Study on Failure Mode of Transmission Tower under Ice Coating

Huang Guo*, Li Maohua, Su Zhigang
China Electric Power Research Institute, Beijing, 100055
*Corresponding author’s e-mail: huangguo@epri.sgcc.com.cn

Abstract. In this article, the failure mechanism of the transmission tower under ice coating is analyzed, and then the failure mode of the transmission tower is studied by numerical simulation. The analysis of the ultimate bearing capacity of the transmission tower under uniform and uneven ice coating shows that the model with auxiliary materials has a higher bearing capacity than the model without auxiliary materials, and the actual bearing capacity of the structure should be between them. The load-bearing capacity of the structure under uneven icing is lower than the load-bearing capacity of the structure under uniform icing. The main material of the tower, the main material of the cross arm and the head of the tower are unfavorable and easy to be damaged.

1. Introduction
Transmission towers under ice coating are easy to damage or even collapse[1-5]. In 2008, southern China experienced long-term, large-scale rain and snow, which led to severe ice disasters on transmission lines, and serious disasters to the power grid system. After the disaster, a lot of manpower and material resources need to be invested in restoration and reconstruction. In this article, the failure mechanism of the transmission tower with ice coating is first analyzed, and then the failure mode of the transmission tower is studied by the numerical simulation.

2. Damage mechanism of ice coating on transmission tower
From the perspective of engineering structure, the transmission line is a hybrid structure system composed of flexible wires and rigid iron towers. The iron tower is the main force-bearing component and plays the role of supporting the wire. The load on the wire is transferred to the foundation through the iron tower. However, the wire also has a certain pulling effect on the tower, and to a certain extent it can also limit the lateral deformation of the tower. It can be seen that the two are interacting and mutually restricting coupling systems. Regarding the force of such a coupled working system, the advantage is that the structure has high redundancy and strong ability to resist external loads. The disadvantage is that once the local force is unfavorable, the entire structure system will be destroyed. The main reasons and mechanisms of iron tower with icing damage are:

a) The ice coating on the wire and the iron tower is too thick, and its effect exceeds the ultimate load-carrying capacity of the transmission line, which directly leads to accidents such as the break of the insulator, the wire break, and the collapse of the iron tower.

b) Excessive unbalanced force is generated at the point of action of the wires to the iron tower, which leads to damage due to excessive force on the cross arm, tower head, etc., and even collapse of the tower with torsion damage, bending damage or bending damage. When a tower collapses, it will release or increase the tension on the wires, and even the wires will be broken. In turn, the unbalanced...
force on adjacent towers increases, and finally the continuous tower collapse. The unbalanced tension on the iron tower comes from the uneven force on the wire, which is mainly caused by factors such as uneven ice coating, uneven ice removal, ground wire breakage, large height difference of the tower, and large difference in span.

3. Failure mode of ice coating on transmission tower
The ice-coating damage of the iron tower mainly includes cross-arm, the head of the iron tower, the tower body, the overall collapse of the tower, and the continuous collapse of towers. In this paper, the mechanical performance and failure modes of the steel tower under different load conditions are studied by an example of the angle steel tower. The load conditions include uniform ice coating and uneven ice coating.

3.1. The analysis of 10mm uniform icing
The structural components of the angle steel tower mainly contain main materials, inclined materials and auxiliary materials. The main materials and inclined materials are the main stress-bearing members, and the auxiliary materials are the structural measure which is mainly used to reduce the slenderness ratio of the main and inclined materials and enhance the stability of the main force-bearing member. At present, auxiliary materials bearing force usually are not considered in the structural design analysis, which is a conservative approach. However, the auxiliary materials will have a certain impact on the calculation results in the analysis of the overall force performance of the iron tower, especially for its ultimate bearing capacity.

The ultimate bearing capacity of the tower under 10mm uniform icing conditions under the two models considering auxiliary materials or not is analyzed by ANSYS software. In the analysis, the geometric nonlinearity and material nonlinearity factors are considered, and the load-displacement curve and failure mode of the structure are obtained.

3.1.1. The analysis of the ultimate bearing capacity without auxiliary materials

It can be seen that the ultimate bearing capacity of the structure is more than one time of the design load. This result shows that the safety of the structure is not enough, which is a certain deviation from the safety of the original design. However, the failure mode of the structure shows that the limit state of the structure under this working condition is that the main material of the tower leg has local bending failure, and the main material generally does not have this local bending failure as the auxiliary material can support the main material to a certain extent. It can be seen that the calculation model without auxiliary materials underestimates the bearing capacity of the structure, making the calculated ultimate bearing capacity lower than the actual value.
3.1.2. The analysis of the ultimate bearing capacity with auxiliary materials

![Figure 3. the load-displacement curve](image1)

![Figure 4. the displacement in damage (mm)](image2)

It can be seen that the ultimate bearing capacity of the structure is about 1.6 times of the design load. In the ultimate state, the plane main material of the cross arm fails in tension, which is different from the local bending failure mode of the main material without auxiliary material. The ultimate bearing capacity of the auxiliary material model is higher, which is also higher than that of the actual structure. There are two main reasons. One is that the auxiliary material has a certain support on the main material of the tower, which changes the failure mode of the iron tower. The structure failure has changed from the partial bending failure of the main body of the tower without considering the auxiliary material to the failure of the main material of the cross arm. Thereby the bearing capacity of the structure has been improved. The second is that the beam elements are adopt in the auxiliary material model. All the members are considered to be axially stressed members, while the oblique and auxiliary materials in the actual structure are hinged members, and many members are eccentrically stressed members. This results in that the carrying capacity is higher than the actual value.

3.2. The analysis of 10mm uneven icing

3.2.1. The analysis of the ultimate bearing capacity without auxiliary materials

![Figure 5. the load-displacement curve](image3)

![Figure 6. the displacement in damage (mm)](image4)

It can be seen from the analysis that the ultimate bearing capacity of the structure is about 60% of the design load, and the connection between the cross arm and the tower body is damaged in the ultimate state.
3.2.2. The analysis of the ultimate bearing capacity with auxiliary materials

![Figure 7. the load-displacement curve](image1)

![Figure 8. the displacement in damage (mm)](image2)

It can be seen from the analysis that the ultimate bearing capacity of the structure is about 55% of the design load, and the oblique material at the tower head is damaged in the ultimate state.

4. Conclusion

The analysis of the ultimate bearing capacity of the transmission tower under uniform and uneven ice coating shows that the model with auxiliary materials has a higher bearing capacity than the model without auxiliary materials, and the actual bearing capacity of the structure should be between them. The load-bearing capacity of the structure under uneven icing is lower than the load-bearing capacity of the structure under uniform icing. The main material of the tower, the main material of the cross arm and the head of the tower are unfavorable and easy to be damaged.

Acknowledgments

This work has been funded by the State Grid Corporation of China. The project name is Research on edge intelligent perception and evaluation technology of health state of transmission tower structure. The project number is 5600-202019160A-0-0-00.

References

[1] Liu C.C., Liu F.D., Mao X.K., Li X.H. (2012) Mechanical Properties of Transmission Tower Line System with Icing Load. Water Resources and Power, 30: 166-168.

[2] Han J.K., Yang J.B., Yang F.L. (2011) Analysis of failure mode of transmission line under icing coating. Engineering Journal of Wuhan University, 44: 184-187.

[3] Wang S.H. (2010) Influence of Ice Accumulation on Mechanical Performance of Overhead Transmission Line. Electrotechnics Electric, 10: 35-39.

[4] Han J.K., Yang J.B., Yang F.L. (2010) Analysis of failure mode on double circuit tangent towers in ice disaster area. Building Structure, 40: 705-708.

[5] Li Z., Yang J.B., Han J.K. (2009) Analysis on Transmission Tower Toppling Caused by Icing Disaster in 2008. Power System Technology, 33: 31-35.