Study of Voltage Distribution and Radial Electric Field under Different Pollution Conditions of 500kV MOA

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Abstract. The surface of the porcelain sleeve will be polluted by local environmental pollution and weather factors such as frost, rain and snow, because of the 500kV MOA is generally arranged outdoors. The surface flashover problem of the porcelain sleeve surface caused by contamination is similar to that of the insulator surface. It is a resistor column with three sections connected in series inside the arrester. The influence of surface contamination on the voltage distribution of the internal resistor and the radial electric field between the resistor and the porcelain sleeve remains to be studied. In this paper, ANSYS is used to establish a two-dimensional axisymmetric simulation model for the surface contamination of 500kV zinc oxide arrester. The electric field distribution of the surface of the arrester is cleaned, evenly polluted and the local drying zone appears. The results show that the uniform contamination is inside the arrester. The electric field has little influence, and the local drying zone will form a locally excessively high radial electric field between the resistor and the porcelain sleeve. Under the reference voltage, the radial electric field exceeds the corona starting field and causes corona discharge, and the acceleration resistor Deterioration of the sheet and the dielectric; the voltage of the resistor piece near the local drying zone is increased to a certain extent, which also accelerates the aging of the resistor chip and jeopardizes the safe and stable operation of the arrester.

1. Introduction

MOA has gradually become the main equipment for overvoltage protection in substations of various voltage levels because of its good operating performances and large flow capacity. The 500kV zinc oxide arrester is generally installed outdoors, applied for the incoming line protection of 500kV main transformer and overhead lines. Therefore, the surface of the porcelain sleeve will be affected by local environmental pollution and weather factors such as frost, rain and snow. The main stain layer is mainly composed of salt and dust accumulated for many years [1-3].

Similar to the contaminated surface of the insulator, the contaminated surface of the arrester porcelain sleeve will lead to an excessively strong local field and flashover on the surface of the porcelain sleeve after undergoing the process of moisture absorption, leakage current increasing, and local desiccation by heat drying [4-6]. Different from the insulator, the inside of the 500kV arrester consists of three resistors sections in series. Whether the contaminated surface of the porcelain sleeve will affect the voltage distribution in the internal resistors sheets and whether a radial electric field will be formed between the resistors sheets and the porcelain sleeve will have a certain impact on the
operation condition of the arrester. Literature [7-8] studied the anti-staining ability of arresters under different voltage levels and different conditions of contaminated surface by artificial contamination test, but the test period is long and the error is large, and it is difficult to know the electric field distribution of each section inside the arrester only through the monitoring of leakage current at bottom. However, the specific electric field distributions under various conditions can be conveniently and accurately obtained by the finite element simulation software. Therefore, this paper researched the radial electric field between the resistors sheets and the porcelain sleeve as well as the voltage distribution in the internal resistors sheets under the contamination condition of the 500kV arrester by establishing the ANSYS simulation model.

2. Simulation model under the contamination condition

The 500kV MOA consists of three arrester sections connected in series. Each section has 55 pie-shaped resistors sheets (190mm in diameter and 22mm in thickness). The wrapping depth of the two corona rings is respectively 950mm and 1350mm. A base with the height of 4m is mounted at the bottom in operation state. The structure of lightning arrester and corona rings is shown as Figure 1. As a result of the symmetry of the arrester's own structure and ignoring the influence of high voltage lead wire and other equipment, a two-dimensional axisymmetric model can be used to simplify the entire simulation calculation process and simulate the distribution characteristics of actual contamination conditions. A contaminated layer with the thickness of 1 mm is added on the surface of the porcelain sleeve, shown in figure 2.

![Figure 1. Structure diagram of MOA](image1.png)  ![Figure 2. Contaminated model of MOA](image2.png)

The contaminated surface of the arrester is mainly composed of soluble salts and insoluble substances such as silica. In the desiccation state, the contaminated layer has good insulation performance, but in rainy or humid weather, it will absorb the moisture, thus significantly reducing its resistivity. The material property parameters of each component in the contaminated lightning arrester simulation model are given in table 1 [9-10].

| Component Name | Resistance/Ω · m | Relative permittivity |
|----------------|------------------|----------------------|
| air            | $10^{-4}$        | 1                    |
| porcelain      | $2.5 \times 10^{12}$ | 4.3                  |
| Zinc oxide     | 1012             | 585                  |
| resistor       |                  |                      |
| Dry contamination | $10 \times 10^{10}$ | 2.8                  |
| Wet contamination | 35               | 82                   |

In the simulation calculation, the corona ring and the base satisfy the first type of boundary condition: the corona ring potential is the continuous running voltage valuing 324kV, and the base
potential is 0V; the symmetry axis satisfies the second type of boundary condition: it is itself an electric field line perpendicular to the equipotential lines everywhere. Figure 3 and Figure 4 show the simulation results of the voltage distribution on the arrester resistors sheets and the radial electric field during normal operation. It can be seen that the voltage distribution on the resistors sheets is relatively uniform at this time; The radial electric field has a relative small value the maximum of which appears on the surface of the protruding shed, about 0.074kV/mm, and the internal radial electric fields about 0.012kV/mm; the equipotential lines are basically parallel, indicating the axial voltage distribution on the porcelain sleeve is substantially consistent with that of the resistors sheets.

![Figure 3. Voltage distribution under clean arrester surface](image1)

![Figure 4. Radial electric field with a clean arrester surface](image2)

3. Simulation calculation for the uniform contamination

The dry contamination has a good insulation performance. As can be seen from Table 1, the electrical property parameters of the dry contamination are close to that of the porcelain sleeve, so it only has a small influence on the electric field distribution inside the arrester. As the simulation result of the voltage distribution on the arrester resistors sheets and the radial electric field are basically the same as that with a clean surface, this section focuses on analysing the uniform wet contamination.

![Figure 5. Voltage distribution of uniform pollution in middle section](image3)

![Figure 6. Contours of clean surface](image4)

Due to the exchange of leakage current at the flange, only the overall voltage borne by each section is changed while the axial voltage distribution in the internal resistors sheets of the single section and the porcelain sleeve is still basically the same. Consequently, the radial electric field between the resistors sheets and the porcelain sleeve has no obvious difference from that under the condition of the clean surface when the single section is uniformly wet and contaminated. Figure 5 shows the simulation results of the radial electric field and equipotential lines under the condition of uniform wet contamination in the middle section. As can be seen, the maximum value of the radial electric field also appears on the surface of the porcelain sleeve, which is about 0.091 kV/mm, and the strength of the internal radial electric field is about 0.019 kV/mm.

The wet contamination has a lower resistivity and a higher relative permittivity than the porcelain sleeve, thus having a certain influence on the electric field distribution. Taking the middle section as
an example, a uniform wet contamination state was set in the simulation calculation, and the simulation result of the voltage distribution on the resistors sheets is shown in figure 6.

As can be seen, the wet contamination on the surface of the porcelain sleeve will overall reduce the voltage borne by the resistors sheets of this section, and overall increase the voltage by the resistors sheets of the remaining two sections. The main reason for this phenomenon is that the wet contamination has a lower resistivity, which increases the leakage current flowing through the surface of the porcelain sleeve. The leakage current exchanges current at the flange between two sections. In the remaining two sections with the clean surfaces, the leakage current will flow through the resistors sheets, causing the rise of voltages borne by the resistors sheets of remaining two sections.

4. Simulation calculation with a local desiccation zone

The contaminated surface of the arrester porcelain sleeve has a small resistivity in the wet state, thus increasing the leakage current flowing through the surface of the porcelain sleeve. However, the porcelain sleeve has a smaller radius where there is no protruding shed (the parts between the big umbrella and small umbrella), a larger current density and a higher heat. As a result, the moisture in the stain layer firstly evaporates to form a local desiccation zone.

It is considered that the local desiccation zone has the same resistivity and permittivity as the dry contamination. This paper took the middle section as the example, and simulated the voltage distribution on the resistors sheets and the radial electric field between the resistors sheets and the porcelain sleeve respectively when the desiccation zone emerges in the upper, middle and lower parts of the section. The results are shown in figure 7.

![Voltage distributions with the desiccation zones in different positions](image-url)
It can be seen from Figure 8 that a radial electric field with large values emerges between the desiccation zone on the surface of the porcelain sleeve and the internal resistors sheets, which is caused by the inconsistent voltage distribution on the surface of the porcelain sleeve with that of the resistors sheets. The desiccation zone has a higher resistivity than the wet contamination. Therefore, when the same amount of leakage current flows, most of the voltage distribution on the surface of the porcelain sleeve is concentrated on the local desiccation zone, while the voltage distribution in the internal resistors sheets is relatively uniform. It can also be seen from the equipotential lines diagram that the equipotential lines are substantially uniformly distributed in the internal resistors, but are concentrated towards the local desiccation zone on the surface of the porcelain sleeve, thereby forming a potential difference between the resistors sheets and the porcelain sleeve at the same height. This potential difference generates a strong radial electric field.

The high voltage borne by the local desiccation zone on the surface of the porcelain sleeve also has a certain influence on the voltage distribution in the internal resistors sheets, as shown in Figure 8. The voltage borne by the resistors near the desiccation zone is slightly increased, and the voltage distribution on the remaining resistors sheets is substantially unchanged.

5. Conclusion
In this paper, ANSYS was used to establish a two-dimensional axisymmetric simulation model of 500kV zinc oxide arrester with the contaminated surface. This paper analysed the electric field distribution under the condition of clean surface, uniform contaminated surface and the local desiccation zone on the surface of the arrester porcelain sleeve, compared the different voltage distributions on the resistors sheets as well as the strength of the radial electric field between the resistors sheets and the porcelain sleeve under the different contamination states, and finally reached the following conclusions:

(1) The uniform dry contamination on the surface of the porcelain sleeve has nearly no effect on the internal electric field distribution inside the arrester. The uniform wet contamination will overall reduce the voltage borne by the resistors sheets in this section. The axial voltage distribution on the internal resistors sheets of single section is basically consistent with that of the porcelain sleeve, and the radial electric field is basically the same as the result with the clean surface, having a relatively small strength;

(2) The local desiccation zone occurring on the surface of the porcelain sleeve is subjected to a higher voltage, which will form a locally excessively strong radial electric field between the resistors sheets and the porcelain sleeve. The maximum radial electric field strength is 0.228 kV/mm at the
operating voltage, but reaches 0.516kV/mm at the reference voltage, which exceeds the initial corona field strength on the insulator surface. Therefore, the corona discharge will occur in the air gap between the resistors sheets and the porcelain sleeve, thus accelerating the deterioration of the resistors sheets and the dielectrics;

(3) The voltage borne by the resistors sheets near the local desiccation zone is increased to some extent, while the voltage distribution of the remaining resistors sheets is substantially unchanged. It can be indicated that the contamination surface of the arrester will not only cause the rise of leakage current and the flashover on the surface of the porcelain sleeve, but also lead to an excessively high internal radial voltage which is a reason for the corona discharge between the resistors and the porcelain sleeve, and an uneven voltage distribution on the resistors sheets which is a reason for aging phenomenon. All of these negative effects will be the important factors in damaging the safe and stable operation of the lightning arrester.

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