Research on the Size of Non-contact High-voltage Electroscope Based on Ansoft Simulation

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Abstract. Aiming at the time-consuming and labor-intensive problems of traditional electroscopes, a non-contact high-voltage electroscope was developed. This article uses the contact network as an example. First, the electric field simulation of the transmission line under Ansoft is performed. At the same time, the voltage and electric field strength changes under different conditions at 1m under the transmission line are analyzed to determine the test height of the high-voltage electroscope. A human substitution model is proposed, and the effect of humans on electric field distortion is analyzed. Secondly, the relationship between the induced voltage on the parallel plates and the distance test circuit of the parallel plates was deduced according to the principle of space capacitor voltage division, and the dimensions of each part of the high-voltage electroscope were initially determined to provide data references for subsequent electroscope designs.

1. Introduction
With the rapid development of electrified railways and the power industry, China's national economy has continued to grow efficiently. The scale of the power grid is constantly expanding. The safe operation of the power grid is directly related to the rapid development of the entire national economy. Only by reducing the occurrence of accidents can the power grid's safe operation capacity be improved and the power grid's safe and stable operation be guaranteed. The catenary is the main component of the electrified railway. It bears the important task of power transmission in the traction substation and the electric machine shop. Therefore, the working status of the catenary will directly affect the transportation capacity of the electrified railway.

High-voltage electroscope is an indispensable electrical safety tool during the maintenance of electrical equipment. [1] According to the maintenance regulations, the rules for power failure, power inspection, ground hanging, and operation must be followed, and the power inspection operation is completed by a high-voltage electroscope. When the power workers overhaul the transmission line or catenary, first determine whether the line is live, and then start other operations. This article uses catenary as a model, and uses Ansoft to simulate the electric field under different models, demonstrates the necessity of the split design of the electroscope, and preliminarily determines the size of the electroscope plate and the height of the electroscope to the ground.

2. Principle analysis of non-contact high-voltage electroscope
The non-contact high-voltage electroscope in this paper is designed based on the principle of space capacitor voltage division. In an ideal case, the equivalent circuit of the device is shown in Figure 1. [2]
A parallel plate is placed under the test line, the inter-plate capacitance, the distributed capacitance between the upper plate and the test line, and the distributed capacitance of the lower plate box to the ground together form a space capacitor voltage dividing device is shown in Figure 2.

The voltage conversion formula can be derived according to the circuit theory:

\[
U_2 = \frac{c_1c_3}{c_2c_3 + c_1c_2 + c_1c_3} U_1
\]  

Order

\[
k = \frac{c_1c_3}{c_2c_1 + c_2c_2 + c_1c_3}
\]

The ratio \(k\) is the main factor affecting the non-contact high-voltage electroscope. It can be seen from equation (1) that the three parts of \(C_1, C_2\) and \(C_3\) determine the magnitude of the ratio \(k\).\[3\]

The approximate formula for testing the line voltage is:

\[
U_1 \approx \frac{R^2 \Delta h e^{-R}}{2000 \text{dr}} U_{21} U_{22} \frac{U_{21} - U_{22}}{U_{22}}
\]

Comparing the measured value with the rated value of the transmission line can determine whether the test line is energized, and can also distinguish whether the test line is an induced voltage or an operating voltage.

3. Electric field simulation under test line

Electric field simulation was performed using Ansoft on three simulation models: test line and earth model, high voltage electroscope and test line model, human and high voltage electroscope, and test line model.\[4\] The simulation results were used to determine the test height of the high voltage electroscope. The influence of people on the electric field under the test line is analyzed through simulation, and the distortion of the electric field is analyzed from the angle of field strength and voltage.

3.1. Simulation model design

Explanation of dimensions, materials and incentives of high voltage electroscope simulation model:

(1) Select the test line with a radius of 5.56mm and a length of 10m. Set the material of the test circuit to "copper". Assume that the excitation of the test line is, and the height from the ground is 6m.
(2) Select the earth model as a circle with a radius of 10m or a square with a side length of 10m and a thickness of 10mm. Set the ground material to "air", the excitation to zero potential, and the color to yellow.

(3) Select the electroscope case with a radius of 40mm and a height of 100mm, and set its material as "polyethylene"; the plate radius is 30mm, and the electrode pitch is 60mm, and set its material as "copper".

3.2. Ansoft simulation analysis

3.2.1. Electric field distribution under test line

At $t = 0$, the overall voltage distribution in the space under the test line is shown in Figure 3.

![Field map of holistic voltage distribution Central cross section](image)

Figure 3. Field map of holistic voltage distribution Central cross section

In order to visually observe the voltage change from a certain point of the test line to the ground, the voltage change curve on the vertical path of the ground geometric center point and the test line is selected as shown in Figure 4.\[5\]

![The curve of voltage on a vertical path](image)

Figure 4. The curve of voltage on a vertical path

From Figure 4, it can be seen that the voltage change is relatively gentle between 0 ~ 5.0m, and the voltage change is steep between 5 ~ 6m. Due to the voltage limit of the rectifier bridge of the electroscope, the measurement height needs to be selected to change gently; The appliance is easy to carry, and the measurement height is not easy to be too high. By observing the voltage change curve, the measuring height of the electroscope was determined to be 1m and 3m.

3.2.2. Voltage distribution of high voltage electroscope under test line

Due to the large selection of the model of the earth and the test line, the electroscope is far away from the line, and the volume of the electroscope is small. The overall voltage distribution of the electroscope at 1m and 3m from the ground is basically the same. Now only the voltage distribution of the high-voltage electroscope at 1m from the ground is analyzed, and the voltage analysis at 3m from the ground will be omitted.
In order to visually observe the voltage change between the electroscope, the vertical path of the center of the upper and lower plates of the electroscope is selected. The voltage change curve is shown in Figure 5. It can be seen that the voltage difference is 1, and the voltage of the plate is less than the withstand voltage value of the rectifier bridge is provided for the reference of the rectifier bridge model selection. It is necessary to select the withstand voltage value of the rectifier bridge to be 2 ~ 3 times the voltage difference, that is, the withstand voltage reference value is between 600 ~ 900V.

![Figure 5. The voltage curve between the plates of the electroscope](image)

3.2.3. Electric field distribution of the human body and the electroscope under the test line
When the operator supports the electroscope to be tested under the test circuit, the human body causes distortion of the surrounding electric field, and the measurement accuracy of the electroscope will decrease. In this electric field analysis, it is assumed that the human body is in direct contact with the earth.[6] Due to the relatively complicated tissues and organs inside the human body, the dielectric constant is much larger than the dielectric constant of the air. The human body can be regarded as a conductor, and the human body and the earth etc Potential, set the ground to zero potential. For the convenience of analysis, a cylindrical model with a radius of 20mm and a height of 2m is used instead of the human body, and the material property is set to “water_sea”.

The voltage curve on the vertical path of the geometric center of the earth and the test line is shown in Figure 6. Due to the influence of the human body, the voltage suddenly changes at 2m, so the high-voltage electroscope should be designed as the transmitting end and the receiving end. Eliminate human interference on the electric field around the electroscope, and reduce the electroscope measurement errors of non-contact electroscopes in high-voltage electric fields.

![Figure 6. The curve of voltage on a vertical path](image)

4. Dimensional investigation of non-contact high-voltage electroscope
In order to size the high-voltage electroscope, make it meet the design requirements. Now the catenary (27.5kV) is used as a model to further determine the size of each part of the device. Ideally, assuming that there is no sagging in the catenary, the relationship between the test line voltage and the induced voltage between the parallel plates is:
\[ U_2 = \frac{U_1}{1 + \frac{R^2}{2d} \ln \frac{h}{r}} \] (4)

According to the contact network design specification, the line height does not exceed 6.5m, let the height be 6m, \( r = 5.56\text{mm} \), take \( R = 55\text{mm} \), in MATLAB, the formula (4) is at the distance \( d = 40\text{mm} \), \( d = 50\text{mm} \), \( d = 60\text{mm} \), the relationship between the induced voltage of the parallel plate and the height of the test line from the parallel plate \( h = 3: 0.5: 5\text{m} \), the relationship as shown in Figure 7. It can be seen from the figure that the voltage difference between the two measurements is about 10V, and the voltage values measured at the same time are less than the withstand voltage of the rectifier bridge W10 by 1kV. Choosing the plate spacing \( d = 60\text{mm} \) is more in line with the design requirements.

When \( d = 60\text{mm} \) and \( r = 5.56\text{mm} \) are selected, in MATLAB, the formula (4) is set at the parallel plate radius \( R = 30\text{mm} \), \( R = 50\text{mm} \), \( R = 70\text{mm} \), and the distance between the parallel plate induced voltage and the parallel plate height \( h = 3: 0.5: 5\text{m} \), the relationship is shown in Figure 8. It can be seen from the figure that the voltage difference between the two measurements when the radius of the plate is \( R = 30\text{mm} \) is greater than the voltage difference between the two measurements when the radius is \( R = 70\text{mm} \) and \( R = 50\text{mm} \). It can be seen that the larger the radius, the smaller the voltage difference. The voltage values measured at radius \( R = 30\text{mm} \), radius \( R = 50\text{mm} \), and radius \( R = 70\text{mm} \) are less than the withstand voltage of the rectifier bridge W10 1kV. In order to better distinguish the two measured values, a larger voltage difference should be selected, so Select the parallel plate radius as \( R = 30\text{mm} \).

According to the above analysis, the size of each part of the transmitting end of the electroscope can be initially determined. Then the design of the electrode plate spacing of the high-voltage electroscope's transmitting end is 6cm, and the radius of the plate is 3cm, which meets the requirements. Based on the minimum height to ground at the sag, it is assumed that the radius of the 35kV transmission line is the same as the radius of the traction network wire. [7]According to formula 1, it can be listed that the 35kV single-pole single-circuit horizontally arranged transmission lines or catenary correspond to the voltmeters at the distance of 3m and 1m from the ground of the high-voltage electroscope, as shown in Table 1. These parameters provide a reference for designing the resistance value of the resistor divider.

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| Voltage level | Voltage on the plate | Ground height |
|--------------|---------------------|--------------|
| 27.5kV       | 570V 530V           | 6            |
| 35kV         | 683.3V 648.4V       | 7.5          |
After the tester's transmitting terminal is shaped, when the rated voltage of the test line exceeds 35kV, the induced voltage on the parallel plate will exceed the withstand voltage of the rectifier bridge at a fixed distance, so the high-voltage tester is not suitable for rated voltages exceeding 35kV line. For the test rated voltage exceeding 35kV, the plates of the high-voltage electroscope can be improved, such as increasing the plate spacing or reducing the plate radius, so that the induced voltage on the parallel plates is lower than the withstand voltage of the rectifier bridge.

5. Conclusion
This article mainly describes the simulation of the electric field of the test line under Ansoft, and analyzes the voltage change under different conditions at 1m under the transmission line. A human substitution model is proposed to analyze the effect of human presence on the electric field distortion. Based on the principle of space capacitor voltage division, the relationship between the induced voltage on the parallel plates and the distance between the parallel plates and the test circuit is deduced. Taking the catenary as a special case, the preliminary dimensions of each part of the high-voltage electroscope are initially determined. The induced voltage on the parallel plate of the high-voltage electroscope is different from the ground height at a certain voltage level, which provides a reference for the selection of the resistance of the voltage divider in the future.

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