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DESIGN OF TRANSMISSION TOWER AND ITS FOUNDATION

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ABSTRACT
The Transmission line towers are one of the important life line structures in the distribution of power from the source to the various places for several purposes. The tower is designed for the wind zone V carrying 132 KV DC. Tower is modelled using constant parameters such as height, bracing system, angle sections, base widths, wind zone, common clearances, span, conductor and ground wire specifications. The loads are calculated using IS: 802(1995). After completing the analysis, the study is done with respect to deflections, stresses, axial forces,slenderness effect, critical sectionsand weight of tower. Using STAAD PRO v8i analysis and design of tower has been carried out as a three dimensional structure. Then, the tower members are designed.

1.0 INTRODUCTION

1.1Transmission line tower

The advancement in electrical engineering shows need for supporting heavy conductors which led to existence of towers. Towers are tall structures, their height being much more than their lateral dimensions. These are space frames built with steel sections having generally an independent foundation under each leg. The height of tower is fixed by the user and the structural designer has the task of designing the general configuration, member and the joint details **(John D Holmes)**.

A high voltage transmission line structure is a complex structure in that its design is characterized by the special requirements to be met from both electrical and structural points of view, the former decides the general shape of the tower in respect of its height and the length of its cross arms that carry electrical conductors**(Visweswara Rao, G 1995).**

Hence, it has given rise to the relative tall structures such as towers. The purpose of transmission line towers is to support conductors carrying electrical power and one or two ground wires at suitable distance. In this study, a 132kV Transmission line tower is modelled using STADD Pro 2006. The towers are designed for wind zones V with constant base width.

1.2 Conductor

A substance or a material which allows the electric current to pass through its body when it is subjected to a difference of electric potential is known as Conductor. The materials which are used as conductors for over head transmission lines should have the following electrical and physical properties.

- It should have a high conductivity
- It should have tensile strength.

- It should have a high melting point and thermal stability.
- It should be flexible to permit us to handle easily and to transport to the site easily.
- It should be corrosion resistance.

1.3 ACSR Conductors

Aluminium has an Ultimate Tensile Strength (U.T.S) of 16 – 20 kg / mm^2 where as the steel has a U.T.S of about 136 kg / mm^2. By a suitable combination of steel and aluminium the tensile strength of the conductor is increased greatly. Thus,there came into use the Aluminium Conductor Steel Reinforced (ACSR).

TABLE 1.1 Conductor Mechanical and Electrical Properties

Voltage	132KV
Code name of Conductor	PANTHER ACSR
No of Conductor/Phase	4
Stranding/Wire diameter	'30/3.00+'7/3.00
Total sectional Area	261.5mm^2
Overall Diameter	21mm
Approx Weight	974kg/km
Min U.T.S	89.67KN
Modulus of Elasticity	8.158E+05
Co-efficient of Linear Expansion	1.78E-05/°C
Max Allowable Temperature	75°C

1.4 Earth wire

The earth wire is used for protection against direct lightning strokes and the high voltage surges resulting there from. There will be one or two earthwire depending upon the shielding angle or protection angle.

2.0 LITERATURE REVIEW

A nonlinear analytical technique for predicting and simulating the ultimate structural behavior of self supporting transmission towers under static load condition was prepared by **Al-Bermani and Kitipornchai(1992).**The proposed method considered both the geometric and material nonlinear effects and treated the angle members in the tower as general asymmetrical thin walled beam column elements. Modeling of the material non linearity for angle members was based on the assumption of lumped plasticity coupled with the concept of a yield surface in the force space

Al –Mashary et al (1992) investigated six 132KV tangent towers that failed in a transmission line in Al-Qassim region, owned by Saudi Consolidated Electrical Company. Two towers failed by bending of cross arms and three towers failed at their base. The governing specifications of ASCE Manual No.52-1971 were followed. The laboratory tests on tensile specimens were satisfactory. A three dimensional analysis of the tower, employing the frame-members for the main legs, showed high localized bending moments in legs causing 30 to 40% over stress. These bending moments were neglected in the original design calculation. These moments although consider as secondary and neglected in common design practice, and significantly high at certain locations and leads to unexpected failures.

Natarajan and Santhakumar (1955) conducted studies on reliability based optimization of transmission line towers. Four independent computer programs for component reliability, reliability analysis, optimization and automation of failure mode generation were developed and linked together. This has enabled more economical design of towers and ensured a particular level of chosen reliability. The weight of optimal tower accounting for reliability as a constrain for tangent cover is only 3 to 4%

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heavier than the tower designed using conventional method

Hemant Patil et al (2010) conducted failure analysis on 400kV S/C horizontal configuration tower by conducting non linear finite element analysis using NE-NASTRAN software. Both geometric and material non linearity's have been included in the analysis. It was predicted that the non linear analysis forces are higher compare to linear analysis force. Further the remedial measures have been suggested for the in stability encountered in the structure

Battista et al (2003) presented a new analytical numerical model for structural analysis of transmission line tower under wind action. 3D- Finite element model was constructed for analyzing the dynamic coupled behavior of transmission line tower under the action of wind. The suspension rods formed by the chains of insulators were identified as the most important component of the system in the analysis of wind flow and tower lines coupled model interactive dynamic behavior and response. The tower structure and all cables were discredited with spatial frame elements.

Elagaaly et al (1992) conducted experiments on 3 dimensional trusses. The trusses were designed such that the target angle would fail first without significant deformations in the remaining members of the truss. Following each test the target angle alone was replaced allowing multiple tests to be conducted in the same setting. Fifty single angle members with each angle were also tested as part of the truss. The results indicates six modes of bucking due to coupling effect of local,flexural,tensional and torssional structural modes. Most of the members failed in local buckling which occurred at bolt hole.

A 230KV transmission line with delta type towers was used for the study. The soil structure interaction was also performed taking in to account two types, medium sand and clay soils. Linear elastic springs and rigid elements were used to simulate the soil and concrete footing. The study of the structural dynamic characteristics has shown that, whichever is the soil type, the first 10 lower natural oscillation frequencies do not change.

METHODOLOGY

3.1 FLOW CHART

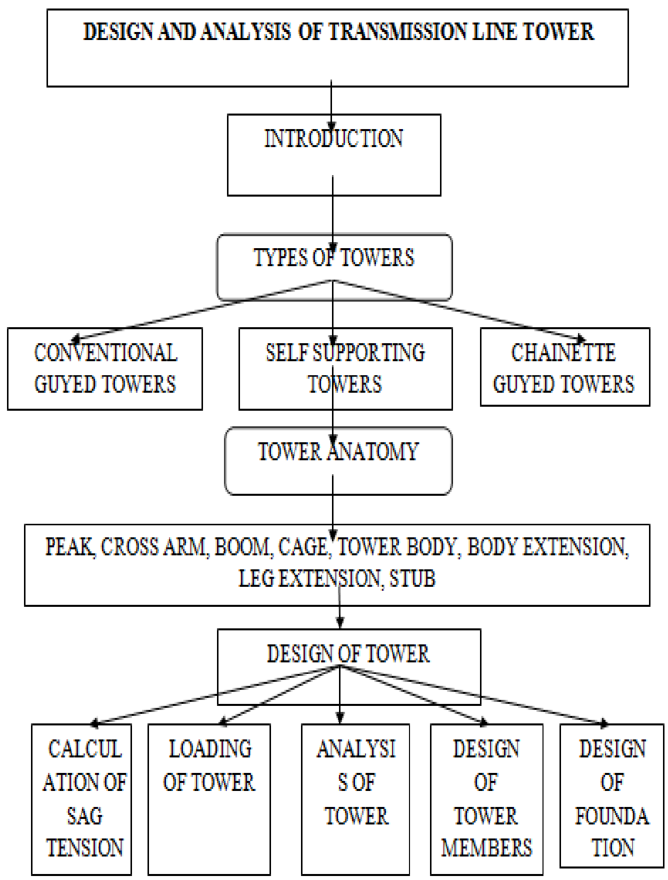

Figure 3.1 Methodology

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4.0 RESULTS

4.1 CALCULATION OF SAG TENSION

Table 4.1 CONDUCTOR SPECIFICATIONS

S.n	Description	Symbol	Unit	Power Conductor
1	Voltage	V	KV	132
2	Span	L		320
3	Power conductor	FOS		4
4	IS398part5/1996)			PANTHER ACSR
5	Overall diameter	D	mm	21
6	Sectional area	A	mm^2	261.5
7	Mass	W	kg/Km	974
8	UTS(Breaking load)	U	kgf	9143.8
9	Modulus of elasticity	E	kgf/Cm^2	8.16E+05
10	Coefficient of linear expansion	α	per C°	1.78E-05
11	Everyday temperature	t	C°	32
12	Sag Tension factors			
13	Wt factor =(W/1000)*(100/A)	δ		0.3724665
14	Wind Load	P_1	-	0
15	Loading factor at still wind =sqrt(1+((1000*p_1)/w^2)	q_1	-	1.00
16	Wind zone			5
17	Basic Wind speed	m/sec		50
18	Reliability level			3
19	Terrain category/Ground roughness			1
20	Height of the clamping point of the top conductor			31.56
21	Height of the clamping point of the Earth wire			36.26
22	Power conductor Sag at 0° at no wind			4.320
23	earth wire Sag at 0°at no wind			3.888
24	Temperature factors	temp		
25	At min temp in °c	0	Eατ0	0.00
26	At EDT in °c	32	Eατ32	464.66
27	At max temp °c	75	Eατ75	1089.05

4.1.1Wind Pressure Calculation as per IS 802/1995

Step1: Reference wind pressureVr = Vb/Ko

- K_0= 1.375 ,Vb=50m/sec
- Ref Velocity
- V_r= 36.3636 m/sec

Step-2: Design wind velocity

- $V_{d=}=V_r x K_1 x K_2$
- K_1= 1.27 , K_2= 1.08
- Design pressure V_d= 49.8764m/sec

Step 3: Design of wind pressure

- Pd=0.6xVd^2
- Pd-Design Pressure=1492.59N/mt^2

Step4: Actual wind pressure:P=PdxCdcxGc (conductor)

- Pd =Design pressure =152.202Kg/m^2
- Cdc =Drag coefficient=1 for conductor
- Gc = Gust response factor to be taken at average height of conductor
- Average height of the conductor = height of the clamping point of the top conductor-2/3x sag at 0^0 c at no wind
- 31.56 - 2/3X4.32=28.6763 m
- From table 7 as per IS 802/1995

• Span	Avg HT	Gc	for 28.676
• 300	20	1.870	1.9437
• 300	40	2.040	
• 400	20	1.830	
• 400	40	2.000	1.9037

- By interpolation for 28.676 mts Ht the Gc for 320 mtrs span is **1.936**
- wind pressure on conductor=294.62 Kg/m^2

4.1.2 For earth wire Gc

- Average height of the Earth wire =height of the clamping point of the Earth wire - 2/3x sag at 0^0 c at no wind
- (36.26) - (2/3 x 3.888)= 33.6643 m

• Span	Avg HT	Gc	for 33.664
• 300	20	1.870	1.9861
• 300	40	2.040	
• 400	20	1.830	1.9461
• 400	40	2.000	

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- considered value for sag tension and load calculation Gc is 1.978
- wind pressure on Earth wire P=PdxCdcxGc =361.29 Kg/m^2

4.1.3 SAG TENSION CALCULATIONS of PANTHER ACSR Conductor

- Span L1=320m
- Any condition of temp, sag tension and wind may be assumed as initial condition.
- Initial (starting) condition is assumed at 32 deg C (EDT) no wind
- Limiting tension at 32 deg C no wind = 25% of UTS of PANTHER ACSR conductor
- To maintain the factor of safety at all conditions as per IS
- Factor of Safety=0.25
- T_{32}°= 9143.8x0.25 =2285.95 kg
- f_1 =(T_{32}°/A)100 =874.16826 kg/cm²
- Tension factor=$L^2 \delta^2 E q^2/24$ = 482870831.9
- K constant = $[f_1-(L^2 * \delta^2 * E * q_1^2)/(24 f_1^2)+E\alpha t_1]$= 706.9416925

At 0° sag & Tension at no wind

- $k-E\alpha t_2$ =706.94
- $L^2 \delta^2 E q_1^2/24$ = 482870831.9
- Formula for change of state
- $f_2^2[f_2-(k-Eat_2)]=L^2\delta^2 E q_1^2/24$
- f_2 =1103.488974
- Tension $T_2=f_2*A/100$ =2885.62 kg
- Sag=$L^2\delta q_1/8f_2$ =4.320 m

At 32° sag & Tension at no wind

- $k-E\alpha t_2$ =242.28
- $L^2 \delta^2 E q_1^2/24$ = 482870831.9
- Formula for change of state
- $f_2^2[f_2-(k-E\alpha t_2)]=L^2\delta^2 E q_1^2/24$
- f_2 =874.16826
- Tension $T_2=f_2*A/100$ =2285.95 kg
- Sag=$L^2\delta q_1/8f_2$ =5.454 m

At 75° sag & Tension at no wind

- $k-E\alpha t_2$ =-382.11
- $L^2 \delta^2 E q_1^2/24$ = 482870831.9
- Formula for change of state
- $f_2^2[f_2-(k-E\alpha t_2)]=L^2\delta^2 E q_1^2/24$
- f_2 =675.649855
- Tension $T_2=f_2*A/100$ =1766.82 kg
- Sag=$L^2\delta q/8f_2$ =7.056 m

At 32° sag & Tension at full wind

- P_2=Px d_cx100%
- 294.62 x 21 /1000X100% =6.187117
- $Q_2 = \frac{\sqrt{w^2+P_2^2}}{\sqrt{W^2}}$ =6.4305064
- $k-E\alpha t_2$ =242.2791005
- $L^2 \delta^2 E q_2^2/24$ = 19967391258.53
- Formula for change of state
- $f_2^2[f_2-(k-E\alpha t_2)]=L^2\delta^2 E q_2^2/24$
- f_2 =2796.153032
- Tension $T_2=f_2*A/100$ =7311.94 kg
- Sag=$L^2\delta q_2/8f_2$ =10.964 m
- Vertical Sag =`=$L^2\delta q_1/8f_2$ =1.705 m

At 0° sag & Tension at 36% wind

- P_2=Px d_cx36%= 294.62 x 21/1000 x 36% =2.2273621
- $Q_2 = \frac{\sqrt{w^2+P^2}}{\sqrt{W^2}}$ = 2.496
- $k-E\alpha t_{2=}$ 706.94
- $L^2 \delta^2 E q_2^2/24$ = 3008064679
- Formula for change of state
- $f_2^2[f_2-(k-E\alpha t_2)]=L^2\delta^2 E q_2^2/24$
- $F_{2=}$ 1721.710291
- Tension $T_2=f_2*A/100$ = 4502.27 kg
- Sag=$L^2\delta q_2/8f_{2=}$ 6.911 m
- Vertical Sag `=$L^2\delta q_1/8f_2$ = 2.769 m

At 32° sag & Tension at 75%full wind

- P_2=Px d_cx75%= 294.62 x 21/1000 x 75% = 4.6403378
- $Q_2 = \sqrt{w^2+P^2}$ = 4.868

$\sqrt{W^2}$

- $k\text{-}E\alpha t_{2}=$ 242.28
- $L^2 \delta^2 E q_2^2/24 = 11442913572$
- Formula for change of state
- $f_2^2[f_2-(k-E\alpha t_2)]=L^2\delta^2 E q_2^2/24$
- $F_{2}=$ 2337.160675
- Tension $T_2=f_2{*}A/100$ = 6111.68 kg
- Sag=$L^2\delta q_2/8f_{2}=$ 9.930 m
- Vertical Sag= `=$L^2\delta q_1/8f_2$ = 2.040 m

Table 4.2 Sag Tension Values for conductor

Temperature	Wind	Tension(kg)	FOS	Vertical sag
32	No wind	2285.95	4.000	5.454
32	100% of FW	7311.94	1.251	1.705
75	No wind	1766.82	5.175	7.056
0	No wind	2885.62	3.169	4.320
0	36% of FW	4502.27	2.031	2.769
32	75% of FW	6111.68	1.496	2.040

Maximum Vertical sag=7.056

Maximum Tension=7311.9

Table 4.3 Sag Tension Values at Different Spans

Span	Sag at 75^0c, No wind	Sag at 32^0c, Full wind
50	0.17	0.04
100	0.69	0.17
150	1.55	0.37
200	2.76	0.67
250	4.31	1.04
300	6.20	1.50
350	8.44	2.04
400	11.03	2.66
450	13.95	3.37
500	17.23	4.16
550	20.84	5.04
600	24.81	5.99
650	29.11	7.03

5.0 CONCLUSION

- This work attempts to optimize the transmission line tower structure for a 132KV double circuit with respect to configuration and different materials as variable parameters.
- Optimization of tower geometry with respect to member forces, the tower configuration having 3 panels and base width 6.05metres is concluded as safe with respect to geometry.
- The tower with 45˚ angle section and K-bracing with 7833.41kg/m3 has the greatest reduction in weight optimization.
- Analysis of tower with STAAD PRO software is showing transmission line tower with a height of 31.53metres with 132KV.
- Tower structures with less height is directly associated in reduction of wind loading and also structure construction.
- Narrow based steel lattice transmission tower structure plays a vital role in its performance especially while considering eccentric loading conditions for high altitude as compared to other normal tower.
- Narrow based steel lattice transmission tower considered in this can safely withstand the design wind load and actually load acting on tower. The bottom tier members have more roles in performance of the tower in taking axial forces and the members supporting the cables are likely to have localized role.
- The vertical members are more prominent in taking the loads of the tower than the horizontal and diagonal members, the members supporting the cables at higher elevations are likely to have larger influence on the behaviour of the tower structure.

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• The effect of twisting moment of the intact structure is not significant.

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