Calculation and Analysis of DC Surge Arrester Temperature Field

Lina Geng¹, Juyong Cui ¹, Shuang Hao²*, Jing Li² and ShuXin Liu²

¹ Electric Power Research Institute of State Grid Liaoning Electric Power Co., Ltd, Shengyang, Liaoning, 110006, China
² Electric and Engineering Department, Shenyang University of Technology, Shenyang, Liaoning, 110870, China
*Corresponding author’s e-mail: 1499661403@qq.com

Abstract. Zinc oxide arresters have been widely used in high-voltage, ultra-high-voltage and ultra-high-voltage power transmission systems due to their excellent non-linear characteristics. However, because there is no gap between the arrester itself, there is a slight leakage current when the zinc oxide arrester is subjected to normal line voltage, which causes the aging of the zinc oxide resistance valve. The degree of aging and the rate of temperature rise are related to the temperature distribution, so it is of great significance to study the temperature field distribution of the DC arrester. This paper takes multi-column zinc oxide arrester as an example. According to the differential equation of heat transfer and the auxiliary equation, the simulation of time-varying temperature field is carried out. The simulation results are helpful to optimize the structure of multi-column parallel arrester and analyze the aging characteristics of valve.

1. Introduction
DC zinc oxide lightning arrester is one of the most important protective devices in HVDC and UHVDC systems. It can effectively prevent various faults produced by overvoltage [1]. But if the arrester endures normal working voltage for a long time, heat will be generated by the leakage current which is one of the reasons for aging of zinc oxide valve sheet. When the aging is serious, the arrester will lose its protection ability. Therefore, it is necessary to study the time-varying temperature characteristics of multi-column DC zinc oxide arrester under normal operating voltage.

Most work has been done on the transient thermal characteristics of arrester, but the analysis and calculation of temperature field of multi-column parallel arrester are relatively few. In reference [2] the temperature rise calculation is carried out by using the finite element model of multi-core parallel structure arrester. In addition, the temperature rise experiment and heat dissipation experiment are also carried out. In reference [3], the calculation methods of various physical quantities affecting the temperature change during the heat transfer process of metal oxide arrester (MOA) are given, and the thermal characteristic tests are carried out. In reference [4], the temperature simulation calculation of single-core gas insulated lightning arrester is carried out.

In this paper, the temperature rise and its distribution with time of YH20WDB1-188 DC arrester under normal non-impulse voltage are calculated. The results can be used to optimize the structure of multi-column arrester
2. Calculation Model of DC ZnO Arrester

2.1. MOA Model Parameters and Structure

Figure 1 is the structure of YH20WDB1-188 ZnO.

![Figure 1. Structural schematic diagram of lightning arrester.](image)

2.2. Basic Hypothesis and Mathematical Computing Model

The calculation is made by the coupling of electric field and temperature field, and the assumptions are as following:

1) Changes in material properties caused by temperature changes are not considered.
2) Ignore the influence of umbrella cover, corona ring and spring on heat dissipation[2].
3) The convective heat transfer coefficient is set to 5W/(m²·K)[4].

The parameters of the arrester coupling model are shown in Table 1.

| Resistor chip | Aluminum pad | Epoxy insulation |
|---------------|--------------|------------------|
| Conductivity/s m-1 | 0.000014 | 0.35 | 0 |
| Relative permittivity | 750 | 81 | 5.5 |
| Thermal conductivity/W·(mK⁻¹) | 52 | 236.5 | 0.32 |

The temperature of the arrester satisfies the following control differential equations:

\[
\frac{d}{dt}(\rho C_p) \nabla T + \frac{d}{dt}(\rho C_p) \mathbf{u} \cdot \nabla T + \mathbf{Q} = \frac{d}{dt}Q_0 + \frac{d}{dt}Q_{rod}
\]

\[q = -d_i k VT\]

Where \( \rho \) is the density of material, \( C_p \) is the heat capacity of material, \( T \) is the temperature of the object, \( \mathbf{u} \) is the velocity, \( q \) is the heat conduction rate, \( k \) is the thermal conductivity of the material, \( q_0 \) is heat source, \( Q_0 \) is convective heat flux.

The electric field equation is as follows:

\[
\nabla \cdot J = Q_{jv}
\]

\[
J = \left( \sigma + \varepsilon_0 \varepsilon_r \frac{\partial}{\partial t} \right) E + J_v
\]

\[E = -\nabla V\]

Where \( \sigma \) is the conductivity, \( \varepsilon_0 \) and \( \varepsilon_r \) are the vacuum permittivity and relative permittivity, \( J_v \) is the current density, \( E \) is the electric field strength, \( V \) is the potential.

The calculation model is shown in Figure 2, And The selected locations are shown in Figure 3 with three target points selected. From right to the bottom left are points 1, 2 and 3.
3. Analysation results

3.1. Calculation results of temperature distribution

The initial temperature in this paper is 283.15K, the voltage applied is 202 kV, and the loading time is 25 minutes. Figure 4 shows the temperature distribution of the arrester.

The simulation results show that the maximum temperature of the arrester is 338K, and the temperature of the upper part of the arrester core is obviously higher than that of the lower part. Which agrees with the operation experience. Figure 5 shows the time variation temperature rise curves at three locations. According to the temperature rise curve, the maximum temperature rise at the upper point 1 is 333.59K, and the maximum temperature rise at the lower point 3 is 326.58K. The difference between the two points is 7.01K.

Theoretically speaking, the area of the top and bottom resistors in contact the heat dissipation conditions are good, so the temperature rise in the middle should be greatest[5] which is also proved in reference [3] the distribution of the resistors in the arrester core is not symmetrical, so the above phenomenon does not occur.

3.2. Effect of Insulation Sleeve on Temperature Change of Surge Arrester

Then the temperature field of a single core is calculated. The three points that are the same as the overall position of the arrester are also selected and named as points 4, 5 and 6. The core is no longer enclosed in the sleeve. The comparison results of the temperature distribution between the single core body and the arrester and the temperature rise at different positions of the single core body are shown in Figure 6.
Compared with the arrester as a whole under the same conditions, the maximum temperature of the single core differs by 12K, and the temperature of the corresponding three points also drops by about 9K. So the insulating sleeve has a vital effect on the heat dissipation performance.

4. Conclusions
The following conclusions are obtained by calculating the time-varying temperature field of a DC zinc oxide arrester.

1. Under the action of non-impulse voltage, the overall temperature of the arrester rises linearly in 25 minutes, the upper point potential is large, the temperature is high, and the rate of temperature rise is the fastest. The rate of temperature rise from top to bottom is decreasing.

2. The simulation results show that the insulation sleeve of the arrester accelerates the temperature rise rate of the inner core and increases the temperature, which has a great hindrance to the heat diffusion of the inner core.

Acknowledgments
This work was supported by Research on Aging Performance and Charge Rate Optimization of DC Arrester (Grant No. 2018GW-06).

References
[1] Lu, J.X. (2013) Current situation and development trend of zinc oxide arrester [J]. Precise Manufacturing & Automation., 2:62-64.
[2] He, Z.M., Chen, W.J., C, X.J., Zhang, B.Y., Yan, X.L. (2012) Method for calculating transient thermal characteristics of multi-column core parallel structure arrester. High Voltage Technology., 38(8): 2129-2135.
[3] Sang, J.P., Wu, L., Liu, Y.W., Yu, L.L. Study on the Thermal Characteristic of Polymeric Housed MOA without gap. (2015) Insulators and Surge Arresters., 3: 62-68.
[4] Oliver, F., Marlene, L., Bernhard, Dr.(2011) Heat Transfer in High-Voltage Surge Arresters. In: Proceedings of the 2011 COMSOL Conference. Stuttgart pp.109-112.
[5] Lee, S.B., Lee, S.Ju, Bok-Hee Lee. (2010) Analysis of thermal and electrical properties of ZnO arrester block. Current Applied Physics., 109(1): 176-180.