Study on Dynamic Properties of Long-span Power Transmission Tower-Cable System

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Abstract: High-rising, long-span and significant flexibility are major characteristics of long-span power transmission tower-cable system. Structural instability may occur in all possibility under wind load and ice loads. This paper presents the study on dynamic properties of long-span transmission tower-cable system under instability condition. Finite element model of a long-span power transmission tower-cable system is constructed. Dynamic properties of tower-cable system under wind load are studied. Then, the influence of ice on the dynamics properties of tower-cable system is further discussed. The result could be taken as the reference in the disaster prediction or the structural design of long-span tower-cable systems.

Keywords: long-span power transmission tower-cable system; structural instability; ice covered; dynamic properties

1 Introduction

Extra-high voltage transmission network, the carrier of power, is the important lifeline system. The long-span power transmission tower-cable system as an integral part of extra-high voltage transmission network, with the common characteristics of high-rise and long-span structures, for instance, tall in height, long span and high flexibility, is possible to cause structural instability and other disastrous accidents by the action of wind load and ice load [1].

Before the accidents occurred, by means of structural health monitoring, structural assessment and take corresponding measures, can reduce the risk of catastrophic accidents, this is the current hotspot of structural engineering [1-5]. The in-depth understanding of dynamic characteristics of long-span power transmission tower-cable system can provide theoretical basis for predict disasters and guide to the design.

This paper presents the study of a long-span power transmission tower-cable system. The finite element model is constructed to analysis the dynamic characteristics of wind load caused instability, and the influence of ice-covered load is further considered.

The tower-cable system under consideration is constructed by National Grid. Both suspension-type and tension-type, the two groups of power transmission towers according to the way they support power lines, are used in the system. The system in this study included 2 towers, 2 ground lines and 8 conductors for simplified computation. As shown in Fig. 1, the tower studied was a bolt connected

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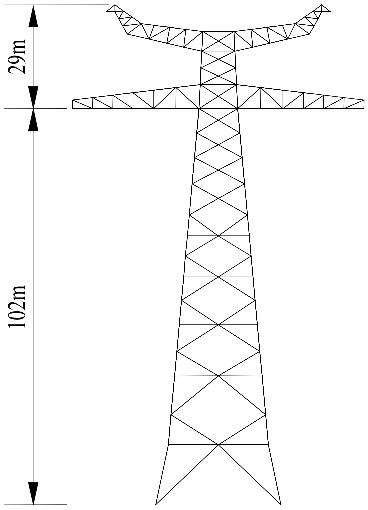
steel angle and steel tubular spatial structure, 131 m high. The main span of this power transmission system is larger than 1000m.



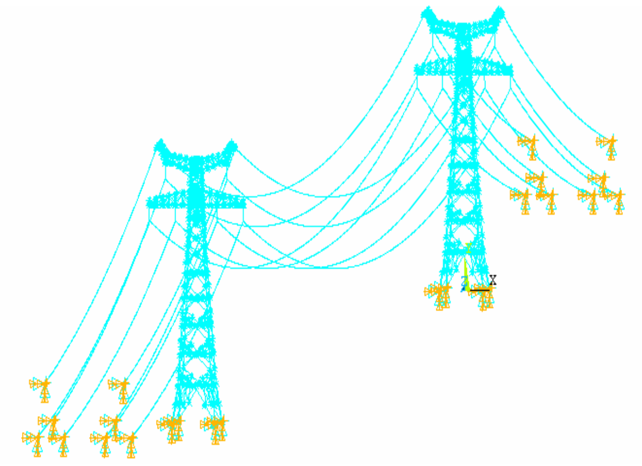
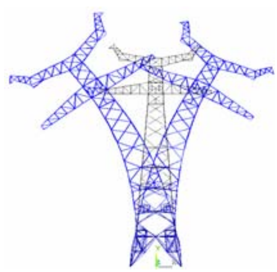


Fig.1 Power transmission tower Fig.2 FEM of tower-cable system

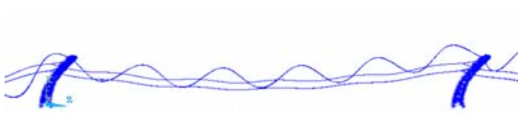
2 Finite element modeling and analysis

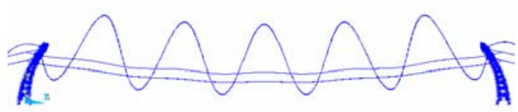
Three-dimensional spatial finite element model of the power transmission system was constructed using ANSYS. The main parts of towers were modeled as beam elements, included the main chords and the main web members. The bracing members were modeled as truss elements or beam elements. The subsidiaries were modeled as lumped mass. The ground lines and conductors were modeled by use of truss element, as well as the simulation of insulators. The shapes of lines were found based on catenary theory and the pre-stresses were also inflicted to lines. Fig. 2 shows the FEM of tower-cable system. The modal analysis was then carried out to get the computational frequencies and mode shapes, 6 Eigen-values and Eigen-vectors were figured out, as show in Table 1 and Fig. 3.

(a) 1st transverse bending

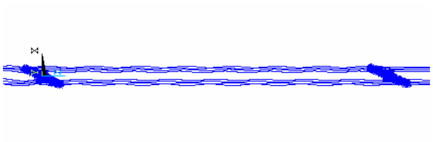


(b) 2nd transverse bending





(c) 1st bending in line direction (d) 2nd bending in line direction



(e) 1st torsion (f) 2nd torsion

Fig.3 Mode shapes of tower-cable system

Table1 Modal frequency of tower-cable system

Frequency (Hz)	Modes
0.789	1st transverse bending
0.797	2nd transverse bending
0.838	1st bending in line direction
0.861	2nd bending in line direction
1.220	1st torsion
1.262	2nd torsion

3 Wind force

Wind speed is a commonly reference to structural engineering design, due to wind loads on structures is a form of force, thus wind speed need to be converted into wind force, usually based on reference [6] to calculate the equivalent force. Wind force is directly bound up with wind speed which is closely related to altitude [7], Fig. 4 is the wind speed distribution with height.

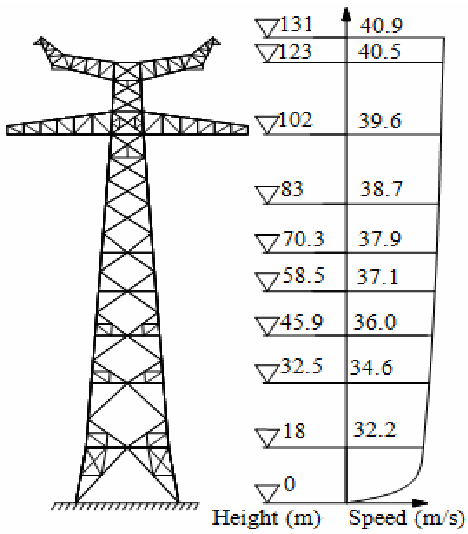


Fig.4 Wind speed distribution

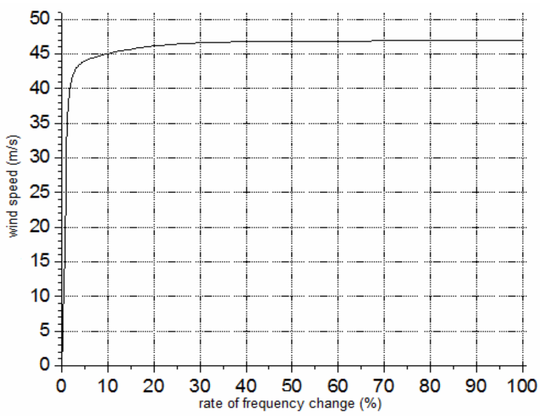
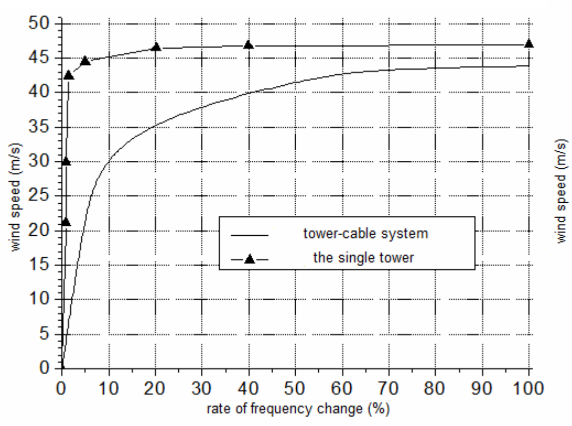


Fig.5 Wind speed-frequency curve

The dynamic characteristics of the single tower in different wind speeds is analyzed, as well as the change of first order frequency (transverse bending), the result is shown in Fig. 5. The rate of frequency change is calculated by $k = (f_0 - f) \times 100 / f_0$, where f_0 is the first order frequency of the unloaded tower, f is the frequency of loaded tower. From Fig. 5, if wind speed is 45m/s, the first order frequency reduced by 10%, if wind speed is 47m/s, the frequency dropped fast, it shows that the stiffness of the transmission tower decreased significantly, and there is the risk of occurrence of catastrophic accidents.

The analysis above is the consideration of the single tower. Actually, strong nonlinear coupling occurs between transmission tower and the cable under wind excited, the mass and the vibration of the line are big influences to the dynamic properties of transmission tower. Analyses were conducted for a wind direction perpendicular to the transmission line, comparison of rate of frequency change between tower-cable system and the single tower is shown in Fig. 6. The rate of frequency change of tower-cable system is bigger than the single tower in the same wind speed, and as the wind speed increased, the difference became clear.



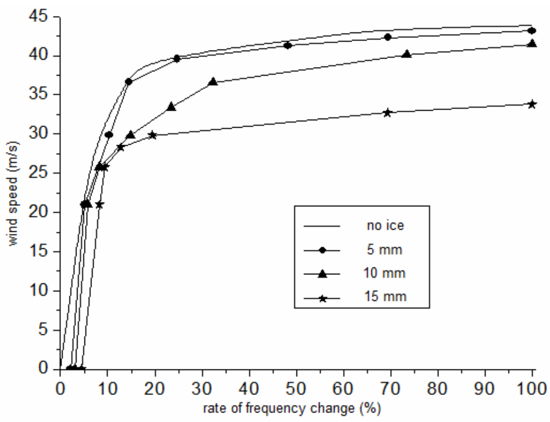


Fig.6 Wind speed-frequency curves

Fig.7 Wind speed-frequency curves

4 Ice load

Ice covered is great harm to the safety of transmission tower-line system [8]. Three cases of the dynamic characteristics of transmission tower-line system with different ice thickness (respectively 5mm, 10mm, and 15mm) are analyzed, the result is shown in Fig. 7.

As shown in Fig. 7, as the increase of ice thickness, the maximum wind speed transmission tower can bear reduced, no ice-covered the speed is 44m/s while 34m/m the thickness is 15mm. Wind speed is 25m/s, the smallest rate of frequency change is 6% (no ice), while the largest close to 10%

(thickness of ice is 15mm). The stiffness of transmission tower decreases significantly if the rate of frequency change is more than 10%.

5 Conclusion

This paper presented analyses of the dynamic characteristics of long-span power transmission tower-line system, the finite element model was constructed, the dynamic properties under instability caused by wind load and ice loads are discussed. The results support the following conclusions:

1) When the wind speed is low, the tower-line system can be simplified to a single tower and focus on static analysis, but when the speed of wind becomes higher, there is no shortcut.
2) The ultimate bearing capacity of tower-line system is smaller than the single tower, the single tower can withstand the maximum wind speed is 47m/s, while the system is 44m/s.
3) The 1^{st} order frequencies in transverse direction of tower-line systems are constant with respect to the thickness of ice. The frequencies change significantly when the wind-speed exceeds a certain value.
4) The ice thickness of line increases, the ultimate bearing capacity of transmission tower decreases.
5) Wind speed is 25m/s, the smallest rate of frequency change is 6% (no ice), while the largest close to 10% (thickness of ice is 15mm). The stiffness of transmission tower decreases significantly if the rate of frequency change is more than 10%.

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