Study on Failure Mode of Key Parts of High Voltage Transmission Tower under Ultimate Load

Fan Gao1*, Yaning Ren1, Deguang Zhang1, Xiangliang Shen1, Lihuan Wang1

1State Grid Hebei Economic Research Institute, Shijiazhuang, Hebei, 050000, China
*Corresponding author’s e-mail: 632406593@qq.com

Abstract. In order to study internal force distribution and failure mode of key parts of high-voltage transmission tower under the action of ultimate load, the micro scale model for the key parts of the tower and the macro scale model for other members are established by the finite element software ABAQUS. And a uniform multi-scale numerical model is established by coupling two scale numerical models. Then apply the limit load on the multi-scale model under the extreme climate condition, and the failure mechanism and failure mode of the transmission tower is obtained under the limit load.

1. Introduction

High voltage transmission tower has many members and complex structure, which is sensitive to external loads such as strong wind and ice. In the extreme climate conditions, tower collapse is easy to occur, resulting in grid paralysis, and significant economic losses. Natural disasters and extreme climate conditions threaten the normal operation of regional power grid seriously. It is of great significance to strengthen the research on the failure mechanism and failure mode of transmission tower under extreme climate conditions to ensure the safe operation of power grid. Under complex stress, the failure of the key parts of the tower often leads to the collapse and damage of the whole tower.

At present, in the research of key parts of transmission tower, solid element is generally used to simulate the key parts. Because the key parts model and the whole tower model are independent, the boundary conditions at the key parts cannot be obtained accurately. The number of elements and nodes is too large to be calculated efficiently, if the whole tower adopts solid elements. Generally, the beam element model is used to study the mechanical characteristics of the whole transmission tower. The calculation efficiency of the beam element model is high, but it can not reflect the failure process of the key parts of the transmission tower. A small-scale finite element model with the characteristic length of millimeter level is established in the key parts of the structure with complex stress, and a large-scale finite element model with the characteristic length of meter level is established in other parts, and a connection is established among different scale models, thus forming a uniform multi-scale model of transmission tower. The uniform multi-scale model finds a balance point in the calculation efficiency and accuracy of numerical simulation, which provides a new idea for the research of tower structure failure mechanism and failure mode [1]-[3].

2. Establishment of Multi-scale Model

There are many members, complicated structures and great changes in stiffness at the neck joints of the transmission tower. Once the neck joints are damaged in extreme weather conditions, it may cause
the collapse of the whole transmission tower. Taking the neck joints of the tower as the research object, a meso scale model of the neck joints of the transmission tower is established by using solid elements in the finite element software ABAQUS, as shown in Figure 1. In the process of mesh generation, hexahedral elements are selected and manual mesh generation is used. In order to meet the requirements of reduced integration operation, the thickness direction of steel pipe and gusset plate is divided into three layers, which are 57581 elements and 75769 nodes [4].

Establish the three-dimensional macro scale model of other parts of the transmission tower by the finite element software ABAQUS, and cut out the key part members at the neck node of the transmission tower, as shown in Figure 2.

Through the assembly "module" in ABAQUS, the macro scale model and the micro scale model are accurately stacked together. Using the "create constraint" command in the "interaction" module, MPC beam element is used to connect the beam element and the solid element model, as shown in Figure 3, and the multi-scale model is finally established, as shown in Figure 4.
3. Load calculation of transmission tower
The wind load standard values of transmission tower conductor wire, ground wire and tower body are calculated respectively. When calculating the wind load of transmission tower body, the transmission tower is divided into nine tower sections, and the calculated wind load of each tower section is applied to the four ends of the windward side of the tower section on average. Due to the ice load of the tower body member is the same direction as the dead weight of the tower body member, and is far less than the dead weight of the tower body member, it can be ignored, so only the ice load of the transmission tower conductor wire and the ground wire is considered. High wind, ice covered and line broken are selected as the calculation conditions of transmission tower under extreme weather conditions.

(1) Strong wind condition: 90° wind, with wind speed of 15m/s, 20m/s, 30m/s and 35m/s respectively, without ice.
(2) Ice covered condition: 90° wind, 5m/s wind speed, and the ice covered thickness of the grounding wire are 38 mm and 43 mm respectively.
(3) Line broken condition: no wind, the thickness of ice covered of conductor wire and ground wire is 35mm, the conductor wire at the right end of cross arm has longitudinal unbalanced tension, the ground wire is not broken, the maximum working tension of conductor is 119.5kN, and the longitudinal unbalanced tension of conductor is 25% of the maximum working tension.

4. Failure mode analysis of transmission tower
In the analysis of the ultimate bearing capacity of the key parts of the transmission tower, the Mises yield criterion is generally adopted. Mises yield criterion stipulates that when the equivalent stress-strain of a certain point reaches a certain value independent of the stress-strain state, the material will yield. When the member is in the general stress state, the strength theory can be used to calculate the stress of the material and judge whether it reaches the yield strength. According to Mises yield criterion, if the distortion potential energy of the material exceeds the specified limit value, the material will have plastic deformation.

The numerical analysis of the model is carried out under three conditions of high wind, ice covered and line broken, by the finite element software ABAQUS. The stable stress, compressive stress and bending stress of the key parts are obtained, according to the calculation results. The members at the key parts of the tower are made of Q345B steel, and the design value of bending strength is 310 MPa. According to the analysis results, the stability stress and strength stress of the members at the key parts do not reach the ultimate strength under the three working conditions of the selected high wind, ice covered and line broken, and the members connected with the key parts do not lose stability or strength damage.

The members at the key parts of the tower are made of Q345B steel, and the yield limit is 345MPa. The finite element software ABAQUS can directly output Mises stress when post-processing. By comparing the output Mises stress with the yield limit, we can judge whether the material has yield failure.

The clouds of Mises stress at key parts of transmission tower under strong wind conditions are shown in Figure 5. Under the strong wind conditions of 15m/s and 20m/s, the maximum values of Mises stress at key parts are 167.6MPa and 297.9MPa, respectively, which do not reach the yield limit. Under the strong wind conditions of 30m/s, the maximum value of Mises stress at the joints of different members of key parts is 476MPa, which exceeds the yield limit. Under the condition of wind speed of 35m/s, the maximum stress of Mises in the key parts of stress concentration is 650MPa, 419.5MPa and 496.4MPa, which exceeds the yield limit, and the key parts are subject to yield failure. Due to the strength stress and the stable stress of the member at the key part do not exceed the limit value under the strong wind condition, the failure of the key part is caused by the yield failure of the material under the strong wind condition.
The Mises stress nephogram at key parts of transmission tower under ice covered condition is shown in Figure 6. When the wind speed is 5m/s and the ice thickness is 38mm, the maximum value of the Mises stress of the structure at the key part is 290.2MPa, which does not reach the yield limit; the maximum value of the Mises stress of the material at the joint of different members of the key part is 345.3MPa, which exceeds the yield limit, and the joint material breaks. Under ice covered condition, the strength stress and stability stress of the member at the key part do not exceed the limit value, so the failure of the key part under ice covered condition is caused by the yield failure of the material.
The Mises stress nephogram at the key parts of the transmission tower under the condition of no wind, 35mm ice thickness and conductor line broken at the right end of cross arm is shown in Figure 7. Under the condition of line broken, the maximum Mises stress of the material at the joint of different members of the key part is 409.1 MPa, which exceeds the yield limit, and the joint material is subject to yield failure. Because the strength stress and the stable stress of the member at the key part do not exceed the limit value under the line broken condition, the failure of the key part under the line broken condition is caused by the yield failure of the material.

5. Conclusion

(1) The multi-scale model of consistent structure behavior is established. The rationality of the multi-scale model is verified by comparison. The coupling between the key nodes of the tower and the whole tower is completed. The boundary conditions of the key nodes under certain working conditions are more accurately determined to ensure the calculation efficiency of the numerical simulation. A good balance is found in the calculation efficiency and accuracy of the numerical simulation of the transmission tower point.

(2) The load of transmission tower under extreme weather conditions such as strong wind, ice covered and line broken is simulated. The failure mode of key parts of transmission tower under extreme weather conditions is obtained by analyzing the calculation results.

(3) Compared with the beam truss model, the multi-scale model can not only accurately determine the boundary conditions of key nodes, but also reflect the failure process and failure mode of the details of the tower, which provides a new idea and a more reliable basis for the design, maintenance and reinforcement of the high-voltage transmission tower.

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