Research on Finite Element Simulation of Typical Down Lead of Transformer Substation

Pan Xiubao¹, Li Peng², Liu Bin², Wang Jingchao², Zhu Yongkun¹, Li Danyu²

¹ State Grid East Inner Mongolia Electric Power Company Limited, Huhehot, 010020, China
² China Electric Power Research Institute, Beijing, 100192, China

Abstract. To calculate the stress status of equipment terminal exactly, this paper establishes the overall simulation models of two types of down lead structure systems, and compares them with the test result. The result shows that for cross line - down lead model and truss - down lead model, a relatively good effect has been obtained for both of them by using cable element to simulate conductor, and the error between the terminal stress simulation result and the test result is controlled within 15%, which means that the finite element simulation model of this paper is exact and reasonable.

1. Introduction
The transformer is an important node of the power grid system, and the stress safety of connection terminals of key main equipment such as its casing pipe, lightning arrester and RI capacitor attracts more and more attention in recent years [1-3]. The higher the voltage level is, the larger the dimensions of main equipment and its connection conductor are, the grater the influence from the wind load will be, and the easier the fatigue or strength damage will be. During the model selection of main equipment and determination of terminal load in the traditional station, the simplified empirical formula will be adopted or the finite element model of local structure will be establish to realize the analysis on terminal stress generally. For above two mentioned methods fail to consider the dynamics influence of down lead and cross line, the error of calculation result is relatively large, and cannot authentically reflect the stress status of terminal.

Based on above background, this paper plans to establish the simulation models of two types of typical down lead structure systems and compare them with the test result, so as to calculate the stress status of equipment terminal, thus laying a solid foundation for the subsequent engineering design.

2. Selection of Typical Down Lead Structure System
According to the difference of hanging structure at the top of the down lead, the down lead system can be divided into cross line - down lead structure and truss - down lead structure. The top of down lead of the former one is connected with the cross line, and the top of down lead of the later one is connected with the portal frame. In this paper, two types of typical down lead systems i.e. the I-string type cross line - down lead structure and single down lead structure are adopted as the analysis objects.

3. Simulation Modeling Method
To compare with the test result, this paper establishes the simulation models of two types of typical down lead structures according to the implemented down lead test model parameters. The models simplify a part of complicated members appropriately, and divide the insulator string into five parts for
equivalence, as shown in Figure 1. From right to left, they are the hanging point part of insulator string, composite insulator, separating plate, cross line clamp and the transverse support member between the separating plate and the composite insulator; in which, the composite insulator adopts the circular section with diameter of 30mm for equivalence, and take the axial elastic modulus as 49GPa according to actual situation of the insulator, with the transverse elastic modulus of 13GPa, and Poisson's ratio of 0.34; the remaining part refers to fittings, and adopt rectangular section for equivalence, and the weight density is converted according to actual mass, and the parameters such as elastic modulus are the same as those of Q345 steel; the connection mode between the cross line clamp part and the separating plate part is hinge joint, so this part of bending moment is released in the simulation model. Except the insulator string, the equipment terminal can be simplified into four parts (Figure 2); for example, the elements of the model from top to bottom are down lead clamp, T-type steel plate, arietiform fittings and wiring column respectively, and their connection modes are all rigid connection; the bottom of wiring column refers to fixed end support, and the support bottom is installed with 3D force sensor, which is used to test the stress situation of equipment terminal; the spacer is simplified by being connected to the closed rectangle on the conductor in a rigid way, as shown in Figure 3, and the section adopts rectangular section; see Table 1 for physical properties of the part material and elastic modulus.

Table 1. Part Dimensions and Material Parameters.

| Name of Parts   | Material                        | Elastic Modulus GPa | Poisson's Ratio | Yield Strength MPa |
|-----------------|---------------------------------|---------------------|-----------------|-------------------|
| cross line      | Aluminum Cable Steel Reinforced | 63                  | -               | -                 |
| Down Lead       | Aluminum Cable Steel Reinforced | 63                  | -               | -                 |
| Composite Insulator | Glass Fiber and Silica Gel | -                   | -               | -                 |
| Conductor Clamp | Aluminum Alloy                  | 70                  | 0.3             | 60                |
| Terminal Board  | Brass                           | 110                 | 0.32            | 100               |
| Wiring Column   | Iron                            | 200                 | 0.3             | 205               |
| Spacer          | Aluminum Alloy                  | 70                  | 0.3             | 60                |

(a) Diagram of Real Object of Insulator String (b) Insulator String Model

Figure 1. Simplified Diagram of Insulator String Model.
4. Comparison between Simulation and Test Result

According to the modeling mode of section 3, this paper establishes the I-string cross line - down lead system, as shown in Figure 4, and the truss - down lead system is as shown in Figure 5; in which, the hanging point part of the insulator string of the cross line - down lead system adopts hinge joint part, and the upper node part of the down lead is of rigid connection with the cross line; during the test, the upper node part of the truss - down lead adopts the spacer which is fixed with hook and hoist to constrain the deformation of down lead, so the upper node part of the down lead in the model adopts hinge support; the wind load is exerted on two nodes on the side of spacer (Figure 6), and the wind load is to be determined according to requirements specified in the code [3,4].

Figure 4. I-string cross line – Down Lead System Model.
Exert node loads to the model, respectively corresponding to the loading forces at the initial status, at the wind speeds of 10m/s, 20m/s, 30m/s and 40m/s in the test. In which, the initial status only takes the system dead weight into consideration, without exerting node load; for the X-axis force of the terminal is the main stress direction, so after completion of computation, it is necessary to extract the X-axis reaction force value of the fixed end support at the bottom of equipment terminal, and then compare it with the test value; in the results of different wind speeds of the model, the reaction force at the initial status has been deducted, and the results are as shown in Table 2 and Table 3.

Table 2. Comparison between I-string cross line System Model and Test Data.

| Wind Speed | Model Data | Test Data | Relative Error |
|------------|------------|-----------|----------------|
| 10m/s      | 0.30       | 0.28      | 5.4%           |
| 20m/s      | 1.13       | 1.29      | 12.8%          |
| 30m/s      | 2.48       | 2.88      | 14.1%          |
| 40m/s      | 4.44       | 5.07      | 12.5%          |

Table 3. Comparison between Truss - Down Lead System Model and Test Data.

| Wind Speed | Model Data | Test Data | Relative Error |
|------------|------------|-----------|----------------|
| 10m/s      | 0.08       | 0.19      | 57.9%          |
| 20m/s      | 0.33       | 0.80      | 59.4%          |
| 30m/s      | 0.73       | 1.76      | 58.5%          |
| 40m/s      | 1.31       | 3.08      | 57.5%          |

5. Model Correction

From the result of section 4, it can be known that there is a relatively large difference between the model data and the test data. The relative error of data of the truss – down lead type is even above 50%, so the model is to be improved. Through analysis, the main cause for occurrence of error is that the conductor simulation mode is not appropriate. The conductor adopted in the test is aluminum cable steel reinforced, with relatively weak anti-bending capability, and the cable unit can be adopted to simulate the function of conductor, without considering the function of bending moment. Therefore, the cross line and down lead in the down lead system are changed into cable unit from the beam unit for simulation; through trial calculation of the model, it is found that the shape of conductor will
influence the reaction force of terminal greatly, so whether the shape of cable unit is selected appropriately will be directly related to the model accuracy. Considering the authentic situation of the test, the maximum verticality of the cable unit simulating the cross line is about 310mm, and the maximum verticality of the cable unit simulating the down lead is about 690mm; and the maximum verticality is realized through the tension of regulating cable unit. After model establishment, the trial calculation of the cross line - down lead system model is conducted, and it is found that the displacement of cross line is too large, not conforming to the actual situation, and considering that the pretension is too small in case of comparing with the actual situation, so a part of bending moment of the cross line clamp and the separating plate in the insulator string is to be released to make the model shows semi-rigid performance. After correction, the I-string cross line - down lead system is as shown in Figure 7, and the truss - down lead system is as shown in Figure 8.

![Figure 7. I-string cross line – Down Lead System Model (Adopting Cable Unit for Modeling).](image)

![Figure 8. Truss - Down Lead System Model (Adopting Cable Unit for Modeling).](image)

Similarly, exert node loads to the model, corresponding to loading forces at the initial status, 10m/s, 20m/s, 30m/s and 40m/s in the test respectively; and the type of analysis on working conditions after modeling of cable unit must be non-linear analysis, and the calculation results are shown as in Table 4 and Table 5.

Table 4. Comparison between I-string cross line - Down Lead System Model and Test Data (Cable Element).

| Wind Speed | Model Data | Test Data | Relative Error |
|------------|------------|-----------|----------------|
| 10m/s      | 0.32       | 0.28      | 12.5%          |
| 20m/s      | 1.12       | 1.29      | 13.3%          |
| 30m/s      | 2.59       | 2.88      | 10.1%          |
| 40m/s      | 4.86       | 5.07      | 4.2%           |
Table 5. Comparison between Truss - Down Lead System Model and Test Data (Cable Element).

| Wind Speed | Model Data | Test Data | Relative Error |
|------------|------------|-----------|----------------|
| 10m/s      | 0.16       | 0.19      | 14.7%          |
| 20m/s      | 0.68       | 0.80      | 15.6%          |
| 30m/s      | 1.51       | 1.76      | 14.5%          |
| 40m/s      | 2.70       | 3.08      | 12.5%          |

After comparison, it is found that a relatively good effect is obtained by utilizing cable element to simulate conductor, and the overall error is controlled within 15%, which means that the model is reliable and effective. Therefore, in case of simulating the finite element to the down lead system, it is suggested that the cable unit should be adopted to simulate conductor.

6. Conclusion

In order to accurately calculate the stress status of equipment terminal exactly, this paper considers the influence of the upper down lead and cross line on the terminal stress of main equipment, and establishes the overall simulation models of two types of down lead structure systems, and compares them with the test result. The result shows that for cross line – down lead model and truss – down lead model, a relatively good effect has been obtained for both of them by using cable element to simulate conductor, and the error between the terminal stress simulation result and the test result is controlled within 15%, which means that the finite element simulation model of this paper is exact and reasonable.

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