Simulation Analysis of Terminal Force of UHV Main Equipment

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Abstract. In this paper, the key stress part of main equipment of the UHV engineering is screened and determined firstly based on principles such as equipment importance, distance away from main equipment, load strength and equipment dimensions; and then, the influence of upper crossing line and down-lead on stress of UHV DC main equipment terminal is taken into consideration, and simulation models of terminal stress of two types of typical key main equipment, i.e. cross line – down-lead and herringbone down-lead are established; next, the comparative analysis between numerical simulation result and test result of herringbone down-lead is conducted to verify correctness of simulation model and test method in this paper.

1. Introduction
The converter station of UHV DC engineering is an important node of power grid system, and the terminal stress safety of its key main equipment such as AC/DC bushing, lightning arrester, and RI capacitor is focused gradually in recent years [1]. With the rising of voltage class, the main equipment usually has greater dimensions, and the equipment top is connected with crossing line and lead, suffers from great stress at the load function terminal, and fatigue or strength damage may occur easily. During the structural design of down-lead in traditional station and model selection of main equipment, the simplified empirical formula is adopted or the finite element model of local structure is established to realize the analysis on stress terminal. The error of calculation result of the former one is relatively large, and the stress status of main equipment terminal cannot be reflected authentically; the later one has relatively large limitation, and the influence of upper down-lead and crossing line of the terminal cannot be taken into consideration sufficiently.

This paper will establish an overall simulation model of main equipment terminal of UHV DC engineering including down-lead and crossing line, and conduct checking by comparing with test result, thus laying a solid foundation for working out the mechanical state of main equipment terminal more precisely.

2. Selection of Typical Stress Structure and Modeling of Finite Element of Key Main Equipment
The refined stress analysis on key main equipment and its connection line of converter station at the design stage is an important premise for guaranteeing safe and stable running of substation equipment. According to engineering characteristics and existing design experience, in this paper, the key stress part of main equipment of UHV engineering is to be screened and determined based on principles such as equipment importance, distance away from main equipment, load strength and equipment dimensions, thus providing basis for establishment of terminal stress model.
2.1. Crossing line – Down-lead Model

![Figure 1. Schematic Diagram of Crossing line – Down-lead Structure of Outdoor DC Field.](image)

The suspension insulator of outdoor DC field crossing line in gale area generally adopts V-series scheme to reduce side displacement and terminal stress; the crossing line of UHV converter station refers to quad-bundle or eight-bundle conductor, and the actual span may exceed 100m; some position in the middle of the crossing line is connected with one or two pieces of down-leads, and the number of bundles of down-lead is consistent with that of crossing line generally, with the height within 10m-30m generally; the down-lead is connected with bushing indirectly via pillar equipment. For such kind of structure, for dimensions of crossing line and down-lead are all relatively large, and the displacement caused by wind pendulum will also generate adverse influence on stresses of down-lead and lower terminal. Therefore, it is necessary to conduct overall modelling to crossing line and down-lead during the finite element calculation, so as to calculate terminal stress precisely, and its simplified stress diagram is as shown in Figure 1.

For insulator and down-lead, the beam unit is adopted for simulation, and the terminal of insulator refers to hinged constraint, and the down-lead bottom refers to fixed constraint. Parameters of various modules of the model are as shown in Table 1, and the V-series single down-lead is adopted. The example of finite element model of crossing line - down-lead established in this paper is as shown in Figure 2.

Table 1. Basic Parameters of Crossing line — Down-lead Model of V-series Single Down-lead Structure.

| Parameters          | Suspension Insulator | Crossing line | Down-lead | Spacer            |
|---------------------|----------------------|---------------|-----------|-------------------|
| Internal diameter, m| /                    | 0.041/0.058   | 0.041/0.058 | /                 |
| External diameter, m| 0.025                | 0.051/0.070   | 0.051/0.070 | 40mm*40mm         |
| Vertical dip angle/degree | 15°                | /             | /         | /                 |
| Included angle      | 25°                  | /             | /         | /                 |
| Material            | Composite            | Aluminium     | Aluminium | Aluminium alloy   |
| Elastic modulus, MPa| 1E10                 | 7E10          | 7E10      | 7E10              |
| Density, kg/m3      | 2500                 | 2700          | 2700      | 2700              |
Figure 2. Example of Crossing line - Down-lead Finite Element Model of V-series Single Down-lead Structure.

2.2. Down-lead Model

Figure 3. Schematic Diagram of Herringbone Down-lead Structure of GIS Converter Transformer Incoming Line Cross Section.

Different from the crossing line - down-lead structure, the top of herringbone down-lead is generally suspended on the portal frame, and the bottom is generally connected with mutual inductor, GIS bushing, lightning arrester and other pillar type equipment. For its height exceeds 10m generally, the down-lead will swing under the function of wind load, thus influencing the terminal stress. Therefore, it is necessary to conduct overall modeling analysis on this part, and adopt beam unit for simulation similarly. See Table 2 for parameters of finite element model, and the model example is as shown in Figure 4.

| Model/Type                | V-series | Quad-bundle | Quad-bundle | Quad-bundle |
|---------------------------|----------|-------------|-------------|-------------|
| Down-lead point position  | /        | 1/3L        | /           | /           |
| Arc sag of crossing line  | /        | /           | 5%          | /           |
| Down-lead arc sag         | /        | /           | 4%          | /           |
Table 2. Basic Parameters of Herringbone Down-lead Structure Model.

| Parameter                        | Down-lead          | Spacer             |
|----------------------------------|--------------------|--------------------|
| Internal diameter, m             | 0.041/0.058        | /                  |
| External diameter, m             | 0.051/0.070        | 40mm*40mm          |
| Material                         | Aluminium          | Aluminium alloy    |
| Elastic modulus, MPa             | 7E10               | 7E10               |
| Density, kg/m³                   | 2700               | 2700               |
| Model/Type                       | Quad-bundle        | Quad-bundle        |
| Down-lead point position         | 1/2H               | /                  |
| Arc sag of long-leg down-lead    | 4%                 | /                  |

Figure 4. Example of Finite Element Model of Herringbone Down-lead.

3. Comparison between Numerical Result and Test Result

3.1. Test Overview

To verify the terminal stress model and analysis method proposed in the Project, the test platform as shown in Figure 5 is established in the laboratory. Steel beam is stretched out of the frame column of experimental hall, and the node plate and upper line of down-lead are adopted to clamp hinged joint; the horizontal equivalent wind load is realized by adopting weight box and clump weight lifted by movable pulley, and the movable pulley is fixed on the scaffold which is erected specially.
In this test, the wind load is calculated as per rules in relevant code [2-4], and it is listed in Table 3 by being converted into clump weight. In the test, the horizontal direction in the plane as shown in Figure 5-2 is regarded as 0 degree direction, i.e. X direction; and the direction out of the plane is regarded as 90° direction, i.e. Y direction. The hanging point deviation distance is x=2,000mm (out of the plane: deviation distance between left bushing and top), and y=2,800mm (in the plane: distance between top and left bushing).

Table 3. Counter Weight of Equivalent Wind Load.

| Function Point | Function Position (m) | 90° Direction (kg) |
|----------------|-----------------------|--------------------|
|                |                       | 15 m/s  | 25.98 m/s |
| F1 (kg)        | 29.80                 | 25.13   | 75.38    |
| F2 (kg)        | 26.70                 | 17.14   | 51.43    |
| F3 (kg)        | 24.50                 | 13.85   | 41.54    |
| F4 (kg)        | 22.30                 | 16.80   | 50.38    |
| F5 (kg)        | 19.00                 | 16.77   | 50.30    |
| F6 (kg)        | 21.0                  | 20.07   | 60.21    |
| F7 (kg)        | 19.0                  | 19.44   | 58.31    |

3.2. Comparison between Numerical Result and Test Result of Terminal Counter Force
In the finite element software, the simulation model is established according to authentic parameters of the test, the displacement cloud chart of calculation result of herringbone down-lead is as shown in Figure 6, and the comparison between test result and simulation result is as shown in Table 4.
Figure 6. Displacement Cloud Chart (m).

Table 4. Comparison between Numerical Result and Test Result.

| Wind Speed                          | 15 (m/s) | 25.98 (m/s) |
|-------------------------------------|----------|-------------|
|                                     | Numerical Result | Test Result | Numerical Result | Test Result |
| X direction – in the plane          | 375.546  | 356         | 715.544         | 544         |
| Y direction – out of the plane      | 158.696  | 107         | 634.456         | 896         |
| Horizontal resultant force (N)      | 407.7    | 371.7       | 956.3           | 1048.2      |
| Relative error of resultant force   | 8.8 %    |             | 9.6%            |             |

From Table 4, it can be known that: the overall error between numerical simulation result and test result is within 10%, and considering the processing error between the down-lead test model and the theoretical model, it can be regarded that the simulation method and result in this paper are exact and reliable.

3.3. Comparison of Internal Force of Wiring Column in the Terminal

Furthermore, after the herringbone down-lead finite element model which contains wiring column is established according to method in this paper, and is compared with strain testing result around the wiring column in the existing reference [5], the strain foil position of the wiring column is as shown in Figure 7, and change results of strain along with wind speed are as shown in Figure 8 - Figure 9 respectively.

Figure 7. Strain Foil Position of Wiring Column.
From Figure 8 to Figure 9, it can be known that within the scope of elasticity, the numerical calculation result of wiring column of model in this paper is consistent with the test result well; at the plastic stage, the result difference is relatively large for the software doesn’t take the plasticity of the constitutive model of the material.

Generally speaking, according to the comparative result between counter force of terminal and internal force of wiring column, the simulation model and method in this paper can be regarded as rational.

4. Conclusion
In this paper, the determining principle of key stress part of key main equipment of the UHV engineering is determined firstly; and then, the influence of upper crossing line and down-lead on stress of UHV DC main equipment terminal is taken into consideration, and simulation models of terminal stress of two types of typical key main equipment, i.e. crossing line – down-lead and herringbone down-lead are established; next, the checking between numerical simulation result and test result of herringbone down-lead is conducted to verify correctness of simulation model and test method in this paper, which can provide reference for other engineering designs.

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