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Structural Optimization and Design of Electric Transmission Tower

Sayed Abul Hossain¹, Bibek Samanta²

Asst. Professor, Dept. of CE, CIET, Bardhaman, India¹

B.Tech Student, Dept. of CE, CIET, Bardhaman, India²

ABSTRACT: Transmission towers have been playing an important role in the power sector and also human life. The paper is focused on optimizing the steel transmission tower. The growing demand for electrical energy can be more economically through developing minimum weight of the tower. Structural design is a crucial topic in engineering since it allows to propose solutions to multiple challenges in modern societies. Design process has been continuously studied and applied in real problems in engineering and many other disciplines. However, this kind of procedures to propose adequate designs has become insufficient nowadays. Design methods need to be reformulated by including optimization techniques since traditional designs are usually effective but they are not the most efficient, in general. In this paper the authors propose an optimization methodology that allows to obtain more efficient solutions than conventional designs of high voltage transmission line towers. The present work, an attempt has been made to make the transmission line tower price effective. The main focus is the design of a 33KV double circuit transmission line tower with rectangular base self-supporting lattice tower, which optimizes the present geometry. Then, the structural behavior of existing tower is studied and Excel programs are developed for calculation of load and by STAAD PRO, evaluation we found the axial stress, compressive stress of the tower member. The structure was modelled and analyzed in STAAD. PRO, the weight of the transmission tower optimized while keeping the base width, height of the tower and basic outline of the tower.

KEYWORDS: Structural Optimization, Transmission Tower,

I. INTRODUCTION

In every country, the need of electric power consumption has continued to increase, the rate of demand being greater in the developing countries. Transmission tower lines are one of most important life-line structures. Transmission towers are necessary for the purpose of supplying electricity to various regions of the nation. This has led to the increase in the building of power stations and consequent increase in power transmission lines from the generating stations to the different corners where it's needed. Interconnections between systems are also increasing to enhance reliability and economy. Transmission line should be stable and carefully designed so that they do not fail during natural disaster. It should also conform to the national and international standard. In the planning and design of a transmission line, a number of requirements have to be met from both structural and electrical point of view. From the electrical point of view, the most important requirement is insulation and safe clearances of the power carrying conductors from the ground. The transmission tower has height of 30m which includes the ground clearance(h_1), maximum sag of the lower most conductors wire(h_2), vertical spacing between the conductors wires(h_3) and vertical distance of earth wire from the uppermost conductor wire(h_4). The earth wire or ground wire is always located at the top of the transmission tower. It has a square base width of 6m. The type of transmission tower considered is a tangent tower having no deviation located on a plain landscape with minimal obstacles. It is located at the wind zone 4 with basic wind speed of 47m/s. The wind pressure on the tower depends on the gust response factor which increases with height. The transmission tower is situated in the seismic sensitive region i.e. Zone III where response reduction factor steel frame with concentric braces is of 4 and the damping for steel structures is 2%. The members are designed for maximum deflection and load for the most critical load combination as per code IS802. The members are also grouped for better fabrication.

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II. FACTOR GOVERNING TOWER CONFIGURATION

- The mid span clearance required from the dynamic behaviour of conductor and lightning protection of the line.
- The minimum clearance to be maintained between conductors and between conductor and tower.
- The minimum clearance of the lower conductor is above ground level.
- The location of ground wires with respect to the outermost conductor.

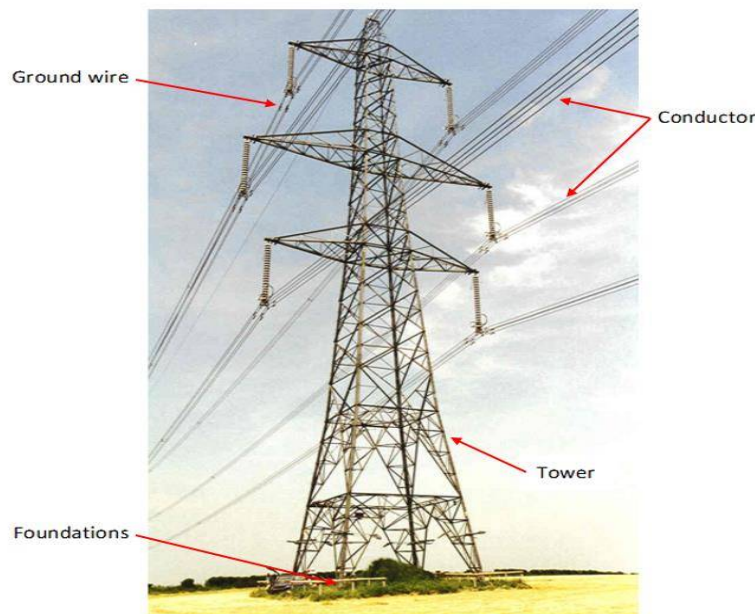


Figure 1.1 Transmission line tower

III. ANALYSIS OF TRANSMISSION LINETOWER

3.0 Technical Specification Given:

Location of project	= Durgapur,	Maximum temperature	= 47 deg C
Minimum temperature	= 5 deg C,	Basic wind speed (m/Sec)	= 47 m/s
Seismic Zone	= III,	Wind Zone	= IV
Reliability level	= II,	Terrain category	= III

3.1 Specification of Tower:

Ruling span between two towers	= 80.00m
Minimum ground clearance of conductor	= 0.7460
Ultimate tensile strength of conductor	= 6734.00 kg
Factor of Safety	= 4.00
Yung modulus of elasticity	= 80000.00 kg/m ² (For final)
Yung modulus of elasticity	= 0.4675 E6 kg/m ² (For initial)

3.2 Calculation of Wind load

Basic wind speed $V_b = 47$ m/s

Wind zone -4, Reliabilitylevel-2, Terrain category – 3

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Reference wind speed = VR = $V_b/K_o = 47/1.375 = 34.182\text{m/s}$

Design wind speed $V_d = VR * K_1 * K_2$ $K_1=1.07, K_2= 1.06$

$V_d = 34.182 * 1.07 * 1.06 = 38.77\text{m/s}$

Design wind pressure $P_d = 0.6 * V_d^2 = 0.6 * 38.77^2 = 902 \text{ N/m}^2$

Max. Temperature of conductor = 75°C Max. Temperature of earth wire = 53°C Everyday temperature = 32°C

Min. temperature = 0°C

For 33KV: Conductor wire

The wind pressure applied on conductor $W_w = 2/3 * P_d * D = 2/3 * 91.96 * 0.0181 = 1.12 \text{ kg/m}$

Total wind load on conductor = $W_w * C_{dc} * G_c$

$C_{dc} = 1, G_c = 2.60$

For 100% wind, $W_{100\%} = 1.12 * 1.00 * 2.60 = 2.912 \text{ kg/m}$

For 36% wind, $W_{36\%} = 0.36 * 1.12 * 1.00 * 2.60 = 1.04832 \text{ kg/m}$

For 75% wind, $W_{75\%} = 0.75 * 1.12 * 1.00 * 2.60 = 2.184 \text{ kg/m}$

3.3 Computation of loading factor for power conductor :

Loading factor for still wind pressure on conductor (q_1) = 1.00

Loading factor for 36% wind pressure on conductor (q_2) = $(w^2 + w_1^2)^{1/2}/w$

W= Self weight of conductor= 0.7460 kg/m, W_1 =Design wind pressure applied on conductor=1.04832kg/m

Loading factor for 36% wind load considered (q_2) = $(0.7460^2 + 1.04832^2)^{1/2}/0.7460$
= 1.725

Loading factor for 75% wind pressure on conductor (q_3) = $(w^2 + w_2^2)^{1/2}/w$

W= Self weight of conductor= 0.7460 kg/m, W_2 =Design wind pressure applied on conductor=2.184kg/m

Loading factor for 75% wind load considered (q_3) = $(0.7460^2 + 2.184^2)^{1/2}/0.7460$
= 3.558

Loading factor for 100% wind pressure on conductor (q_4) = $(w^2 + w_3^2)^{1/2}/w$

W= Self weight of conductor= 0.7460 kg/m, W_3 =Design wind pressure applied on conductor=1.04832kg/m

Loading factor for 75% wind load considered (q_3) = $(0.7460^2 + 1.04832^2)^{1/2}/0.7460$
= 3.935

3.4 Computation of maximum Tension and Sag for power conductor:

Consider the supports of conductors are at one level. The horizontal component of wire pull T_2 (Tension)

BY parabola equation

$$T_2^2 \left\{ T_2 - \left[T_1 - \frac{W^2 \times q_1^2 \times L^2 \times E_c \times A}{24 \times T_1^2} \right] \right\} = \frac{W^2 \times q_2^2 \times L^2 \times E_c \times A}{24}$$

Dividing the expression by A and introducing the notation f for stress and also introduce $\delta = \frac{W}{A}$. We have

$$f_2^2 \left\{ f_2 - \left[f_1 - \frac{\delta^2 \times q_1^2 \times L^2 \times E_c \times A}{24 \times f_1^2} \right] \right\} = \frac{\delta^2 \times q_2^2 \times L^2 \times E_c \times A}{24}$$

Now the temperature factor for $(t \times \alpha \times E_c)$ as under -:

Temperature difference $t = t_2 - t_1$

When temperature is 5°C $t = 5 - 32 = -27$ Then $t \times \alpha \times E_c = -27.00 \times 1.78\text{E-}05 \times 80000 = 38.448$

When temperature is 75°C $t = 75 - 32 = 43$ Then $t \times \alpha \times E_c = 43.00 \times 1.78\text{E-}05 \times 80000 = 61.232$

When temperature is 32°C $t = 32 - 32 = 0$ Then $t \times \alpha \times E_c = 0.000 \times 1.78\text{E-}05 \times 80000 = 0.000$

When temperature is 50°C $t = 50 - 32 = 18$ Then $t \times \alpha \times E_c = 18.00 \times 1.78\text{E-}05 \times 80000 = 25.632$

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Loading factor :-

$$\delta = \frac{W}{A} = 0.7460/1.58 = 0.47215 \text{ kg/cm}^2/\text{m}$$

Tension factors as under :-

At still wind condition $q_1 = 1$

$$Z = \frac{\delta^2 \times q_1^2 \times L^2 \times E_c \times}{24} = \frac{0.4722^2 \times 1.00^2 \times 80^2 \times 80000}{24} = 4755784.86$$

At 36% wind pressure on conductor $q_2 = 1.725$

$$Z = \frac{\delta^2 \times q_2^2 \times L^2 \times E_c \times}{24} = \frac{0.4722^2 \times 1.725^2 \times 80^2 \times 80000}{24} = 14154315.88$$

At 100% wind pressure on conductor $q_3 = 3.935$

$$Z = \frac{\delta^2 \times q_3^2 \times L^2 \times E_c \times}{24} = \frac{0.4722^2 \times 3.935^2 \times 80^2 \times 80000}{24} = 73654647.97$$

Working stress of conductor as under :-

Working tension in conductor $T_1 = 6734.00/4 = 1683.5 \text{ kg}$

Working stress of conductor $f_1 = T_1/A = 1684/1.58 = 1065.51 \text{ kg/cm}^2$

Stress constant as under :-

Now find the stress constant K given by formula

$$\text{Put } K = f_1 - \frac{\delta^2 \times q_1^2 \times L^2 \times E_c \times A}{24 \times f_1^2} = 1065.51 - \frac{0.4722^2 \times 1.00^2 \times 80^2 \times 80000}{24 \times 1065.51 \times 1065.51} = 1061.317$$

So the above equation will be $f_2^2 \times \{f_2 - [K - t \times \alpha \times E_c]\} = Z$

Case- I : Starting Condition : Conductor temperature 5°C (minimum) & 100% wind pressure applied

The equation for final stress

$$f_2^2 \times \{f_2 - [K - t \times \alpha \times E_c]\} = Z$$

$$f_2^2 \times \{f_2 - [1061.317 - 38.448]\} = Z$$

$$f_2^3 \times \{f_2 - [1061.317 - 38.448]\} = 73654647.97$$

$$f_2^3 - 1099.77 \times f_2^2 = 73654647.97$$

$$f_2 = 1030.3970$$

$$\text{So } f_2 = 1030.3970 \text{ kg/cm}^2$$

Tension of conductor:

$$T = f_2 \times A = 1030.3970 \times 1.58 = 1628.03 \text{ kg}$$

Sag of the conductor at mid span:-

$$\text{Deflected Sag } S_D = \frac{L^2 \times \delta \times q_3}{8 \times f_2} = \frac{80^2 \times 0.4722 \times 3.935}{8 \times 1030.40} = 1.44 \text{ m}$$

$$\text{Angle of declination } \theta = \tan^{-1} W_1 / W = \tan^{-1} (0.2912 / 0.746) = 75.63^\circ \text{ from vertical}$$

$$\text{Vertical Sag } S_V = S_D \times \cos \theta = 1.44 \times 0.24817 = 0.36 \text{ m}$$

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Sag table at different cases and height of tower:

Case No.	Description of cases	Tension at mid span of conductor (kN)	Deflected Sag (S_D)	Vertical Sag (S_V)	Length of conductor(L)= $L+(W2 \times L3)/(24 \times T2)$
I	Conductor temp of 5 ⁰ C and 100% wind pressure applied	1628.027 kg = 16.28 kN	1.44 m	0.36 m	80.00 m
II	Conductor temp of 5 ⁰ C and 36% wind pressure applied	1755.743 kg = 17.557 kN	0.59 m	0.34 m	80.00 m
III	Conductor temp of 75 ⁰ C and no wind pressure applied (still wind)	852.295 kg = 8.523 kN	0.00 m	0.70 m	80.02 m
IV	Conductor temp of 32 ⁰ C and 100% wind pressure applied	1769.654 kg = 17.697 kN	1.33 m	0.33 m	80.00 m
V	Conductor temp of 5 ⁰ C and 100% wind pressure applied	17331.115 kg = 17.331 kN	1.36 m	0.34 m	80.00 m

GEOMETRY OF TOWER

- Height of the tower= 30m
- Base width of the tower= 6m
- Length of every wings of the tower =4.12m
- Ground clearance =5.60m
- Vertical spacing of conductor= 0.45m
- Horizontal spacing of conductor= 0.45m
- Height of Insulator string = 1.82m

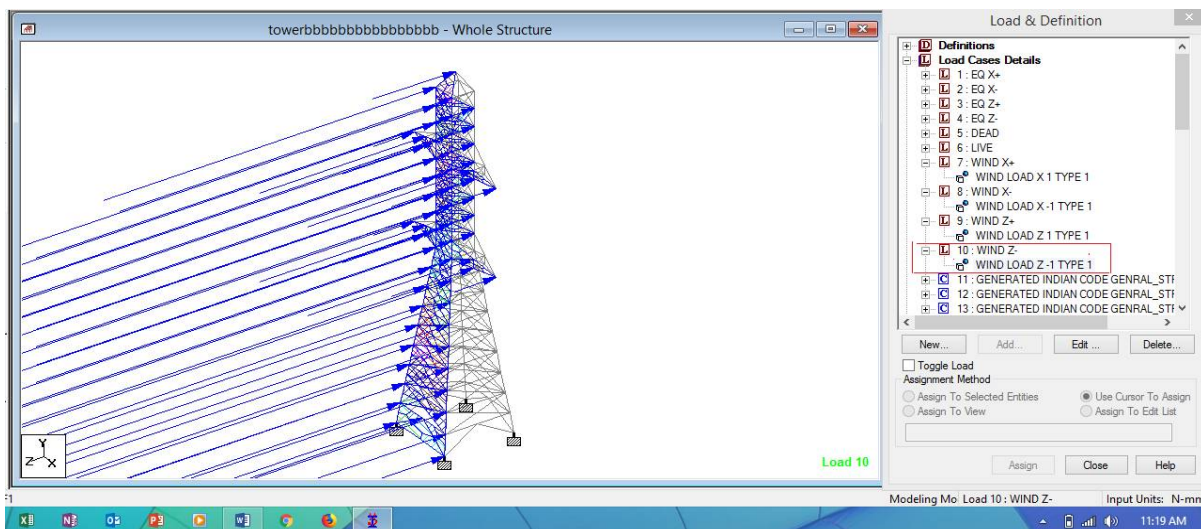


Fig1: WindLoads acting on transmission tower under normal condition

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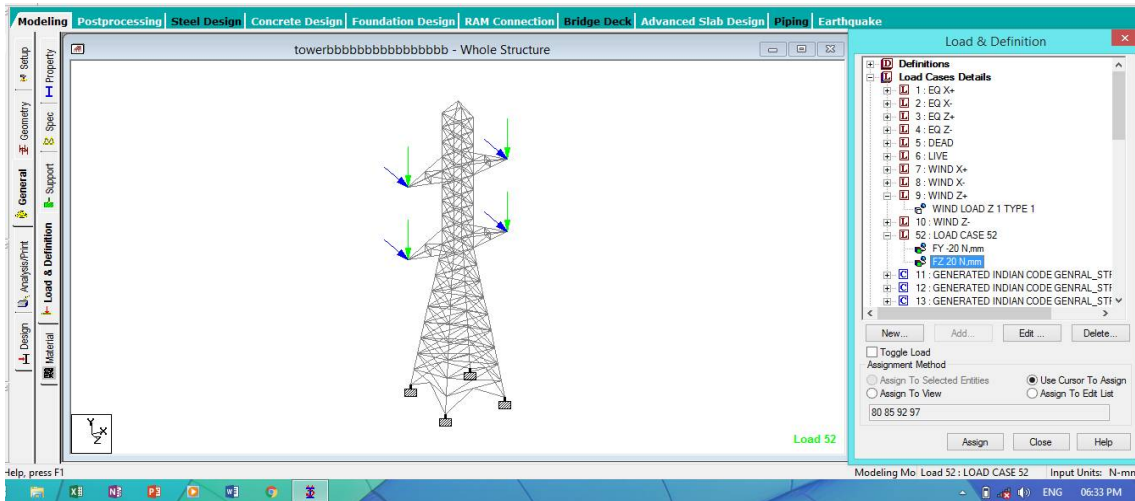


Fig2:-Cable Loads acting on transmission tower

IV.RESULT

4.0 Compression and Tensile force acting on the tower and obtained from STAAD Pro-V8i are as,

LEG MEMBER				BRACINGS				OTHER DIAGONALS			
Beam	L/C	Compression kg	Tension Kg	Beam	L/C	Compression kg	Tension Kg	Beam	L/C	Compression kg	Tension Kg
34	1	3.45E+05	4.54E+05	5	1	14841.721	-18561.540	111	1	-0.985	0.893
35	1	1.98E+05	4.35E+05	11	1	15860.281	-19121.327	112	1	0.943	0.839
36	1	1.55E+05	4.60E+05	16	1	16901.445	-21732.498	113	1	0.998	0.917
37	1	2.34E+05	4.28E+05	33	1	17650.345	-20672.245	114	1	0.118	0-936
185	1	2.65E+05	3.70E+05	70	1	4560.368	21328.234	122	1	0.925	0.674
186	1	2.44E+05	3.23E+05	71	1	5643.345	21563.345	123	1	-0.945	0.698
187	1	2.48E+05	3.49E+05	87	1	4175.298	18745.327	124	1	0.820	0.705
201	1	4.87E+05	3.18E+05	88	1	4347.367	19665.720	125	1	-1.265	0.715
202	1	4.67E+05	3.15E+05	89	1	4347.3676	19374.713	126	1	0.385	0.729
203	1	4.46E+05	3.12E+05	90	1	4347.367	19427.460	127	1	0.482	0.714
204	1	4.40E+05	3.10E+05	91	1	4347.367	19761.320	143	1	-0.489	0.732
205	1	4.16E+05	3.08E+05	92	1	4347.367	19162.254	144	1	0.798	0.740
206	1	4.24E+05	3.05E+05	99	1	5120.265	20365.185	145	1	-0.842	0.741
310	1	3.38E+05	2.38E+05	100	1	5367.456	20985.905	146	1	0.741	0.743
3111	1	3.10E+05	2.45E+05	101	1	5425.234	20834.267	147	1	0.587	0.749

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4.1 Different Values of stresses obtained from STAAD - Pro V8i are

LEG MEMBER		
Beam	L/C	Axial N/mm ²
34	1	650.00
35	1	606.05
36	1	597.30
37	1	650.10
38	1	653.12
72	1	-636.08
75	1	-630.05
78	1	-487.24
82	1	397.34
185	1	580.05
186	1	622.94
187	1	424.17
201	1	590.09
202	1	370.09
203	1	452.35
204	1	672.56
205	1	334.17
206	1	234.20
310	1	483.78
311	1	524.05

BRACINGS		
Beam	L/C	Axial N/mm ²
5	1	93.85
11	1	-75.15
16	1	69.45
33	1	10.35
37	1	9.19
63	1	170.00
64	1	125.80
65	1	-172.70
69	1	8.371
70	1	-6.46
71	1	-9.48
87	1	14.50
88	1	-17.80
89	1	-129.80
90	1	-138.80
91	1	-243.70
92	1	-250.71
99	1	-8.37
100	1	-18.23
101	1	64.39

OTHER DIAGONALS		
Beam	L/C	Axial N/mm ²
111	1	-0.009
112	1	0.008
113	1	-0.007
114	1	0.003
115	1	0.005
116	1	-0.004
117	1	0.002
118	1	-0.03
121	1	0.02
122	1	0.005
123	1	-0.006
124	1	0.002
125	1	-0.007
126	1	0.005
127	1	0.004
143	1	0.006
144	1	0.003
145	1	0.002
146	1	-0.001
147	1	0.004

V. CONCLUSION

The optimal designs obtained satisfy all the specifications included in the actual norms and can be directly applied in practice since they satisfy all the safety conditions imposed. According to this idea, real structural models are analyzed by using 3D articulated latticed structure models. From the above study it is found that this type of design based on finite element modeling is essential for the design of tower structure. However it can be also concluded that Wind load in static manner may always is not effective for this type of tall towers. Dynamic wind loading has to be considered for analysis and design of tall towers. Wind load is predominant in this type of tall tower structures rather than seismic force. Temperature load is also an important action in case of transmission line towers. Also the sag tension for different ambient temperature is important. A sag template shall be prepared for the determining sag scenario of the conductors.

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