Test and Simulation of Potential Distribution of UHV AC Arrester under Different Conditions

Pipei ZHANG*, Wei SHI, Hui WANG, Jingwen SUN and Peng WANG
State Grid Shandong Electric Power Research Institute, Jinan 250003, China

E-mail: sddky_zpp@163.com Tel: 0531-67982649

Abstract. UHV AC arresters will be degraded to varying degrees due to the operating environment, including long-term moisture, breakdown and short circuit of the resistor, which makes the increasing unevenness of potential distribution, leading to a larger area of damage and even a safety accident such as arrester explosion. Hence it’s need to analyze the potential distribution of arrester under different conditions. This article carried out a series of tests of the potential distribution of UHV AC arresters when partial damp and partial short -circuit using optical fiber current method, and established the corresponding ANSYS 3D simulation model according to the actual structure and the test method, which is used to calculate the potential distribution under the corresponding test conditions. The consistency of the test and simulation results verified the correctness of the simulation model.

1. Introduction
UHV AC arrester (hereafter referred to as ‘arrester’) is the main overvoltage protection device in UHV substation. However, due to the influence of the operating environment, arrester will undergo different degrees of deterioration during long-term operation, resulting in a more uneven potential distribution and a larger area of damage, so it is necessary to analyze the potential distribution of arrester under different conditions[1-5].

The optical fiber current method is currently the main test method for measuring the potential distribution of arresters. While, the potential distribution simulation mainly uses the finite element method to establish a 2D or 3D model of the arrester and the test space and divide the finite element mesh, and the potential distribution problem is transformed into an electrostatic field problem[6-9]. It was tested and simulated in [10-12] that the potential distribution of arresters with different voltage levels, which verified the rationality of the simulation model, and also analyzed the potential distribution under different voltage equalization structures. However, there is a lack of testing or simulation analysis of the potential distribution after the arrester has deteriorated.

This article carried out a series of tests of the potential distribution of UHV AC arrester when partial damp and partial short-circuit using optical fiber current method, and established the corresponding ANSYS 3D simulation model according to the actual structure and the test method, which is used to calculate the potential distribution under the corresponding test conditions. The consistency of the test and simulation results verified the correctness of the simulation model.

2. Test site and simulation model of arrester
UHV AC arrester used in this test consists of 5 arrester sections connected in series (numbered Ⅰ, Ⅱ, Ⅲ,Ⅳ, V from top to bottom). The height of each section is 2100mm, and there is a single column with
46 resistors in each section. Resistors are shaped like cakes, with a diameter of 105mm, thickness of 22.5mm, and the resistors are connected by aluminum gaskets of the same size. The internal structure and test site of the arrester are shown in Figure 1.

Figure 1. Structure and test of the arrester.

According to the actual structural size of the arrester, the ANSYS 3D simulation model is established, and a rectangular outer air domain of 30000 × 30000 × 20000 (unit: mm) was established to simulate the air area of the external space of the test site, as shown in Figure 2.

SOLID123 in ANSYS is selected as the analysis unit to assign the relative permittivity of each component of the arrester, and the tetrahedral mesh is divided into the arrester and the air region. Since the electric field inside the metal conductor is 0 in the electrostatic field, and the surface potential of the metal conductor is equal, the metal conductor does not participate in the meshing, and the node potential is coupled with the degrees of freedom in the surface of the component such as a flange, a grading ring, an aluminum gasket, etc. The relative permittivity of each component of the arrester is shown in Table 1.

| Component          | Relative permittivity |
|--------------------|-----------------------|
| Air                | 1                     |
| Flange, gasket, etc.| No meshing            |
| Porcelain sleeve   | 6                     |
| Insulation pole    | 3.8                   |
| ZnO resistor       | 585                   |

Finally, the boundary condition is applied to the 3D model, and the test voltage $U_T$ of the arrester is applied to the uppermost flange and the grading ring, and 0V is applied to the outermost surface of the air area, the base and the bottom flange. Then an electrostatic field can be solved for the arrester.

3. Test and simulation under partial damp
During the long-term operation of the arrester, the resistor and the sealing component will gradually deteriorate, causing the damp of the resistor. In the field test, the surface glaze layers of the resistor in section I, section I & II were destroyed in a high temperature and high humidity environment successively, so that the potential distribution test of the arrester under partial damp was carried out. The measurement results are shown in Table 2 and Table 3.
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                      | 1.39      | 1.83       | 2.16        | 1.93       | 1.38      |
| 2                      | 1.41      | 1.91       | 1.99        | 1.84       | 1.40      |
| 3                      | 1.43      | 1.98       | 1.84        | 1.75       | 1.42      |
| 4                      | 1.46      | 2.06       | 1.67        | 1.67       | 1.45      |
| 5                      | 1.49      | 1.84       | 1.51        | 1.59       | 1.48      |
| 6                      | 1.51      | 1.67       | 1.38        | 1.51       | 1.51      |
| 7                      | 1.56      | 1.51       | 1.54        | 1.43       | 1.55      |
| 8                      | 1.60      | 1.38       | 1.61        | 1.36       | 1.59      |
| 9                      | 1.63      | 1.84       | 1.67        | 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                      | 1.70      | 1.73       | 2.48        | 1.91       | 1.85      |
| 2                      | 1.61      | 1.61       | 2.40        | 2.02       | 1.70      |
| 3                      | 1.63      | 1.62       | 2.33        | 1.99       | 1.61      |
| 4                      | 1.50      | 1.63       | 2.26        | 1.70       | 1.62      |
| 5                      | 1.67      | 1.64       | 2.20        | 1.42       | 1.63      |
| 6                      | 1.60      | 1.65       | 2.09        | 1.60       | 1.64      |
| 7                      | 1.61      | 1.66       | 2.00        | 1.80       | 1.65      |
| 8                      | 1.62      | 1.67       | 1.92        | 1.71       | 1.66      |
| 9                      | 1.63      | 1.69       | 2.06        | 1.72       | 1.67      |

Following the field test method, the surface of resistor in section I, section I & II was covered with a water film with a thickness of 2mm successively in the 3D model of arrester, and the potential distribution of the axisymmetric section was obtained as shown in figure 3 and figure 4.

![Figure 3. Potential contour when damp in section I.](image1)

![Figure 4. Potential contour when damp in section I & II.](image2)

The voltage bearing ratio calculated by the simulation is shown in figure 5 and figure 6 together with the voltage bearing ratio calculated by the optical fiber current method in the field test.
Figure 5. Potential distribution when damp in section I.

Figure 6. Potential distribution when damp in section I & II.

It can be seen that the voltage bearing ratio of the resistor in damp part is reduced, and the voltage bearing ratio of the other resistor is raised to some extent, where the damp area is larger, the voltage bearing ratio of the undamped resistor is higher. In both cases, the maximum voltage bearing ratio appears in section III. When damping in section I the simulation result is 1.41 and the test is 1.37, and when damping in section I & II the simulation result is 1.48 and the test is 1.44. The overall potential distribution is more uneven, and if not processed in time, it will cause more resistors to deteriorate.

4. Test and simulation under partial short-circuit
When the resistor is damped or deteriorated severely, a creeping discharge or even a breakdown of the resistor may occur, and the resistor is corresponding to a short-circuit state. In the field test, one-third of the resistors in section II, the overall section II were short-circuited by short wiring successively, and the measurement results are shown in table 4 and table 5.

| Measuring point number | Section I | Section II | Section III | Section IV | Section V |
|------------------------|-----------|------------|-------------|------------|-----------|
| 1                      | 1.74      | —          | 2.57        | 2.16       | 1.99      |
| 2                      | 2.03      | —          | 2.5         | 2.10       | 1.91      |
| 3                      | 2.59      | —          | 2.45        | 1.99       | 1.84      |
| 4                      | 2.71      | —          | 2.40        | 1.97       | 1.87      |
| 5                      | 2.64      | 2.88       | 2.33        | 1.94       | 1.80      |
| 6                      | 2.54      | 2.82       | 2.27        | 1.80       | 1.72      |
| 7                      | 2.47      | 2.72       | 2.20        | 1.64       | 1.61      |
| 8                      | 2.20      | 2.66       | 2.11        | 1.56       | 1.45      |
| 9                      | 1.99      | 2.60       | 2.03        | 1.48       | 1.38      |

| Measuring point number | Section I | Section II | Section III | Section IV | Section V |
|------------------------|-----------|------------|-------------|------------|-----------|
| 1                      | 3.84      | —          | 4.81        | 4.3        | 2.6       |
| 2                      | 4.28      | —          | 4.80        | 4.1        | 2.46      |
| 3                      | 4.42      | —          | 4.61        | 4          | 2.38      |
| 4                      | 4.16      | —          | 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      |
Following the field test method, one-third of the resistors in section II, the overall section II were set as suspension conductors successively in the 3D model of arrester, and the potential distribution of the axisymmetric section was obtained as shown in figure 7 and figure 8.

![Figure 7. Potential contour when 1/3 short-circuit in section II.](image)

![Figure 8. Potential contour when overall short-circuit in section II.](image)

The voltage bearing ratio calculated by the simulation is shown in figure 9 and figure 10 together with the voltage bearing ratio calculated by the optical fiber current method in the field test.

![Figure 9. Potential distribution when 1/3 short-circuit in section II.](image)

![Figure 10. Potential distribution when overall short-circuit in section II.](image)

It can be seen that the voltage bearing ratio of the short-circuit part becomes 0, and the voltage bearing ratio of the other resistor has different degrees of rise, where the short-circuit area is larger, the voltage bearing ratio of the un-damped resistor is higher. The maximum voltage bearing ratio appears in section II when one-third short-circuit in section II, where the simulation result is 1.72 and the test is 1.66. The maximum voltage bearing ratio appears in section III when overall short-circuit in section II, where the simulation result is 2.17 and the test is 1.94.

5. Conclusion
In this paper, based on the combination of simulation and experiment, according to the processing method of UHV AC arrester in field test, the corresponding simulation model was established in
ANSYS, and the potential distribution of UHV AC arrester when partial damp and partial short-circuit was analyzed. The conclusions reached are:
1) The voltage bearing ratio of the resistor in damp part is reduced, and the voltage bearing ratio of the other resistor is raised to some extent, where the damp area is larger, the voltage bearing ratio of the un-damped resistor is higher. The maximum voltage bearing ratio is slightly higher than that during normal operation and the overall potential distribution is more uneven;
2) The voltage bearing ratio of the short-circuit part becomes 0, and the voltage bearing ratio of the other resistor has different degrees of rise, where the short-circuit area is larger, the voltage bearing ratio of the un-damped resistor is higher. The maximum voltage bearing ratio is much higher than that occurs during normal operation;
3) The measurement results of potential distribution under various test conditions are basically consistent with the simulation results, indicating that the simulation modal under different operating conditions established in this paper can simulate the actual situation realistically.

References
[1] LI X J 2008 Analyzing the basic parameters of currents of metal oxide surge arrester High Voltage Engineering 34(1) 37-39
[2] YIN X K, SHAO T and GAO X 2002 Present state and future of detecting methods of MOA High Voltage Engineering 28(6) 34-36
[3] GU D X, WANG B S and LI Z Q 2012 Feasibility of lowering the rated voltage of 1000kV substation MOA High Voltage Engineering 38(2) 295-302
[4] HU S H 2016 Research on Pole Bus Metal Oxide Surge Arrester for ±800kV UHVDC Converter Station High Voltage Apparatus 34(8) 34-45
[5] CHEN J, GUO J and QIU A C 2015 Experimental investigation on the response characteristics of metal oxide varistors under very fast transient overvoltage Proceedings of the CSEE 35(13) 3436-42
[6] SUN H and LI X W 2009 Study of the influence of mounting height on the potential distribution for zinc oxide arrester Electrical Engineering 12 13-16
[7] MA Y, GUO J and JIAO L X 2015 Study on the influence of the grading ring structure on potential distribution of MOA for 750kV AC system Insulators and Surge Arresters 1 139-143
[8] ZHU Y, ZHANG J F and GUO J 2016 Study on the influence of grading shunt capacitors configuration on potential distribution in UHV MOA without gap Insulators and Surge Arresters 2 140-144
[9] WU L 2015 Study on the potential distribution testing method for arresters Insulators and Surge Arresters 3 110-114
[10] Han S J, Zou J and He J L 2005 Calculation of the potential distribution of high voltage metal oxide arrester by using an improved semi-analytic finite element method IEEE Trans on MAG 41(5) 1392-95
[11] SUN H and LI X W 2010 Finite element calculation and experiment of potential distribution for a 500kV porcelain zinc oxide arrester High Voltage Apparatus 46(3) 23-27
[12] CHE W J, CHIBA T and ZHANG X X 2009 Research on potential distribution characteristic 1000kV porcelain housed metal oxide surge arrester Proceedings of the CSEE 29(12) 53-57