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Dynamic Analysis of Transmission Tower

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Abstract:

Transmission line towers carry heavy electrical transmission conductors at a sufficient and safe height from ground. In addition to their self-weight they have to withstand all forces of nature like strong wind, earthquake and snow load. Therefore transmission line towers should be designed considering both structural and electrical requirements for a safe and economical design. This paper introduces different types of transmission tower and its configuration as per Indian Standard IS-802. A typical type of transmission line tower carrying 220kV double circuit conductors is modeled and analyzed using STAAD-Pro considering forces like wind load, dead load of the structure and earthquake load as per Indian Standard IS1893:2000(part 1).

The transmission tower has height of 40m which includes the ground clearance(h1),maximum sag of the lower most conductors wire(h2),vertical spacing between the conductors wires(h3) and vertical distance of earth wire from the uppermost conductor wire(h3).The earth wire or ground wire is always located at the top of the transmission tower. It has a square base width of 11.5m. 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 6 with basic wind speed of 55m/s. The wind pressure on the tower depends on the gust response factor (GT) which increases with height.

The transmission tower is situated in the most seismic sensitive region i.e. Zone V 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. Steel optimization has been carried out to find the most suitable and economical section for the design.

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 cross-section of conductors, the spacing between conductors, and the location of ground wires with respect to the conductors will decide the design of towers and foundations. The major components of a transmission line consist of the conductors, ground wires, insulation, towers and foundations. Most of the time transmission lines are designed for wind and ice in the transverse direction. However, the Indian Sub-continent is prone to moderate to severe earthquakes seismic loads may be important because the transmission line towers and the cables may be subjected to higher force and stressed during ground motion. However, the major concern of the transmission line during high earthquakes may be that the large displacements do not causes the cables to touch each other or any surrounding objects, causing power failure and accidents. Therefore, earthquake forces may be important in design in high earthquake zones of the country.

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In this project Seismic behavior of transmission line is determined from the dynamics analysis of the tower and the cable subjected to earthquake ground motion.

Types of towers clause 6 IS 802 (Part 1/Set 1) : 1995:

The selection of the most suitable types of tower for transmission lines depends on the actual terrain through which the line traverses. Experience has, however, shown that any combination of the following types of towers are generally suitable for most of the lines:

Suspension towers :

Suspension towers are used primarily on tangents but often are designed to withstand angles in the line up to two degrees or higher in addition to the wind, ice, and broken-conductor loads. If the transmission line traverses relatively flat, Featureless terrain, 90 percent of the line may be composed of this type of tower.

Tension towers :

As they must resist a transverse load from the components of the line tension induced by this angle, in addition to the usual wind, ice and broken conductor loads, they are necessarily heavier than suspension towers

Table 1. Type of tower

A) Small angle towers (0" to 15') with tension string	Deviation of 0" to 15".
B) Medium angle towers (0" to 30") with tension string	Deviation of 0" to 30".
C) Large angle towers (30" to 60") with tension string	Deviation of 30" to 60".
D) Dead-end towers with tension string	To be used as dead-end (terminal) tower or Anchor tower.
E) Large angle and dead-end towers with tension string	To be used for line deviation from 30" to 60" or for dead-ends.

Following are the different parts of a transmission tower,

1) Peak of the tower
2) Cage or hamper of the tower, that supports the cross arm.
3) Cross arm for carrying conductors.
4) Tower body, includes bracing
5) Legs of the tower

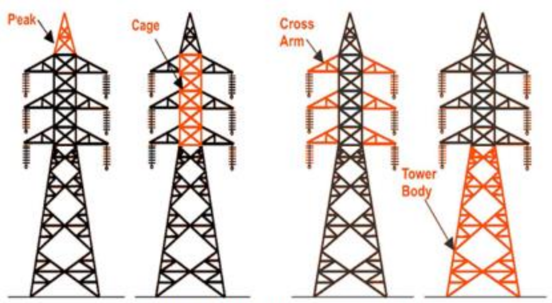

Figure 1. Parts of transmission tower

Tower configuration:

The selection of a best outline and the bracing system patterns contributes to a great extent in developing an economical and safer design of a transmission line tower. For a particular tower configuration selected, the outline decided shall satisfy both electrical and structural requirements at the same time the configuration should be economical. The square type broad base tower are the most economical and most commonly used in India.

The tower outline diagram comprises
(a) Tower height considered from ground level
(b) Length of the cross-arm, and phase spacing
(c) Tower width at (i) base (ii) top hamper
(d) Bracing pattern considered.

Determination of tower height:

The factors that govern the height of the tower are:
1. Minimum permissible ground clearance (h1)
2. Maximum sag of the lowermost conductor wires (h2)
3. Vertical spacing between conductors (h3)
4. Vertical distance between ground wire and top conductor (h4)

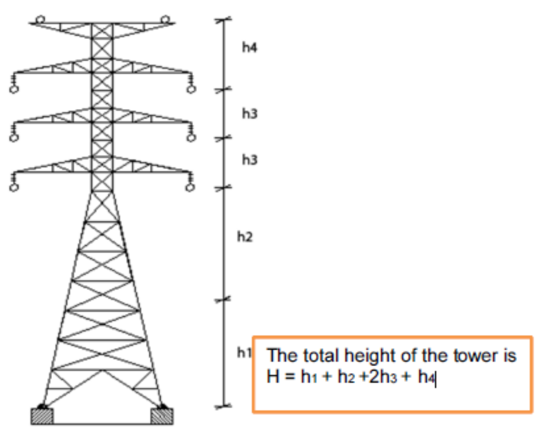

Figure 2. Tower height

Minimum permissible ground clearance (h1):
For safety, power carrying conductors along the path of the transmission line should maintain minimal clearance to ground, highways roads, rivers, railways tracks, telecommunication lines, other power lines, etc.., as according to the Indian Electricity Rules, or as per Indian standards. Rule 77(4) of the Indian Electricity Rules, 1956, suggests the following minimum clearances above ground of the lowest point of the conductor:

The clearance above ground shall not be less than the following figures plus the height of the nearby obstacles. The values of minimum ground clearance for the various voltages ranging from 66kV to 400 kV, are:
66kV – 5.47m
132kV – 6.10m
220kV – 7.01m
400kV – 8.84m

Maximum sag of the lowermost conductor (h2):
The power carrying conductors sags due to its self-weight and the sag is maximum when the temperature is maximum and when there is no wind condition. The maximum sag occurs at the mid-section between the two towers in open country.

Spacing of conductors (h3):
They should be adequate vertical space between the conductors so that they do not touch each other during dynamic loads such as during high earthquake and high wind. The following is the vertical clearances generally allowed at the mid of the span between the conductors.

Table 2 Vertical clearance permissible of the middle of span

Span(m)	Vertical clearance permissible of the middle of span.(mm)
200	4,000
300	5,500
400	7,000
500	8,500

Vertical clearance between ground wire and top conductor (h4):
The vertical spacing between conductors and the earth wires is governed by shield angle, i.e. angle which the line joining the ground wire and the outermost conductor makes with the vertical which is required to protect the conductors wires and the transmission tower form the direct lighting strokes. Generally the shield angle varies from 25o to 30o which depend on the overall configuration of the transmission tower and the amount of voltage the transmission line carries.

LOADS:
The load acting on the towers are
1. Dead load. Self-weight of the tower and the conductors and wires.
2. Wind load calculated as per IS 802 (part1/sec 1): 1995
3. Earthquake load as per IS1893(part 1):2000

Wind load, clause 8 IS 802 (Part l/Set 1) : 1995:
Figure 5 shows basic wind speed map of India as applicable at 10 m height above mean ground Level for the six wind zones of the country. Basic wind speed 'Vb' is based on peak gust velocity averaged over a short time interval of about 3 seconds, corresponds to mean heights above ground level in an open terrain (Category 2) and have been worked out for a 50 years return period [Refer IS 875 (Part 3) : 1987]India is divided into 6 wind zones. Basic wind speeds for the six wind zones (see Fig.
5) are

Table 5 basic wind speed

Wind Zone	Basic Wind Speed, V_b m/s
1	33
2	39
3	44
4	47
5	50
6	55

Design Wind speed, Vd
To get the design wind speed the basic wind speed is modified to include the following effects:
a) Risk coefficient, K1; and
b) Terrain roughness coefficient, K2.
Hence it may be expressed as follows:
Vd=VR × K1 × K2
Risk Coefficient, K1

Table 6. The values of risk coefficients K_1 for different wind zones for the three reliability levels

Reliability Level	Coefficient K_1 for Wind Zones					
	1	2	3	4	5	6
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	1·00	1·00	1·00	1·00	1·00	1·00
2	1·08	1·10	1·11	1·12	1·13	1·14
3	1·17	1·22	1·25	1·27	1·28	1·30

Terrain Roughness Coefficient, K_2

Terrain Roughness Coefficient, K2

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Table 7. The values of coefficient K, for the three categories of terrain roughness corresponding to 10 minutes averaged wind speed.

Terrain Category	1	2	3
Coefficient, K_1	1·08	1·00	0·85

Terrain Roughness Coefficient, K2

The values of coefficient K, for the three categories of terrain roughness corresponding to 10 minutes averaged wind speed

Terrain Category	1	2	3
Coefficient, K_1	1·08	1·00	0·85

Terrain categories:

a)Category 1 -Exposed open terrain land scape with few or no obstacles.
This category includes open seacoasts, deserts and flat treeless, deserts and flat treeless plains.

b)Category 2-Open terrain with scattered obstructions having height generally between 1.5 m to 10 m. This category includes normal country lines with very few obstacles.

c)Category 3 -Terrain with number of closely spaced obstructions. This category includes urban areas and forest areas.

Design Wind Pressure, Pd:

The design wind pressure which is distributed along the height of the towers, conductors and insulators shall be determined by the following expression:

$$P_d=0.6V_d^2$$

P_d=design wind pressure in n/m²
V_d=design wind speed in m/s

Transverse load:

The transverse load consists of loads at the points of conductor and ground wire support in a direction Parallel to the longitudinal axis of the cross arms, plus a load distributed over the transverse face of the structure due to wind on the tower Thus total transvers load.

$= F_{wt} + F_{wc} + F_{wi}$

where

F_{wi} and F_{wc} are to be applied on all conductors/ground wire points and F_{wt} to be applied on tower at ground wire peak and cross arm levels and at any one convenient level between bottom cross arm and ground level for normal tower. In case of tower with extensions, one more application level shall be taken at top end of extension.

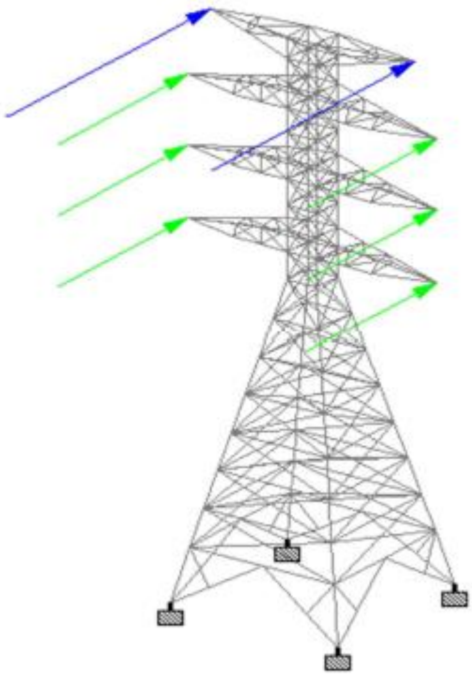

Figure 8. Transverse load

Vertical load:

Vertical load is applied to the ends of the cross- arms and on the ground wire peak and consists of the following vertical downward

Components:

1. Weight of bare or ice-covered conductor, as specified, over the governing weight span.
2. Weight of insulators, hardware, etc., covered with ice, if applicable.
3. Arbitrary load to provide for the weight of a man with tools. Dead load of the wire and insulator disk=7000 N =7kN.

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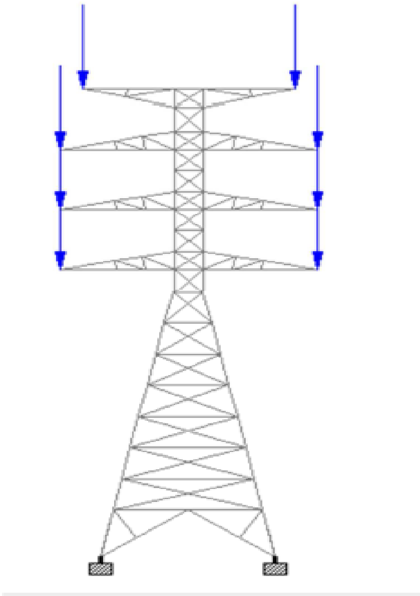

Figure 9. Vertical load

Earthquake load:

Steel frames shall be so designed and detailed as to give them adequate strength, stability and ductility to resist severe earthquakes in all zones classified in IS 1893 (Part 1) without collapse. Frames, which form a part of the gravity load resisting system but are not intended to resist the lateral earthquake loads, need not satisfy the requirements of this section, provided they can accommodate the resulting deformation. Following figure show the seismic parameters considered for defining the earthquake load case in STAADPro

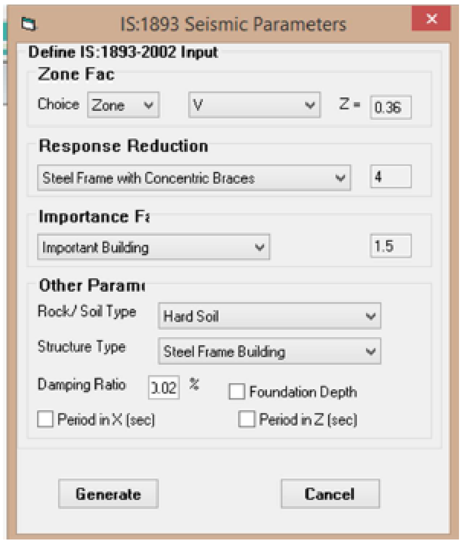

Figure 10. Earthquake load parameters

STAADPRO ANALYSIS:

GEOMETRY:

Total of 665 no of beam angle section ranging from ISA150x150x18 to ISA45x45x10 are modeled using coordinated system.

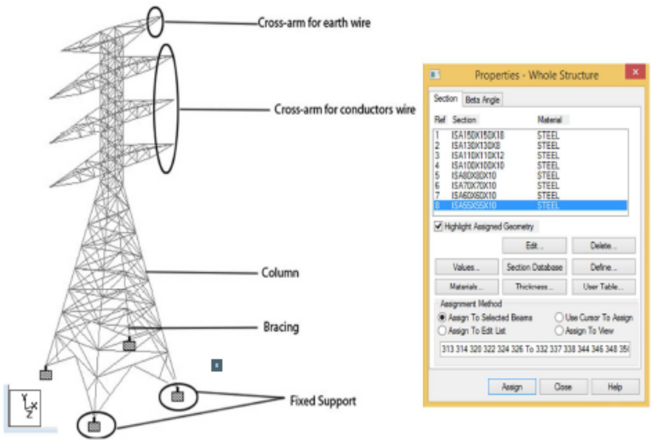

Figure 11. Tower model in STAADPro

The column and the bracing at the lower part of the transmission tower has been assigned with higher angle section than that of upper part of the tower. This is due to the fact that the lower members have to withstand more loads than that at upper part.

RESULTS:

Displacement:

			Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	47	9 GENERATE	5.593	-2.907	-0.729	6.345	0.001	-0.002	-0.001
Min X	52	9 GENERATE	-5.593	-2.907	-0.728	6.345	0.001	0.002	0.001
Max Y	88	10 GENERAT	0.109	16.254	-299.793	300.233	-0.019	-0.001	-0.000
Min Y	220	10 GENERAT	0.173	-21.741	-299.827	300.614	-0.020	-0.001	-0.000
Max Z	247	9 GENERATE	2.751	6.046	350.745	350.808	0.021	-0.003	0.001
Min Z	246	10 GENERAT	2.749	6.040	-350.742	350.804	-0.021	0.003	0.001
Max rX	127	9 GENERATE	2.923	-13.985	[illegible]	335.827	0.021	0.003	-0.001
Min rX	126	10 GENERAT	2.923	-13.983	-335.525	335.829	-0.021	-0.003	-0.001
Max rY	46	10 GENERAT	-1.112	-3.075	-21.859	22.102	0.000	0.013	-0.003
Min rY	49	9 GENERATE	-1.112	-3.074	21.858	22.102	-0.000	-0.013	-0.003
Max rZ	29	9 GENERATE	-0.161	3.386	3.909	5.174	0.001	0.007	0.003
Min rZ	17	9 GENERATE	0.162	3.386	3.908	5.174	0.001	-0.007	-0.003
Max Rs	246	9 GENERATE	-3.659	-14.412	350.745	351.060	0.020	-0.003	0.001

Table 12. Displacement result

Maximum displacement of 350mm in the direction on wind due to the load combination 9 (1.7xdead load and 1.7xwind load).

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	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
Max Fx	26	10 GENERAT	34	879.575	-0.111	-0.512	-0.032	1.557	-0.269
Min Fx	14	9 GENERATE	9	-780.987	-2.620	1.964	-0.031	3.460	3.101
Max Fy	284	10 GENERAT	85	-19.761	14.813	11.538	0.365	1.210	-0.033
Min Fy	598	9 GENERATE	88	-57.469	-14.664	-11.156	-0.365	1.486	-0.071
Max Fz	599	10 GENERAT	92	59.263	-1.596	12.831	-0.188	-2.592	-0.260
Min Fz	280	9 GENERATE	89	4.318	1.743	-13.230	0.189	-2.041	-0.223
Max Mx	598	10 GENERAT	218	1.483	0.168	1.821	0.412	-1.591	-0.081
Min Mx	284	9 GENERATE	85	20.615	-0.012	-2.205	-0.412	-1.283	-0.042
Max My	143	9 GENERATE	2	2.723	-0.397	3.872	-0.026	8.116	0.362
Min My	133	10 GENERAT	4	2.723	-0.397	-3.872	0.026	-8.116	0.362
Max Mz	9	9 GENERATE	18	-629.590	-4.200	1.332	-0.030	0.963	4.120
Min Mz	21	10 GENERAT	29	804.159	-3.274	-1.062	-0.030	0.626	-3.988

Table 13 . Force summary

Graph

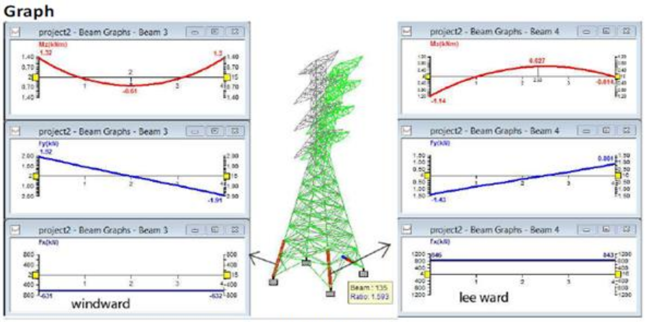

Figure 13. Graphs

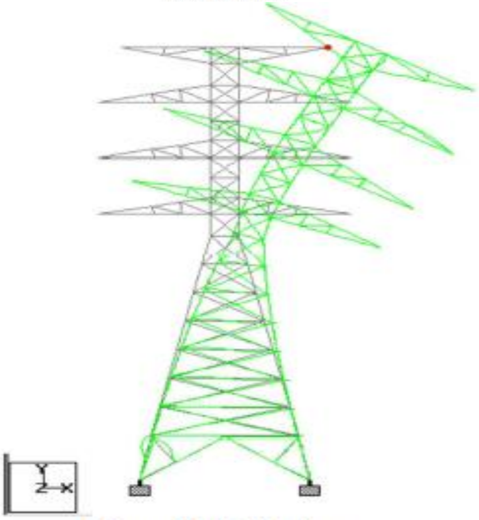

Figure 12. Deflection

Force summary: Table 13 . Force summary, Maximum compression force is experienced by beam 284 by load combination (9) and maximum tensile forced is at beam 598 due to load combination (10) i.e. member at the windward side experiences tension and members at the leeward side experiences compression

STEEL TAKE-OFF

	PROFILE	LENGTH(METE)	WEIGHT(KN)
ST	ISA150X115X15	92.01	26.520
ST	ISA100X100X10	182.53	26.684
ST	ISA90X90X10	270.57	35.397
ST	ISA75X75X10	116.33	12.529
ST	ISA70X70X10	97.83	9.785
ST	ISA110X110X8	83.00	10.852
ST	ISA60X60X10	491.84	41.561
ST	ISA55X55X10	136.87	10.535
		TOTAL =	173.864

Table 15. Steel takeoff as per STAADPro analysis

Steel takeoff:

The following table gives the total amount and type of ISA sections required for the safe and economical transmission tower.

References:

1. Jordan Journal of Civil Engineering, Volume 7, No. 4, 2013
2. STAAD PRO, Bentley Corporation.
3. IS 802 Part 1 Sec 1 1995 Code of practice for use of structural steel in overhead transmission line towers, Part 1
4. IS 1893:2000 part 1
5. Mohamed Mohsen El-Attar (1998) ”Non-linear dynamics and seismic response of Power Transmission Lines”, PhD Thesis, McMaster University, Canada