Study on the Temperature Distribution of UHV Arrester Considering the Influence of Wind Speed and Sunlight

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Abstract. Infrared temperature measurement plays an important role in the live detection of UHV arrester with its advantages of high efficiency and accuracy. However, the surface temperature of arrester will be affected by wind speed, sunlight and other external factors, which brings certain difficulties to infrared temperature measurement and fault diagnosis. Based on the principle of finite element, this paper established a three-dimensional temperature field simulation model of UHV AC arrester coupled with thermoelectricity, so as to use the model to simulate and analyze the temperature distribution of arrester under the influence of different wind speed and sunlight. The results show that the increase of wind speed strengthens the air convection and heat dissipation, which makes the maximum surface temperature decrease and the temperature rise decrease due to the internal defect heating of the arrester; the surface temperature of the arrester increases with the increase of solar radiation intensity, and the temperature of the sunny side is higher than that of the back, but the change of temperature rise is not great. The conclusion can be used as a reference for infrared temperature measurement of arrester in nonideal environment.

1. Introduction
UHV AC zinc oxide arrester is an important over-voltage protection equipment in UHV substation, which is generally arranged at the main transformer and outgoing line side of GIS [1]. When the resistance inside the arrester is damped and deteriorated, the surface temperature characteristics will change, so that the operation condition of the UHV arrester can be diagnosed by means of infrared temperature measurement [2]. However, the arrester belongs to the voltage heating type equipment, which has the characteristics of small calorific value and low surface temperature rise, and its surface temperature is also affected by external environmental factors, such as light intensity, wind power, etc., which will inevitably bring difficulties to infrared temperature measurement and fault diagnosis. If waiting for the appropriate environmental conditions, the working efficiency will be reduced, or even the defects will not be found in time, so it is necessary to study the internal and external temperature distribution characteristics of UHV arrester under the influence of environmental factors.

Literature [3-5] combined with several examples of arrester fault, summarized the infrared diagnosis method of arrester internal defects, and verified the effectiveness and importance of infrared temperature measurement technology in the diagnosis of arrester internal defects. In [6,7], the temperature rise of the internal resistor of the arrester when it was damped, aged or broken down was tested and analyzed by using the optical fiber sensor, and the temperature rise characteristics of the internal resistor column under various conditions were summarized. However, the temperature characteristics reflected on the surface of the porcelain sleeve when the internal resistor was
deteriorated were not monitored and analyzed in the test. Moreover, the temperature rise test cycle of arrester is long and with many error factors, and it is impossible to simulate the outdoor field operation environment. If the simulation software can be used to establish the calculation model of arrester temperature field which comprehensively considers the influence of wind speed, sunlight and other factors, it can quickly and accurately study and analyze the internal and external temperature distribution of arrester under the influence of external environment factors.

In this paper, a three-dimensional temperature field simulation model of UHV AC arrester was established. Then the solar radiation and wind speed were transformed into the corresponding boundary conditions and applied to the temperature field simulation model, so as to analyze the temperature distribution of UHV arrester under the influence of external environmental factors.

2. Temperature distribution simulation model of UHV arrester

When the surface of the arrester is clean, the leakage current on the surface of the porcelain sleeve can be ignored, and the zinc oxide resistor is the main heat source inside the arrester.[8,9] The heat generated is mainly divided into two parts: leakage current and dielectric loss, whose expressions are,

\[ P_i = \frac{U^2}{R} \]  \hspace{1cm} (1)
\[ P_j = U \alpha \cot \delta \]  \hspace{1cm} (2)

Where, \( P_i \) and \( P_j \) are the heat generated by the leakage current and dielectric loss of the resistor, \( R \) and \( C \) are the equivalent resistance and capacitance under the insulating state of the ZnO Resistor, \( \delta \) is the dielectric loss angle of the resistor, \( U \) is the voltage borne by the resistor, and \( \omega \) is the frequency.

Carry out the electric field simulation of the arrester, and take the total calorific value \( P = P_i + P_j \) of the resistor obtained by formula (1) and formula (2) as the excitation source of the temperature simulation, the simulation results of the internal and external temperature distribution of the arrester can be further obtained.

The three-dimensional temperature field simulation model of UHV arrester thermoelectric coupling established is shown in figure 1, which is mainly composed of grading ring, 5 series arrester sections and base. The electrical and thermal material properties of each component of arrester are shown in table 1 [10]. At the same time, the external temperature is set as 10°C, the convective heat transfer coefficient between the external surface of the arrester and the external air is 5 W/m²·°C, and the continuous operation voltage of 638kV is applied at the high-voltage end of the arrester. The internal and external temperature distribution of the arrester when the normal operation and the overall deterioration of the second section resistor achieved is shown in figure 2 and figure 3.

![Figure 1. 3D temperature simulation model.](image)
Table 1. Material property of each component

| Component     | Relative permittivity | Thermal conductivity (W/m²·°C) |
|---------------|------------------------|-------------------------------|
| Air           | 1                      | 1.002                         |
| Porcelain sleeve | 4.3                  | 1.163                         |
| Metal         | 5000                   | 1500                          |
| Resistor      | 585                    | 49                            |

It can be seen that when the arrester is in normal operation, the temperature distribution on the outer surface is relatively uniform, the maximum temperature is 17.7°C, and the temperature rise is less than 0.2K. The maximum temperature of the internal resistance piece is 27.5°C, the temperature of the second section and the third section is higher than that of the other three sections as a whole, which is caused by the uneven voltage distribution. The second section and the third section bear higher voltage, so the temperature is higher (the function of the grading ring prevents the first section from bearing higher voltage). And the temperature of the resistor in the middle of each section is higher than that of the resistor at both ends, which is caused by the heat dissipation of the metal flange at both ends.

When the second section of the arrester is deteriorated as a whole, the first section and the third section have local high temperature. This is because the voltage of the deteriorated resistor is reduced, making the adjacent two sections bear higher voltage, resulting in the temperature rise. At this time, the maximum temperature of the external surface of the arrester is 20.4°C, and the temperature rise is about 2.3K; the maximum temperature of the internal resistor is 42.1°C, and the temperature rise is about 23.4K.

3. The influence of wind speed on the temperature distribution of arrester

The influence of wind speed on the temperature distribution of arrester is mainly reflected in the convective heat transfer between the outer shell of arrester and the outside air. The surface heat transfer coefficient $h$ (W/m²·°C) is used as a parameter to characterize the convective heat transfer intensity, and its numerical value can be approximately considered to be directly proportional to the wind speed $v$(m/s), and the relationship is [11]

$$h = 5.0 + 4.7v$$

(3)
According to the corresponding relationship in formula (3), when the wind speed is 1, 3, 6 and 9 (unit: m/s), the temperature distribution under the overall deterioration of the second section of the UHV arrester is simulated. The simulation results of the surface temperature under various wind speeds are shown in figure 4.

![Temperature distribution of arrester surface under different wind speeds](image)

**Figure 4.** Temperature distribution of arrester surface under different wind speeds.

In order to observe the temperature difference of arrester surface under different wind speeds, the same temperature scale is used in the temperature gradient diagram shown in figure 4. It can be seen that with the increase of wind speed, the smaller the color difference of arrester surface temperature gradient map, which means the smaller the surface temperature difference. From the simulation results, the hot spot temperature of the arrester, the reference temperature (the surface temperature of the porcelain shell in the non-heating area) and the temperature rise are obtained and shown in table 2. With the increase of wind speed, the convective heat dissipation of air is strengthened, and the maximum surface temperature and temperature rise caused by internal heating are reduced under the same deterioration degree of the arrester. When the wind speed reaches 9m/s, the maximum temperature difference on the surface of the arrester is 0.5K, and the arrester belongs to the equipment of voltage induced heat. The defect judgment value of infrared temperature measurement is that the temperature rise is greater than 0.5-1K. If the infrared temperature measurement is carried out under the wind speed greater than or equal to 9 m/s, it may be difficult to find the defect simulated in this paper.

| Wind speed (m/s) | Hot spot temperature (℃) | Reference temperature (℃) | Temperature rise (K) |
|------------------|--------------------------|---------------------------|----------------------|
| 1                | 20.4                     | 18.1                      | 2.3                  |
| 3                | 19.7                     | 18.1                      | 1.6                  |
| 6                | 19.1                     | 18.2                      | 0.9                  |
| 9                | 18.7                     | 18.2                      | 0.5                  |

4. The influence of sunlight on the temperature distribution of arrester

The sun transmits energy to the arrester through radiative heat transfer, which affects the temperature distribution on the arrester surface. In order to simulate the solar radiation in the simulation model, ASHRAE sunny day model recommended by American Society of Heating, Refrigeration and Air Conditioning Engineers is adopted in this paper, and its expression is [12]
In the formula, $I_{DN}$ is the solar radiation intensity value (unit: w/m$^2$) of the earth surface on a clear day, $A$ is the solar radiation under zero atmospheric mass, $B$ is the extinction coefficient of the atmosphere, and $\alpha$ is the solar altitude angle. For the convenience of calculation, the scattering radiation from the atmosphere and the reflection radiation from the earth's surface are ignored in this paper, so the solar radiation intensity obtained from equation (4) can be applied to the outer surface of the arrester according to the second kind of boundary conditions.

Figure 5 (a)–(c) shows the simulation results of the temperature distribution on the sunny side of the second section of the UHV arrester when the solar radiation intensity is 100, 200 and 400(unit: w/m$^2$) respectively under the same temperature scale. It can be seen that with the increase of solar radiation intensity, the overall surface temperature of the arrester towards the sun is higher, while the temperature difference between the heating area and other areas is still obvious.

![Temperature distribution of arrester under different sunlight](image)

**Figure 5.** Temperature distribution of arrester under different sunlight.

When the second section of UHV arrester is deteriorated as a whole, the simulation results of temperature distribution on the dorsal side of the arrester are basically the same under different solar radiation intensities, since the temperature scale is consistent with the sunny side, the overall color is darker, but the relatively obvious heating area can also be seen. It can also be seen from the hot spot temperature, reference temperature and temperature rise data of arrester surface temperature given in table 3 that although the maximum value of arrester surface temperature is affected by solar radiation intensity and whether it is sunny or not, the temperature rise does not change much. Therefore, in infrared temperature measurement, it is important to pay attention to the temperature rise rather than the maximum value of temperature, which can basically eliminate the influence of light and accurately identify the internal defects of arrester.

| Direction     | Solar radiation intensity (W/m$^2$) | Hot spot temperature (°C) | Reference temperature (°C) | Temperature rise (K) |
|---------------|------------------------------------|---------------------------|----------------------------|---------------------|
| Sunny side    | 100                                | 19.9                      | 18.0                       | 1.9                 |
|               | 200                                | 20.5                      | 18.7                       | 1.8                 |
|               | 400                                | 22.2                      | 20.2                       | 2.0                 |
| Dorsal side   | —                                  | 19.5                      | 17.6                       | 1.9                 |

**Table 3.** Simulation data of arrester surface temperature under different sunlight.
5. Conclusion
In this paper, a three-dimensional thermo electric coupling model of UHV arrester is established. The temperature distribution of the arrester under normal and internal deterioration conditions is simulated. And the temperature distribution of the arrester under the influence of different wind speed and light is calculated by using the model. The conclusion is as follows:

1) The increase of wind speed strengthens the air convection and heat dissipation, which makes the maximum surface temperature drop and temperature rise decrease when defect heating in the internal of the arrester, even lower than the judgment threshold of the arrester's infrared temperature measurement defect. Therefore, if the infrared temperature measurement is carried out when the wind speed is high, it may be difficult to find the defect in time;

2) The surface temperature of the arrester increases with the increase of the solar radiation intensity, and the sunny side is higher than the dorsal side, but the temperature rise has little change. Therefore, in the infrared temperature measurement, we should focus on the temperature rise rather than the maximum value of the temperature, which can basically eliminate the influence of light, and accurately identify the internal defects of the arrester.

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