Dynamic Analysis of Electrical Transmission Line Towers
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Abstract:
The electrical 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. Modeling of transmission tower by using finite element method. 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 resultant of transmission tower structure due to wind load at one static instant time on vertically and transversely position of transmission tower using ANSYS. Also studied free vibrational or modal analysis characteristics of the transmission tower by determining 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 according to IS 802 part 1 – 1995.

Keywords: ANSYS, FEM, static analysis, modal analysis and dynamic analysis due time varying loads, 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. Also transmitting electric power through the transmission tower lines are one of most important life-line structures. 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. 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 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. 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. 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 220kV Transmission line tower is modeled using ANSYS. The major components of a transmission line consist of the conductors, ground wires, insulation, towers and foundations.

II. LITERATURE REVIEW

Research Publications
2.1 Modeling of Transmission Tower
When designing transmission towers with conventional geometries and conductor arrangements the engineer has many design codes and guides available. For the study purpose the data available for 220 KV transmission line tower. The body of a typical single circuit tower subjected to the different load combinations is considered for the parametric study of the effect of the parameters on the weight of tower. Different combinations of the parameters are selected and the weight of the structure under the given system of loads is found. Height of the tower is kept constant and variation in other parameters listed earlier is considered. Total towers are analyzed and designed for various geometric configurations. The following are literature review of modal analysis of transmission tower

Y. M. Desai, et.al.\textsuperscript{[1]} This paper studied about a three-noded isoperimetric cable element having three translational and a torsional degree-of-freedom at each node is
developed to model a conductor. Support insulator strings and remote conductor spans are represented by linear static springs. A transmission line’s interactions with a support tower are modeled through the tower’s equivalent stiffness at the conductor’s suspension point. The scheme can be utilized to integrate dynamic equilibrium equations involving not only geometric and material nonlinearities but also nonlinear damping. The finite element model has been employed to successfully simulate field galloping records. It is shown that it is necessary to consider a multi rather than a single span for a conservative estimate of the galloping amplitudes to enable sufficient clearances to be designed between adjacent conductors.

### 2.2 Free vibration analysis of transmission tower

The frequency at which the oscillatory motion takes place is called natural frequency of the systems. The natural frequency of tower is to be calculated by using any of standard methods involving discretization of structure and assuming it to be homogeneous material. Modal analysis is the study of the dynamic properties of structures under vibrational excitation. The following are literature review of modal analysis of transmission tower.

**J.B. Kosmatka and J. M. Ricles [11]** this paper developed a non-destructive methodology is presented for detecting structural damage in structural systems. The procedure is based on using experimentally measured modes and frequencies in conjunction with vibratory residual forces and a weighted sensitivity analysis to estimate the extent of mass and/or stiffness variations in a structural system. Determination of the residual forces and weighted sensitivity analysis involves the use of an analytical model that is correlated to the experimental baseline data from a reference state. This reference state defines the undamaged structural configuration. The method is demonstrated by using a ten-bay space truss as an experimental test bed for various damage scenarios. The experimental results show that the method can accurately predict the location and severity of stiffness change as well as any change in mass for different damage scenarios. The use of an analytical model that is correlated to the baseline test data is shown to improve the prediction; however, reasonable results are also obtained using an uncorrelated analytical model.

### 2.3 Dynamic analysis of transmission tower due to wind load

In order to research the effects of conductor wires on transmission tower under wind load, considering the theory of flat cable assumptions, the vibration equation of transmission tower-line system under wind load was deduced. Strong wind is the most dangerous natural disaster for transmission line. Strong wind can induce flashover of the transmission line, and the transmission tower will be destroyed for the extreme case. The following are the literature of the dynamic analysis of transmission tower.

C.F. Carril, et.al. [15] This paper summarizes today’s expanding communication systems, a large number of lattice towers to support cellular antennas are being constructed in Brazil. Due to the lightweight of these structures, wind forces are the primary concern in the design. An experimental investigation on the subject was carried out at the Boundary Layer Wind Tunnel Laboratory, University of Western Ontario (UWO), and Canada. Three section models were designed and constructed based on existing lattice towers built in Brazil. The wind incidence angle; the tower solidity; the shielding effect; the influence of the wind turbulence on the drag coefficient were analyzed. Measurements were made of the mean and RMS drag and crosswind forces. The results were compared with some existing codes and standards including the Canadian (NBCC, 1995), American (ASCE7-95, 1995), Australian/New Zealand (AS/NZS1170.2-2002), Australian (AS 3995-1994), British (BS8100, 1986), Euro code 1 (European Committee for Standardization, 1995) and Brazilian (NBR 6123, 1988).

**Overview of Literature Review**

At present there is less information available on effects of wind load on unconventional type Electric transmission tower. The Indian Standard Code IS 802 (Part 1):1995 only provides information regarding conventional type of Electric transmission tower. From literature mentioned above, it can be observed that very limited research studies have been conducted for modal analysis of transmission tower. Information on Transient simulation of wind is also very less as it depends on many factors such as dimension of model, mesh parameters, boundary conditions. Experimental work of modal analysis and dynamic analysis of transmission tower also has less information.

### III. FINITE ELEMENT MODELLING

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 analyzed is discretized 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.
3.1 Dimension Geometry Description Transmission Tower

(a) Type of Tower:
   i. A-type with 0° deviation located in plain country suspension tower with circuit carrying 220kV power.

(b) Height of Tower
   i. Minimum ground clearance plus maximum sag of lower most wire = 25m
   ii. Vertical spacing between the conductor = 5m
   iii. Vertical spacing between conductor and the ground wire = 5m
   iv. Total height of tower = 35m
   v. Base width of the tower = \( \frac{1}{3} \times 11.5 \) m of the total height of tower = 11.5m (square base)
   vi. Width of top hamper = 2 m
   vii. Length of the cross arm = 7.57 m from the edge of the hamper = 7.57 + 2 + 7.5 = 17 m
   viii. Type of bracing = diamond bracing system
   ix. Span of tower is 150m between two towers
   x. Conductor Material: ACSR, (Aluminium Conductor Steel Reinforced)

IV. MODAL ANALYSIS

4. Modal Analysis Using FEM

The goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of structure during free vibration. It is common to use the finite element method (FEM) to perform this analysis because, like other calculations using the FEM, the object being analyzed can have arbitrary shape and the results of the calculations are acceptable. The types of equations which arise from modal analysis are those seen in eigen systems. The physical interpretations of the eigenvalues and eigenvectors which come from solving the system are that they represent the frequencies and corresponding mode shapes. Sometimes, the only desired modes are the lowest frequencies because they can be the most prominent modes at which the object will vibrate, dominating all the higher frequency modes.

4.1 Results and Discussion

The purpose of a mode analysis is to find the shape and frequencies at which the structure will amplify the effect of load. In this section we will list some examples why we may need this information and how to use answers. The Table 4.1 has given below show the different types of mode shapes and their natural frequencies.

<table>
<thead>
<tr>
<th>Mode shape set</th>
<th>Natural frequency (Hertz)</th>
<th>Type of mode shape for various DOF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.7452</td>
<td>1-mode shape for Longitudinal DOF ( (u) )</td>
</tr>
<tr>
<td>2</td>
<td>1.7756</td>
<td>1-mode shape for Lateral DOF ( (v) )</td>
</tr>
<tr>
<td>3</td>
<td>2.3705</td>
<td>1-mode shape for Twisting DOF ( (\theta) )</td>
</tr>
<tr>
<td>4</td>
<td>3.2305</td>
<td>2-mode shape for Longitudinal DOF ( (u) )</td>
</tr>
</tbody>
</table>
V. WIND STATIC ANALYSIS

5. Loading

The transmission tower is mainly subjected to dead load, wind load and earthquake load. In that wind load is the major governing factor for changing behavior of transmission tower.

5.1 Dead load

The tower body, cross arms and cage were mounted on transmission tower. So weights of these components were taken to be considered for the analysis.

5.2 Live load

In this case there was not any type of Live load acting on transmission tower, so live load considered should be zero.

5.3 Wind load: based on (IS 802 part 1-1995)

Calculation of wind pressure, \( P_d \)

Basic wind speed \( (V_b) = 55 \text{ m/s for zone 6} \)

Meteorological reference wind speed, \( V_R = \frac{V_b}{k_o} \)

Therefore, \( V_R = \frac{50}{1.375} = 40 \text{ m/sec} \)

5.3.1 Design wind speed, \( V_d \)

\( k_1 = \text{Risk coefficient}=1.3 \text{ for zone 6 with reliability level 3.} \)

\( k_2 = \text{Terrain roughness coefficient} = 1.08 \text{ for terrain category 1} \)

\( V_d = 40 \times 1.3 \times 1.08 \times 1 = 56.16 \text{ m/s} \)

5.3.2. Design wind pressure, \( (P_d) \)

\( P_d = 0.6 \times 56.16^2 = 1890N/m^2 \)

5.3.3 Calculation of wind load on wires

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

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

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

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

3) Wind Load on top Conductor \( (G_c = 2.05) \) 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 \( (C_{dc}=1.2, d=20, G_c=2.07) \) at a height of 40m

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

5.4 Result and Discussion of Wind Static Analysis

The Transmission tower is analyzed statically by considering the wind load acting at an instant of time. The result of the static analysis is obtained in the form of maximum deformation, directional deformations, bending moment and shear force. The obtained result is checked for the permissible limits. The maximum stresses should be lower than the elastic limit of the material. There should not be large deflection which may cause extra bending in the transmission tower.

5.4.1 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.

Total transverse 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.

5.4.2 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 down ward.

Components:
1. Weight of insulators, hardware, etc.,
2. Arbitrary load to provide for the weight of a man with tools.
3. Dead load of the wire and insulator disk=7000 N = 7KN.

VI. 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 modeled 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

\[ M \ddot{x} + C \dot{x} + Kx = (c_{\text{tmd}} \ddot{x}_{\text{tmd}} + kx_{\text{tmd}}) = F(t) \quad \text{Eq (6.1)} \]

\[ m_{\text{tmd}} (\ddot{x}_{\text{tmd}} + \ddot{x}) + c_{\text{tmd}} \dot{x} + k_{\text{tmd}} x = 0 \quad \text{Eq (6.2)} \]

Where, \( M \), \( C \), \( K \) are the mass, damping and stiffness matrix for the structure, respectively. \( x \), \( \dot{x} \) and \( \ddot{x} \) are the displacement, velocity and acceleration vectors for the structure respectively. \( F(t) \) is the wind-induced loading vector. \( x_{\text{tmd}} \), \( \dot{x}_{\text{tmd}} \) and \( \ddot{x}_{\text{tmd}} \) are the displacement, velocity and acceleration for the TMD, respectively. \( m_{\text{tmd}} \), \( c_{\text{tmd}} \) and \( k_{\text{tmd}} \) are the mass, damping and stiffness for the TMD, respectively.

**Results and Discussion**

The transition tower line system is performed in Finite Element Technique (Ansys). 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 non-linear time history analysis, the tower-line system with optimal TMD is studied, respectively. The response contains the axial force and displacement.

In this method, vibration decreasing ratio is introduced to investigate the effect of optimal TMD. It can be defined as:

\[ \delta = \frac{R_0 - R_1}{R_0} \times 100\% \quad \text{Eq (6.3)} \]

Where \( \delta \) is vibration decreasing ratio. \( R_0 \) is the maximum response of structure without optimal TMD, and \( R_1 \) is the maximum response of structure with optimal TMD.

The Fig. 6.1 and Fig. 6.2 illustrate the comparison of axial force and displacement time history curve with optimal TMD. It can be seen from the figures 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%. A Fig. 6.5 shows the comparison of axial force time history. It can be seen that the axial force is significantly decreased by optimal TMD with the decreasing ratio is around 12.9%. A Fig. 6.5 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 Fig. 6.5 that with the growth of height, the optimal TMD exert a more effectively act to transmission tower.

**VII. CONCLUSION**

The objective of the study was to propose the structural aspects for proposed electric transmission tower that overcomes the vibrations. The study also focused on finding the structural capability of transmission tower by carry out modeling, static analysis, free vibration analysis and dynamic analysis. This chapter discusses the various conclusions on the study project.

**7.1 Summary of Conclusion**

**7.1.1 Wind Static Analysis**

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.

**7.1.2 Free Vibration Analysis**

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 behaviour 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.

The free vibration analysis summary gives the first fundamental frequency and time periods from frequency summary Table 4.1. 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 due to wind load problems of electric transmission tower.

7.1.3 Dynamic Analysis due to Wind Load

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.

The response contains the axial force and displacement and the comparison between axial force and displacement time history curve with optimal TMD. It can be seen from the Fig 6.1 and Fig 6.2 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.

7.2 Scope for future study

We 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, it could be coupled with its conceptualisation based on optimal tune mass damper.

VIII. REFERENCES


