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Analysis and Design of Vertical and Horizontal Configurations of Cross-arms in A Transmission Line Tower.

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***Abstract*—Tower constitutes a very vital component of transmission lines. With the increase in the transmission voltage levels, the heights as well as weights of towers have also increased and so as their cost. The transmission line towers constitute about 28 to 42 percent of the cost of a transmission line. Therefore optimization in design of towers can bring about significant economy in the cost of transmission lines. A single transmission line consists of many transmission towers. So material saving in a single tower will lead to a considerable effect to the final cost of the project. Moreover, the increasing demand of electrical energy can also be met economically by developing different light weight configurations of transmission line towers. In this work, an attempt is made to make the transmission line more cost effective by changing the geometry (shape) of transmission tower. To meet this objective a 132kV double circuit self-supporting angle tower is taken with vertical and horizontal configuration of cross-arms. A three-dimensional analysis of each of these different configuration towers has been carried out using STAAD.Pro.V8i software. Each of these tower members are then designed as an angle sections. It is to be noted that for optimizing any member section, the entire wind load computations have to be repeated and hence the analysis and design process simultaneously. Then, these two towers are designed and compared.**

Keywords — Self-supporting angle tower; vertical configuration; horizontal configuration; cross-arms.

I. INTRODUCTION

An attempt has been made to make the transmission line more cost effective by changing the geometry (shape) of transmission tower. A 132kV double circuit transmission line with angle towers is selected. Here, changing the geometry of transmission tower is constituted by replacing vertical configuration of cross-arms with horizontal configuration of the same. It is to be noted that changing the configuration of cross-arms do not alter its desired requirements. As a result of which one can say that if there is requirement of total six conductor wires, then in vertical configuration of transmission tower there will be three cross-arms each carrying two conductor wires while in horizontal configuration of transmission tower only two cross-arms will be there of which bottom and top cross-arms carry four and two conductor wires respectively.

Note: In this paper, Vertical Configured Tower and Horizontal Configured Tower will be abbreviated as VCT and HCT respectively in all further discussions.

The following work has been done:

- The sag tension calculation for conductor and ground wire using parabolic equation.
- Towers are configured keeping in mind all the electrical and structural constrains.
- Loading format including reliability, security and safety pattern is evaluated. Then, both the towers of different configurations are modelled using STAAD.Pro.V8i.
- The wind loading is calculated on the longitudinal face of the both the towers.
- Then, both the towers are analysed as a three-dimensional structure using STAAD.Pro.V8i.
- Finally, tower members are designed as angle sections.

II. INPUT PARAMETERS

The following parameters for transmission line and its component are assumed from I.S. 802 Part1/Sec 1:1995, I.S. 5613 Part 2/Sec 1:1989.

- Transmission Line Voltage: 132 kV
- Angle of Line Deviation: 30 degrees
- Terrain Category: 1
- Return Period: 150 years
- Wind Zone: 2
- Basic Wind Speed: 39 m/s
- Basic Wind Pressure: 68.10 kg/sq.m

- Tower Type: Self-Supporting Tower, Angle Type Tower
- Tower Geometry: Square Base Tower
- No. of Circuits: Double Circuit
- Tower Configuration: Vertical and Horizontal Conductor Configuration
- Bracing Pattern: Warren Type (Double Web System)
- Cross Arm: Pointed
- Body Extension: Not Considered
- Steel Used: Mild Steel & High Tensile Steel
- Slope of Tower Leg: 83 degree (40º to 90º Permissible)
- Shielding angle: 30 degree
- Conductor Material: ACSR (Aluminium Conductor Steel Reinforced)
- Conductor Configuration: Panther
- Maximum Temperature: 75°C (ACSR)
- Number of Ground Wires: Single
- Peak Type: Triangular
- G.W. Type: Earth wire – GAL Steel 7 / 3.15
- Maximum Temperature: 53°C (7 / 3.15)
- Insulator Type: Single Tension String
- Size of Insulator Disc: 0.255*0.145 m
- Number of Insulator Discs: 10
- Length of Insulator String: 1.82 m
- Minimum Ground Clearance: 6.1 m
- Creep Effect: Not Considered
- Width at Hamper Level: 2.5 m (For both the towers)
- Width at Base: 7.6 m (For both the towers)
- Minimum Thickness of Member:
  - Leg Member, G.W. Peak and Lower Member of C.A.: 5 mm
  - Others: 4 mm
- Permissible Weight Span:
  - Normal Condition:
    Maximum: 488 m
    Minimum: 0 m
  - Broken Wire Condition:
    Maximum: 195 m
    Minimum: -200 m
- Normal Span: 335 m

A. Sag Tension for Ground-wire and Conductor

Indian standard codes of practice for use of structural steel in over-head transmission line towers (i.e. IS 802(Part 1/Sec 1):1995) have prescribed following conditions for the sag tension calculations for the conductor and the ground wire:

a) Maximum temperature (75°C for ASCR and 53°C for ground wire) with design wind pressure (0% and 36%).

5613: Part 2: Sec: 1: 1989 for both the conductor and ground wire.

b) Every day temperature (32°C) and design wind pressure (100%, 75% and 0%).

c) Minimum temperature (0°C) with design wind pressure (0% and 36%).

Sag tensions are calculated by using the parabolic equations as discussed in the I.S.

Parabolic Equation

$$F_2^2*(F_2 - (K - \alpha*t*E)) = (L^2\delta^2q_2^2E)/24 \qquad (1)$$

Take $K = F_1 - (L^2\delta^2q_2^2E)/24F_1^2$

TABLE I. Sag tension for ground wire

Temperature variation ºC	0		32			53
Wind variation %	***0***	***36***	***0***	***75***	***100***	***0***
Tension = F x A (kg)	656.04	1532.22	714.27	3775.63	5481.88	760.25
Sag = wL²/8T (m)	9.17	3.93	8.43	1.59	1.10	7.92

TABLE II. Sag tension for conductor (ASCR)

Temperature variation ºC	0		32			75
Wind variation %	***0***	***36***	***0***	***75***	***100***	***0***
Tension = F x A (kg)	1676.75	2973.88	1968.40	6611.14	9260.29	2580.32
Sag = wL²/8T (m)	8.15	4.59	6.94	2.07	1.48	5.30

B. Configuration of Towers

Configurations of both the towers are done by first fixing the outline of the towers as per the Indian Standard requirements.

- The base width of both the towers is kept same i.e. 7.6 m.
- The width at the hamper level for both vertical and horizontal tower configuration is reduced to 1/3 of the base width i.e. approx. 2.5 m.
- The height of the VCT is taken 44.85 m and the height of HCT is taken 38.83 m after accounting for shield angle.

Thus both the towers are having their legs inclined till hamper level (for tower body). Both towers are having straight legs above hamper level (cage). The height of both the towers is kept same till hamper level i.e. 20.35 m. As stated above there is variation in heights of both the towers mainly because top most of the three cross-arms is absent in HCT. Moreover, horizontal grounded metal clearance for both the towers is the same.

TABLE III. Configuration of tower

Parameters	**Vertical Configured Tower**	**Horizontal Configured Tower**
Base width	7.6 m	7.6 m
Hamper width (B.C.A)	2.5 m	2.5 m
Hamper width (M.C.A)	2.5 m	2.5 m
Hamper width (T.C.A)	2.5 m	-
Height till B.C.A level	20.35 m	20.35 m
Height till M.C.A level	27.35 m	28.28 m
Height till T.C.A level	34.35 m	-
Total Tower Height from G.L	44.85 m	38.83 m
Horizontal Gr. metal clear. at:		
B.C.A level	5.25 m	5.25 + 4.5 = 9.75 m
M.C.A level	4.90 m	4.90 m
T.C.A level	4.75 m	-

III. WIND LOADS ON TOWERS

Wind loads on both the towers are calculated as per I.S. 802 (Part 1/Sec 1):1995. For quick and easy calculations excel programs are separately developed according to Indian Standards.

A. Design Wind Pressure

To calculate design wind pressure on conductor, ground wire, insulator and panels:

$$\mathbf{P_d = 0.6 \times V_d^2} \qquad (2)$$

where,

P_d = design wind pressure in N/m2

V_d = design wind speed in m/s

To calculate design wind pressure

$$\mathbf{V_d = V_R \times K_1 \times K_2} \qquad (3)$$

V_R = 10min wind speed (or) reduced wind speed

$$\mathbf{V_R = V_b/k_0} \qquad (4)$$

V_b = basic wind speed

K_0 =1.375 [conversion factor]

K_1 = risk coefficient

K_2 = terrain roughness coefficient.

B. Wind Loads on Conductor/Ground Wire

To calculate wind loads on conductor and ground-wire

$$\mathbf{F_{wc} = P_d \times C_{dc} \times L \times d \times G_c} \qquad (5)$$

where,

F_{wc} = wind load on conductor

P_d = design wind pressure

C_{dc} = drag coefficient for ground wire=1.2 drag coefficient for conductor = 1.0

L = wind span

d = diameter of conductor/ground wire

G_c = gust response.

C. Wind Load on Insulator

To calculate wind load on insulator

$$\mathbf{F_w = P_d \times C_{di} \times A_I \times G_I} \qquad (6)$$

where,

A_I = 50% area of insulator projected parallel to the longitudinal axis of string

G_I = gust response factor for insulator

C_{di} = drag coefficient, to be taken as 1.2

D. Wind Load on Panels

To calculate wind load on panels

$$\mathbf{F_w = P_d \times C_{dt} \times A_e \times G_T} \qquad (7)$$

where,

C_{dt} = drag coefficient for panel considered against which the wind is blowing.

A_e = effective area of the panel.

G_T = gust response factor for towers.

TABLE IV. Wind loadings on panel points

Height from G.L. (m)	VCT Wind Load (kg)	Height from G.L. (m)	HCT Wind Load (kg)
0	1068	0	1115
5.85	1862	5.85	1961
10.75	1409	10.75	1436
14.85	1047	14.85	1022
17.95	752	17.95	734
20.35	517	20.35	503
21.80	386	21.80	430
23.25	510	23.76	530
25.65	533	26.32	530
27.35	387	28.28	422
28.75	344	29.83	750
30.15	423	38.83	557
32.25	499	-	-
34.35	440	-	-
35.85	768	-	-
44.85	574	-	-
Total	11519	**Total**	9990

The VCT is facing the maximum total wind load followed by the HCT. This implies that the member sectional area exposed to wind is maximum in the vertical configured tower. Moreover, height is also more compared to VCT and it plays an important role in wind load calculation. The lowest three panels of the HCT is having the highest wind load followed by the VCT.

IV. Modelling of Towers

Modelling of towers has been carried out in STAAD Pro.V8i software. Fig. 1 shows geometry of vertical and horizontal configuration of transmission towers.

V. ANALYSIS OF TOWERS

Once modelling part is completed, application of loads is carried out. This include wind loads at all panel points and also wind loads at conductor and ground-wire attachment points based on all three conditions viz. reliability, security and safety. Then after 3D analysis of both the towers is carried out in STAAD Pro.V8i. Panel-wise analysis results are shown in tabulated form.

TABLE V. Maximum forces in the leg members

Panel No.	Vertical Configured Tower		Horizontal Configured Tower	
	Compressive (kg)	*Tensile (kg)*	*Compressive (kg)*	*Tensile (kg)*
1	111578	107717	78284	74538
2	113867	110026	75463	71758
3	109068	105672	69179	65989
4	114866	111316	69476	65934
5	109039	105751	61520	58586
6	100824	97683	55737	52817
7	95336	925901	47597	46016
8	76280	73963	34892	33767
9	63169	611272	21857	21474
10	49119	471431	15159	14521
11	43082	41644	14095	14017
12	34781	33558	-	-
13	21275	21059	-	-
14	15097	14464	-	-
15	14198	14119	-	-

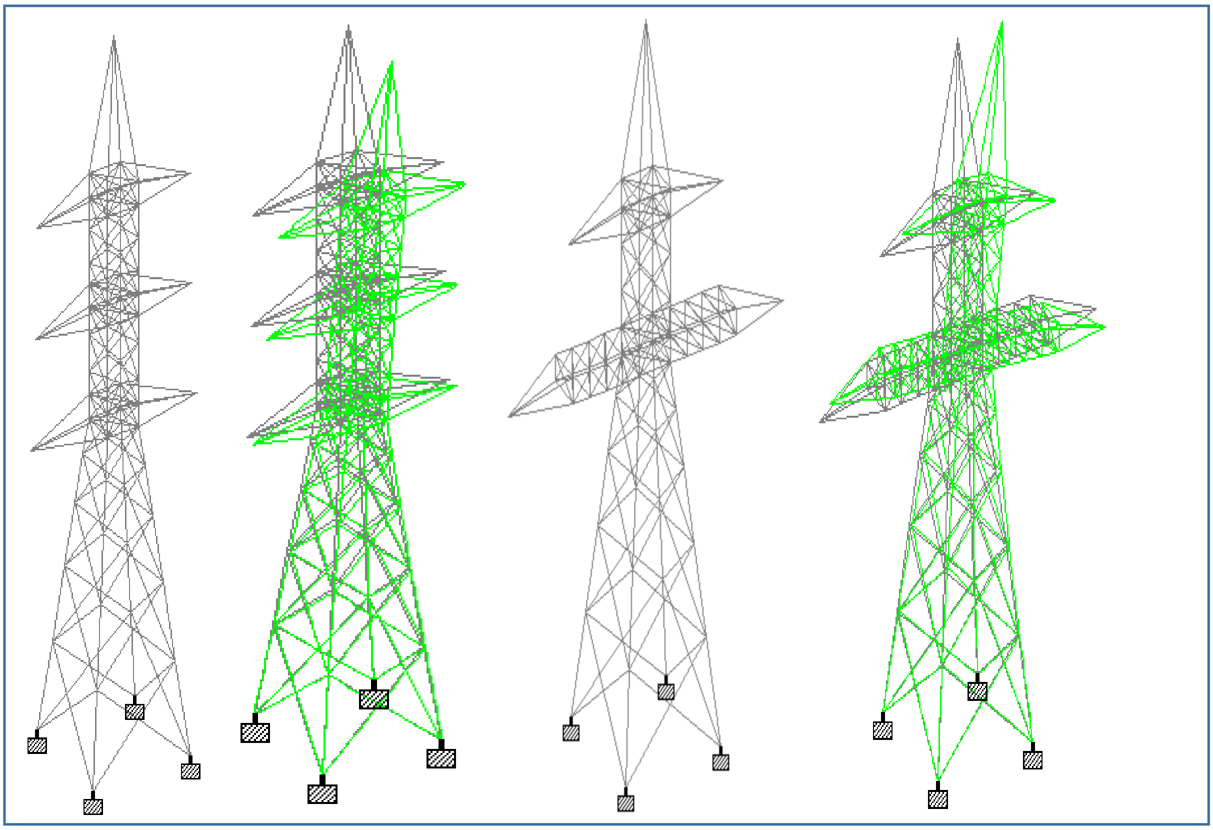

Fig. 1. Modelling of Vertical and Horizontal Configurations of Towers.

TABLE VI. Maximum forces in the bracing members

Panel No.	Vertical Configured Tower		Horizontal Configured Tower	
	Compressive (kg)	*Tensile (kg)*	*Compressive (kg)*	*Tensile (kg)*
1	8447	8367	11053	10504
2	10640	10669	13361	13958
3	13731	13631	17986	17169
4	16876	16848	21147	22066
5	20666	20690	27068	25904
6	22483	22290	19673	19466
7	20508	20492	12710	12796
8	24579	24244	14415	13944
9	21145	21115	12378	12463
10	13635	13527	4488	4427
11	11184	11139	-	-
12	12695	12471	-	-
13	12471	12370	-	-
14	4864	4869	-	-

VI. DESIGN OF TOWERS

For the design of members of both the towers excel program has been developed based on the parameters of I.S. 802(Part 1/Sec 2):1995. Trial and error process is followed to get optimized sections. Factor of safety of 1.08 is taken for leg members and 1.13 for bracing and cross-arm members.

TABLE VII. Maximum forces in cross arm members

Panel Id	Vertical Configured Tower		Panel Id	Horizontal Configured Tower	
	Compressive (kg)	*Tensile (kg)*		*Compressive (kg)*	*Tensile (kg)*
Bottom cross-arm			**Bottom cross-arm**		
Upper	8042	9164	**Upper 1**	20150	20238
Lower	16209	15129	**Lower 1**	36800	26727
Middle cross-arm			-	-	-
Upper	6573	7645	**Upper 2**	6186	7117
Lower	16688	15658	**Lower 2**	13996	13113
Top cross-arm			**Top cross-arm**		
Upper	5937	6897	**Upper**	4788	5750
Lower	14965	14050	**Lower**	16711	15793

Table VIII. Design of leg members

Panel No.	Vertical Configured Tower				Horizontal Configured Tower			
	Material	*Angle Section*	*Design Length (cm)*	*FOS*	*Material*	*Angle Section*	*Design Length (cm)*	*FOS*
1	HT	120x120x10	118.80	1.08	MS	150x150x12	118.80	1.08
2	HT	120x120x10	124.50	1.09	MS	150x150x12	124.50	1.11
3	HT	120x120x10	104.00	1.14	MS	110x110x16	104.00	1.12
4	HT	120x120x10	105.00	1.08	MS	110x110x16	105.00	1.11
5	HT	120x120x10	81.34	1.18	MS	120x120x12	81.34	1.10
6	HT	120x120x10	72.50	1.29	MS	110x110x12	72.50	1.11
7	HT	120x120x8	72.50	1.10	MS	100x100x12	98.00	1.11
8	HT	110x110x8	120.00	1.13	MS	120x120x8	128.00	1.12
9	HT	100x100x7	85.00	1.16	MS	75x75x8	98.00	1.14
10	HT	90x90x6	70.00	1.16	MS	70x70x6	77.50	1.22
11	HT	80x80x6	70.00	1.15	MS	70x70x6	114.63	1.13
12	MS	90x90x10	105.00	1.10	-	-	-	-
13	MS	75x75x8	105.00	1.14	-	-	-	-
14	MS	70x70x6	75.00	1.23	-	-	-	-
15	MS	70x70x6	114.62	1.12	-	-	-	-

TABLE IX. Design of bracing members

Panel No.	Vertical Configured Tower				Horizontal Configured Tower			
	Material	*Angle Section*	*Design Length (cm)*	*FOS*	*Material*	*Angle Section*	*Design Length (cm)*	*FOS*
1	MS	75x75x5	150.84	1.20	MS	75x75x6	150.84	1.21
2	MS	70x70x6	123.50	1.25	MS	80x80x6	123.5	1.20
3	MS	75x75x6	100.50	1.15	MS	75x75x8	100.5	1.16
4	MS	75x75x8	117.00	1.17	MS	90x90x8	117	1.20
5	MS	90x90x7	92.50	1.15	MS	90x90x10	92.5	1.22
6	MS	100x100x7	72.25	1.17	MS	75x75x8	72.25	1.14
7	MS	80x80x8	72.25	1.18	MS	70x70x6	79.5	1.21
8	MS	80x80x10	86.75	1.18	MS	75x75x6	89.5	1.13
9	MS	80x80x8	75.50	1.14	MS	65x65x6	79.5	1.13
10	MS	70x70x6	71.75	1.15	MS	40x40x5	73.5	1.36
11	MS	75x75x5	71.75	1.15	-	-	-	-
12	MS	70x70x6	81.50	1.20	-	-	-	-
13	MS	70x70x6	81.50	1.23	-	-	-	-
14	MS	40x40x5	73.00	1.18	-	-	-	-

TABLE X. Design of cross-arm members

Panel Id	Vertical Configured Tower				Horizontal Configured Tower			
	Material	*Angle Section*	*Design Length (cm)*	*FOS*	*Material*	*Angle Section*	*Design Length (cm)*	*FOS*
	Bottom cross-arm				**Bottom cross-arm**			
Upper	MS	60x60x6	136.25	1.20	Upper 1	90x90x7	131	1.19
Lower	MS	90x90x6	131.25	1.13	Lower 1	110x110x10	131	1.20
	Middle cross-arm				-	-	-	-
Upper	MS	60x60x5	132.25	1.29	Upper 2	50x50x6	122.25	1.17
Lower	MS	90x90x6	126.5	1.14	Lower 2	75x75x6	116.75	1.17
	Top cross-arm				**Top cross-arm**			
Upper	MS	55x55x5	124.5	1.26	Upper	50x50x4	105.8	1.25
Lower	MS	80x80x6	118.75	1.19	Lower	75x75x8	126.5	1.24

VII. RESULTS AND DISCUSSION

As both the towers are designed with enough factor of safety, the self-weight of different towers obtained is as follows:
Vertical Configured Tower: 6661 kg
Horizontal Configured Tower: 6842 kg

- The self-weight for the VCT is found to be 2.65% less than that of the VCT.
- The VCT is facing the maximum total wind load followed by the HCT. This implies that the member sectional area exposed to wind is maximum in the VCT.
- The lowest three panels of the HCT is having the highest wind load followed by the VCT. This might be because higher angle sections are required in HCT compared to VCT and higher angle section leads to higher exposed area.
- The VCT is found to have higher amount of axial forces in the leg members in comparison with the HCT.
- However, the VCT is found to have lesser amount of axial forces in the bracing members compared to the HCT till lowest five panels.
- The axial forces in the upper members of top cross-arm for VCT is more compared to HCT and vice versa for the lower members of top cross-arm.

VIII. CONCLUSIONS

- Configuration of towers has revealed that both the towers are having the different heights but same base widths.
- Reliability, security and safety conditions have been kept the same for all the three towers. Wind loading is calculated for each tower leading to the following results:
  Vertical Configured Tower: 11519 kg
  Horizontal Configured Tower: 9990 kg
- Analysis result is showing maximum compressive forces in leg members of the lowest panel (panel one):
  Vertical Configured Tower: 111578 kg
  Horizontal Configured Tower: 78284 kg
- Design has been done to conserve every kg of steel where ever possible. Hence, the design of towers has availed the following outcome:
  Total Weight of Vertical Configured Tower: 6661 kg
  Total Weight of Horizontal Configured Tower: 6842 kg
- Thus, it is observed that vertical configured self-supporting tower exhibits a saving of 2.65**%** in the weight of structural steel. But it is to be noted that leg members of VCT HT steel sections are required to sustain the external loads(refer Table 8). On the other hand, all leg members of the horizontal configured tower required only MS sections to sustain the external loads.
- HT steel sections are more costly compared to MS sections. Thus VCT will cost more compared to HCT.

REFERENCES

[1] "Dynamic Response of Power Transmission Towers under Wind Load" by Li Pengyun, Lin Jiedong, Nie Ming, Zhong Wanli, Huang Auguo - SciVerse Energy Procedia 17 (2012) 1124-1131.

[2] "OPTIMUM DESIGNS FOR TRANSMISSION LINE TOWERS", by G.Visweswara Rao, Computer & Structures vol.57.No.1.pp.81-92, 1995 Elsevier Science Ltd.

[3] I.S. 802 (Part -1/Sec 1)1995, "Use of Structural Steel in Overhead Transmission Line Towers - Code of Practice".

[4] I.S. 5613 (Part-1/Sec 2):1985, "Code of Practice for Design, Installation and Maintenance of Overhead Power Lines".

[5] I.S. 802(Part1/Sec2):1995, "Use of Structural Steel in Overhead Transmission Line Towers – Code of Practice".

[6] Central Board of Irrigation and Power (CBIP), "Transmission Line Manual", Publication No. 268.

[7] "Transmission line Structure" Text Book on Transmission line Structure by Murthy and Santhakumar A.R.

[8] "Transmission line Structure" Text Book on Transmission line Structure by Dayaratnam.