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RESEARCH ARTICLE

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DYNAMIC ANALYSIS OF ELECTRICAL TRANSMISSION TOWER USING FINITE ELEMENT TECHNIQUE

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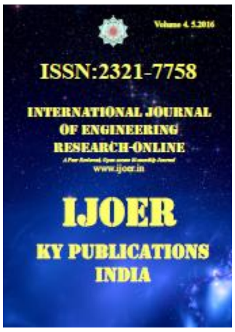

ABSTRACT

The electrical transmission 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. . A model of the transmission tower used effective element types on various components of transmission tower for static and dynamic analysis. Further determine the static response and corresponding stress resultants of transmission tower structure due to wind load at one static instant time on vertical and transversely position of transmission tower using ANSYS. Also studied free vibrational or modal analysis characteristics of the transmission tower by determine the frequencies and mode shapes of transmission tower using ANSYS and validating the finite element based results with closed form solution. At last elaborate study on the transient dynamic analysis of transmission tower using ANSYS with emphasis on the evaluation of dynamic response of transmission tower due to time varying wind load with various wind velocity like displacement and axial force.

Keywords: Transmission tower, FEM, ANSYS, static analysis, modal analysis and dynamic analysis due time varying loads.

1. INTRODUCTION

In every country, the need of electric power consumption has continued to increase, the rate of demand being greater in the developing countries. The 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. 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. 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.

2. AIM AND OBJECTIVES

- Modelling of Transmission of tower as per codal provisions.
- To find out the static response of transmission tower like deflections due to self-weight of the transmission tower using ANSYS.
- To determine static response and corresponding stress resultants of transmission tower structure due to wind load using ANSYS like deflections, directional deformation, and shear force and bending moment.
- To study free vibrational or modal analysis characteristics of the transmission tower by determine the frequencies and mode shapes of transmission tower using ANSYS.
- Dynamic analysis of a transmission tower using ANSYS.

3. TYPES OF TRANSMISSION TOWERS

There are two types of transmission towers are there, they are

Suspension Tower.

Tension Tower

Towers based on Deviation angle.

3.1 Suspension Tower: The Suspension towers are used primarily on tangents but often are designedto 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.

3.2 Tension Tower: 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.

3.3 Towers based on deviation angle:

1	Small Angle Towers(0^0 to 15^0) with tension string	Deviation of 0^0 to 15^0.
2	Medium angle towers (0^0 to 30^0) with tension string	Deviation of 0^0 to 30^0
3	Large angle towers (30^0 to 60^0) with tension string	Deviation of 30^0 to 60^0
4	Dead-end towers with tension string	To be used as dead-end (terminal) tower or Anchor tower
5	Large angle and dead-end towers with tension string	To be used for line deviation from 30^0 to 60^0.

Following are the different parts of 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 and
5) Legs of the tower

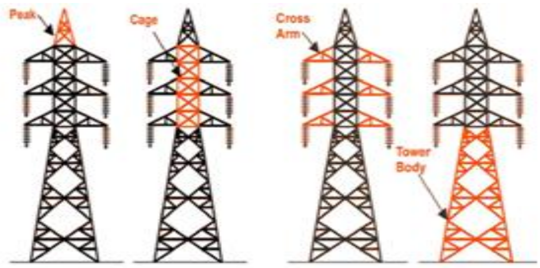

FIG.1 PARTS OF TRANSMISSION TOWER

4. FINITE ELEMENT MODELLING OF TRANSMISSION LINE

The basis of the finite element method is the representation of a body or a structure by an assemblage of subdivisions called finite elements. The Finite Element Method translates partial differential equation problems into a set of linear algebraic equations. The finite element method is a numerical technique of solving differential equations describing a physical phenomenon. It is a convenient way to find displacements and stresses of structures at definite physical coordinates called nodes. The structure to be analysed is discredited into finite elements connected to each other at their nodes. Elements are defined and equations are formed to express nodal forces in terms of the unknown nodal displacements, based on known material constitutive laws. Forces and initial displacements are prescribed as initial conditions and boundary conditions. A global matrix system is assembled by summing up all individual element stiffness matrices and the global vector of unknown nodal displacement values is solved for using current numerical techniques. Many software programs are available in the market for the analysis of structures by this method. In the present study, the computer program ANSYS is used for the analyses performed

4.1 Dimensional geometry description

The type of the tower is straight-line angle tower for double-circuit, the height of which is 35 m and the width of which is 11.5m as shown in Fig.2. The span of wire is 150m.

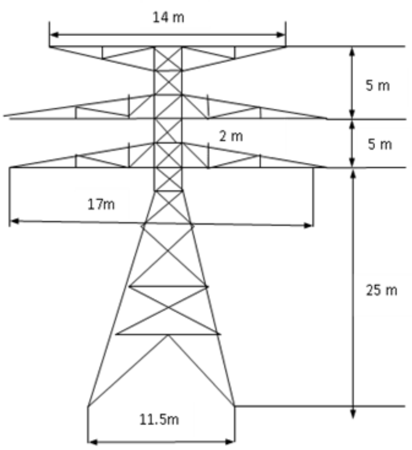

FIG. 2 Dimensional Geometry of tower

- A-type with 0˚ deviation located in plain country suspension tower with circuit carrying 220*kv* power
- Minimum ground clearance plus maximum sag of lower most wire = 25m
- Vertical spacing between the conductor = 5m
- Vertical spacing between conductor and the ground wire = 5m
- Total height of tower=35m
- Base width of the tower = $\frac{1}{3} to \frac{1}{6}$ of the total height of tower
- =11.5m (square base)
- Width of top hamper = 2 m
- Length of the cross arm=7.57from the edge of the hamper =7.57+2+7.5=17m
- Type of bracing = diamond bracing system
- Span of tower is 150m between two towers
- Conductor Material: ACSR, (Aluminium Conductor Steel Reinforced)

4.1.2 Element Type: The main members of the transmission tower (Truss members) are simulated by element LINK 180, the secondary members of the transmission tower (conductor wires) are simulated by element CIRCUIT 124 and insulators are simulated by element SOLID 65.

4.1.3 Real Constant: The real constants for this model are shown in Table 1.Individual elements contain different real constants. No real constant set exists for the Solid65 element.

Table-1 Real Constants for this model.

Real Constant number	Element Type	Parameter	Value	Description
1	LINK (180)	Cross Sectional Area (m^2)	230	Steel
		Initial Strain (mm/mm)	0	
2	Solid 65	Cross Sectional Area (m^2)	0.76163	Insulator
		Initial Strain (mm/mm)	0	
3	Circuit 124	Cross Sectional Area (mm^2)	525	Conductor
		Initial Strain (mm/mm)	0	

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4.1.4 Material Properties: The material properties of steel, insulators and conductor given below in Table.2

Table . 2 Material Properties

Designation	Values of steel	
Steel	Density (γ)	7850 Kg/m^3
	Elastic Modulus (E)	2e^5 N/mm^2
	Poisson ratio (υ)	0.3
Conductor	Density (γ)	2770 Kg/m^3
	Elastic Modulus (E)	55080 N/mm^2
	Poisson ratio (υ)	0.33
Insulator	Density (γ)	4000 Kg/m^3
	Elastic Modulus (E)	2.1 e^5 N/mm^2
	Poisson ratio (υ)	0.45

4.1.4 Modelling and Meshing of various component of Transmission Tower.

The Modelling of various components of transmission tower are showd in Fig No 3.

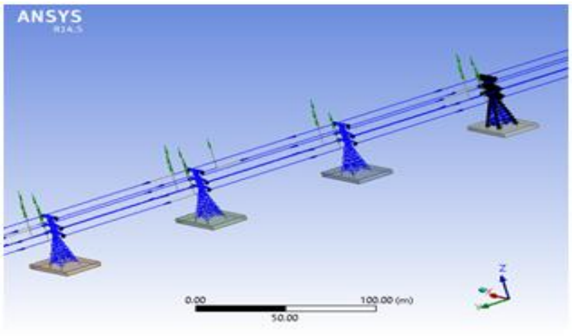

FIG NO. 3 Modelling of various components

Every conductor wires and ground wires are meshed into 21 elements. Every insulator is meshed into 168 elements. The meshing of various component of Transmission Tower as shown in Fig 4.

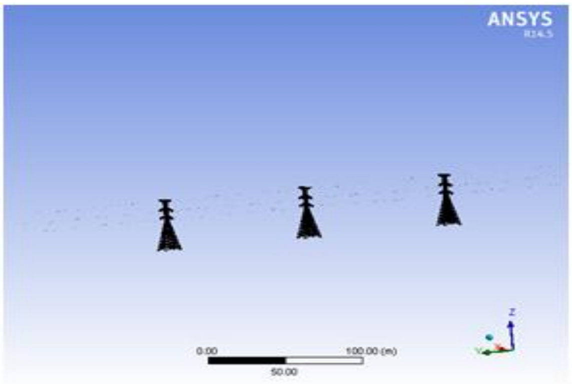

FIG NO.4 Meshing of various components of tower.

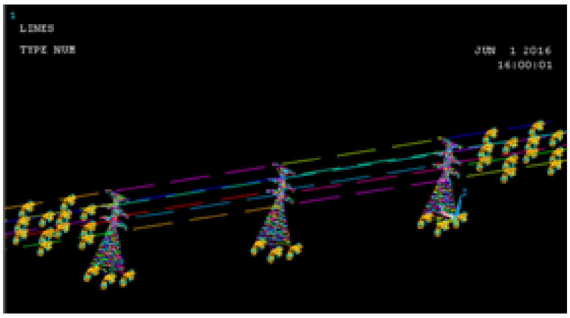

FIG NO.5 Boundary constrain Conditions Application

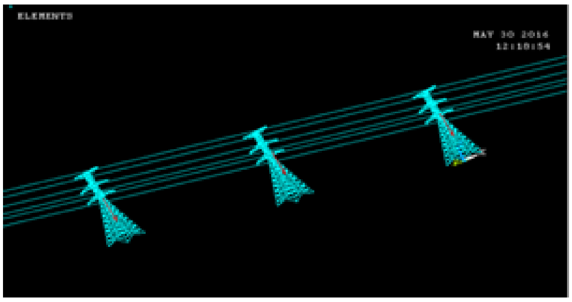

FIG.NO 6 Application of standard earth gravity for transmission tower

5. WIND STATIC ANALYSIS OF TRANSMISSION TOWER.

It is done by using IS-875(Part-3) code. The design wind speed is calculated corresponding to wind of consideration and then wind pressure corresponding to the design wind speed is calculated and finally the wind load is calculated.

5.1 WIND LOAD CALCULATION : Basic wind speed, Vbis 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 given below in Table 3.

Table 3 : 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,

Where

Vb= Basic wind speed in m/s

k1= Risk coefficient

k2=terrain, height and structure size factor

k3=Topography factor

Table 4 gives the values of risk coefficients k1 for different wind zones for the three reliability levels

TABLE .4 Risk Coefficient, k1

Reliability Level	Coefficient k_1 for wind zones					
	1	2	3	4	5	6
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

TABLE 5 Terrain roughness coefficient.

Terrain category	1	2	3
Coefficient,K_2	1.08	1.0	0.85

Terrain Categories:

Category 1: Exposed open terrain land scape with few or no obstacles.

Category 2: Open terrain with scattered obstructions having height generally between 1.5 m to 10 m.

Category 3: Terrain with number of closely spaced obstructions.

Design Wind Pressure, Pd

$$P_d = 0.6V_d^{\ 2}$$

Where Pd=design wind pressure in N/m2 at height z

Vd=design wind velocity in m/s at height z

Table 6 shows the design wind pressures 'Pd' for the three reliability level and pertaining to six wind zones and the three terrain categories are

Table 6: Design Pressures

Reliability level	Terrain category	wind pressure P_d for wind zones					
		1	2	3	4	5	6
1	1	403	563	717	818	925	1120
	2	346	483	614	701	793	960
	3	250	349	444	506	573	694
2	1	470	681	883	1030	1180	1460
	2	403	584	757	879	1010	1250
	3	291	422	547	635	732	901
3	1	552	838	1120	1320	1520	1890
	2	473	718	960	1130	1300	1620
	3	342	519	694	817	939	1170

Wind load on tower,Fwt

Where,

Pd= design wind pressure, in N/m2,

Cdt = drag coefficient is given in Table 5.5,

Ae= total net surface area of tower in m2.

Gt =gust response factor, depends on the height above ground.

Table 7:Drag coefficient, Cdt for tower

Solidity ratio	Drag coefficient (C_{dt})
Up to 0.05	3.6
0.1	3.4
0.2	2.9
0.3	2.5
0.4	2.2
0.5 and above	2.0

Wind Load on Conductor and Ground wire

The following expression gives the wind load that each conductor and ground wire carries:

Where,

Pd = Design wind pressure, in N/m2

Cdc = Drag coefficient, taken as 1.0 for conductor and 1.2 for ground wire

L = Wind span, in meters

d = Diameter of cable, in meters and

Gc = Gust response factor, which take account the turbulence of the wind at different height

L=150 m

Calculation of wind pressure, Pd

Basic wind speed (Vb)=55 m/s for zone 6

Meteorological reference wind speed,

$$V_R = \frac{V_b}{k_o}$$

$$V_R = \frac{50}{1.375} = 40\ m/\sec$$

Design wind speed, Vd

k1= Risk coefficient=1.3 for zone 6 with reliability level 3

k2=Terrain roughness coefficient

k2=1.08 for terrain category1 m/s

$$V_d = 40 \times 1.3 \times 1.08 \times 1 = 56.16$$

Design wind pressure (Pd),

$$P_d = 0.6 * 56.162^2 = 1890 N/m^2$$

Calculation of wind load on wires

1) Wind Load on lowest Conductor (Gc=1.9) at a height of 25m

$$= 1890 \times 1 \times 0.016 \times 150 \times 1.9 = 8618 N = 8.618 KN$$

2) Wind Load on mid Conductor (Gc =2) at a height of 30m

$$= 1890 \times 1 \times 0.016 \times 150 \times 2 = 9072 N = 9.072 KN$$

3) Wind Load on top Conductor (Gc =2.05) at a height of 35m.

$$= 1890 \times 1 \times 0.016 \times 150 \times 2.05 = 9300N = 9.3KN$$

4) Wind Load on insulator wire (Cdc=1.2, d=20, Gc=2.07) at a height of 40m.

$$= 1890 \times 1 \times 0.016 \times 150 \times 2.07 = 9400N = 9.4KN$$

Total Traverse Load= $= F_{wt} + F_{wc} + F_{wi}$

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

The Fig.7 to Fig. 10 shows results obtained due to application of transverse load. The maximum and minimum deformations of transmission tower are 4.7 cm and 0 cm. The maximum and minimum directional deformations of transmission tower are 0.053 cm and 0 cm. The maximum and minimum bending moment of transmission tower are 9251.2 N-m cm and 0 N-m. The maximum and minimum shear forces of transmission tower are 9165.2 N and 0 N. The maximum and minimum variation shows red and blue colour from Fig.7 to Fig. 10.

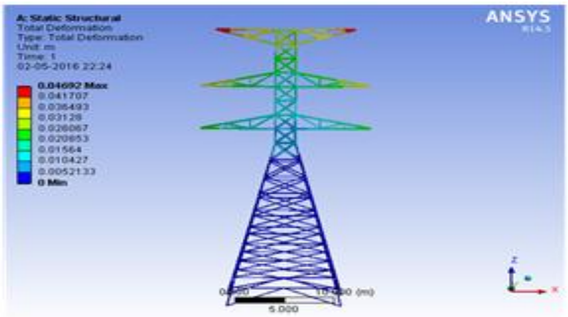

FIG. 7Total deformation for transversally applied load

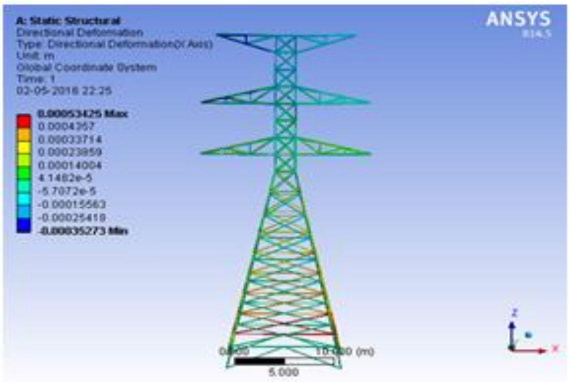

FIG.8Directional deformation for transversally applied load

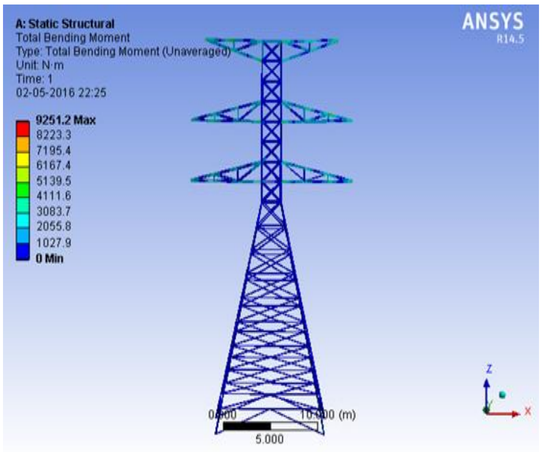

FIG.9Bending moment for transversally applied load

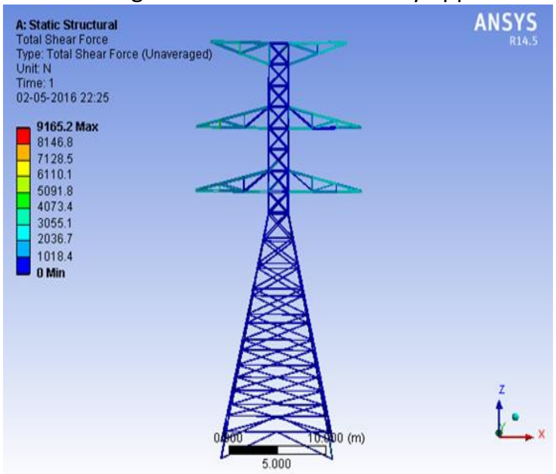

FIG. 10.Shear force for transversally applied load

VERTICAL LOAD

Dead load of the wire and insulator disk=7000 N

The results of transmission tower are deformation, directional deformation, bending moment and shear force which shows displacement, force and deformation. The Fig.11 to Fig. 12 shows results obtained due to application of vertical load. The maximum and minimum bending moment of transmission tower are 298.51 N-m cm and 0 N-m. The maximum and minimum shear forces of transmission tower are 465.45 N and 0 N. The maximum and minimum variation shows red and blue colour from Fig.11 to Fig.12.

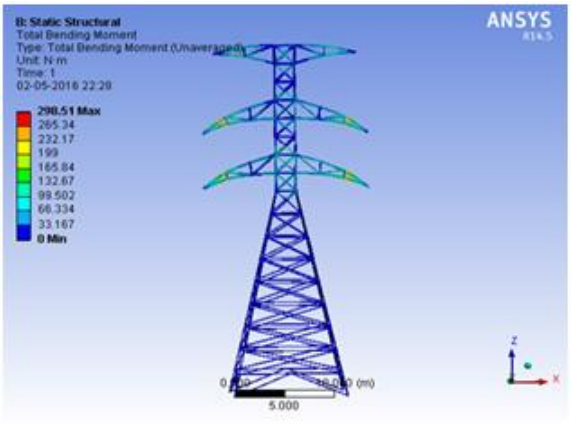

FIG. 11 MAXIMUM AND MINI. BENDING MOMENT

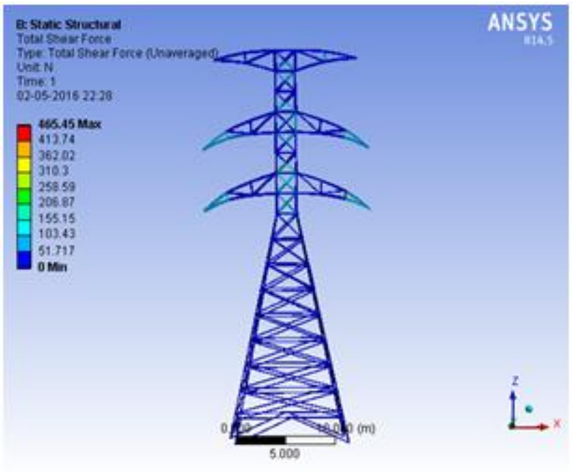

FIG. 12: MAXIMUM AND MINI. SHEAR FORCE

6. FREE VIBRATION ANALYSIS OF TRANSMISSION TOWER

Fundamental time period, $T=\frac{2\pi}{\omega}$

$$=\frac{2*3.14}{1.7452}$$

= 3.6 SEC

Time step= Δt=3.6/50=0.072 sec

As a result of manual calculation the time step in seconds is found to be 0.0717 for electric transmission tower. Fig 13to 23 illustrates the first 10 mode shapes of electric transmission tower. Fig 4.1 and Fig 4.2 illustrates the first and second mode shape of electric transmission tower, whose natural frequency is found to be 1.7452and 1.7756 Hertz. Fig 4.3 and Fig 4.4 illustrates the first mode shape of electric transmission tower, whose natural frequency is found to be 2.307 and 3.230 Hertz. Fig 4.5 and Fig 4.6 illustrates the fifth and sixth mode shape of electric transmission tower, whose natural frequency is found to be3.316 and 3.652 Hertz. Fig 4.7 and Fig.4.8 illustrates the seventh and eighth mode shape of electric transmission tower, whose natural frequency is found to be 3.6625 and 4.0284 Hertz. Fig 4.9 and Fig 4.10 illustrates the ninth and tenth mode shapeof electric transmission tower, whose natural frequency is found to be 4.4526 and 4.5385 Hertz.

Table 8 Modal Analysis Results Showing Natural Frequencies (ω) in Hertz:

Mode shape set	Natural frequency (Hertz)	Type of mode shape for various DOF
1	1.7452	1-mode shape for Longitudinal DOF (u)
2	1.7756	1-mode shape for Lateral DOF (v)
3	2.3705	1-mode shape for Twisting DOF (θ)
4	3.2305	2-mode shape for Longitudinal DOF (u)
5	3.316	2-mode shape for Twisting DOF (θ)
6	3.652	2-mode shape for Lateral DOF (v)
7	3.6625	3-mode shape for Longitudinal DOF (u)
8	4.0284	3-mode shape for Twisting DOF (θ)
9	4.4526	3-mode shape for Lateral DOF (v)
10	4.5385	4-mode shape for Longitudinal DOF (u)

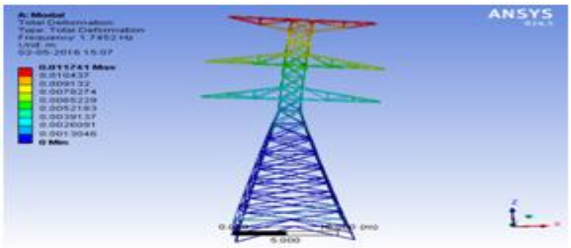

FIG 13 1-mode shape for longitudinal DOF of frequency of 1.7452 Hz

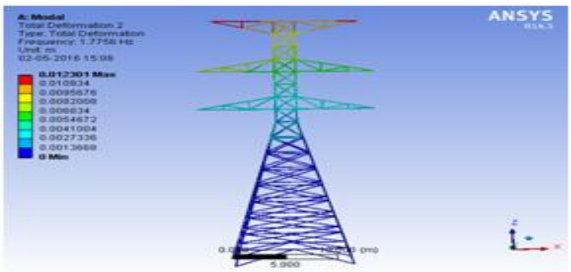

FIG 14 1-mode shape of lateral DOF of frequency of 1.7756 Hz

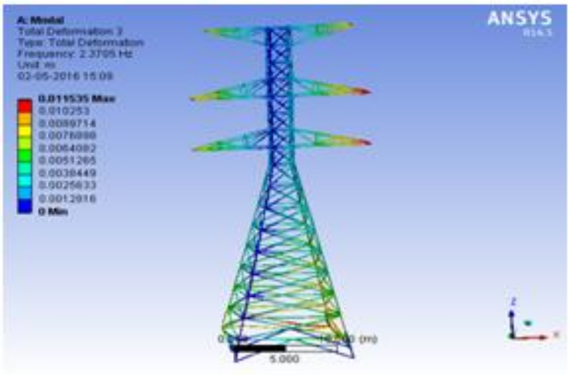

FIG 15 1-mode shape of twisting DOF of frequencies of 2.3705 Hz

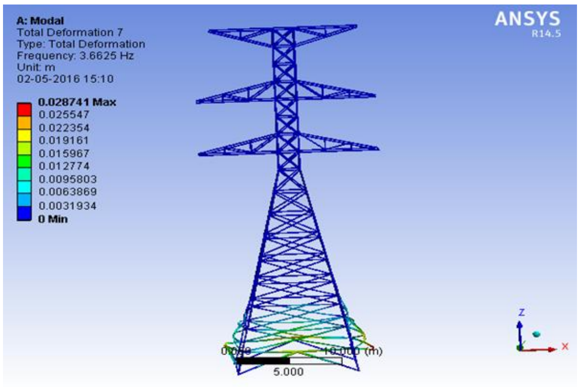

FIG19 3-mode shape of longitudinal DOF of frequency of 3.6625Hz

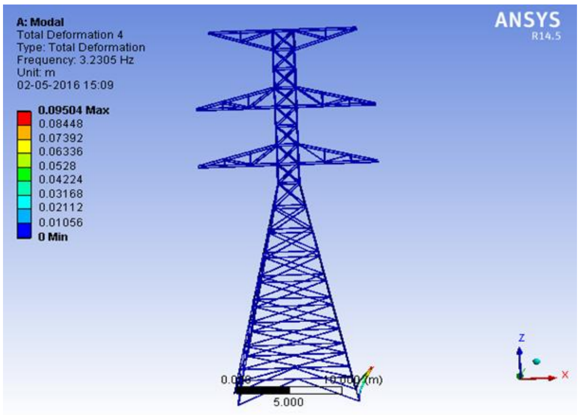

FIG 16 2-mode shape of longitudinal DOF of frequency of 3.2305Hz

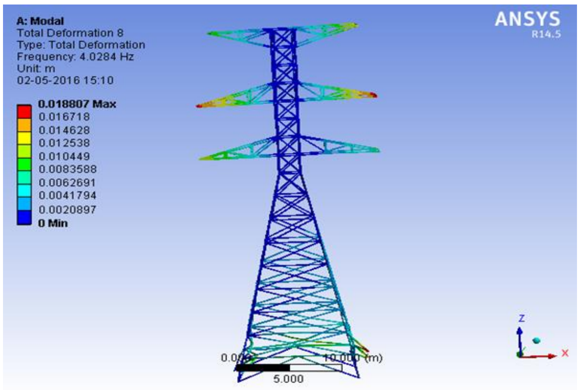

FIG 20 3-mode shape of twisting DOF of frequency of 4.0824 Hz

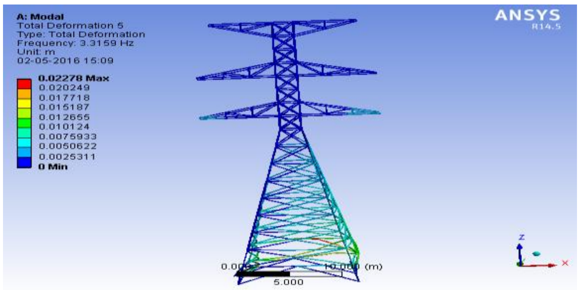

FIG 17 2-mode shape of twisting DOF of frequency 3.3159 Hz

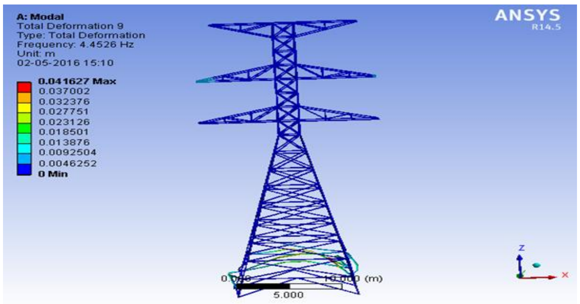

FIG 21 3-mode shape of twistingDOF of frequency of 4.4526Hz

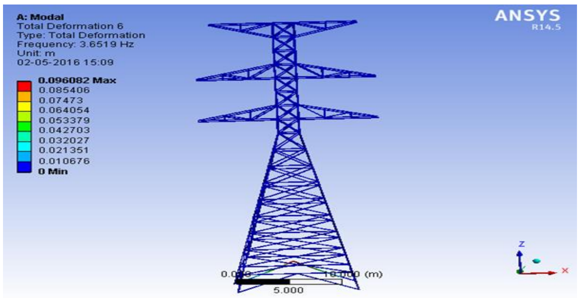

FIG 18 2-mode shape of lateral DOF of frequency of 3.652Hz

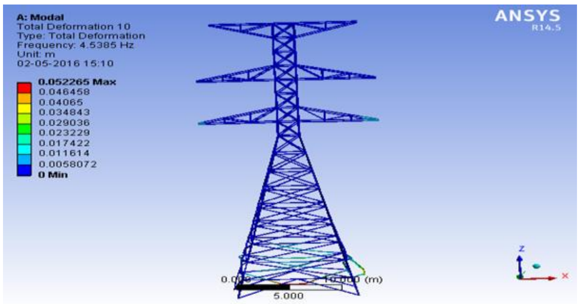

FIG 22 4-mode shape of longitudinal DOF of frequency of 4.5385Hz

7. FORCED VIBRATION ANALYSIS OF TRANSMISSION TOWER DUE TO TIME VARYING WIND LOAD

Equations of Motion for a Structure TMD System

The tuned mass damper and structure are assumed to vibrate with the same frequency. With the opposite movement exerted by tuned mass damper to structure, the purpose of vibration control is obtained. Assume that a structure can be modelled as a single degree of freedom system, and a tuned mass damper is installed, reducing vibration. The equation of motion of the structure for the TMD control can be expressed as

$$M\ddot{x} + C\dot{x} + Kx - (c_{tmd}\,\dot{x}_{tmd} + kx_{tmd}) = F(t)$$

$$m_{tmd}(\ddot{x}_{tmd} + \ddot{x}) + c_{tmd}\,\dot{x} + k_{tmd}\,x = 0$$

Where, M, C, K are the mass, damping and stiffness matrix for the structure, respectively. x, and are the displacement, velocity and acceleration vectors for the structure, respectively .F (t) is the wind-induced loading vector. , and are the displacement, velocity and acceleration for the TMD, respectively. and are the mass, damping and stiffness for the TMD, respectively.

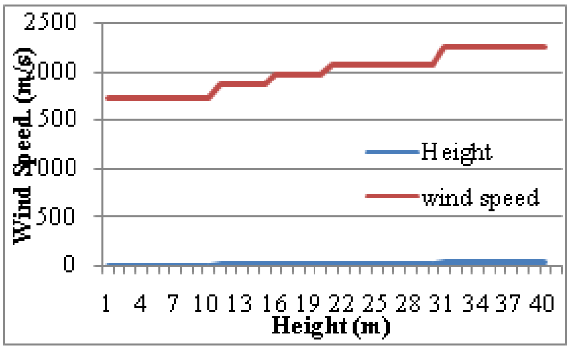

FIG.23 GRAPH B/W HEIGHT V/S WIND SPEED

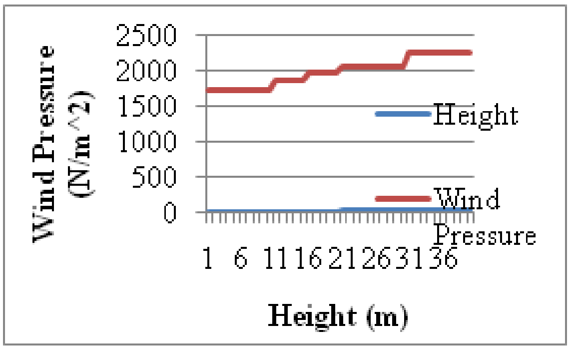

FIG.24 HEIGHT V/S WIND PRESSURE

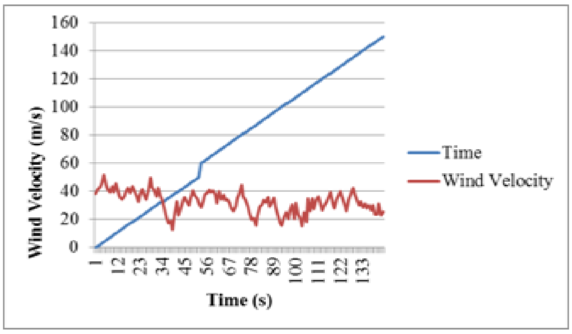

FIG 25: Time(s) vs Wind Velocity (m/s)

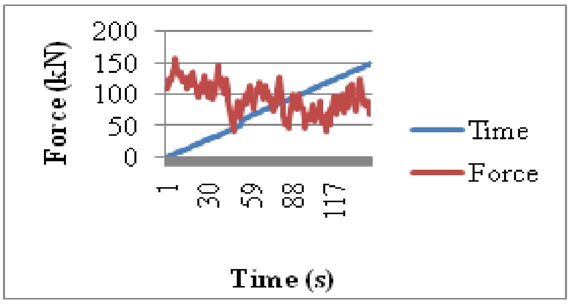

FIG 26: Time(s) vs Wind Force (kN)

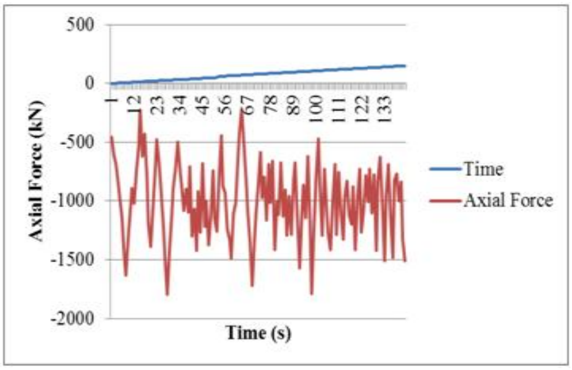

FIG 27 :Time(s) vs Axial Force (kN)

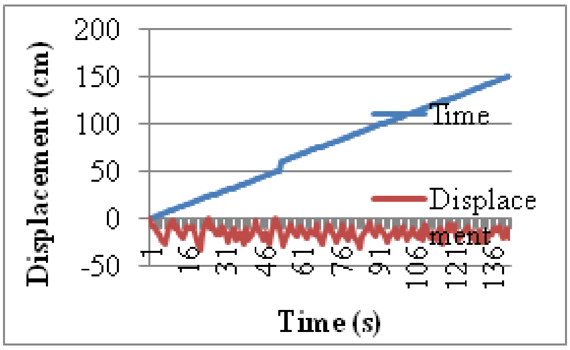

FIG 28: Time (s) vs Displacement (cm)

8. CONCLUSION

8.1 Wind Static Analysis

I. The static response of the transmission tower like deformation and rotation on all direction and the corresponding stress resultants like bending moment and shear force on corresponding direction due to static transverse and vertical loads applied on electric transmission tower systems are within allowable or safe limit.

8.2 Free Vibration Analysis

I. The studies on free vibrational characteristics of electric transmission tower have been carried out since the modal parameters like natural frequencies and mode shapes are important for understanding the dynamic behavior of the structure. The electric transmission tower systems with continuously distributed mass have infinite number of natural frequencies, however, only few lower of those frequencies have practical significance. The finite element model of electric transmission tower has been considered for the free vibration analysis of electric transmission tower. The subsequent studies on complex forced vibration dynamic analysis due to wind load problems have been carried out based on the satisfactory performance of the evaluated modal parameters.

II. The free vibration analysis summary gives the first fundamental frequency and time periods from frequency summary Table 8. The first fundamental frequency and time periods gives the time step in seconds is found to be 0.0717 for the purpose of forced vibration dynamic analysis dueto wind load problems of electric transmission tower.

8.3 Dynamic Analysis due to Wind Load

I. The transition tower line system is used in simulation analysis. The proportional damping is adopted in tower line system, since the system is composed of both cable and tower. The damping ratio of ground and conductors is 1% and the damping ratio of the tower is assumed to be 2%. The wind load time history obtained in above work is exerted on specified position of tower line system. Based on ANSYS nonlinear time history analysis, the tower-line system with optimal TMD is studied, respectively.

II. The response contains the axial force and displacement. The comparison of axial force and displacement time history curve with optimal TMD.It can be seen from the Fig 27 and Fig 28 that optimal TMD can reduce the axial force and displacement. The displacement response of tower with optimal TMD curve is smaller than it without control and the decreasing ratio is about 7.6%. It can be seen that the axial force is significantly decreased by optimal TMD with the decreasing ratio is around 12.9%. A graph demonstrates curve of maximum axial force of a series of vertical tower elements along the height of tower, the values in optimal TMD curve at any height is all smaller than those in curve without control. It also can be seen from the graph that with the growth of height, the optimal TMD exert a more effectively act to transmission tower.

9. Scope for future study

- To further carry out investigations on finite element modelling of Electrical transmission Tower effectively. So that it nullifies incorrect applicability of modal analysis and dynamic analysis .
- To effectively bring about the optimisation of structural aspects of electrical transmission tower which could be coupled with its conceptualisation based on optimal tune mass damper

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