Dynamic Response of a Cat Head Type Transmission Tower-line System under Strong Wind

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Abstract: Transmission tower plays important role in the power system and it is security sensitive in various working conditions, such as wind and ice. In this paper, a method to obtain the dynamic response of a cat head type transmission tower under strong fluctuating wind was proposed. The coupled tower-lines finite element model was established in ABAQUS, and the equivalent acceleration of fluctuating wind was simulated by MATLAB. Then the displacements and stresses time histories were obtained. The method introduced in this paper can be used to assess the safety of tower under different fluctuating wind with different directions and provide a reference of the tower in the design stage.

1. Introduction

Electric power is a basic industry related to the national economy and people’s livelihood. And in the process of efficient utilization of electric energy, the role of the overhead high voltage transmission lines is very obvious [1]. The highest voltage class of transmission line in China has already reached 1100kV. Once the transmission tower-line system is destroyed by the wind or ice load, the consequences could be severe. Meanwhile, the disaster caused by wind is high frequency and large area. Therefore, it is important work to grasp the dynamic response of transmission tower under strong wind in the design stage.

The dynamic response of transmission tower is mainly studied by field measurement, wind tunnel test and numerical computation. However, it is difficult to conduct a test on the power lines in operation because of the high voltage [2]. The wind tunnel test is a main research method to investigate the dynamic response under different working loads. But the principle of similitude is also difficult to complete satisfaction and at great expense [3]. In recent years, with the rapid development of computer technology, the numerical calculation method is continuous innovation, and the application of numerical simulation in practical engineering becomes more and more widely [4-6].

In this paper, a fine finite element model of a 500-kV cat head type transmission tower was set up by means of the software ABAQUS/CAE. The numerical model was assembled by beam and truss mixed element which is determined by the force conditions. The quadruple split conductor which connected with V type insulator string and suspension string was built through the catenary method. The fluctuating wind was simulated in MATLAB. After computation, the dynamic response under fluctuation wind load can be obtained. The results can be used to judge the safety of tower under different wind load and can provide a reference for the engineer in the design stage.
2. The Modelling of Transmission Tower-line System

A typical 500kV extra high voltage (EHV) characteristic line model is shown in figure 1. The tensile section consists of a two-span 400m-400m lines without height difference. And it is a four-split conductor, with the LGJ-400/50 sub-conductor which is made of aluminum cable steel reinforces. The transmission tower is a typical cat-head tower with a design of 48.2m and the maximum width of the tower head is 21.4m. The cross sections of the tower are composed of steel angle sections and the tower members are made of Q235, Q345 and Q420 respectively. The parameters of the transmission lines are shown in Table 1.

The three dimensions (3D) finite element model of the coupled transmission tower line system with one tower and two spans of transmission lines is set up by means of ABAQUS software. The transmission lines are modelled with cable element. In ABAQUS/CAE, the 3D truss element with zero Young’s Modulus can simulate this element. At the initial moment, the shapes of transmission lines will change to balance their weight. A method proposed in reference [7] which does not require iteration is used to find the shape of transmission line at the initial moment.

The interphase spacers are discretized with the beam element and the distance between them is 25m. The relationship between the interphase spacers and conductors can be modeled by ‘Beam’ in ABAQUS. Three phase conductors are connected with the cat head type transmission tower by means of suspension string and V-type string respectively. The connection between suspension string and tower is set as ‘Jion + rotation’. The legs of tower and the end of the conductor and ground wire which are connected the strain towers with strain insulator string are assumed to be fixed in the finite element model.

![Figure 1. Finite element model of tower-line system](image)

### Table 1. Mechanical parameters of the transmission lines

| Parameter          | Conductor   | Ground wire |
|--------------------|-------------|-------------|
| Type               | LGJ-400/50  | GJ 100      |
| Diameter (mm)      | 27.63       | 13          |
| Cross-sectional area (mm²) | 451.55     | 100.83      |
| Density (kg/m³)    | 3280        | 8350        |
| Elastic modulus (GPa) | 67.89      | 18.5        |

3. Determination of the Fluctuating Wind

The wind generally includes mean wind and fluctuating wind. There are various power spectrals of fluctuating wind proposed by researchers, and the frequently-used in engineering is Kaimal spectral which is varies with height. It is expressed as below,

\[ S(z, f) = \frac{200 f V^2}{f (1 + 50 f c)^{5/3}} \]  

where \( V^* \) is the shear speed, and can be written as,
\[ V_* = 0.35 \frac{\overline{V}(z)}{\ln(z/z_0)} \]  
(2)

where \( z_0 \) is the height coefficient of ground roughness, \( f \) is the frequency, \( z \) is the height relative to the ground, and

\[ f_* = f \frac{z}{\overline{V}(z)} \]  
(3)

The relationship between the average speed \( \overline{V}(z) \) at the height of \( z \) and \( \overline{V}_{10} \) at the height of 10 meter is exponent as follow

\[ \frac{\overline{V}(z)}{\overline{V}_{10}} = \left( \frac{z}{10} \right)^a \]  
(4)

where \( a \) is the coefficient which influence by landform.

The fluctuating wind is simulated by means of MATLAB. The speeds of several characteristic points are shown in figure 2 and the reference wind speed is equal to 30m/s. Then the power spectra can be obtained by means of spectrum analysis which is carried on the obtained fluctuating wind speed. The compared results between the power spectra of simulated wind speeds and Kaimal model are shown in figure 3. The trends of them are very consistent. The figure 4 shows the correlation functions of wind speed at typical point and other points. It can be seen from the results that as the increase of distance between two points, the correlation decrease. Therefore, the fluctuating wind speed samples which are simulated by the MATLAB is reasonable.
Figure 4. The correlation functions of wind speed at typical point and other points

4. Dynamic Response under Wind Load

The numerical simulation consists of two steps. In the first step, find the equilibrium state of tower-line system under gravity. Then the dynamic response under wind load which act on the tower and lines can be obtained base on the state. The wind load can be computed by the equation which introduced in the design code [8]. And the tower can be divide into several parts depend on the structure feature and height. The loads are all applied on by means of different equivalent accelerations which are varied with time.

After the computation, the displacements and stress distribution of the cat head type transmission can be obtained. The maximum stress of the tower is one of the main materials, as shown in figure 5. And the displacement time history of typical point at head of tower which is signed in figure 5 is shown in figure 6. It can be seen from the results that maximum stress are all less than the corresponding yield stress. The tower is safety under the wind load which introduced in this paper. However, the dangerous region should be pay attention because of the large axial forces in the beam may induce the loose of the connected bolts.

Figure 5. The maximum stress of the cat head type tower
5. Conclusion
This paper takes a 500kV cat head type tower as a research object. And the overall model of the tower and line system of a typical tensile section is established by ABAQUS. Then, the dynamic response of the tower under fluctuating wind load which simulated in MATLAB is carried out. The results shows that the maximum equivalent stresses are all within the safe range of the material and meet the design requirements. The dangerous region is one of the main material structures in tower body. The method introduced in this paper can be used to assess the safety of tower under different fluctuating wind with different directions and provide a reference of the tower in the design stage.

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