Electric Field Simulation of Equipotential Live-line Work in 500kV Cup-type-tower

Tao Guo¹, Shichun Wang¹, Lianggang Xu¹, Hongyun Shi¹ and Yongxin Liu²

¹ Guizhou Power Network Limited Company Transmission Operation and Maintenance Branch, Guizhou Province 550000, China
² School of Electrical Engineering and Automation, Wuhan University, Wuhan, Hubei Province 430000, China

124104474@qq.com

Abstract: As an important part of the power grid, the safe and reliable operation of overhead transmission lines is of great significance. In order to ensure the reliability and continuity of power supply in power grid, the overhaul mode of live-line work is usually adopted. At present, there is little research on live-line work of overhead transmission line overhaul arrester at home and abroad. In order to ensure the safety of live-line work operators, this paper models and simulates live-line work of overhauling surge arrester with support clearance in 500 kV cup-type-tower. The distribution of electric field on the surface of live-line work operators under this line structure is calculated and analyzed, which can provide reference for the personal safety of live-line work operators.

1. Introduction
As people's living standards continue to improve, in order to meet the demand of the further development of the power grid, the live working has become an important means to line operation maintenance [1]-[4].500 kV transmission line as an important part of the power grid. Through the live-line work we can in the first time grasp the running situation of power grid equipment, To ensure the security, stable and reliable operation of the grid is of great significance [5].

Lightning activities are frequent in Southwest China. According to statistics, lightning trips of 500 kV lines under the jurisdiction of Guizhou Power Grid Transport and Inspection Company accounted for 65% of the total number of trips in 2002-2013 [6].Surge arrester can improve the line lightning resistance level, reduce the probability of fault tripping [7]-[9].Power grid companies have taken measures to install line-surge arrester on high-voltage transmission lines in mountainous areas. During the long-term operation of arresters, faults such as discharge counter problems, damp or aging defects of valve plates, poor connection of lead and terminal plates will occur [10]-[11].After the application of lightning arrester on 500 kV transmission line, the electric field distribution around insulator string has changed due to the structure of arrester. In order to ensure the safety of operators in live-line work, it is necessary to study live-line work of overhead transmission line overhaul arrester combined with actual lines.

2. Calculating Method of Electric Field in Live Work
In this paper, SolidWorks software and Comsol finite element analysis software are used to model and simulate the equipotential working conditions of arrester lines. The statistical data in GB-T10000-88
Chinese Adult Body Size are mainly referred to when establishing the corresponding standard worker model [12]. In order to simplify the analysis difficulty properly, the human body model is simplified as far as possible when building the model. The head of the human body is simulated by sphere, the upper body is simulated by cuboid, and the height is chosen as 175 cm. Cylindrical models are used in the arms and legs, and the standing and sitting postures of the human body are established, respectively, as shown in Figure 1.

![Body standing posture](image1)
![Body sitting posture](image2)

**Figure 1.** Human Model of Operators in Live Working.

According to the practice of a project in southwest China, the model of arrester is established, as shown in Figure 2(a) and the model of 500 kV cup-type-tower with support gap arrester, as shown in Figure 2(b). According to the working conditions of live working overhaul arresters in Southwest China, typical equipotential working positions are selected between insulators on conductors and arresters in the middle and right phases respectively, and the live-line work model of equipotential overhaul arresters is established, as shown in Figure 2(c).

![Support gap arrester](image3)
![500 kV cup-type-tower](image4)
![Live-line work](image5)

**Figure 2.** SolidWorks Models.

In actual operation, the ground potential of three-phase conductor is constantly changing. When transforming into electrostatic field problem, different fixed voltage must be applied to each phase conductor. According to the cosine function relationship of three-phase voltage, if the initial phase angle of one phase is 0 degrees, the other two phases lag and advance 120 degrees respectively. When one phase voltage reaches the maximum value, the other two phases reach the maximum value of -1/2, respectively.

A three-dimensional finite element analysis model of 500 kV transmission line of cup-type-tower with support gap arrester is established, which includes support gap arrester, cup-type-tower, composite insulator, equalizing ring, connecting plate, phase conductor (split conductor) and other connecting fittings. All entities are surrounded by a semi-cylindrical air body with a radius of 120 M.

When calculating, the maximum operating phase voltage amplitude \( U_m = 500 \times 1.1 \times \frac{2500}{\sqrt{3}} = 449 \ \text{kV} \) of 500 kV AC line is loaded on the nearest conductor, voltage equalizing ring, shielding ring and high voltage end fittings, while the other two phases are loaded with voltage \( U_m/2 = 224 \ \text{kV} \). Loading 0
potential to frame, low-pressure end fittings and external air boundary.

3. Simulation and Calculation
Comsol software is used to model and calculate the equipotential live-line work of overhaul arrester and the working condition of entering equipotential live-line work respectively.

3.1 Equipotential Live-line Work
Distribution of electric field on human body surface in equipotential live-line work of middle and right phases obtained by simulation are shown in Figure 3.

The surface field strength of workers at different equipotential working positions is shown in Table 1.

![Electric Field Distribution Map of Human Body Surface](image_url)

(a) middle phase (b) right phase

**Figure 3.** Electric Field Distribution Map of Human Body Surface in Equipotential Live-line Work.

| Electric field strength | Position 1 | Position 2 |
|-------------------------|------------|------------|
| Top                     | 1011.5     | 1370.5     |
| Face                    | 978.6      | 1050.7     |
| Chest                   | 996.8      | 989.9      |
| Hand                    | 1320.2     | 1480.1     |
| Tiptoe                  | 374.4      | 169.6      |

3.2 Enter equipotential live-line work
When entering the equipotential field, the surface field strength of live-line work operators is mainly related to the way of entry and the distance between conductors [13]-[14]. At present, hanging basket method, level ladder method and sliding rail hanging chair method are widely used in equipotential live-line work in our country. The operators of live-line work take sitting posture to enter equipotential. From this, the typical positions of entering the equipotential range from 1 to 6 are synthetically determined, as shown in Figure 4.
Figure 4. Typical Position Diagram for Entering Equipotential Live-line work.

The electric field distribution on the human body surface is obtained by simulating each position, and the results are shown in Figure 5.
The surface field strength of workers entering different positions of equipotential live-line work is shown in Table 2.

Table 2. Surface Electric field strength of Operators entering equipotential live-line work (kV/m).

| Electric field strength | Position 1 | Position 2 | Position 3 | Position 4 | Position 5 | Position 6 |
|-------------------------|------------|------------|------------|------------|------------|------------|
| Top                     | 76.3       | 45.1       | 31.6       | 72.1       | 43.1       | 43.3       |
| Face                    | 85.1       | 47.3       | 33.1       | 76.2       | 43.5       | 43.2       |
| Chest                   | 87.2       | 47.5       | 34.5       | 78.4       | 43.7       | 46.1       |
| Hand                    | 221.5      | 49.7       | 35.9       | 87.1       | 45.2       | 46.4       |
| Knee                    | 449.6      | 51.3       | 39.1       | 89.2       | 44.9       | 49.7       |

4. Conclusion

From the calculation results of entering the equipotential live-line work, we can get that when the workers usually use the sitting position near the wire, the electric field intensity of the small radius of curvature of the hands, toes and knees of the workers is larger. Because the head and face are relatively far away from the wire, the field intensity is relatively small. In the process of entering and leaving equipotential, we should try our best to keep the body stretching and avoid crouching, so as to avoid large electric field intensity due to the small radius of curvature of human body.

In the process of equipotential live-line work, the maximum field strength of human body surface can reach 1480 kV/m. In the process of entering equipotential live-line work, the field strength of human body surface increases with the approaching of conductor. Combining with the national standard GB/T6568-2008 "Shielding Clothing for Live Work", in order to ensure the personal safety of operators, operators need to wear shielding clothing or electrostatic protective clothing to repair lightning arrester live work.

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