Study of Potential Distribution of UHV AC Arrester in Different Conditions

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Abstract. As is known to all, uhv ac lightning arrester will be attenuated to varying degrees due to long-term operation on site, including environmental temperature and humidity, breakdown of valve plate and short circuit, leading to uneven capacitor voltage divider, and causing explosion and other dangerous safety accidents in extreme cases. Therefore, it is very important to analyze the electric field potential distribution characteristics of arrester under different operating environment and conditions. In this paper, the equipotential distribution of uhv ac arrester in local damping and local short circuit test is verified theoretically and practically by using fiber optic current method. Based on the field structure and theoretical analysis, the ANSYS 3d theoretical model is constructed to analyze the actual test conditions. The oneness of field test and theoretical calculation shows the accuracy of theoretical calculation.

1. Introduction

UHV ac lightning arresters (hereinafter referred to as "arresters") are used to protect the main equipment of 1000kV uhv substation from external lightning shock. As we know, long-term operation of lightning arrester in outdoor harsh environment will lead to different degrees of damage and deterioration of the resistance valve sheet, and in extreme cases will cause uneven distribution of capacitor and rupture of valve sheet, leading to fault trip. Therefore, it is particularly important to analyze the potential segment characteristics of arrester in different operating environments [1-5].

Optical fiber current method is a common measurement method used to detect the equipotential section of the resistance valve plate of lightning arrester. By adopting the potential energy distribution method and using the finite element analysis method to construct the two-dimensional or three-dimensional model of the arrester and detection space, and the finite element mesh is divided into electrostatic field problem of electric field potential distribution [6-9]. Literature [10-12] has carried out theoretical analysis and practical verification of electric field potential distribution characteristics of arresters with different voltage levels, verified the validity of the simulation model, and proposed the internal electric field potential distribution characteristics with different voltage levels and different structures. However, after the deterioration of the resistance characteristics of the valve plate of the lightning arrester, the potential distribution is not tested or simulated.

In this paper, the optical fiber current method is used to conduct a series of tests on the potential distribution of uhv ac arrester in the case of local damping and local short circuit, and the corresponding ANSYS three-dimensional simulation model is established according to the actual structure and test method, which is used to calculate the potential distribution under the corresponding
test conditions. The consistency of test and simulation results verifies the correctness of the simulation model.

2. Test site and simulation model of arrester
The UHV AC arrester for laboratory testing established in this paper consists of 5 unit sections (numbered I, II, III, IV, V from top to bottom). The height of each arrester is 2100 mm, and there are 46 resistance valves in each arrester. The single resistive valve plate has the shape of a round cake with a radius of 52.5 mm and a height of 22.5 mm. Different resistance valve plates are connected by the same size aluminum connecting block. The internal structure and test layout of the arrester are shown in Figure 1.

![Figure 1. Test model of arrester.](image1)

Set up a laboratory of 30×30×20 (unit: m) to simulate the real use environment of the site. Using ANSYS 3D modeling technology, the internal structure of the true lightning arrester is established, which is used for the simulation and theoretical calculation of the experimental model. The model is shown in Figure 2.

![Figure 2. 3D model and air domain of arrester.](image2)

The SOLID123 module in the simulation software ANSYS is used as a modeling unit to assign a dielectric constant to each resistance valve unit of the arrester. The hexahedral mesh represents the body area of the arrester and the air area, respectively, because the electric field distribution of the metal material is zero in the electrostatic field, and the surface potential of the metal conductor is the same, so neither the flange, the equalizing ring, the aluminum washer, and other metal conductors are present. As a calculation unit. The relative dielectric constants of the internal components of the arrester are shown in Table 1.

| Component                      | Relative permittivity |
|--------------------------------|-----------------------|
| Air                            | 1                     |
| Flange, gasket, etc.           | No meshing            |
| Porcelain casing               | 6                     |
| Epoxy rod                      | 3.8                   |
| ZnO resistance valve           | 585                   |

Finally, set the boundary conditions for the simulation model, apply the test voltage UT to the metal flange and the voltage equalizing ring on the arrester, apply 0V voltage to the outermost surface of the air region, the base and the bottom flange, and simulate the grounding condition. Finally, simulate the electrostatic field problem of the arrester.

3. Test and simulation under partial damp
During the continuous long-term operation of the arrester, the resistance valve and the metal flange seal will gradually deteriorate, resulting in water or moisture inside the arrester, which will be affected
by moisture and leakage current, which will affect the operating characteristics of the arrester. During the test, it was found that the glaze layer on the surface of the I, I, II resistance valve plate was gradually damaged under the condition of increasing temperature and humidity, and the equipotential voltage distribution of the arrester was tested and verified. The test results are shown in Tables 2 and 3, respectively.

Table 2. Test data of full current when damp in section I.

| Measuring point number | Section I | Section II | Section III | Section IV | Section V |
|------------------------|-----------|------------|-------------|------------|-----------|
| 1                      | 1.38      | 1.82       | 2.15        | 1.92       | 1.38      |
| 2                      | 1.39      | 1.92       | 1.99        | 1.84       | 1.40      |
| 3                      | 1.42      | 1.97       | 1.84        | 1.74       | 1.42      |
| 4                      | 1.45      | 2.05       | 1.66        | 1.67       | 1.45      |
| 5                      | 1.48      | 1.85       | 1.51        | 1.58       | 1.48      |
| 6                      | 1.51      | 1.66       | 1.38        | 1.51       | 1.51      |
| 7                      | 1.55      | 1.52       | 1.55        | 1.43       | 1.55      |
| 8                      | 1.59      | 1.39       | 1.61        | 1.35       | 1.59      |
| 9                      | 1.62      | 1.83       | 1.68        | 1.29       | 1.63      |

Table 3. Test data of full current when damp in section I & II.

| Measuring point number | Section I | Section II | Section III | Section IV | Section V |
|------------------------|-----------|------------|-------------|------------|-----------|
| 1                      | 1.71      | 1.72       | 2.47        | 1.92       | 1.84      |
| 2                      | 1.62      | 1.61       | 2.40        | 2.02       | 1.70      |
| 3                      | 1.64      | 1.62       | 2.33        | 1.99       | 1.61      |
| 4                      | 1.50      | 1.63       | 2.26        | 1.70       | 1.62      |
| 5                      | 1.66      | 1.64       | 2.20        | 1.42       | 1.63      |
| 6                      | 1.61      | 1.65       | 2.09        | 1.60       | 1.64      |
| 7                      | 1.61      | 1.66       | 2.00        | 1.80       | 1.65      |
| 8                      | 1.63      | 1.67       | 1.92        | 1.71       | 1.66      |
| 9                      | 1.64      | 1.69       | 2.06        | 1.72       | 1.67      |

The three-dimensional model of the arrester was used to simulate the field test. The water film with a thickness of 2 mm was applied to the surface of the I, I, and II resistors. The simulated electric field potential distribution of the symmetric cross section is shown in Figure 3 and Figure 4, respectively.

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Figure 5 and Figure 6 show the comparison of the electric field distribution obtained by modeling and simulation and the field distribution obtained by the resistive current method.
As shown above, the voltage distribution ratio of the electric field distribution in the arrester resistance valve plate is reduced, and the electric field distribution voltage of the other valve plate is increased to some extent, wherein the resistance plate has a large damping area and the voltage load is higher than the undamped resistance. In both cases, the electric field carrying voltage is the largest in Section III. Under the first section of the valve, the simulation result is 1.41, and the test result is 1.37. Under the first and second valve sections, the simulation result is 1.48, and the test result is 1.44. It can be seen that the overall potential distribution of the arrester is more uneven. If no effective measures are taken, it will lead to more performance and degradation of the resistance valve.

4. Test and simulation under partial short-circuit

According to the results of the simulation experiment, if the performance of the arrester resistance valve plate is deteriorated or severely attenuated, it is easy to cause the valve face to discharge or flash breakdown. According to the field test results, the electric field voltage distribution of the short circuit or the second section of the second section of the resistor valve is shown in Table 4 and Table 5.

| Measuring point number | Section I | Section II | Section III | Section IV | Section V |
|------------------------|-----------|------------|-------------|------------|-----------|
| 1                      | 1.73      | —          | 2.56        | 2.15       | 1.98      |
| 2                      | 2.02      | —          | 2.51        | 2.11       | 1.92      |
| 3                      | 2.58      | —          | 2.44        | 1.99       | 1.83      |
| 4                      | 2.72      | 2.88       | 2.41        | 1.98       | 1.88      |
| 5                      | 2.64      | 2.82       | 2.34        | 1.94       | 1.81      |
| 6                      | 2.54      | 2.72       | 2.27        | 1.80       | 1.72      |
| 7                      | 2.47      | 2.66       | 2.20        | 1.64       | 1.61      |
| 8                      | 2.20      | 2.54       | 2.11        | 1.56       | 1.45      |
| 9                      | 1.99      | 2.64       | 2.03        | 1.48       | 1.38      |

| Measuring point number | Section I | Section II | Section III | Section IV | Section V |
|------------------------|-----------|------------|-------------|------------|-----------|
| 1                      | 3.85      | —          | 4.82        | 4.31       | 2.61      |
| 2                      | 4.27      | —          | 4.80        | 4.1        | 2.45      |
| 3                      | 4.43      | —          | 4.61        | 4          | 2.38      |
| 4                      | 4.15      | —          | 4.64        | 3.8        | 2.3       |
| 5                      | 4.07      | —          | 4.48        | 3.66       | 2.15      |
| 6                      | 3.98      | —          | 4.20        | 3.3        | 2.09      |
| 7                      | 3.92      | —          | 4.09        | 3          | 1.99      |
| 8                      | 3.76      | —          | 3.81        | 2.8        | 1.9       |
| 9                      | 3.55      | —          | 3.61        | 2.7        | 1.81      |
According to the field test, the second quarter arrester resistance valve piece and the second section arrester valve piece are sequentially set as the high voltage conductor in the model to obtain the electric field potential distribution characteristics of the axisymmetric section, as shown in Fig. 7 and Fig. 8 respectively.

Figure 7. Potential contour when 1/3 short-circuit in section II.

Figure 8. Potential contour when overall short-circuit in section II.

Potential distribution when 1/3 short-circuit in section II and Potential distribution when overall short-circuit in section II are shown in figure 9 and figure 10, respectively.

Figure 9. Potential distribution when 1/3 short-circuit in section II.

Figure 10. Potential distribution when overall short-circuit in section II.

As shown above, the resistance valve plate in which the short circuit occurs in the arrester body has a voltage distribution of 0; and the voltage distribution of the remaining resistance valve plate is increased to different extents. The distribution voltage can be seen in the second section of the arrester resistor valve as shown in Section II. The simulation result was 1.72 and the test result was 1.66. If the second section of the resistor valve is short-circuited as a whole, the maximum voltage distribution is shown in the third section. The simulation result is 2.17 and the test result is 1.94.

5. Conclusion

Based on modeling simulation and measured results, ANSYS simulation software is used to construct the electric field voltage distribution calculation model of UHV arrester, and simulate the potential distribution of the arrester resistance valve in different situations such as damp, flashover and final breakdown. The following conclusions are drawn:

1) Partial deterioration of the arrester resistor valve will result in a decrease in insulation performance, so that the same section of the arrester resistor will bear the voltage increase. When the damping area is large, the electric field voltage distribution of the end resistor valve is higher, and the maximum load voltage drop is higher than the normal load. High, and the overall potential distribution of the resistance valve is more uneven;
2) The short-circuiting resistor valve shares the electric field voltage to 0, so that the same section of the arrester resistor takes up the voltage. When there are more short-circuited valves, the other parts of the valve take the higher voltage. The maximum voltage carrying ratio is much higher than the maximum voltage carrying ratio during normal operation;

3) Under the theoretical simulation results and different test conditions, the obtained electric field voltage distribution results of the resistance valve are basically the same, which can explain that the simulation model constructed in this paper can simulate the field measurement conditions more realistically.

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