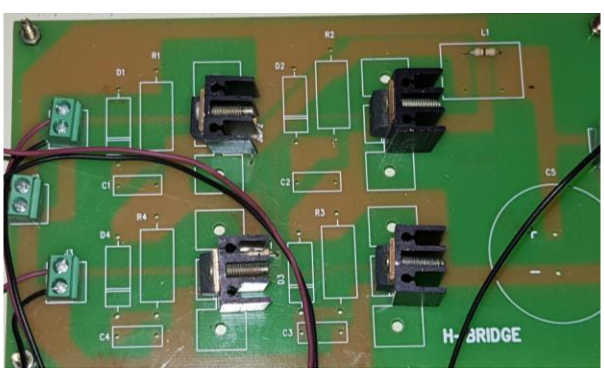


Fig. 20 Inverter with IRF840 MOSFET

E. PULSE GENERATOR DSPIC33F

Here we are using DSPIC33F IC as a pulse generator for Inverter. Pin diagram of DSPIC33F is shown in Fig.21 DSPIC33F is employed for 16-bit MCU embedded application. This is used to vary pulse range for MOSFET used in inverter circuit.

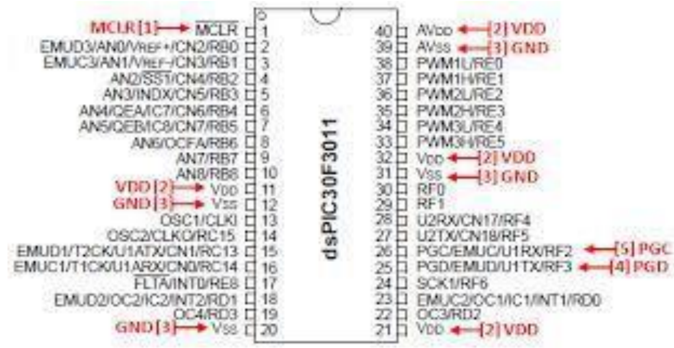


Fig. 21 Pin diagram of DSPIC33F IC

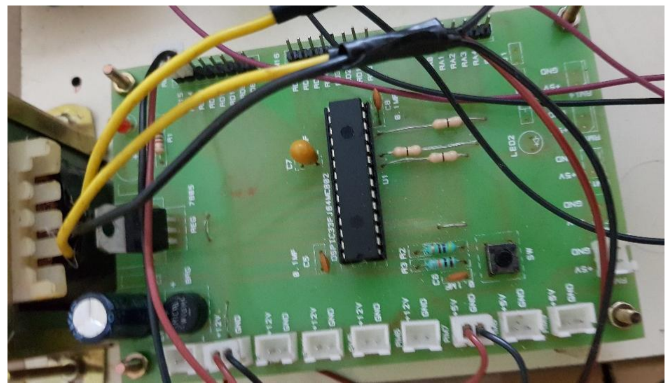


Fig. 22. Pulse generator for Mosfet

F. DRIVER CIRCUIT

The IRS2110/IRS2113 has high speed, power and Voltage. The IGBT drivers has an independent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. Logic inputs are compatible with standard CMOS or LSTTL output, down to 3.3 V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. Propagation delays are matched to simplify use in high frequency applications. The floating channel can be used to drive an N-channel power MOSFET or IGBT which operates up to 500 V or 600 V.

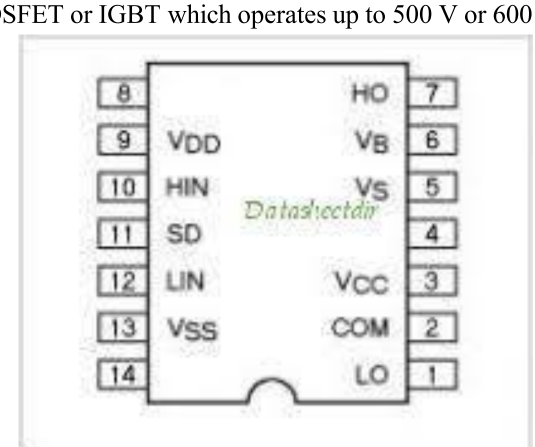


Fig. 23. Pin Diagram of IRS2110 Driver Circuit

G. TRANSMITTER COIL /RECEIVING COIL

The image of Transmission and receiving coil is shown in Figure 24.We just wounded both the coils in the form of double QDQ structure and additional compensated winding was placed in center.

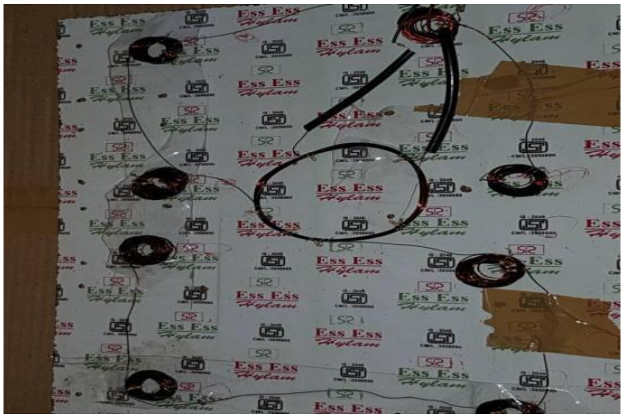


Fig. 24. Transmission and receiving coil

H. BATTERY POWER

As this Hardware is prototype model we are using 12 voltage researchable battery used at the receiving side. The voltage output from the receiving coil is again converted into DC and fed into Battery.

Fig. 25. Rechargeable battery

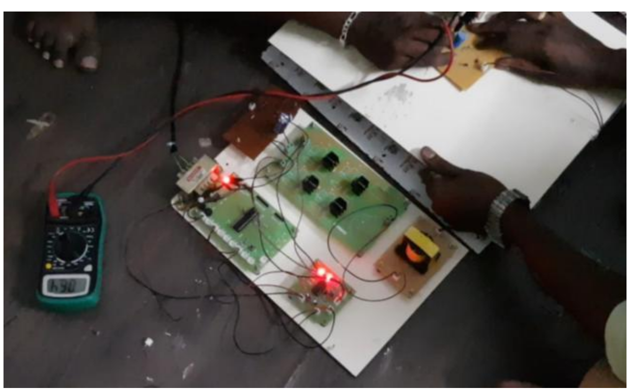
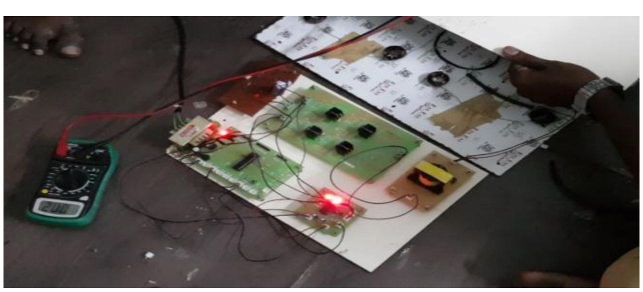


Fig. 26. Voltage before misalignment



VI. CONCLUSION

Thus, the Implementation of improved Wireless battery charger for electrical vehicle has been simulated with help of MATLAB and designed a hardware kit successfully. A new topology of coil design was proposed in order to achieve High misalignment tolerance. It aims to reduce coil size and to achieve better efficiency at misalignment state. Thus, the installation shape and cost were reduced by reducing coil size. solar panel was replacing grid setup by which we can able to reduce grid line extension cost for India .so instead of getting power from grid, charging station will use solar panel to transmit direct dc supply. Moreover, to resolve the problem of increasing efficacy at misalignment tolerance Series -series LCC compensation method was implement. High frequency inverter was used in order to transmit maximum frequency range to TX/RX coil.

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A Parking Management System Using Wireless Sensor Networks

Abstract—**In this paper, we conceive and develop a prototype of a car parking management system. The system gives a real-time snapshot of the monitored parking equipped by a Wireless Sensor Network (WSN). The developed application consists of two parts; one embedded in sensor nodes and another one executed at the pc containing interfaces. Moreover, this system enables to develop a Web application which allows the driver to reserve a free place in the parking or to guide him to localize a place using the parking map with all details of the way to reach it.**

Keywords-Wireless Sensor Networks; CC2430; SmartRF04EB; ZigBee; J2EE

I. INTRODUCTION

The industrials, researchers and engineers work on this new technology both in the civilian and military sectors that demand the use of many nodes, even hundreds or thousands ones. That's why more applications have been developed in order to solve several problems in data acquisition and environment control. Moreover, these nodes must be capable of sensing, processing and communicating physical parameters like temperature and pressure through the global wireless network. This paper focuses on the design of a system based on WSN technology to acquire the state of one parking with some autonomous nodes placed in each place inside the parking. The contribution of our paper consists of presenting the different techniques, methods and protocols that can be used to manage the parking with WSN technology and to develop a web server that facilitates the remote control, management and reservation inside the parking. The paper's plan is as follows: To begin, we are going to deal with the related work. Then the second section presents the IEEE 802.15.4 standard that defines the physical layer in all ZigBee devices, this standard is used by the sensor nodes to communicate with each others. Section 3 is devoted to ZigBee standard. The system architecture is lately displayed in section 4. It exposes the main components of the system details. The software architecture is figured out in section 5. The description of the system application is presented in section 6, followed by a brief conclusion.

II. RELATED WORK

Nowadays, Wireless Sensor Networks are a very promising research field since they find applications in many different areas. The networks of wireless sensors can revolutionize the way of conceiving and of building the complex physical systems[1]. They can have an important utility in different applications when it is a question of treating and of collecting data resulting from the environment [2]. Sensors' networks have several applications covering varied domains such as the military, the health, the environmental, the automobile, the domestic, the security and the intelligent houses, etc. Many works used the Wireless Sensor Network (WSN) technology in the automobile field [3], [4], [5], and [6]. The SmartGrains project [3] is developed in order to resolve the problems of car parking. The solution consists in deploying of vast networks of intelligent sensors on the places. Autonomous in energy, these sensors detect vehicles, and then communicate between them by radio waves to relieve real-time information. The principle of the project rests on a system with sensors' network which allows giving a statistical view onto the percentage of activity (occupation) by zone of the places of car parking. The arrival of a vehicle, which contains materials ferromagnetic, deforms locally the intensity of the magnetic field. An algorithm developed by Smart Grains analyzes this deformation to deduct the presence from it or the absence of a vehicle over the sensor. The sensors have a double function: the first one is to detect the state of the occupation of a place; the second is to establish a wireless network allowing conveying the information up to a relay.

Figure 1: Interface of the application ParkSense

This application gives only a statistics onto the state of the various zones of the city: saturated, free or blocked zone. Another application of sensors' network in the automobile domain is the solution SFPark of San Francisco [4]. The solution is based on the use of a wireless electronic devices stuck on the ground indicating in real time the available places. The signals which they emit are passed on in parking meters installed on pavements to be then conveyed towards an exchange of supervision. The application contains an interface of display (posting) on Web, so that the motorist can reach via his (her) Smartphone. The application offers to the customer an interface which shows the mapping of the city and the various parking with the level of availability. These works present many limits: The shown cartography indicates only the address of the street and do not give either the plan of the parking lot or the distribution of places in this last one, what prevents the customer from choosing the place where it is going to park, so that he cannot have the route of access towards the wished place, also this cartography shows only a simple statistics by number or by level of occupation of the state of the various zones of the city or the streets of the city and these applications developed do not give to the customer the possibility of reserving remotely a place what does not resolve completely the problem of searching where to park his (her) vehicle. The solution Smart Parking (SPARK) management system [5] consists of a WSN, Sink, Parking Management, Automated Guidance, and Entrance Display. WSN subsystem detects the status of parking space with hybrid sensing techniques and transmits status information through RF (Radio Frequency).The parking status report from WSN subsystem is collected by sink subsystem which delivers them to the parking management subsystem. It acts as a gateway between external networks and wireless sensor network. Whenever sink subsystem sends data to the parking management subsystem, the gateway transceiver module associated with the subsystem receives the data, processes it and forwards to the database module and vice versa. The automated Guidance Subsystem treats the stored information in the database and displays it to the users. It shows the availability of the parking lots in all three directions (Left/Right/Ahead).The entrance Display Subsystem is placed at the entrance of the parking. It shows the status of the parking lots to the users before entering the parking area. The solution SPARK is a prototype system; it was deployed at Ubiquitous Computing Research Centre (UCRC). The application WSN-based [6] intelligent car park management system is a prototype system implemented to provide visualizing, monitoring, and analyzing tools to display and interpret sensory data of parking. This solution consists of the sensor nodes which can be deployed to a car parking field. These sensor nodes collect the real-time occupation information and vehicle information. The collected information can be transmitted to a gateway via wireless communication among the sensor nodes which is connected to a database server via Internet. The customer connects to the network of the parking can have the availability of places, the state of the parking and vehicle information via an interface. Work in this paper puts heavy weight on optimization for a system which detects the presence of a vehicle in a parking by means of wireless sensor's network and develop a Web application which allows the driver to reserve remotely a free place in the parking lot and to guide it to localize the chosen place. This application has to offer to the driver cartography of the parking with the details of the availability of places as well as the route to reach it.

III. IEEE 802.15.4 Standards Overview

A. *Physical Layer (PHY)*

Define The IEEE 802.15.4 standard defines the physical layer (PHY) in all ZigBee devices. The PHY is responsible for data transmission and reception by using certain radio channel and specific modulation and spreading technique [7]. The IEEE 802.15.4 standard specifies two Physical layers that represent three operational frequency bands. These three bands include: 868 MHz (used in Europe), 915 MHz (used in America), and 2.4 GHz (used worldwide) [8]. The868 and 915 MHz bands are in one PHY while the 2.4 GHz band is in the second PHY. There is a single channel between868 and 868.8 MHz, 10 channels between 902 and 928 MHz, and 16 Channels between 2.4 and 2.4835 GHz [7].

B. *Medium Access Control (MAC) Layer*

In addition to the PHY, the IEEE 802.15.4 standard defines the medium access control sub layer for all ZigBee devices. The MAC sub layer protocol serves as the interface between the PHY and the higher layer protocols. The functions of the MAC include synchronization, frame validation, acknowledged frame delivery, association, and disassociation [9]. Also, the MAC controls the access to the radio channel by employing some methods like the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism [9]. CSMA/CA is a network contention protocol that listens to the network in order to avoid collision [10].

IV. The ZigBee Standard

ZigBee [11] standardizes the higher layers of the protocol stack. The network layer (NWK) is in charge of organizing and providing routing over a multi hop network (built on top of the IEEE 802.15.4 functionalities), while the Application Layer (APL) intends to provide a framework for distributed application development and communication. The APL comprises the Application Framework, the ZigBee Device Objects (ZDO), and the Application Sub Layer (APS). The Application Framework can have up to 240 Application Objects (APO) that is user defined application modules which are part of a ZigBee application. The ZDO provides services that allow the APOs to discover each other and to organize into a distributed application. The APS offers an interface to data and security services to the APOs and ZDO. An overview of the ZigBee protocol stack is shown in Figure 2 [11].

A. *The Network Layer*

ZigBee identifies three device types. A ZigBee end-device corresponds to an IEEE RFD or FFD acting as a simple device. A ZigBee router is an FFD with routing capabilities. The ZigBee coordinator (one in the network) is an FFD managing the whole network. Besides the star topology (that naturally maps to the corresponding topology in IEEE 802.15.4), the ZigBee network layer also supports more complex topologies like the tree and the mesh (Figure 3) shows examples of these topologies. Among the functionalities provided by the network layer are multi hop routing, route discovery and maintenance, security and joining/leaving a network, with consequent short (16-bit) address assignment to newly joined devices [11].

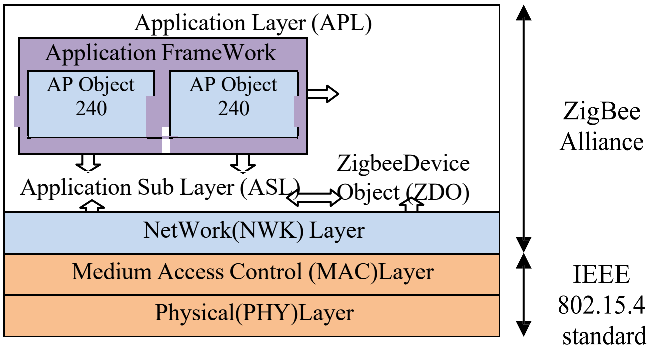

Figure 2: ZigBee functional layer architecture and protocol stack

B. The Application Layer

A ZigBee application consists of a set of Application Objects (APOs) spread over several nodes in the network. An APO is a piece of software (from an application developer)that controls a hardware unit (transducer, switch,lamp) available on the device. Each APOis assigned a locally unique endpoint number that other APOs can use as annex tension to the network device address to interact with it. The ZigBee Device Object (ZDO) is a special object which offers services to the APOs: it allows them to discover devices in the network and the service they implement. It also provides communication, network and security management services. The Application Sub layer (APS) provides data transfer services for the APOs and the ZDO. Figure 2 illustrates the various components in the Application Layer [11].

V. HARDWARE ARCHITECTURE

The system consists of 5 sensor nodes spread inside the parking and one base node or base station CC2430 (bs) (Figure 3). Each node contains one system-On-Chip CC2430 and implemented on one battery board (BB). In fact, the role of each sensor node is to send the appropriate place state in the parking with the RF link to its neighbour node until it reaches the base station node. In other words, the node state is one binary information which can be one when a car parks and zero if it leaves the occupied place. The base node CC2430 (bs), placed in the SmartFR04EB board is connected to the personal computer through its serial link. So, the running program inside this node will receive the information from other nodes at regular intervals. The information can be stored in one database server. Thus, we can visualise the wireless sensor network (WSN) state through the internet network to give the appropriate command to the system. In fact, the web system provides an efficient way to configure the WSN and improve the system management.

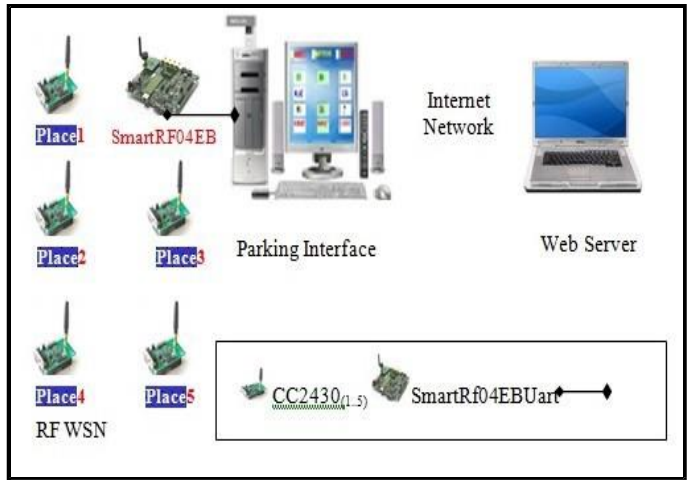

Figure 3: Hardware Architecture

A. SmartRF04EB (Evaluation Board)

The SmartRF04EB is a host-board for the Evaluation Module (EM). It has an on-board 8051microcontroller for use with the transceivers, and can also be used to program the SoCs. It features a range of peripherals, including:

- 1 LCD;
- 4 LEDs;
- 5 way push-switch;
- 2 potentiometers;
- Audio in/out.

It also has all the connections you need to connect your own peripherals or microcontroller.

Figure 4: SmartRF04EB

B. BB-Battery Board

Here, we can find the system on chip battery board (BB). The main function of this board is to power the CC2430EM (Evaluation Module) or CC2431EM with use of two AA batteries. It can in addition be powered by a lab powered connected directly to GND and VDD on the board. The Low-Power RF BB is a simple battery module for use with an EM.

It has one LED, one push switch, one power switch and I/O connector A and B, gives access to all I/O on the SoC and to some additional pins. It allows you quickly deploy a SOC network [12]. On this Battery Board, we can find the Evaluation Module, which contains the minimum Components for a RF part to function.

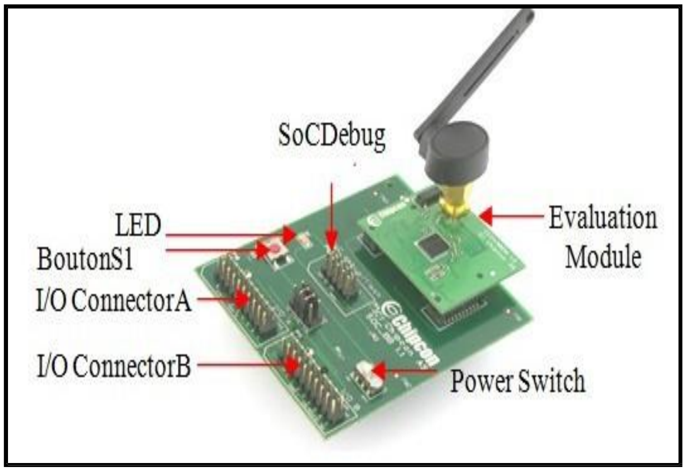

FIGURE 4: System on Chip Battery Board with CC2430EM

C. System-on-Chip CC2430

The CC2430 comes in three different versions: CC2430-F32/64/128, with 32/64/128 KB of flash memory respectively. The CC2430 is a true System-on-Chip (SoC) solution specifically tailored for IEEE 802.15.4 and ZigBee™ applications. It enables ZigBee™ nodes to be built with very low total bill-of material costs. The CC2430 combines the excellent performance of the leading CC2420 RF transceiver with an industry-standard enhanced 8051 MCU, 32/64/128 KB flash memory, 8 KB RAM and many other powerful features. Combined with the industry leading ZigBee™ protocol stack (Z-Stack), the CC2430 provides the market's most competitive ZigBee™ solution. The CC2430 is highly suited for systems where ultra low power consumption is required. This is ensured by various operating modes. Short transition times between operating modes further ensure low power consumption.

D. 8051 CPU

The CC2430 includes an 8-bit CPU core which is an enhanced version of the industry standard 8051 core. The enhanced 8051 core uses the standard8051 instruction set. Instructions execute faster than the standard 8051 due to the following:

- One clock per instruction cycle is used as opposed to 12 clocks per instruction cycle in the standard 8051;
- Wasted bus states are eliminated. Since an instruction cycle is aligned with memory fetch when possible, most of the single byte instructions are performed in a single clock cycle.

VI. SOFTWARE ARCHITECTURE

The design of the software in this package is based on the layered architecture as depicted in the following Figure 5:

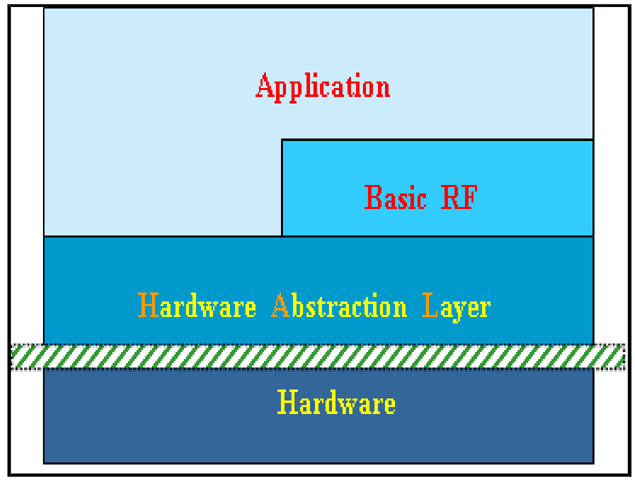

Figure 5: Software architecture

- Application layer: This Software package contains several applications examples with access to Basic RF and HAL (Hardware Abstraction Layer).
- Basic RF: This layer offers a simple protocol for transmission and reception on two-way RF link.
- Hardware Abstraction Layer: Contains functionality for access to the radio and onboard peripherals modules like LCD, UART, joysticks, buttons, and timers [13].

A. Basic RF

The Basic RF layer offers a simple protocol for transmission and reception on a two-way RF link. The Basic RF protocol offers the service for packet transmission and reception. It also, offers secure communication by use of CCM-64 authentication and encryption/decryption of packets. The security features of Basic RF can be compiled in by defining the compile switch SECURITY_CCM in the project file. The compile time inclusion of security features is done to save code space for the applications where security features are not needed [13].

The protocol uses IEEE 802.15.4 MAC compliant data and acknowledgment packets. However, it does not offer a full MAC layer, only a simple data link layer for communication between two nodes. Basic RF contains only a small subset of the 802.15.4 standard:

- Association, scanning or beacons are not implemented;
- No defined coordinator/device roles (peer-to-peer, all nodes are equal);
- No packet retransmission. This must be taken care of by the layer above Basic RF.

B. Basic RF Instructions

1) Startup

a) Initialization: Make sure that the board peripherals and radio interface is initialized i.e. halBoardInit() musthave been called first.

b) Create a basicRfCfg_t structure, and initialize its members: If the security features of Basic RFare used, the higher layer is responsible for allocating and assigning the 16 bytes key.

*c) Call basicRfInit(): T*o initialize the packet protocol.

2) Transmission

a) Create a buffer with the payload: To send the maximum payload size for Basic RF is 103 Bytes.

b) Call basicRfSendPacket(): To check the return value.

3) Reception

a) Perform polling by calling basicRfPacketIsReady(): To check if a new packet is ready to bereceived by the higher layer.

b) Call basicRfReceive(): To receive the packet by higher layer. The caller is responsible forallocating a buffer large enough for the packet and 2 Bytes buffer space for the RSSI value [13].

VII. IAR EMBEDDED WORKBENCH FOR 8051

IAR Embedded Workbench is a set of highly sophisticated and easy-to-use development tools for embedded applications. It integrates the IAR C/C++ Compiler™, assembler, linker, librarian, text editor, project manager, and C-SPY Debugger in an integrated development environment (IDE).With its built-in chip-specific code optimizer, IAR Embedded Workbench generates very efficient and reliable FLASH/PROM able code for the 8051 microcontroller. In addition to this solid technology, IAR Systems also provides professional worldwide technical support. Thus, we have used this environment to write then download program of each node inside his FLASH EPROM.

VIII. DESCRIPTION OF APPLICATION

To automate the management of the car parking, we installed a network of wireless sensors in each site, which detects the presence of the vehicle in the latter. For this, we will implement an interface dedicated to the administrator to view real-time the status of various locations in the parking lot. On the other side of our system, the client connects through its web browser to visualize this park status. The browser supports various application resources by establishing a connection with the Web server. However, the server Web load states of the sensors stored in the database. The interface of our host site car displays a map of parking that has a detailed plan indicating the location of different available places and the route to reach them.

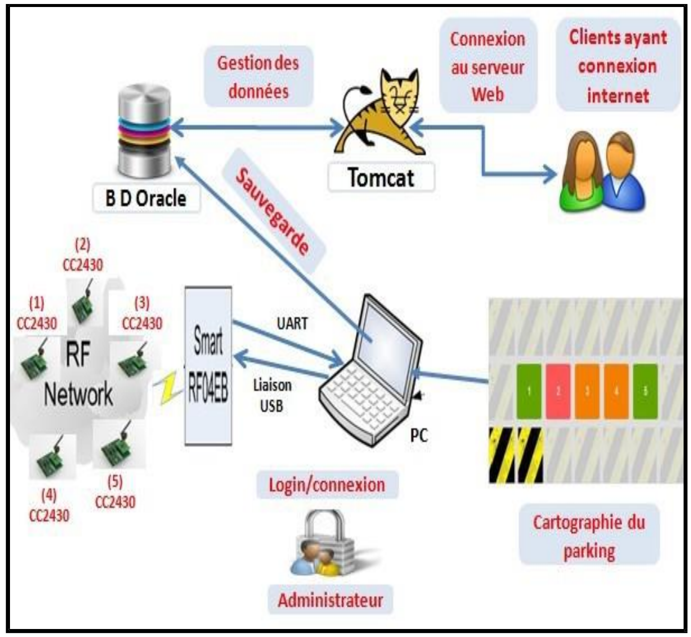

Figure 6: Software architecture

As shown in Figure 6, the developed application consists of three modules; WSN environment, the visualization interface and the web application.

1) WSN Environment

The application, executed by the WSN, is composed by two modules "Node" and "SmartRf04EB". The first one is running on sensor nodes, while the second one is executed on the main node CC2430 (bs) installed on the SmartRF04EB. So, if one car arrived inside the parking, the "Node" module will send the binary information "1" joined with the node appropriate address which reflects the occupied place inside the parking. Otherwise, the binary information "0" joined with the node appropriate address, if one car leaves its place inside the parking. This binary information is send through the WSN, until it reaches main node CC2430 (bs). When the information is received by the main node CC2430 $_{(bs)}$, through the RF link, it will be sent to the Personal Computer or the laptop through the serial port where it will be visualised.

- The "Node" module

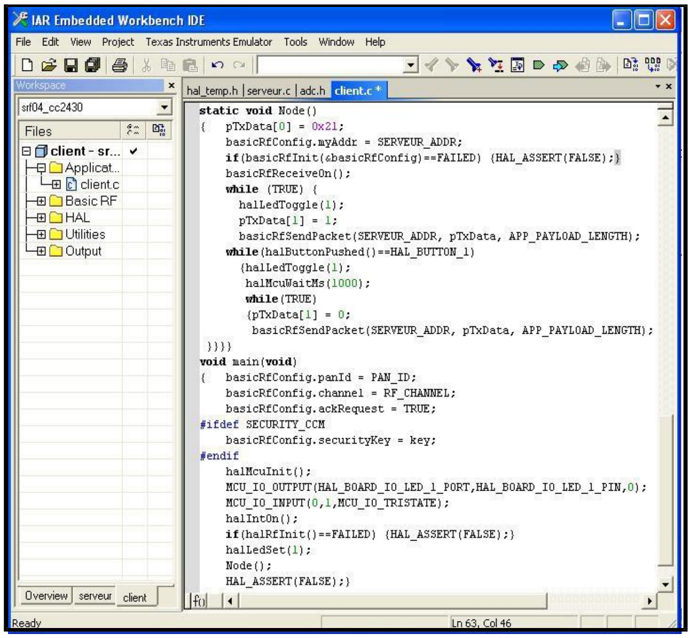

Figure 7: The Node interface

- The "SmartRF04EB" module

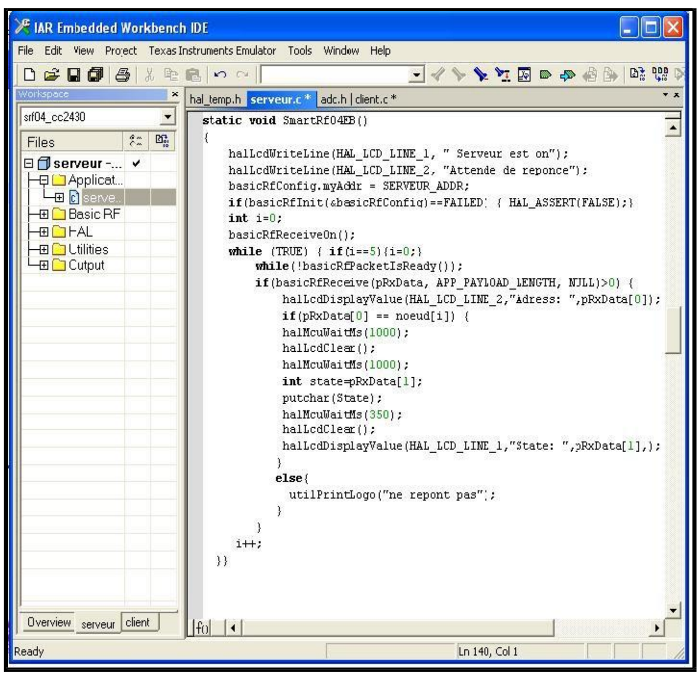

Figure 8: The SmartRF04EB interface

2) *Visualization Interface*

When the parking place state is received by the SmartRF04EB node, it will be send later through the serial port to the personal computer where it will be visualised by one interface developed by visual basic 6.0 as depicted in the following figure 9:

Figure 9: Visualization Interface

So, in this interface we can see the occupied places inside the parking are place 2 and place 5; otherwise the other places are free. For the "Nb Oc" indicates the number of cars that parked in that place in one day.

3) *Web Application*

The technology used to develop the web application is J2EE [14]. The web page was created using the JSP [15].The code of application is written using servlets [16]. The servlets connects to the database Oracle [17] and are executed on a web server. The web server used in our application is apache tomcat [18].

This web application is shown in Figure 10.

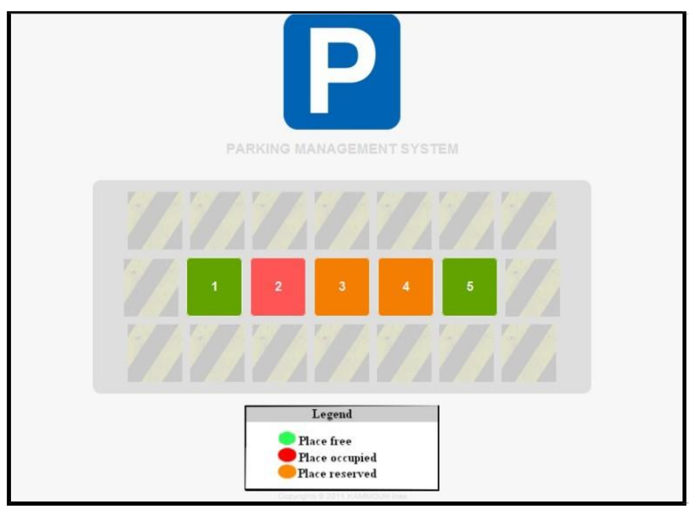

Figure 10: Cartography of parking

The customer having an internet connection seizes the Web address of the parking to get the cartography of this parking. This cartography shows the plan of the parking with the arrangement and the state (free, occupied, and reserved) of various places. The customer can choose a free place to reach the parking and have the route of access towards the place chosen or to make a remote reservation of this place. In the case of the reservation of a place, the system generates to the customer a booking code. Has his (her) next connection the customer is asked to authenticate with this code to be able to take the reserved place and have the route to reach it.

IX. CONCLUSION

The development of Wireless Sensor Networks rise new challenges to engineers in several fields. In this paper, we have developed a system based on this new technology for data acquisition and control which contributes to environment monitoring. This system includes two aspects; hardware and software. The hardware is composed of one base node CC2430 (bs) connected to the SmartRF04EB and other nodes CC2430. Each sensor node contains a System-On-Chip CC2430 that contains the processor. This processor executes the necessary program on each node. The application permits to manage the parking with one Web server in order to benefit from the distant control and monitoring. Thus, this Web server permits the customers to benefit from a remote connexion in order to consult the parking state, reserve a place and reach the place access way. Knowing about the evolution of technology, we are able to enlarge our future work. This future work is to develop a synchronisation algorithm to coordinate between transmissions of each node. In the system, we have used five sensor nodes to acquire the parking state and send it to the main node CC2430 (bs) in the SmartRF04EB as a final destination. To cover a large distance, we can use several nodes, for example hundred of nodes and the distance between two nodes is twenty meters, so each node can send its information to its near node until the ultimate destination or the main node CC2430 (bs). So, the role of each node is to acquire the place from its location, receive and send information to the next node until we reach the last destination. By this way, the WSN will be installed in large parking area, in order to supervise it.

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Advanced Redundancy Technology for a Drive System Using In-Wheel Motors

In electric vehicles that use in-wheel motors, the right and left traction forces become unbalanced if a motor malfunctions by motor lock or loss of traction, generating yaw moment. Control methods were designed to reduce this effect by stopping the motor output on the opposite side of the same axle. By using a prototype "Eliica" car, the maximum yaw rate and lateral acceleration were compared for a breakdown of one motor with the results from the "Sensitivity to lateral wind" indicated in Z108-76 of the Japanese Automobile Standards Organization. Under redundancy control, the test results were confirmed to be below the tolerance limits

Keywords: Wheel Motor, Inverter, Control System, Vehicle Stability, Safety

1. INTRODUCTION

Several prototype electric vehicles (EVs) with motors installed in each wheel that exploit the torque characteristics of the in-wheel motor [1] have been developed by KEIO University. Unlike an internal combustion engine, an electric motor can generate maximum torque from standing still to a high speed.

The purpose of our research is to develop redundancy technology for the drive system of EVs that use in-wheel motors by constructing a control method for use in the case of motor malfunction, that optimizes the composition of the drive system parts to maintain the vehicle's advantages and safety.

An EV that uses in-wheel motors has the following three advantages:

1) The freedom of the car's design increases because the motor is excluded from the usual engine compartment. As a result, a vehicle body shape with low air drag and excellent collision safety can be achieved comparatively easily.

2) The independent direct control of the traction force of each wheel can be used for such applications as traction control and dynamic stability control with excellent results [2].

3) When one motor breaks down, driving can continue with the other motors.

The third advantage in particular is achieved in EVs of the in-wheel motor type, in which two or more motors are installed. On the other hand, in such an EV, the right and left traction forces become unbalanced if one motor breaks down and yaw moment is generated in the z-axis, which passes through the center-of-gravity point (CG) of the vehicle. Therefore, a control method for the situation in which a motor breaks down is important for achieving redundancy for a drive system that uses in-wheel motors.

Our intention is to enhance the merits of function and safety of EVs by achieving a redundancy technology for drive systems that use in-wheel motors.

First in this report, the influence on vehicle stability by a motor malfunction is described. Next, the results of a fault tree analysis (FTA) of the case in which the right and left traction forces become unbalanced are presented. Then, based on these results, an optimum formation of a drive system that uses in-wheel motors and a control method of redundancy technology are proposed. Finally, by using a prototype vehicle "Eliica" which these technologies were added, the utility of this study was evaluated.

2. INFLUENCES ON VEHICLE STABILITY BY UNBALANCED TRACTION FORCES

Figure 1 shows the vehicle model of the eight-wheel-drive (8WD) Eliica. The 8WD has nearly the same dynamics as 4WD, the difference being that 8WD has four axles, which are numbered 1 through 4 from the front, and the first two axles are steered.

The cornering forces and the traction forces that occur on each tire are defined as shown in the figure as C_{fl1}, C_{fr1}, C_{fl2}, C_{fr2}, C_{rl1}, C_{rr1}, C_{rl2}, C_{rr2}, and T_{l1}, T_{r1}, T_{l2}, T_{r2}, T_{l3}, T_{r3}, T_{l4}, T_{r4}, respectively. The yaw moment generated around the z-axis at the CG can be expressed by equation 1. It can be seen that the right and left traction forces become unbalanced if one motor malfunctions by motor lock or loss of traction and yaw moment is generated. As a result, vehicle stability may deteriorate.

In the case of the Eliica, upon reaching 100 km/h

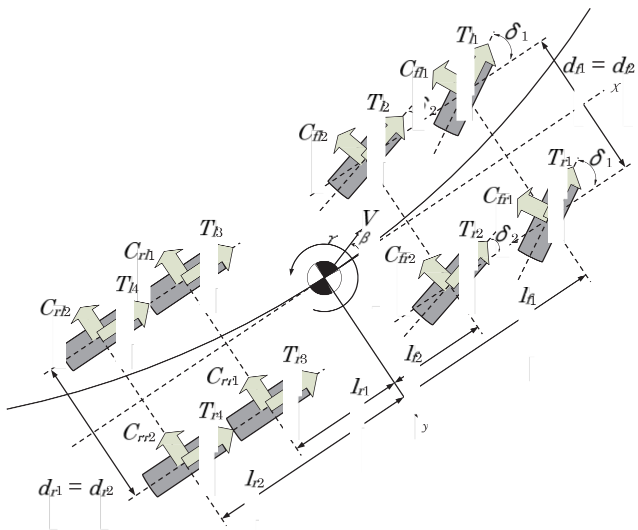

Fig. 1 Vehicle model of eight-wheel-drive Eliica

$$mV \quad T_{l1}+T_{r1}+T_{l2}+T_{r2}+T_{l3}+T_{r3}+T_{l4}+T_{r4}-RES \quad (V)$$

$$mV(\dot{E}+J) \quad C_{fl1}+C_{fr1}+C_{fl2}+C_{fr2}+C_{rl1}+C_{rr1}+C_{rl2}+C_{rr2}$$

$$IJ. \quad l_{f1}(C_{fl1}+C_{fr1})\cos G_1+l_{f2}(C_{fl2}+C_{fr2})\cos G_2$$
$$-l_{r1}(C_{rl1}+C_{rr1})-l_{r2}(C_{rl2}+C_{rr2})$$
$$+\frac{1}{2}d_{f1}(T_{l1}-T_{r1})+\frac{1}{2}d_{f2}(T_{l2}-T_{r2})$$
$$+\frac{1}{2}d_{r1}(T_{l3}-T_{r3})+\frac{1}{2}d_{r2}(T_{l4}-T_{r4}) \qquad Eq.(1)$$

V longitudinal velocity

RES rolling resistance and air drag

ù side-slip angle at CG

Û yaw rate

G_1, G_2 steering angle

I yaw inertia of vehicle

d_{f1}, d_{f2}, d_{r1}, d_{r2} tread

l_{f1}, l_{f2}, l_{r1}, l_{r2} wheel base

while accelerating, if the traction force of a motor on one side is lost, yaw moment of about 1700 Nm is generated. On the other hand, if a malfunction by motor lock occurs, the influence of the braking force from the tire causes the vehicle stability to deteriorate compared to a malfunction by loss of traction. If it is assumed that the coefficient of friction between the tires and the test road is 1.0, yaw moment of about 4400 Nm occurs if a motor locks on one side. The maximum torque that the Eliica can handle at 100 km/h is 90 Nm.

3. ANALYSIS OF BREAKDOWN FACTORS THAT CAUSE UNBALANCED TRACTION FORCES

The factors that would cause the right and left traction forces to become unbalanced were analyzed by fault tree analysis (FTA), which is a recognized technique to anatomize quantitatively over the entire system the breakdown factors leading to a specified defect phenomenon. Figure 2 shows the resulting fault tree.

The following three defect incidents were identified:

1) The traction force of a wheel on one side is lost by a malfunction of the motor or the inverter.

2) The motor output of a wheel on one side is limited by a temperature increase of the motor or the inverter.

3) A wheel on one side is locked by a stuck reduction gear, bearing, or brake.

Furthermore, the basic phenomena that lead to these defects were analyzed. A basic phenomenon is a top-level breakdown factor. These are shown within circle symbols in the figure.

The purpose of FTA is to optimize the design of the basic phenomena so that the top-level breakdown probability is zero. However, as good as that design may be, there is a need to realize a redundancy control that can allow continued safe driving if a top-level breakdown occurs. To achieve this, the next chapter examines methods to control the above three defect phenomena caused by top-level breakdowns.

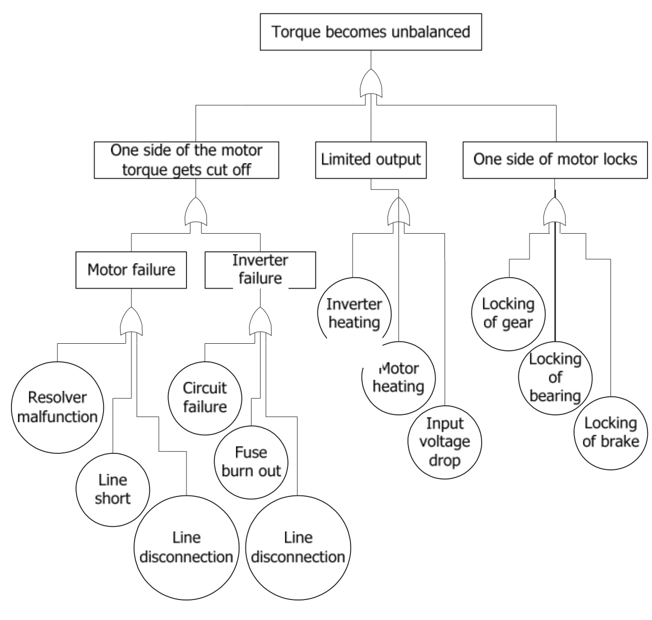

Fig. 2 Fault tree analysis of the phenomena that lead to unbalanced traction forces

4. REDUNDANCY TECHNOLOGY FOR THE DRIVE SYSTEM

In this chapter, first the drive-system components of an EV using in-wheel motors are compared with those of a conventional EV, and the system composition that is most suitable for EVs is suggested. Next, methods to control the defect phenomena that lead to unbalanced right and left traction forces that are inextricably linked to the system hardware composition are proposed.

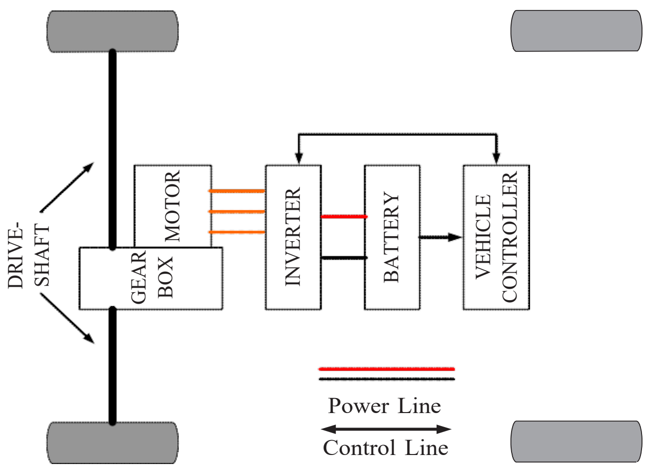

Fig. 3 Block diagram of drive system of conventional EVs (Front-wheel drive)

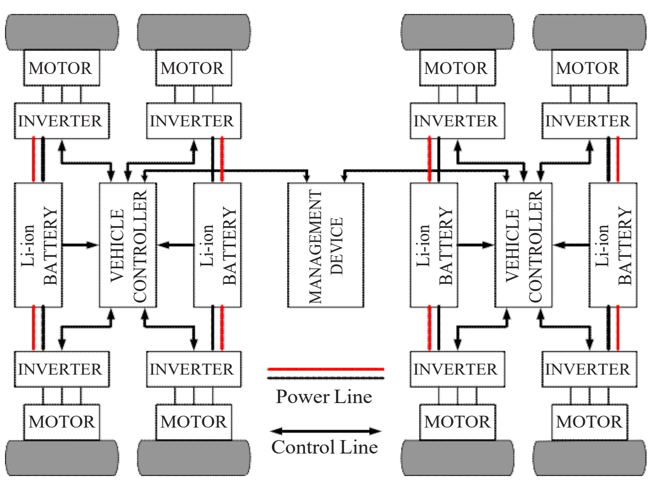

Fig. 4 Block diagram of Eliica's drive system with redundancy (All-wheel drive)

4.1 Optimization of the Drive-System Components

Figures 3 and 4 show the compositions of the drive systems of conventional EVs and of the Eliica [3]. The drive system of a typical EV consists of one motor, an inverter, and a pair of batteries, which are all controlled by a single control unit. On the other hand, the advantage of the 8WD Eliica, with eight in-wheel motors, is that it can continue driving unless all motors break down. However, it is necessary for the inverter, batteries, and vehicle controller to be made redundant so that the multiple motors can be advantages.

As shown in Figure 4, a pair of batteries supplies two inverters on the same axle, and a vehicle controller controls each pair of front and rear axles. In addition, to govern the two vehicle controllers, a management device was created. If a battery fails, the drive can continue in 6WD. Moreover, yaw moment is not generated, because the power supplies to the motors on the same axle are shut at the same time. The processing contents of the two vehicle controllers are installed in the management device. The management device verifies the control contents of the two vehicle controllers, and if the vehicle controllers are not in accord, the control is separated and the vehicle continues running by 4WD.

With the minimum 2WD, Eliica can satisfy a standard value of acceleration and slope ability defined in a technical standard for a vehicle.

Error detection and torque control of a motor are the roles of an inverter, and the monitoring and ordering of an inverter are the duties of a vehicle controller. Therefore, if the communication speed between vehicle controllers and inverters is slow, control after detection of trouble is late, and sufficient deterrent of yaw moment is not provided. For this research, a Controller Area Network (CAN) with fast transmission speed and superior reliability was adopted. The two-headed arrows in Figure 4 show the machinery connected in CAN. The single-headed arrows indicate serial communication (RS232C). Multiple devices are connected to CAN on the same bus, and messages are transmitted by unique ID. By using this system, an ID system exclusively for torque order was made, so the torque order value from a vehicle controller could be transmitted to each inverter at the same time. In addition, by using CAN, the communication state is watched with hardware. Therefore, there is less CPU load in comparison with serial communication.

By adopting CAN as the communication method and dividing the vehicle controller into two, a complete redundancy control in less than 10 ms after the two vehicle controllers detect a malfunction of a motor was achieved. Here, redundancy of the drive system components is provided by the hardware composition.

4.2 Redundancy Control Methods in the Event of a Motor Malfunction

This section explains the redundancy technology for control of the three defect phenomena when right and left traction forces become unbalanced. The FTA analysis in chapter 3 revealed these phenomena, which cannot be controlled by only using hardware composition.

4.2.1 Redundancy Control Methods

The first redundancy control method is for when the traction force of a wheel on one side is lost, for which the breakdown factors are usually from malfunctions of the motor or inverter. Such problems are detected by not only an error message by CAN, but also a point-of-contact signal output to a vehicle controller from an inverter. When a vehicle controller detects the loss of a motor's traction force, it stops the opposite motor on the same axle (Plan A). An additional technique to balance the traction forces of the right and left is to adjust the sum of the traction forces on each side (Plan B).

However, the vehicle controllers of Eliica are divided to control each of the four motors on the front and rear axles independently. In addition, calculation of the torque to instruct each motor becomes complicated because the treads are different between the front and rear axles. Therefore, Plan A was measured because of the stand point of simplicity and controllability.

The second redundancy control method is for when a motor's output is limited. An inverter limits a motor's output by a temperature rise of the motor or inverter, or by a drop of input voltage to the inverter. The vehicle controller converts the torque instruction based on the accelerator signal and sends the value to all inverters. Ideally, all inverters should limit the output of their respective motors by the same timing, but in reality this varies because of different precisions of individual temperature sensors, A/D converters, and so on. As a result, the right and left traction forces become unbalanced. When a motor's output is limited, a flag is turned on at the limit of the motor's output and actual torque that is set in the inverter's messages by CAN communication. When the flag is on, a vehicle controller compares the actual torques of the four inverters with the instruction torque, and calculates the limit applied, and instructs smaller torque on the motor on the same axle.

The third redundancy control method is for when a motor on one side becomes stuck. A motor sticks when the reduction gears of the motor, the bearings, or the brakes become stuck. A vehicle controller watches the error flags and the rotational speeds of the four motors by using CAN information from the four inverters. If the rotational speed of either motor becomes zero and the vehicle controller judges it to be stuck, it stops the opposite motor on the same axle. A vehicle controller does not stop a normal motor on the same axle and should provide regenerative braking if equation 1 is obeyed. However, there was a tendency for the yaw rate and lateral acceleration to become worse than for a state without control as a result of this evaluation, when regenerative braking was applied during cornering. Therefore, a control method to stop the traction force was adopted.

4.2.1 Flow Chart of the Control Algorithm

Figure 5 shows a flow chart of this control algorithm. First, the vehicle controller diagnoses the state of each device when the ignition switch is turned on. If errors are not detected, the vehicle becomes READY. In STEP 1, the vehicle controller reads the state of the shift switch in 'NEUTRAL' position. When a shift position

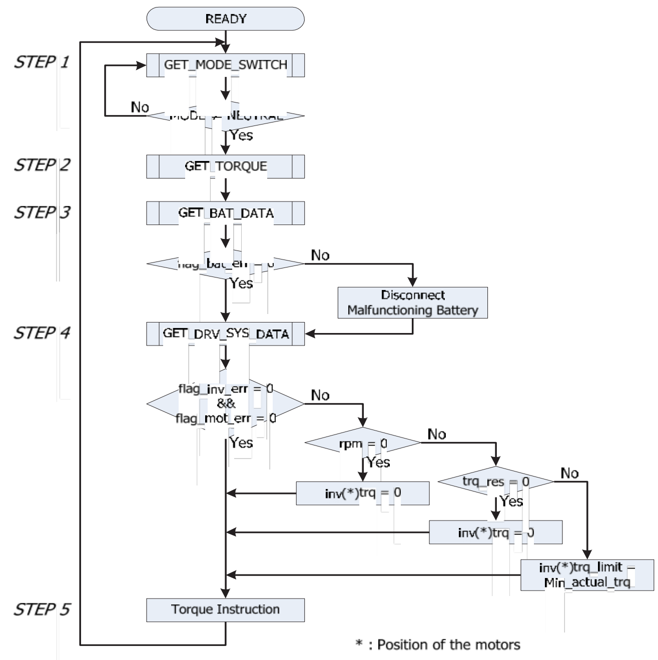

Fig. 5 Flow chart of redundancy control

of 'DRIVE' or 'REVERSE' is chosen, the process advances to STEP 2.

In STEP 2, the vehicle controller reads the position of the accelerator and calculates the instruction torque to be sent to the inverters with a previously programmed conversion table.

In STEP 3, the vehicle controller reads data, including the maximum and minimum cell voltage, the cell temperature, the state of charge (SOC), and any error codes from the management units of the four pairs of batteries, then it diagnoses any malfunctions. If the vehicle controller detects a malfunction of the batteries, it stops driving the inverter connected to the broken pair of batteries and shuts down the circuit.

In STEP 4, the vehicle controller reads data, including the actual torque, temperatures of the motors and inverters, rotational speeds, and any error codes from the inverters, then judges whether there are any malfunctions of the motors and inverters. The actual torque is calculated by multiplication of a torque constant that is particular to a motor and the phase current of the motor.

If the vehicle controller detects a malfunction of the motors or inverters, it specifies the cause of the problem with error codes. If a motor on one side becomes stuck or loses traction force, the opposite motor on the same axle is stopped. If a motor's output on one side becomes limited, the vehicle controller has the opposite inverter limit the torque to the maximum that its motor can produce at that moment.

Finally in STEP 5, if trouble was not detected, it just transmits the torque conversion value determined at

STEP 2. If a problem is detected, the torque conversion value found in STEP 2 is divided by the coefficient of motor torque (Ct),

$C_t = N_m$ 峯 4 挪挪挪*Eq.* (2)

where Nm is the number of inoperative motors, and the calculated instruction torque is sent to the working inverters.

This procedure insulates the driver from problems with the acceleration in the event of a malfunction. It results in sustaining the acceleration when the accelerator is pressed that is equivalent to the usual acceleration of 0.2g that is frequently experienced in city driving, although the maximum acceleration is less than normal. In addition, in the same way as the acceleration while cruise control, the torque lost with a malfunctioning motor is distributed to the other normal motors by a feed-forward control.

Fig. 6 Photo of Eliica

Table 1 Specifications of the Eliica

Length, width, height (m)	5.1, 1.9, 1.365	
Max. power (kW)	80×8 motors	
Max. torque (Nm)	100×8 motors	
Gear ratio	3.257	6.923
Max. velocity (km/h)	370	190
0 – 100 km/h time (s)	9.02	4.11
0 – 160 km/h time (s)	14.64	7.04
0 – 370 km/h time (s)	49.90	-

5. EVALUATION

By using a prototype "Eliica" car, in which these technologies were installed, a running test was executed to evaluate the redundancy of the drive system by combining the method for controlling motor malfunctions and the composition of the car's driving system [4]. The Eliica is an EV powered by lithium-ion batteries. Its acceleration time from 0 to 100 km/h is only 4.11 s, much better than the poor acceleration performance that had been long assumed to be characteristic of EVs [3].

Figure 6 shows the exterior and Table 1 the specifications of the Eliica.

5.1 Experimental Procedure

The system was evaluated on a straight track and on a track with a turn of radius 200 m under the following conditions:

1) Upon reaching 100 km/h while accelerating (maximum acceleration 0.68g).
2) While running at 100 km/h constant speed.
3) Upon reaching 60 km/h while decelerating from 100 km/h (0.2 and 0.7g, respectively).

Under each of these conditions, the yaw rate, steering angle, longitudinal acceleration, lateral acceleration, instruction torque, and actual torque after generating a motor malfunction (loss of traction or motor lock) in either the first or fourth axle on the right were measured. The velocity is measured by a GPS speed meter (RACELOGIC Ltd, VBOX2), which is also a data logger, the yaw rate and the acceleration rate are measured by X-Y axes acceleration transducers with gyro (RACELOGIC Ltd, YAW02), and the steering angle is measured by encoder steering angle sensor (SOHGOH KEISO Co. Ltd, TA-382BS). The gyro and the steering angle sensor were connected to the VBOX2. The torque signal value and the actual torque were measured by a protocol monitor (LINEEYE Co. Ltd, LE7200), which looks at the messages between the main control unit and the inverter. Also, the phase current was measured to estimate the actual motor torque Tm by using the equation 3, which is theoretical formula of the motor.

$T_m = K_t$ ˜ *I(u, v, w)* 挪挪挪*Eq.* (3)

A prior test result showed that a malfunction of the left motor had a similar effect one in the right motor. In addition, a motor malfunction in the second or third axle was taken to have the same effect as one in the first or fourth axle.

A motor malfunction was generated at a chosen time by a switch installed on the instrument panel. After a failure, the car was steered as smoothly as possible to hold the lane, and the accelerator or the brakes were maintained in the same state for a while.

The defect phenomenon of limited output of a motor on one side is not included in this paper, because the effect is smaller than the loss of traction of a motor on one side. Moreover, the result of testing a battery malfunction is omitted for the same reason.

5.2 Evaluation Method

The maximum values of yaw rate and lateral acceleration were compared with results of the "Sensitivity to lateral wind" recorded with Z108-76 of the Japanese Automobile Standards Organization (JASO) [5]. For example, a crosswind stability examination showed the maximum yaw rate and lateral acceleration at 100 km/h to be 5°/s and 0.17g, respectively. Since these values were typical of what a car on the market might generally encounter, if the behavior changes that took place due to a fault of the motor were below these values, safe operation would be maintained.

5.3 Test Results

5.3.1 Test Results without Redundancy Control

Figures 7a and b show the results without redundancy control. The results enclosed in the square region are within tolerance limits. For a motor malfunction of the first axle on the right, the tolerance limits were exceeded under all conditions of acceleration (Fig. 7a). For a motor malfunction of the fourth axle on the right (Fig. 7b), the tolerance limits were exceeded by three conditions: motor lock during a right turn under acceleration and both loss of traction and motor lock during a left turn under acceleration.

Moreover, while turning, the ride stability became significantly worse when the motor on the fourth axle on the right was locked during high acceleration. A lock during a left turn had a particularly bad influence on the ride stability under these examination conditions. In addition, a motor lock was worse than the loss of motor traction under both conditions.

The reason why the test results exceeded the tolerance limit under every condition upon the motor malfunction of the first axle on the right during high acceleration is due to the steering angle created by the yaw moment directly affecting the handle.

Also, for the reason why the test results for four right motors malfunctions had lesser condition in which the tolerance limit was exceeded compared to the right motor malfunction on the first axle is because there is a difference in the way the maneuverability is affected upon the location of the malfunction. This is due to the yaw moment created beforehand because of the cornering force created upon turning. However, from figure 7(a) and 7(b), four right motors malfunctions had worse result than the right first axle motor malfunction upon left turn during acceleration test. This is due to the driver's slow response because the yaw moment created when rear motor malfunctions does not directly affect the steering wheel. Also, when the right four motors malfunctions during a left turn, the yaw moment created by the fourth axle is opposite from the vehicle's rotating direction and therefore causes a decrease in stability in the rear of the vehicle, and the drivability worsens.

As a representative example of the test, the result, which exceeded the tolerant limit the most, is indicated by figure 7(c). This occurred when the right motor on the 4th axle locks during high acceleration while turning left. In the figure, velocity, acceleration rate both forward and backwards, lateral acceleration, and yaw rate is indicated and the "Test Flag" indicates the point of when the malfunction occurred. In 0.7 seconds after the malfunction, the yaw rate is about 7.8°/s, the lateral acceleration increased about 0.33g, causing

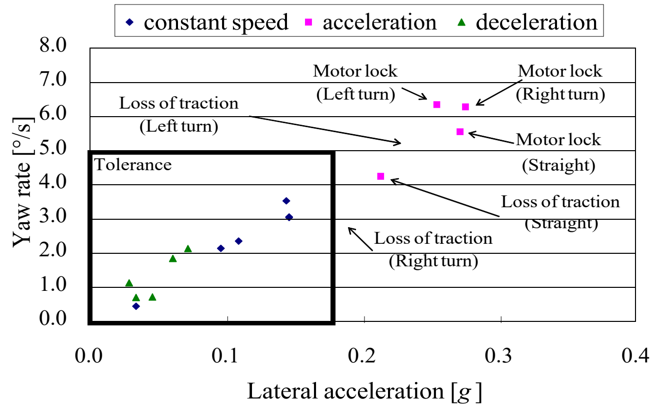

Fig. 7(a) Motor malfunction of the first axle on the right without redundancy control

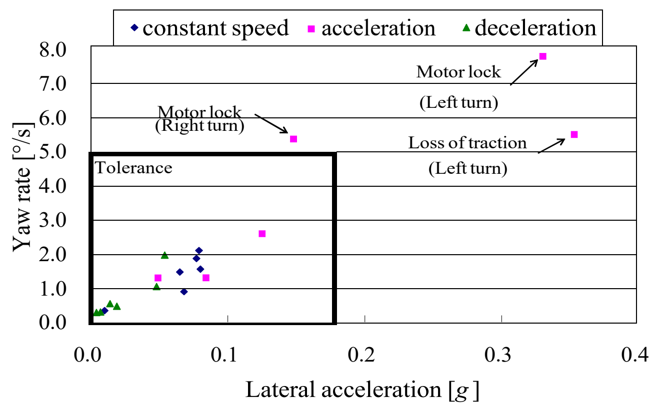

Fig. 7(b) Motor malfunction of the fourth axle on the right without redundancy control

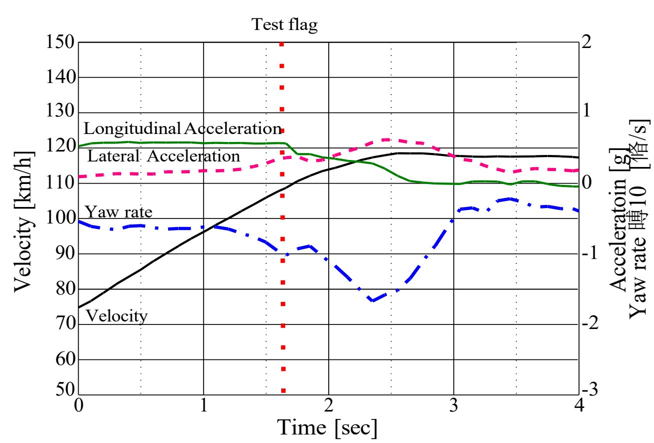

Fig. 7 (c) Motor lock of 4th axle in the right (Left turn at maximum acceleration) insecurity in drivability. Therefore, after the malfunction, it is difficult to hold the acceleration pedal. So in the case upon actual driving, the acceleration pedal was put back and the vehicle position was corrected by steering, as it is apparent from the acceleration rate.

From these results, the need for control upon motor malfunction during high acceleration has been confirmed for improved drivability.

5.3.2 Test Results with Redundancy Control

Figures 8a and b show the examination results with the addition of redundancy control. The ability to suppress both yaw rate and lateral acceleration below the tolerance limits by the introduction of redundancy control under each running condition has been confirmed. In particular, driving could be continued easily immediately after a loss of traction. Moreover, when a motor locked, the vehicle could be stopped safely.

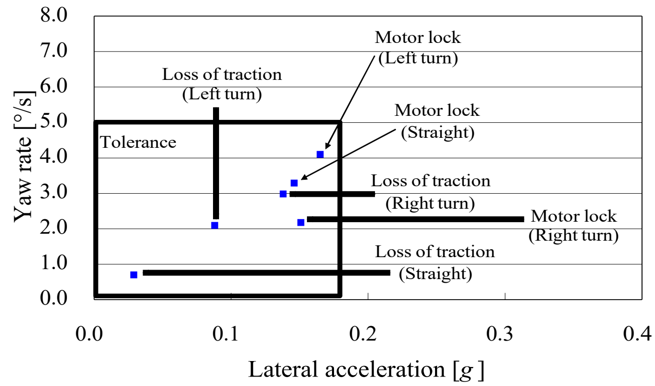

Fig. 8(a) Motor malfunction of the first axle on the right with redundancy control

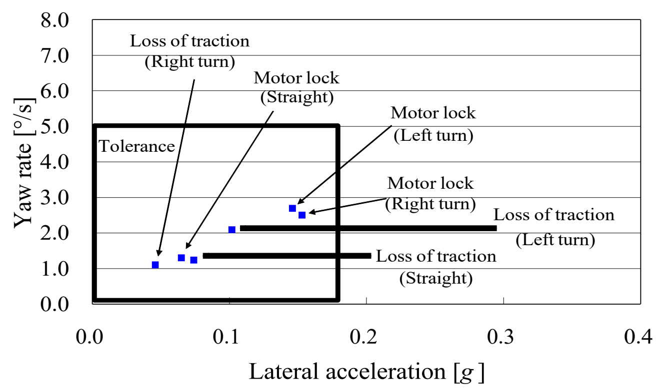

Fig. 8(b) Motor malfunction of the fourth axle on the right with redundancy control

6. CONCLUSIONS

In an EV that uses in-wheel motors, as predicted by theory, when traction forces of the right and left became unbalanced by the malfunction of a motor, it has been experimentally confirmed that the vehicle stability deteriorates. Although vehicle dynamics vary among individual vehicles, in the case of the prototype "Eliica" car, when one motor experienced loss of traction or locked while accelerating on a straight track or on a curve with a 200-m radius, the yaw rate and lateral acceleration that were generated exceeded the results of the "Sensitivity to lateral wind" recorded with Z108-76 of JASO, and ride stability deteriorated.

To test a solution, when a motor lost traction force or locked, the opposite motor on the same axle has been stopped. As a result, when a motor lost traction force, yaw moment and lateral acceleration were restrained, and redundancy control allowed driving to continue with other working motors. Moreover, the vehicle could be stopped safely under the fault condition of motor lock.

To limit the load, the vehicle controller reads the instruction torque of an inverter and applies the same instruction torque to the other motor on the same axle as a limiter. Furthermore, for a more effective redundancy drive system, a pair of batteries supplies two inverters on the same axle, and a vehicle controller is connected to each pair of front and rear axles.

Few EVs use in-wheel motors. However, all-wheel-drive vehicles, which can control the driving force of each wheel freely, are put to practical use in internal combustion engine vehicles (ICEVs) from safety concerns, recently. Therefore, if EVs were to replace ICEVs, demand for in-wheel motors will increase, because performance superior to ICEV is expected for in-wheel motors, which respond quickly and can control driving forces easily.

The proposed method for controlling a motor malfunction can be used not only in all-wheel-drive vehicles that use in-wheel motors, but also in the safety planning of 2WD and hybrid vehicles that have independent right and left motors.

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Globally Cool Vehicles: When Only Electric Will Do

Global Warming, Energy Independence and Healthier Air are the driving forces behind the search for alternative-to-gasoline fueled transportation. Though not as widely publicized, congestion worsens these problems by wasting fuel and generating more emissions while waiting for traffic to move. Myers Motors believes that the easiest and fastest way to zero emissions and energy independence at the least total cost for personal transportation will come through pure electric vehicles. Electric vehicles already run on zero total emissions for those getting their power from hydro, solar, nuclear and wind; this will expand to include clean coal, waves and other technologies we haven't heard of yet. Battery technology exists today to power the range requirements on over half the vehicles in America, yet electric vehicles are more talked about than made. Myers Motors' unique method for introducing electric vehicles to the American public focuses on making highway-speed electrics vehicles available at a reasonable price to promote real world ownership..

Keywords: Electric vehicle, fast market entry, Myers Motors, environmental effectiveness

1. INTRODUCTION

Society faces three major environmental problems today: global warming, a desire for energy independence and the need for healthier air … and one less obvious practical problem: congestion. Easily available and inexpensive oil-based transportation built the society we enjoy today, but cost more than anyone ever bargained. We now have the opportunity to make transportation choices that will either dramatically improve or dramatically worsen these particular challenges.

How great are these challenges? Ten years ago no one could have predicted that the general public would be so concerned that the topic of global warming would rate more than 5 million references about it would appear monthly on the web, or that it would lead to an Oscar for a former U.S. Vice President.

If the frenzy about climate change wasn't enough, no newscast seems complete without lamenting the latest oil price hike and how we'll pay for it at the pump. Overall, the debate about Peak Oil has shifted from whether it will happen to when it will happen. Additionally, a growing group of political and military experts have expressed concern about our financial and political security if we continue to rely so heavily on imported oil. Energy independence has been an election campaign buzz word since at least 2004 with more than 200 bills containing the words "energy independence" introduced to federal legislators just this year.

Studies have linked exposure to auto emissions with asthma, emphysema, heart disease, and cancer. Reports over the last few years have shown that living in areas with heavy traffic can shorten life, and, just this year it was reported that children can experience reduced lung capacity if they live too close to heavily traveled roadways. Over $60 billion in US health costs can be attributed to air fouled by burning oil in vehicles [ ].

1.1 Global warming

Our global climate maintains a delicate balance in order to support life. Large fluctuations in the temperature can cause significant damage. The basic premise behind today's concern is the trend of temperature changes that can be seen to parallel human activity since the Industrial Revolution began. As industry developed, burning of fossil fuels dumped a growing amount of emissions into the air. This process accelerated greatly with the introduction of internal combustion engine use in transportation. As the amount of emissions increased, the planet's natural ability to recycle the air and release solar heat back into space became challenged, especially as more and more forests were removed to make room for sprawl. This led to an increase in the atmospheric concentration of carbon dioxide greater than 30%, keeping the sun's heat closer to the Earth [ ].

While the plant has experienced historic temperature extremes, it is uncertain how long it took for those changes to develop or how great the fluctuation was. These changes have also never happened with such a large human population in place. A few of the crises experts predict may accompany temperature rises include:

o Increasing frequency and severity of heat waves
o Increasing frequency and severity of storm systems
o Increased desertification
o Declining availability of freshwater
o Decreased food production
o Rising sea levels and coastal flooding.

The areas with the poorest populations will likely suffer the most from these changes [ ].

Careful reduction and rapid of the amount of carbon and other greenhouse gases discharged into the air may mitigate the effects of climate change. However, the longer actions are delayed by debate, the more devastating the damage may be.

1.2 Energy Independence

Two-thirds of the oil used by Americans is devoted to transportation. America only needed to import 19% of its crude oil in 1960. In 2006 it imported over 70% [ ], effectively obtaining every drop of oil used for transportation from overseas. Because 99% of American transportation relies on oil products, a disruption in supply would ripple throughout its economy as individuals are unable to reach their employment.

While our neighbors Canada and Mexico are the two largest oil suppliers, approximately one-third of our imported oil comes from regions that are politically unstable or unfriendly toward America [ ]. The June 2006 threat by OPEC to reduce investment in new oil production, driving prices upward, in response to the U.S. developing biofuel as an alternative fuel source [ ] is one example of the threat imposed by depending on other nations to supply such a vital resource.

In addition to relying on foreign sources for oil, oil-dependent nations risk financial problems and social disruption if the oil supplies are disrupted by severe weather, such as hurricanes, or terrorist actions that may destroy the oil supply chain. Even routine maintenance that takes refineries off-line for a few weeks can drive up the price of oil products.

The push to develop vehicles based on domestically produced energy stems from the realization that it would bring stability to the American transportation system as well as reduce the national trade deficit by approximately 30% [ ].

1.3 Healthier Air

The California Air Resources Board 2004 report that stated "This impact of vehicle-related pollution on children's lung function is likely to have life-long adverse health [consequences] [ ]." Gasoline-powered and diesel-powered vehicles emit a host of chemicals that impact animal and human health. The impact of these pollutants is so great that the U.S. EPA actually states "[d]riving a private car is probably a typical citizen's most "polluting" daily activity [ ]."

The following table links typical vehicle emissions with the health problems associated with each.

In addition to these chemicals, autos emit particles small enough to bypass the body's natural defense. Smaller than 2.5 micrometers in diameter, these emissions have been shown to increase hospital emissions for respiratory illnesses, including asthma, bronchitis, and pneumonia. Risks are higher for people living in close proximity to heavily traveled routes [ ].

1.4 Congestion

More than 91 million people choose to drive to work alone, overflowing roadways with vehicles transporting mostly empty seats [ ]. Single occupancy continues after work as well since the driver goes alone for 38% of all personal vehicle trips taken. This trend has gained 11 percentage points over the last 20 years and carpooling dropped 8% over the same period [ ]. The increase in single-occupant travel has driven urban vehicle miles traveled up by 168% since 1980, leading to more congested roadways [ ].

Solo drivers using vehicles designed for multiple occupants contribute to congested roadways, escalating lost productive time, wasted fuel, and pollution. This congestion was estimated by The 2005 Annual Urban Mobility Report published by Texas A&M University to waste nearly 4 billion hours, to burn more than 2 billion gallons of excess fuel, and to lose slightly more than $63 billion because of congestion delays in 2003, just in the 85 urban areas studied [ ].

Increased congestion leads to demands for more roadways and parking facilities to meet the needs of the driving public. However, building additional impervious surfaces alters soil absorption of rain and adds stress to drainage systems. This can lead to flooding in areas and increased soil erosion. Run-off from roadways that have been treated for ice can make its way into groundwater impacting plant and animal life.

These problems point to the need for vehicles sized to meet realistic driving patterns, especially in households having multiple vehicles.

Chemical/Chemical Family	Associated Health Problems	Other Problems
Hydrocarbons	Irritates eyes	Contributes to ground-level ozone
	Damages lungs	
	Aggravates respiratory problems	
	Potential to cause cancer	
Nitrogen Oxides (NOx)		Contributes to ground-level ozone.
		Contributes to acid rain production
Carbon Monoxide	Reduces oxygen flow	
	Can induce chest pain for people with heart problems	
	Can impair exercise capacity	
	Can reduce visual perception and manual dexterity	
	Can limit ability to perform complex tasks [i]	
	Can impair learning	
Carbon Dioxide		Greenhouse gas contributing to global warming

Table1: Health Problems Associated with Specific Automotive Emissions

2. REASONS EV's SURPASS OTHER ALTERNATIVE-FUEL TECHNOLOGIES

2.1 Alternatives

While eking out a few miles per gallon improvement on current automobiles is a step in the right direction, it is too small to make a credible difference in the challenges we face today. Hybrid electric systems provide a greater mileage boost than simply improving IC engine efficiency, but ultimately remain oil-dependent. They may have a place as a bridge technology, but, especially in light of available alternatives, do not provide any long-term hope for our transportation system.

Plug-in hybrids offer promise for long distance driving, but still use oil-products. They tap into the power grid and can reduce oil use, but are not necessary for daily driving. However, the additional weight from gasoline, the internal combustion system, and exhaust components carried by hybrids make them less energy efficient than a battery-powered electric vehicle, especially for daily driving.

The naïve assumption that if a product begins as a crop it must be good has led to unquestioning public acceptance of biofuels as a viable alternative to break our dependence on fossil fuels and reduce air pollution. However, current methods of producing biofuels can have the opposite effect. While it is true that the carbon released from burning biofuels is cancelled by the growth process, some countries are destroying forests in order to develop land to grow the crops needed for processing into fuel. In addition, current farming methods require a great deal of oil use for farming equipment, transportation, and fertilizers – effectively shifting the oil use and reducing it to a lesser extent than the public generally understands.

Recent discussions point to the deficit in carbon sequestration when countries choose deforestation to make room for more biofuel crops. Not only do biofuels perform worse in capturing excess carbon, deforestation releases huge amounts into the atmosphere. Mac Post, a biofuel expert at the Oak Ridge National Laboratory, agreed saying, "If you're clearing high-content ecosystems to offset CO2 emissions, you're digging a hole. By what I can tell, it's a pretty deep hole, and you may not climb out" [ ]. Indonesia illustrates this as the current worst case scenario because it has quickly become the "third largest producer of carbon emissions" by clearing large areas of rain forest and using chemical fertilizers [ ].

The potential for increased profit financial gain by planting crops desired for biofuels also forces farmers to make a precarious choice: grow fuel or food? A September 2007 report published by the Department of Energy's Energy Information Administration stated that

[T]he competition for arable land that would result from increased corn production at the levels needed to satisfy the 25-percent RFS could significantly raise all food and feed prices in the United States. The current generation of corn and soy biofuels crops are grown almost exclusively on prime agricultural land in the Midwest. It is not clear that sufficient land resources would be available for large-scale expansion of corn and soybean cultivation, given the intense competition with conventional agricultural products for arable land [ ].

The rising price of a gallon of milk already highlights the competition between biofuel crops and food production for the limited amount of fertile land available. The BBC's Jeffrey A McNeely made this observation:

The grain required to fill the petrol tank of a Range Rover with ethanol is sufficient to feed one person per year. Assuming the petrol tank is refilled every two weeks, the amount of grain required would feed a hungry African village for a year [ ].

Despite the noble thinking driving the biofuels industry, it can only become sustainable if production of the fuels:

- o Does not challenge food supplies
- o Does not increase water demands during the growth or refining process
- o Does not lead to depletion of soil nutrients or erosion
- o Does not require deforestation to "create" more arable land
- o Does not disturb natural habitats
- o Does not require petroleum products in the cultivating, harvesting, processing, or transporting of the vegetation or completed fuel product
- o Can be profitable using fair labor practices for everyone from the field to the pump
- o Can be made from plant indigenous to the region or
- o Can be grown in areas that do not grow vegetation under normal circumstances

In other words, if you can make the desert bloom without irrigation depleting other water sources and create fairly administered, well-paying jobs at every level of production, biofuels may be a viable option to replace a small percentage of our transportation needs. But even then, in order to replace American oil use with ethanol at the expected increase in fuel demands by 2050 would require planting 1.7 billion acres, or approximately 90% of U.S. soil [ ].

Hydrogen can be used either by a specially designed internal combustion engine or with a fuel cell that converts the hydrogen into electricity through a chemical reaction. No harmful emissions result in using hydrogen in either case. The public generally hears reports of how hydrogen can be split out of water using renewable energy sources. However, because this process is so inefficient, almost all of today's hydrogen production is made from natural gas. The methane in natural gas releases carbon monoxide and hydrogen when mixed with high temperature steam.

According to the U.S. Department of Energy's hydrogen website:

> The long-term vision of the hydrogen economy will take several decades to achieve. Initially, government will play a key role in conducting the R&D to achieve the "technology readiness" needed to allow industry to make decisions on commercialization in the 2015 timeframe.

The DOE admitted that the technology will be ready to start making decisions about commercialization in 2015. In other words, industry can begin deciding on how to implement wide-scale commercial usage of hydrogen – if the technology is ready. Both water electrolysis and natural gas production of hydrogen fail as a supply wide-spread use as a transportation fuel. Water electrolysis loses a significant amount of energy that could be stored in batteries and drive an electric vehicle much further than the resulting hydrogen could. Natural gas production of hydrogen has carbon monoxide as an emission. In either case, massive infrastructure needs developed in order to deliver the hydrogen to consumers and vehicles may not be commercially profitable for quite some time. We cannot afford to wait nearly a decade before taking steps to change transportation. The eminent pressures of global warming, the cry for energy independence, and the need for healthier air demand that we take action now.

The quickest and most effective way to tackle the threats facing us today is to jump as quickly as possible to fully electrified vehicles for the majority of our daily driving needs.

2.2 Environmental Effectiveness

Well to wheel studies published in 1999 by the Argonne National Laboratory compared the total emissions of electric vehicles to gasoline-powered vehicles from mining fuels all the way through driving the vehicles. This study demonstrated that for electric vehicles (EV) the overall emissions plummeted by nearly 90% when compared to gasoline-powered vehicles (GV), even when using a relatively "dirty" power grid to charge. The most dramatic changes occurred in the urban setting where overall EV emissions dropped by 15.59-100% compared to GV. When averaged across the country, the level of every pollutant measured decreased significantly except nitrous oxide (NOx) and sulphur oxides (SOx) [ ]. While both of these levels increased using the pre-1999 technology, better controls at power plants since then had cut emissions of NOx by 30.9% and the major SOx measurement, sulphur dioxide, fell16.9% by 2005, despite a 9% increase in electricity production since the report was published [ ].

Additionally, renewable energy sources such as solar, hydro, or wind power can utilize EVs better than any other technology currently available. Channeling the electricity from the renewable source to the batteries and then directly to the electric engine is more efficient than using the electricity to process either biofuel or hydrogen. While wind power has been maligned as unreliable because it is only abundant at night, trickle charging EVs while the owners sleep creates a synergy that leverages the best of both technologies.

2.3 Ease of Implementation

Electric vehicles (EV) require far fewer parts than internal combustion engines. EVs do not need to be made from materials more resistant to corrosion, as with biofuels and today's EV technology can meet the majority of daily driving needs and be updated with advanced battery systems as they become available. The major challenges facing EVs are:

- o Overcoming public misinformation on EVs,
- o Building general consumer confidence in EVs,
- o Building a steady supply stream of components,
- o Reducing the price of those components and manufacturing, and
- o Funding the exorbitant cost of preparing a traditional car for market.

The biggest constraint on EVs is the cost of production. The current expense of building an electric vehicle should come down naturally as a demand is built and utilities of scale allow for more cost-effective building techniques. The high cost of production hampers the ability to build enough volume to bring down costs. As fuel costs increase and public awareness grows, the demand for EVs should grow through natural market forces. Financial incentives from local, state, and federal governments can accelerate the process, however, our representatives need to be educated in the advantages of pure electric vehicles. The EV industry also needs to lobby those representatives effectively to counter pressure from traditional auto manufacturers.

In any case, it will be easer to bring the cost of a $30,000 electric vehicle down to the $15,000 price range consumers want than to bring the $1,000,000 cost of today's fuel-cell vehicles down to the $20,000 range consumers may find acceptable.

Electric vehicles also have the advantage of plugging into an infrastructure as familiar as recharging a cell phone. While some manufacturers may promote rapid charging systems, most offer charging on the 110 or 240 volt outlets already found in homes. On the other hand, most cars sit over 22 hours per day and so a rapid charging system isn't needed unless the goal is to make an electric vehicle operate exactly like a car. For the vast majority of how people use their public transportation, long charging times, while the driver is at work or home, are more than sufficient.

2.4 Fast Market Entry

Traditional automotive companies have several advantages. They have vast financial resources and decades of process development that newcomers find difficult to challenge. Most of the alternative transportation technologies under discussion still require years, if not decades of development before being offered. Electric vehicles that meet the majority of daily driving needs are available today and can be offered wide-scale as soon as the purchase price comes down to meet the average consumer's budget.

One of the greatest challenges is the cost of meeting regulations for four-wheeled vehicles so some manufacturers offer low-speed electric vehicles to develop the market. Their acceptance for close-to-home trips in small towns and golf course communities is growing. However, most drivers need a highway speed vehicle to commute on a daily basis.

One method of introducing highway speed vehicles is to develop three-wheeled electric vehicles that are recognized as three-wheeled motorcycles. This category of vehicle does not require as stringent of safety testing before being allowed onto roadways. Developing high-quality three-wheeled electric vehicles for highway use also allows for rapid market entry and real-world testing of new technologies as they are developed.

2.5 Lowest Cost

Government and private investors have already channeled billions into hydrogen research and development without being able to offer consumers a viable alternative. Biofuel costs are growing because our current pipeline system cannot withstand the corrosive nature of ethanol. Remedying this problem will require building an entirely new pipeline system. Plant growth is season dependent so producers will need to find a way to store biomass until it is needed for refining, or find a method to store the completed product without a great deal of loss to evaporation – both additional infrastructure expenses.

Electric vehicles are available today without developing a wide-spread infrastructure. The $94 million dollars slated in 2005 to build 24 hydrogen fueling stations in California could have been used to offer $5,000 incentives for the purchase of electric vehicles instead. If that had happened, the 18,800 new EV drivers could be saving gas to the tune of approximately 8,950,435 gallons a year. The cost to place the same number of fuel cell vehicles on the road? Just under $19 billion [ ].

Expanding that principle to Department of Energy's EERE FreedomCAR and Vehicles Technologies (FCVT) Program budget further demonstrates the practicality of EVs. Over $396 million dollars were budgeted for years 2004 through 2007, with an additional $126.6 million requested for 2008 [ ]. This total of $522.9 million dollars could have provided $5,000 incentives for 104,580 new EVs.

While the gasoline-gallon equivalent costs of ethanol and hydrogen continue to rise, developments in renewable energy systems and increasing economies of scale promise to drop the cost of renewable energy. Electric vehicle drivers can have truly zero-emissions vehicles. As demand drives down the initial purchase cost of EVs and batteries, the total cost of ownership for an electric vehicle could become less than the total cost of ownership of a traditional gasoline-powered vehicle.

In contrast to the financial burden of developing these complex infrastructures for biofuels and hydrogen, the existing electric power infrastructure has enough excess resources to power 84% of cars, pickup trucks, and sport utility vehicles in the United States. This would save the equivalent of 6.5 million barrels of oil daily – just over half of the amount of imported oil [ ].

3. ELECTRIC VEHICLES HAVE A BRIGHT FUTURE

The future for electric vehicles looks bright from here because environmental, political, environmental, and health concerns are demanding a change be made now. No other technology is poised to take the lead as quickly as electric vehicles. Existing technology and battery systems already meet the majority of daily driving needs. The available smaller vehicles meet the needs over 91 million commuters who choose to commute to work and school alone each day.

The future is also bright because multiple media outlets continue to focus on the stated problems and what changes need made to generate improvements. The multiple stories presented on alternative fuel vehicles each week educate the public of coming options and demand is increasing. Manufacturers will have no choice but to find a way to offer consumers what they demand, forcing steps in the right direction. Additionally, driving an environmentally friendly vehicle has become a status symbol, which will increase demand as well.

The future also looks bright because ramping up production to meet the growing demand will require developing mass production techniques and a supply stream that will ultimately lower the costs of making, and buying an electric vehicle. Dropping prices and positive consumer experiences will drive even more growth. When the total cost of owning an EV rivals the total cost of owning a traditional oil-powered car, the market for EVs will mushroom.

3.1 The Technology Meets Today's Driving Needs

The average driving range of an electric vehicle using lead acid batteries remains around 30 miles. While this does not cover taking the family on vacations, over 60% of households already have two or more vehicles [ ], and many of the second vehicles are used primarily for one person's individual commuting. With an average commute of 12 miles to work and parking the vehicle for the eight hour work day, he or she has ample charge left for the evening commute. An even better scenario exists if the employer offers the ability to recharge at work, allowing employees to have a full 30 miles of driving range when they leave. In that scenario, the lead acid batteries range increases to up to 60 miles daily.

But lead acid batteries are just the beginning. The great production electric vehicles of the 1990s proved the efficacy of nickel metal hydride (NiMH) batteries. Drivers reported ranges up to 150 miles for an EV1 and some have put nearly100,000 miles on the original battery pack. Lithium ion batteries promise ranges approaching 200 miles and long life. Both of these technologies cost considerably more than traditional lead acid batteries, but recent variations on chemistries show promise of reaching the goal of longer ranges, reduced price, and extended battery life.

3.2 Growing Publicity Increases Public Demand

The movie "Who Killed the Electric Car" reawakened the general population to the world of electric vehicles. The media promoted the controversy stirred by the movie on every network and EV drivers became local heroes when they drove their EV to the theater where it was playing. General Motors responded to the allegations in the movies by fanning the EV flame with announcements about their proposed plug-in hybrid, the Volt. The momentum grew as other large manufacturers announced their plans, and current EV manufacturers enjoyed the attention.

Additional media attention focused on changing laws to accommodate low-speed electric vehicles on public roads. A test drive in America's only affordable, all-electric, highway legal (75 mph) available for delivery today vehicle, the NmG, blows away any misconceptions about EVs being slow or unwieldy.

The Myers Motors experience has been that every customer receives a call from their local media within a week or two of the delivery of their NmG leading to calls and e-mails from people who have seen the coverage. The uniqueness of owning a highway speed electric vehicle has resulted and will continue to result in media exposure until they become commonplace.

The chicken or the egg dilemma effects electric vehicle production. Many consumers state they would buy one if they could pay a price comparable to gasoline-powered vehicles. The current high prices keeps the demand low enough that many EVs are hand built using expensive special order parts. Equipment manufacturers cannot afford would need to guarantee a steady supply of certain components without the funding in place to manufacture larger quantities. This cycle keeps the EV price elevated and suppresses demand.

However, as investment in the EV industry grows and reduces the price, the demand for EVs will increase. The growing industry will be able to support increased production of specialty parts and encourage research that will improve the entire industry. As the practicality of EVs becomes widely apparent to consumers, fair market forces will determine the value of EVs in a way that sustains the supply stream of components to meet demand.

4. THE MYERS MOTORS' UNIQUE METHOD FOR INTRODUCING ELECTRIC VEHICLES TO THE AMERICAN PUBLIC

The current methods other manufacturers use for making electric vehicles more widely accepted range from lobbying for low-speed vehicles on public roadways to building high-end sports cars with a price tag to match. Myers Motors takes another approach starting with how consumers actually use vehicles. Myers Motors also strives to price vehicles as fairly as possible and connect interested consumers with our ownership network.

4.1 Start with How Consumers Actually Use Vehicles

Most vehicles are designed with one purpose, transport as many individuals and items as far as possible on every trip. This design had merit when owning a private vehicle was a luxury and owning more than one was almost unheard of. However, today 60% of households own two or more vehicles leading to 91 million drivers (79.4% of workers) traveling alone every day [ ], usually in vehicles designed to carry four to seven passengers. It is an inefficient use of energy to transport that much vehicle, it is also highly wasteful. Even in electric vehicles, a full-sized vehicle requires more energy to drive than a lightweight vehicle designed for one or two people. A look at the typically less congested HOV lanes compared to multiple lanes of single occupant traffic further emphasizes the practicality of single occupant vehicles.

While single-occupant travel has driven urban vehicle miles traveled up by 168% since 1980, the urban road miles only grew by 51% during that time creating even more congestion [ ]. Robert Q. Riley points to many studies linking smaller vehicle size with reduced congestion in his book, Alternative Cars in the 21st Century: A new personal transportation paradigm. According to Riley, including a small percentage of half-length cars in a free-flowing traffic arrangement, such as the expressway, increased capacity by at least 10%. He also stated that computer modeling showed up to a 70% increase in capacity within cities where traffic signals influence the flow [ ].

Switching to smaller vehicles for daily commutes into urban areas can also reduce the need to create additional parking lots and structures. Designating 20% of parking spaces to smaller vehicles can yield a 30% increase in available spaces. The number of spaces can more than double by switching 67% of spaces to two-thirds-width vehicles. The savings would be even greater by changing parking lot rows to accommodate half-length vehicles as well.

The benefits of reducing the amount of land necessary for parking can be a financial boon for a community, as well as allow land to be targeted for more practical use. The money saved by not building yet one more parking deck can cover the costs with repainting parking lines in existing structures, or finance incentives to switch to smaller vehicles, or pay for enforcement when greedy drivers monopolize multiple spaces. Additional savings achieved by not paying for additional staff and maintenance fees for new decks can also be used to provide charging stations for EVs or preferential rates for drivers using smaller vehicles. Of course, municipalities could also pass the savings along to taxpayers by not raising taxes in order to pay for more decks.

The abundance of multiple vehicle ownership and single-passenger trips, wasted energy, and severe congestion problems all indicate that society is ready for smaller, task specific vehicles.

4.2 Price Vehicles as Fairly as Possible

Another part of Myers Motors' plan is to provide highway-speed vehicles at a relatively affordable price. While current production constraints force the cost for all highway-speed vehicles to exceed average gasoline-powered vehicles, our goal is to reduce our costs as quickly as possible. This will allow us to offer practical electric vehicles at a price the general population can afford.

Offering EVs at a price that competes with gasoline-powered vehicles will bring the greatest benefits by empowering individuals to take responsibility for how their transportation affects the world around them.

Just as Henry Ford opened the door of car ownership to the masses, Myers Motors strives to make electric vehicles financially competitive for average individuals.

4.3 Connect Interested Consumers with Ownership Network

Myers Motors vehicles have been in production long enough for our customers to have real-world driving experience. This network also allows people to see Myers Motors vehicles in use on their local streets. Not only are most of our drivers excited about the idea of sharing their experiences on our website, when prospects approach Myers Motors and want an unbiased opinion, many of our drivers will gladly talk to them and answer their questions. Our ownership network allies with us in educating the public about electric vehicles in general, and Myers Motors in particular.

4. CONCLUSION

Transportation plays a more important role in our future than how to get from Point A to Point B. Oil-based transportation pours contaminants into our atmosphere that contribute significantly to our climate crisis. America has placed itself in a precarious position politically and financially by allowing 99% of our transportation to depend upon a substance that we must import. This is especially true given our dependence on foreign entities that do not support American ideals. Additionally, breathing the fumes from gasoline- and diesel-powered vehicles results in health problems for many adults and risks the development of our children who live closest to busy roadways. We exacerbate these problems by choosing to drive oversized vehicles that contribute to congestion and hog energy to transport typically just one person.

Several alternatives have been offered and each has developed a following. Stricter mileage standards, hybrid electric vehicles and plug-in hybrid electric vehicles reduce oil consumption a little, but fail to provide substantial change. Biofuels appear green, but current production methods may actually worsen the problems targeted by their use. Hydrogen-powered vehicles may become a boon to society in the future, but current hydrogen productions do not do enough to reduce emissions. Plus, we cannot afford to wait until hydrogen vehicles become commercially viable to make the changes necessary. Only electric will do because they are ready now, they do not require massive infrastructure development for refueling, electricity production is becoming cleaner, and today's vehicles will be to incorporate power storage advances as they become available.

As a global society, the path we choose will influence every aspect of our lives, the quality of the air we breathe, the stability of our weather patterns, the cost and availability of our food, and our children's health. We need to choose wisely.

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Energy on Demand

The increasing demand and subsequent increasing price of fossil fuels have coupled with concern over global warming to encourage interest in sustainable forms of energy and "greener" transportation. Hybrid vehicles are slowly gaining ground on traditional vehicles, bringing improved fuel efficiency and greater consumer interest in electric vehicles. The availability of mass-produced electric vehicles, however, has remained elusive. Better batteries – or other methods of energy storage appropriate for use in transportation applications – are seen as key technologies for the continued advancement of hybrid and all-electric vehicles. Although simple batteries have been in existence for 200 years, energy storage has never been more at the forefront of vehicle design than it is today.

Industry, government, and academia are collaborating in an effort to identify and overcome the technological hurdles of energy storage in transportation applications. In the United States, the FreedomCAR and Vehicle Technologies program and the U.S. Advanced Battery Consortium (USABC) developed ambitious targets for energy storage technology for use in electric vehicles (EVs) and hybrid electric vehicles (HEVs) (Table 1) [1]. Additional USABC targets are summarized in the article by Duong et al. in this issue. Performance indicators for three leading battery chemistries – lead-acid, nickel-metal hydride (NiMH), and lithium-ion (Li-ion) – are also presented elsewhere in this issue (see article by Van Mulders et al.).

Upon comparing these USABC targets and current performance indicators, it becomes apparent that the development of all-electric vehicles is limited by the low specific energy and high cost of commercially available batteries. These barriers are not new; indeed they have been the focus of electric vehicle battery research for over 30 years [2]. Yet, with specific energies of up to 140 Wh/kg [3, 4], even Li-ion battery systems fall far below the specific energy benchmark set by gasoline (12,722 Wh/kg) [5]. The low specific energies of current battery systems effectively limit the range of all-electric vehicles and therefore encourage the development of hybrids. Hybrid vehicles utilize the high specific energy of liquid fuels in the relatively inefficient internal combustion engine to extend the limited driving range afforded by the relatively low specific energy (but highly efficient) battery systems. Thus, a trade-off between driving range and energy efficiency is established.

*Advanced Technologies for Transportation Research Program
University of Tennessee at Chattanooga
615 McCallie Ave, Dept 2252, Chattanooga, TN, 37403
Fax: 423-425-5464

Examination of the USABC goals demonstrates that there are market niches for a variety of battery capabilities depending on the level of hybridization demanded – i.e., the "purpose" of the battery. Lead-acid batteries, the oldest of the three technologies, have sufficient specific energy and power for mild hybridization and less demanding all-electric applications and a significant cost advantage over other chemistries. Moving towards greater levels of hybridization and/or more demanding applications generally requires the greater specific energy and specific power of the NiMH and Li-ion chemistries. Indeed, NiMH and Li-ion batteries can achieve the USABC targets for specific power under laboratory conditions [6, 7]. These chemistries, however, involve significantly higher costs [5]; thus, demonstrating increased fuel efficiency, decreased emissions, or other desirable properties is necessary to justify the notably higher price tag.

Calendar life and cycle life are also critical issues, as these areas involve quality of performance, durability, market acceptance, and manufacturer warranty liability. Cycle life is strongly affected by the level of discharge the battery experiences between chargings. The usable state of charge directly governs the amount of energy that is available between chargings. The ability of the battery to withstand the level of discharge routinely expected in a given application is critical. Lead acid batteries, for instance, have shortened cycle life with routine shallow discharges [8], inhibiting more extensive use in HEVs.

Additionally, other issues revolve around information that is only partially represented in the selected data above. The target for temperature operating range is also a barrier in that many battery systems perform best in a fairly narrow range of temperatures (e.g., 25°C - 35°C), and changes in temperature can drastically impact battery performance and cycle life. Controlling battery temperature during operation can also be critical for maintaining safety standards and preventing thermal runaway, particularly for lithium-based chemistries. As specific energy increases, so

	Power-assist HEV Battery (Minimums)	Plug-in HEV Battery (40 mi range, EV mode)	EV Battery	Ultracapacitors (42V Power Assist)
Specific Energy (Wh/kg)	7.5	97	150	3
Specific Power - discharge (W/kg)	625 (10 sec)	317 (10 sec)	300 (30 sec)	650 (2 sec)
Temperature Operating Range (°C)	-30 to +52	-30 to +52	-40 to +50	-30 to +52
Cycle life	300,000	300,000	1,000	750,000
Calendar life (yr)	15	15	10	15
Specific cost ($/kWh)	1667	293	150	2167

Table 1: FreedomCAR and USABC energy storage goals

does the possibility for safety issues and the necessity of designing for abuse tolerance [9]. Hence, it is critical that the battery system monitor performance and relevant operating conditions such as temperature and respond appropriately to prevent damage to the vehicle or user.

Although they typically receive less attention than batteries as energy storage solutions, ultracapacitors are also prime targets for continued development. Ultracapacitors have higher power and lower energy density than batteries and are well-suited for mild hybridization and high power vehicle applications. Commercially available ultracapacitors currently have specific energies ranging from 1.1 – 8 Wh/kg [8, 10] as compared to the USABC target of 3 Wh/kg and specific powers ranging from 800-1400 W/kg as compared to the target of 650 W/kg for use in power-assist hybridization. A key issue currently prohibiting more extensive use of ultracapacitors in hybrid applications is cost. Currently, acquisition cost [11] is an order of magnitude higher than the USABC goal. The extended cycle life of ultracapacitors, however, may in some applications more than compensate for the higher cost.

The articles contained in this issue highlight current research efforts in battery and ultracapacitor technology. Battery system design is emphasized, including methods of controlling temperature and monitoring performance. Novel approaches to sizing batteries to minimize fuel consumption and greenhouse gas emissions in HEVs are discussed. A new permanent magnet propulsion system demonstrating higher power for high performance EVs is also presented. Extensive use of simulations demonstrates how energy storage solutions can be designed to meet the needs of a specific market segment, thereby providing additional direction for imminent vehicle deployments as well as long-term research.

The ability to store and provide energy as demanded by the driver is indeed a key technology for the development of fuel-efficient, environmentally friendly transportation. A number of hurdles – calendar life, operating temperatures, abuse tolerance, production cost – have yet to be perfectly met by any one technology. Current commercial vehicles clearly demonstrate, however, that utilizing additional energy storage maximizes the abilities of the HEV's engine and paves the road to cleaner and more efficient transportation technologies of the future.

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