Effect of Varying Wind Speeds across Six Wind-Zones on Tower Design for Indian Transmission Lines

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Presently a single set of Conductor Swing angle-Clearance (θ-C) combinations is specified and used across the entire country for each voltage of transmission lines in India. With the introduction of six wind zones in the country with considerably varying wind speeds, expectations arise that different 'θ –C' combinations could be introduced in the six wind zones for better optimisation and cost savings in tower designs. A detailed analysis of this aspect is presented in this paper and it is shown that, despite a mathematical justification for adopting different and widely varying 'θ –C' combinations for the six wind zones, there will not be much significant techno economic advantage for 66kV and 400kV lines if the presently used single set of 'θ –C' combination is replaced by different zone-wise combinations. For132kV and 220kV lines, however, there could be some significant cost savings if such a change is considered. However such a change will require introduction of different designs of lines in the six wind zones and consequent problems like delay in execution of projects, extra expenditure on tower designs/tests, maintenance of lines, multiplicity of spares and loss of cost advantage due to bulk orders. A detailed cost/benefit analysis is therefore recommended before adopting any change on this account.

Keywords: Swing angle; Conductor clearance; Horizontal spacing

NOTATIONS

- C : clearance (in air) between the (live) conductor and the nearest (earthed) structural member/s of the tower (commonly known as conductor clearance), cm
- D : conductor diameter, mm
- h : horizontal span, m
- H : horizontal spacing of conductors, cm
- K : D/w, v/h
- v : vertical span, m
- w : conductor weight, kg/m
- W_b : basic wind speed, m/s
- W_m : mean wind speed, km/h
- θ : angle of swing of the insulator string and conductor under the influence of wind, degrees
- δH : variation of the horizontal spacing of conductors, %

INTRODUCTION

The Indian power systems mainly have 66kV, 132kV, 220kV and 400kV transmission lines although some lines of 800kV and 500kV HVDC have also now been constructed. The conductor sizes for these lines have also been generally standardized to help faster implementations of transmission projects and minimize the requirement of spares. Twin-MOOSE, ZEBRA and PANTHER ACSR conductors are commonly used on 400kV, 220kV and 132kV lines, respectively. The 66kV lines however use either DOG ACSR or, for heavily loaded lines, WOLF ACSR.

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The parameters commonly used on these lines are shown in Table 1. From this table it may be seen that a single set of 'θ-*C*' combinations is specified for each line voltage. These 'θ-*C*' combinations were adopted on the basis of data/experience then available in India and other countries. They are being used uniformly in all parts of India for more than four decades and have given a generally trouble-free performance.

Based on long-term metrological data, India has now been geographically divided in six wind zones as shown in the basic wind speed map of India [1]. The basic wind speeds, W_b, for different wind zones of India, in this map are as shown in column 2 of Table 2.

The speed of the wind exerts a pressure on the conductors and the supporting insulator strings, resulting in a swing of the suspension assembly (or jumper strings in a tension assembly) through an angle θ, which varies with the speed/pressure of the wind. On the other hand, a higher wind speed helps faster deionisation of insulating air space between the (live) conductor and the nearest (earthed) structural members of the tower and thus results in smaller conductor clearance, *C*, for the same probability of flashover.

With greatly varying values of wind speeds in six wind zones, it is evident that the maximum (and other intermediate) values of swing angle θ for any given conductor would considerably vary over these wind zones, resulting in higher values of θ for higher

Table 1 Swing angle vs clearance combinations and other parameters for Indian high voltage lines

Line Voltage	Conductor (Acsr)				Normal	Susp. String	θ-C Combination	
	Code Name	Standing	Diametred, mm	Weight (W), kg/m	Span, m	Length, cm	Q degree	C, cm
66kV	Dog	6*4.72mm A1 +7*1.57mmSt	14.15	3.940	250	96.5	15	91.5
							30	76.0
							45	61.0
	Wolf	30*2.59mmA1 +7*2.59mmSt	18.13	7.274	250	96.5	15	91.5
							30	76.0
							45	61.0
132kV	Panther	54*3.00mmA1 +7*3.00mmSt	21.0	9.760	325	163.0	15	153.0
							30	137.0
							45	122.0
220kV	Zebra	54*3.18mmA1 +7*3.18St	28.62	1.619	375	234.0	15	213.0
							30	183.0
							45	167.5
400kV	Twin Moose	54*3.53mmA1 +7*3.53St	2*31.77	2*2.0015	400	385.0	22	305.0
							44	186.0

Table 2 Values of basic wind speed, (W_b) and mean wind speed (W_m) for six wind zones for Indian transmission lines

Wind Zone	Basic Wind Speed, W_b, m/s	Mean Wind Speed, W_n, km/h
Wind Zone 1	33	110
Wind Zone 2	39	130
Wind Zone 3	44	147
Wind Zone 4	47	157
Wind Zone 5	50	166
Wind zone 6	55	183

wind speeds and *vice versa*. On the other hand, the required values of conductor clearance, C, will reduce with higher wind speeds and *vice versa*.

It is therefore apparent that this aspect, if suitably determined and incorporated, would indicate different requirements of 'θ–C' combinations for the six wind zones. Thus, higher wind zones would require higher values of θ but smaller values of C while lower wind zones would require lower values of θ but higher values of C. It appears that these different 'θ–C' combinations for the six wind zones may result in more optimised design/improved performance of the transmission lines in respective wind zones.

A need for review of the presently used 'θ –C' combinations for different transmission lines, on a rational and scientific basis for the six wind zones of India, is therefore being urgently felt to ascertain, whether a change in the presently used 'θ –C' combinations is required and, if so whether it would be desirable to adopt two or more 'θ -C' combinations for each line to optimally cover these six wind zones.

An attempt to investigate and answer these questions on the basis of the latest available experience/data has been made in this paper.

EVALUATION OF CONDUCTOR SWING ANGLE

Based on the results of a test project, a relationship between the wind speed and the conductor swing angle is shown in Transmission Line reference Book[2], which is applicable to electrical design of the transmission lines, especially for switching surges but also, fairly closely, for the other over-voltages due to lightning and power frequency.

The aforesaid Figure however uses mean wind speed. A comparison of the parameters of the mean wind speed, W_m and the basic wind speed, W_b, brings out the following aspects; W_m is the mean wind value averaged over 1 minute period whereas W_b is the peak gust velocity averaged over a short time interval of about 3 s. This requires[3] a conversion reduction factor of 1.17 to be applied to W_b to obtain W_m.

For determination of W_m a span length of 300m was used whereas the span lengths for Indian lines vary from 225 m to 400 m. However, the value of W_m is not expected to vary significantly over this range.

The test site for W_m corresponded very closely to the Terrain Category-2 of Indian Standards[1] (normal cross-country lines with very few obstacles). However, in order to have conservative results, a terrain roughness factor of 1.08 may be applied to W_b to account for the highest wind speeds of category 1 (coastal areas, deserts etc) of Indian Standards.

W_b is based on a 50 year return period and as this reliability level is considered sufficient for transmission lines up to 400kV, no correction factor is required on this account[1]

Applying the aforesaid correction factors as also a conversion factor of 3.6 (from m/s to km/h), the value of W_b and the corresponding values of W_m for the six wind zones in India are shown in the[1] Table 2.

The values of swing angle, θ, corresponding to a given value of mean wind speed, W_m, can be determined[2], if the value of the factor $K = D/w \times (v/h)$ for the span/s under consideration is known. For a typical plane, rolling terrain, the value of (v/h) generally lies between 1.0 and 1.2. Using the values of other parameters shown in Table 1 for the respective lines, the typical values of factor K for the five lines under consideration are shown in columns 4 and 6 of Table 3, for v/h=1.0 and 1.2, respectively.

With these typical values of factor K, the 'W_m–θ' curves for the five lines under consideration have been intra/extrapolated from Figure. A.11.3.3 of Referrence. 2 and are shown in Figures 1(a)

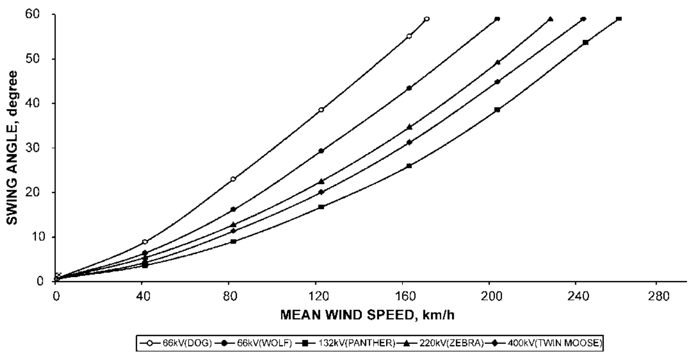

Figure 1(a) Mean wind speed against swing angle for Indian lines (v/h=1.0)

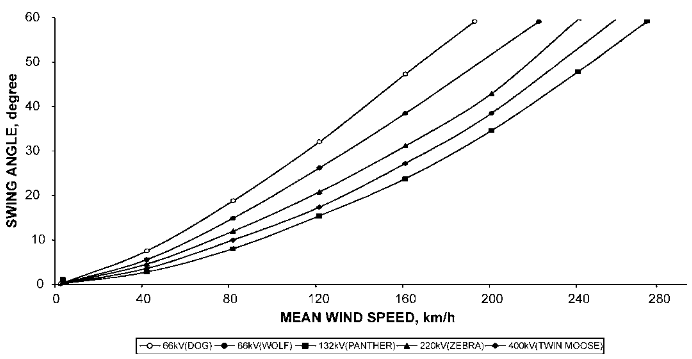

Figure1(b) Mean wind speed against swing angle for Indian lines (v/h=1.2)

Table 3 Value of factor , K, and mean wind speed , W_m corresponding to swing angles used for typical Indian transmission lines (for v/h=1.0 and 1.2

Line voltage, kV	Swing Angle of Insulator String, θ, deg	Conductor Clearance, c, cm	Ratio (v/h = 1.0) Value k	w_m, km/h	Ratio (v/h) =1.2 Value K	W_m, km/h
66	15	15	35.91	58	29.92	66
	30	30		97		112
	45	45		134		152
66	15	15	24.92	77	20.77	80
	30	30		121		132
	45	45		163		178
132	15	15	12.97	112	10.81	119
	30	30		173		182
	45	45		217		230
220	15	15	17.68	90	14.73	92
	30	30		145		155
	45	45		188		205
400	22	22	15.88	128	13.23	138
	44	44		196		215

and 1(b) for v/h =1.0 and 1.2, respectively. Next using the relationship shown in these two figures the following results are obtained;

The values for mean wind speed, which correspond to the presently used swing angles for the five transmission lines, are determined. These are shown in columns 5 and 7 of Table 3, for v/h = 1.0 and 1.2, respectively.

The maximum values for swing angles, which correspond to the mean wind speeds specified for the six wind zones of India (column 3 of Table 2), are determined. These are shown in columns 4 to 9 and 10 to 15 of Table 4, for v/h = 1.0 and 1.2, respectively.

EVALUATION OF CONDUCTOR CLEARANCE

As is well known, the requirement of clearance C, between the (live) conductors and the nearest (earthed) structural member of the tower, varies with the wind speed due to the latter's effect on deionisation of the intervening space. The relationship between clearance and wind speed has been investigated in several documents but the results vary considerably, due to a number of complex factors involved. For the present case, however, the pattern of variation of conductor clearance C (column 3 of Table 3) with mean wind speed W_m (columns 5 and 7 of Table 3), corresponding to different values of swing angles (column 2 of Table 3) adopted for each of the five transmission lines, which has given a satisfactory performance over a fairly long period, should provide a dependable guide. This 'W_m-C' relationship for the five typical Indian transmission lines is shown in Figures 2(a) and 2(b) for v/h =1.0 and 1.2, respectively. It is observed that this relationship

Table 4 Maximum swing angles, corresponding conductor clearances, conductor-tower spacing and percentage deviation for Indian lines

Transmission Line	Parameter	Value In-Use	v/h=1.0, Wind Zone, Mean Wind Speed , W_m , km/h						v/h=1.2 Wind Zone Mean Wind Speed, W_m , km/h					
			1 **110**	**2** **130**	**3** **147**	**4** **157**	**5** **166**	**6** **183**	**1** **110**	**2** **130**	**3** **147**	**4** **157**	**5** **166**	**6** **183**
66kV Dog	θ , deg	45	35	43	50	54	58	65	29	36	43	48	51	57
	C , cm	61	71	63	56	52	49	42	77	70	64	61	57	51
	H , cm	129	126	129	130	130	131	130	124	127	130	133	132	132
	δH , %	—	-2.3	0.0	0.8	0.8	1.6	0.8	-3.9	-1.6	0.8	3.1	2.3	2.3
66kV Wolf	θ , deg	45	26	34	39	43	46	53	23	30	35	39	42	47
	C , cm	61	81	74	68	64	61	55	82	76	70	67	65	59
	H , cm	129	123	128	129	130	130	132	120	124	125	128	130	130
	δH , %	—	-4.7	-0.8	0.0	0.8	0.8	2.3	-7.0	-3.9	-3.1	-0.8	0.8	0.8
132kV	θ , deg	45	15	19	22	25	28	34	13	17	21	23	26	30
	C , cm	122	154	147	142	139	136	130	156	150	145	142	139	134
	H , cm	237	196	200	203	208	213	221	193	198	203	206	211	216
	δH ,%	—	-17.3	-15.6	-14.3	-12.2	-10.1	-6.8	-18.6	-16.5	-14.3	-13.1	-11.0	-8.9
220kV	θ , deg	45	21	26	31	34	38	44	18	23	27	31	34	39
	C , cm	168	203	194	186	182	178	170	206	198	191	187	184	177
	H , cm	333	287	297	307	313	322	333	278	289	297	308	315	324
	δH ,%	—	-13.8	-10.8	-7.8	-6.0	-3.3	0.0	-16.5	-13.2	-10.8	-7.5	-5.4	-2.7
400kV	θ , deg	44	18	23	27	30	34	39	15	20	23	27	30	34
	C ,cm	186	337	302	272	254	239	209	349	318	291	276	262	235
	H , cm	454	456	452	447	447	454	451	449	450	441	451	455	450
	δH ,%	—	0.4	-0.4	-1.5	-1.5	0.0	-0.7	-1.1	-0.9	-2.9	-0.7	0.2	-0.9

between W_m and C very closely follow a straight line, and can be represented by the respective expressions which have also been shown on these figures.

Using these relationships, the requirement of conductor clearance C, is next worked out for values of wind speed for the six zones (column 3 of Table 2) and are shown for the five typical lines and for v/h=1.0 and 1.2, in Table 4.

REVIEW OF ' θ -C' COMBINATIONS

It is apparent from Table 4 that 'θ–C' combinations presently in use for the typical Indian lines will require a major change/ variation over the six wind zones. However this will mean introduction of different designs of lines in six zones and consequent problems like delay in execution of projects, extra expenditure on tower designs/tests, maintenance of lines, multiplicity of spares and loss of cost advantage due to bulk orders. It is therefore necessary that before introducing such major changes, the net impact of these changes be practically analysed to assess the real techno economic benefit, if any, that will accrue from them.

The techno economic impact of 'θ–C' combinations on the design of transmission towers can be estimated from their effect on the horizontal spacing, H, of the conductors as it is the later parameter which is mainly affected by these combinations and translates their effect into reduction of line cost. Any increase of the horizontal spacing increases the width and correspondingly the height (for the same shield angle of the ground wires), of the tower that, in turn, will increase the weight and cost of the towers. Although the vertical spacing of conductors is also changed due to a change of conductor clearance with 0°- swing angle, but as the latter corresponds to a no-wind condition, it is not expected to undergo much change for different wind zones for the same line.

The horizontal spacing of conductors is thus the main parameter which is affected by 'θ –C' combinations and which in turn affects the dimensions of the tower and consequently, the cost of the line. It would, therefore, be interesting to know the variation of this parameter if the different 'θ –C' combinations, shown for the six wind zones (with v/h =1.0 and 1.2) in Table 4, are adopted.

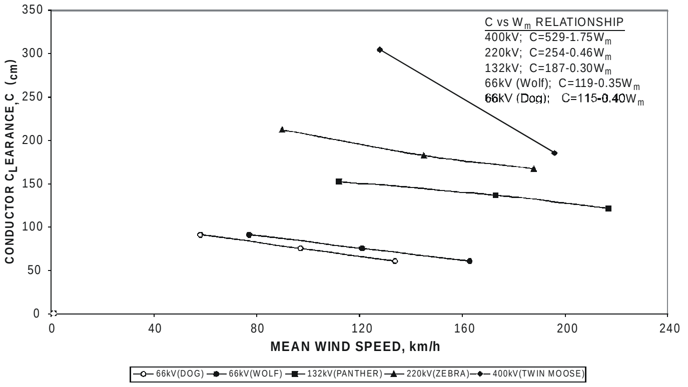

Figure 2(a) mean wind speed against conductor clearance for Indian lines (v/h=1.0)

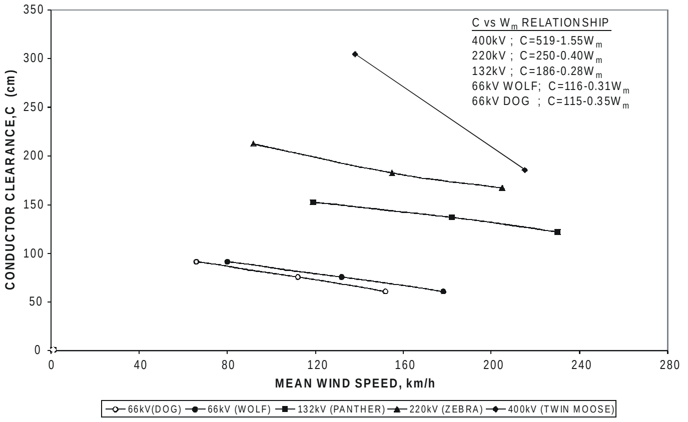

Figure 2(b) Mean wind speed against conductor clearance for Indian lines (v/h=1.2)

VARIATION, δH, OF HORIZONTAL SPACING

The horizontal spacing, *H*, of conductors for a single circuit, suspension tower for the five types of lines with the presently used values of 'θ –*C*' combinations, are shown in column 3 of Table 4.

The values of *H* have been determined using well established methodology[4] for different values of 'θ –*C*' combinations worked out as above for six wind zones for each of the five typical lines, and are shown in columns 4 to 9 for *v/h*=1.0 and columns 10 to 15 for *v/h*=1.2.

The variation, δ*H*, of horizontal spacing for the six wind zones with respect to the present values of this parameter is also shown (as %) in Table 4 for the five lines.

It is noted from Table 4 that, For both the 66kV lines, the variation in the horizontal spacing of conductors is within 5% (except one value of 7%) as compared to the presently used values For 400kV line, this variation is even less, *ie*, within 3%. However, for 132kV and 220kV lines there is significant negative variation (reduction) in the horizontal spacing of conductors ranging from –6.8% to –18.6% for 132 kV lines and from –2.7% to –16.5% for 220kV lines.

CONCLUSIONS

A detailed exercise contained in the foregoing paragraphs shows that, on a purely mathematical basis, the presently used single set of 'θ –*C*' combinations (for lines of each voltage) which are in use for several decades all over the country, would require major changes across the now introduced, six wind zones. This in turn will require introduction of different designs of lines in six zones and consequent problems like delay in execution of projects, extra expenditure on tower designs/tests, maintenance of lines, multiplicity of spares and loss of cost advantage due to bulk orders.

It has also been highlighted that a techno economic advantage/cost savings in tower design can only accrue, if any change in 'θ –*C*' combination results in a significant reduction in the horizontal spacing of conductors.

Analysing the impact of these greatly varying 'θ –*C*' combinations across the six wind zones on the horizontal spacing of the conductors, it is found that the increase in conductor swing angle θ, with higher wind zones, is largely offset by a corresponding reduction in the conductor clearance *C*, due to higher wind speeds. Accordingly, despite a large variation of 'θ –*C*' combinations across the six wind zones, the Horizontal spacing of conductors generally undergoes less than 5% variation over these zones for 66kV and 400kV lines. For 132kV and 220kV lines, however, there is still some significant reduction in horizontal spacing across the six wind zones.

It may therefore be concluded that, despite a mathematical justification for adopting different and widely varying 'θ –*C*' combinations for the six wind zones, there will not be much significant techno economic advantage or cost savings for 66kV and 400kV lines if the presently used single set of 'θ –*C*' combination is replaced by different zone-wise combinations. For132kV and 220kV lines, however, there could be some significant cost savings if the presently used single set of 'θ –*C*' combination is replaced by, say, two sets of judiciously selected 'θ –*C*' combinations covering zones 1 to 3 and 4 to 6, respectively. Such a change will, however, still require introduction of different designs of lines and consequent problems like delay in execution of projects, extra expenditure on tower designs/tests, maintenance of lines, multiplicity of spares and loss of cost advantage due to bulk orders.

It is therefore recommended that while no change in presently used 'θ –*C*' combinations need be made for 66kV and 400kV lines, a more detailed cost/benefit analysis needs to be carried out before adopting two or more sets of '$\theta - C$' combinations for zone-wise designs of 132kV and 220kV lines.

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