Simulation of Internal and External Electric Field of UHV DC Polar Bus Arrester under Pollution Conditions

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Abstract. Due to the adsorption effect of DC electric field on pollution particles, the pollution accumulation of DC arrester is more serious than that of AC arrester. In addition, the UHV DC polar bus arrester also has a parallel resistance pole inside, the external electric field and the internal radial electric field will be affected by the pollution distribution. In this paper, the electric field simulation model of UHV DC polar bus arrester under the condition of pollution was established, which was used to calculate and analyze the electric field on the surface of the insulating coat and the radial electric field between the resistance pole and the insulating coat when the overall pollution and the local dry belt of the arrester occur. The results showed that the overall pollution of the arrester would lead to the increase of the surface field strength and the internal radial field strength. While the value was small, it would not cause corona and flashover. When the partial dry belt occurred, it would form the partial high surface field strength and radial field strength on the surface of skirt and the air gap between the resistance piece and the insulating coat, which would cause flashover on the surface of the insulating jacket, corona discharge and penetration discharge between the resistance piece column and the insulating coat.

1. Introduction
With the continuous advancement of UHV DC transmission technology, more and more UHV converter stations are put into operation one after another, and UHV DC polar bus arrester (hereinafter referred to as ‘polar bus arrester’) is important overvoltage protection devices in the DC field of converter stations. The polar bus arrester is generally arranged outdoors, so the surface of the insulating jacket will be affected by local environmental pollution and weather factors such as frost, rain and snow, and a pollution layer mainly composed of salt and dust will be formed over many years.[1-3] Moreover, the adsorption of the direct current electric field on the contaminated particles makes the pollution of DC equipment more serious than that of AC equipment. Therefore, it is necessary to study and analyze the distribution of the internal and external electric fields of the polar bus arrester under the pollution condition.

It was studied in [4,5] that the pollution-resistant capacity of AC and DC arresters under different voltage levels and different pollution conditions through the form of artificial pollution test, but the test period was long, the error was large, and it is difficult to know the electric field distribution inside and outside of each section only through the monitoring of the bottom leakage current. In [6,7], the test of the contamination characteristics of the DC line insulators and the simulation of electric field under different pollution conditions were conducted. The results showed that the surface pollution distribution of the DC insulators was affected by various factors such as the position of the skirt, the
voltage distribution and the wind speed and direction. Moreover, after the pollution layer underwent the process of water absorption, leakage current increase, heat drying and local drying zone appearing, local high field strength and flashover phenomenon would occur on the surface of the insulator. The polar bus arrester also has three columns of parallel resistors inside the insulating jacket. The change of the surface electric field of the insulating jacket and the radial electric field between the resistor and the insulating jacket caused by pollution distribution will have a certain impact on the operating condition of the arrester.

In this paper, based on the distribution characteristics of pollution in the DC field, the electric field simulation model of the UHV DC polar bus arrester was established. And the surface electric field of the insulating jacket and the radial electric field between the resistor and the insulating jacket of polar bus arrester in terms of overall pollution and local drying zone were calculated and analyzed.

2. Pollution simulation model of polar bus arrester

The ±800kV UHV DC Bus Arrester is composed of five arrester sections in series, each section has a height of 2852 mm, and three resistors in parallel, which is divided into three resistor packaging units (the number of resistors column in the upper, middle and lower three units is 14, 16, 14 respectively). Resistors are pie-shaped, 106mm in diameter and 23mm in thickness. Aluminium gaskets with the same diameter and height of 20 mm are used to separate them. The schematic diagram of the overall and internal structure of the pole bus arrester is shown in figure 1. Because of the uniform potential distribution of the resistors in the polar bus arrester under DC operating voltage, the voltage distribution of each section is similar, and the influence of DC bus and other equipment is neglected, a single arrester section in the polar bus arrester is selected to establish the simulation model in this paper, which can simplify the simulation process. At the same time, the electric field simulation model of arrester surface pollution is established by adding a layer of pollution layer with a thickness of 1 mm on the outer surface of the porcelain jacket as shown in figure 2. The resistivity of the pollution layer reflects different contamination states.

The pollution on the jacket surface of polar bus arrester is not uniform distribution. The upper surface of skirt can be washed by rain water, whose self-cleaning effect is stronger than the lower surface, resulting in the lower surface pollution heavier than the upper surface. The salt density and ash density of the lower surface are 5-7 times as high as the upper surface. Because DC voltage has sedimentation effect on contaminated particles, more contaminated particles will be adsorbed on the surface of insulating coat at higher field strength. The simulation results of the average field strength on the surface of each skirt of the insulating jacket of single-section arrester under the
continuous DC operating voltage of 165 kV are shown in figure 3. The field strength on the surface of the jacket is U-shaped from top to bottom, i.e., the two ends are high and the middle is low, so the pollution density on the top and bottom skirts is higher than that on the middle skirts. Pollution on the arrester jacket is mainly composed of soluble salts and insoluble materials such as silica. The greater the salt density, the stronger the water absorption, the easier the contamination layer is to be damped and the smaller the resistivity. Table 1 refers to [10-12] and the material property parameters of each part of the pollution simulation model are given in combination with the surface pollution characteristics of the DC arrester jacket.

Table 1. Material property of each component.

| Component                | Resistivity/(Ω • m) |
|--------------------------|---------------------|
| Air                      | 1014                |
| Insulating jacket        | 2.5×10^{12}         |
| ZnO resistor             | 1012                |
| Pollution on upper surface | 4.2×10^{4}         |
| Top skirts               | 35                  |
| Middle skirts            | 960                 |
| Bottom skirts            | 230                 |

3. Simulation of overall pollution

According to the parameters set in table 1, the electric field distribution of the single section in polar bus arrester under 165 kV DC continuous operating voltage is simulated. The electric field distribution on the surface of the insulating jacket is shown in figure 4. The local high electric field strength appears at the apex of all umbrella skirts, and the maximum values appear at the top and bottom, which are 0.373 kV/mm and 0.296 kV/mm, respectively. This is due to the different pollution density on the upper and lower surfaces of skirts. The resistivity of the contaminated layer changes abruptly at the junction of the upper and lower surfaces. However, the resistivity of the pollution layer on the top and bottom of the insulating jacket is more different, which leads to the increase of the electric field strength at the apex of the skirt and the appearance of the maximum value.
The air area between the resistor column and the insulating jacket is selected as the observation object of the radial electric field, and the whole coordinate system is adjusted to the cylindrical coordinate system. The radial field strength distribution when overall pollution and surface cleaning is shown in figure 5 and figure 6. The radial field strength of overall pollution increases with respect to surface cleaning, and concentrates at the top and bottom of the air gap, where the maximum value is 0.109 kV/mm. It can be seen from the surface potential distribution of the insulating jacket in two cases that the overall pollution causes the change of the potential distribution of the insulating jacket, which is no longer consistent with the uniform potential distribution of the internal resistor column, thus leading to the increase of the radial electric field.

No matter the maximum surface field strength or the maximum radial field strength, it does not exceed the initial corona field strength of 0.45 kV/mm on the insulator surface. Therefore, the overall pollution on the surface of the insulating jacket of the arrester will not lead to corona and flashover.

![Figure 5. Radial electric field and voltage distribution of clean surface.](image1)

![Figure 6. Radial electric field and voltage distribution of overall pollution.](image2)

### 4. Simulation when local drying zone occurs

Polar bus arrester jacket surface pollution will lead to leakage current increasing, heating increasing, and make pollution drying to form a local drying zone. Considering that the upper surface of skirt has low pollution density, less moisture content and can accept sunlight, this paper considers that the drying zone first appears on the upper surface of skirt. The insulation performance of dry pollution is good, which can be approximately considered to be consistent with the resistivity of insulation jacket. In this paper, the internal and external electric field distribution of dry zone at the top, middle and bottom of the insulating jacket is simulated.

Figure 7 shows the distribution of field strength on the surface of insulating jacket when the local drying zone appears at different locations. It can be seen that the field strength at the drying zone is much higher than that at the rest of the jacket surface. This is because the resistivity of the local drying zone is much larger than that of the wet pollution at other parts. In the DC field, the voltage and resistivity are proportional to each other. Most of the voltage drop is borne by the drying zone, and the locally excessive field strength also occurs here. The maximum field strength of local drying zone is 8.089 kV/mm, 6.471 kV/mm and 7.990 kV/mm when it appears at the top, middle and bottom, respectively. The relationship between the magnitude and the cause is similar to that of the overall pollution in Section 3.

No matter where the drying zone appears, the maximum surface field strength produced by the drying zone far exceeds the initial corona field strength of 0.45 kV/mm on the insulator surface and the breakdown field strength of air of 3 kV/mm, which will lead to flashover discharge along the insulating jacket of the arrester and accelerate the deterioration of the insulating material.
Similarly, the air area between the resistor column and the insulating jacket is taken as the object of observation, and the radial field strength distribution is shown in figure 8 after the whole coordinate system is set as the cylindrical coordinate system. It can be seen that the larger radial electric field appears in the air region at the same location as the local drying zone, and the numerical value is shown in table 2.

The positive value indicates that the direction of the radial electric field is that the resistor points to the insulating jacket, while the negative value is opposite. The maximum radial field strength is similar when the local dry zone appears at the top and bottom, but in the opposite direction.

Further observation of the contours of the resistor column and the surface of the insulating jacket in both cases in figure 9 shows that when the drying zone appears at the top, most of the voltage is borne by the drying zone, and the contours are concentrated at the top, while the potential distribution of the resistor column remains uniform.

The potential of the resistor column at the same height is higher than that of the insulating jacket, thus forming the radial electric field from the resistor column to the insulating jacket. When the drying zone appears at the bottom, the analysis process is similar, except that the insulating jacket at the same height is at high potential, thus forming the radial electric field from the insulating jacket to the resistor column.
When the drying zone appears in the middle, as shown in figure 9, the contours of the outer surface concentrates in the middle, and the potential of the upper resistor column is higher than that of the insulating jacket of the same height, while the lower part is opposite. Therefore, two radial field strengths with opposite directions and similar values are formed on the upper and lower sides of the drying zone. It can be seen that the inconsistency of the potential distribution between the resistor column and the insulating jacket is the main reason for the increase of the radial field strength when the local drying zone appears on the surface of the skirt.

When the local drying zone appears in the top and the bottom, the maximum radial field strength exceeds the breakdown field strength of air, which will lead to the breakdown of the air gap between the resistor column and the insulating jacket, and endangering the safe and stable operation of the arrester.

When the local drying zone appears in the middle, the air gap at both the upper and lower sides share the inconsistency of the internal and external potential distribution, so the maximum radial field strength formed is smaller than that of drying zone appearing at the top and bottom, but it also exceeds the initial field strength of corona on the surface of insulating materials. Long-term corona discharge also accelerates the aging of resistors and insulating materials.

| Table 2. Maximum radial field strength of local drying zone at different location. |
|--------------------------|------------------|
| Location of drying zone  | maximum radial field strength (kV/mm) |
| Top                      | 7.892            |
| Middle                   | 2.495/-2.612     |
| Bottom                   | -7.153           |

5. Conclusion

In this paper, the single section of arrester is taken as the research object, and the electric field simulation model of UHV DC polar bus arrester under the condition of pollution is established. The electric field on the surface of skirt and the radial electric field between resistor and insulating jacket are calculated and analyzed when overall pollution and local dry zone occurs. The following conclusions are drawn:

1) When polar bus arrester is overall polluted, the surface and internal radial field strengths of the insulating jacket increase due to the different pollution density at different locations on the surface of the insulating jacket, and there are maximum values at the top and bottom, but the smaller values do not cause corona and flashover;

2) When the local drying zone appears on the surface of the insulating jacket, the surface electric field strength at the drying zone increases sharply, far exceeding the breakdown electric field strength of the air, which will lead to flashover discharge along the surface of the insulating jacket of the polar bus arrester and accelerate the deterioration of the insulating material;

3) The larger radial electric field appears at the same height as the local drying zone. When the drying zone appears at the top and bottom, the maximum radial electric field strength is similar and opposite, but its value exceeds the breakdown electric field strength of air. When the drying zone appears in the middle, two opposite and similar radial electric field strengths are formed at the upper and lower sides of the drying zone, and its value is smaller than breakdown electric field strength of air, but exceeds the initial corona field strength on the surface of insulating materials. It can be seen that the flashover of insulating jacket surface, corona discharge and penetrating discharge between resistor column and insulating jacket will occur on the surface of polar bus arrester after being polluted, wetted, heated and dried. The deterioration of resistor and insulating material will be an important factor to endanger the safe and stable operation of arrester.
a). Drying zone at the top.

b). Drying zone in the middle.

c). Drying zone at the bottom.

**Figure 8.** Radial electric field of local drying zone in different location

a). Drying zone at the top.

b). Drying zone in the middle.

c). Drying zone at the bottom.

**Figure 9.** Voltage distribution of local drying zone in different location
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