Analysis of the mechanism of thermal collapse of MOA valve plates caused by multiple lightning strikes

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Abstract. Multiple lightning strikes are a common phenomenon in nature, and their impact on the power system cannot be ignored. MOA is an important device for lightning protection in power systems, but under certain conditions multiple lightning strikes can cause thermal collapse of MOA. In order to study the mechanism of the thermal collapse of MOA valve plates caused by multiple lightning strikes, a microscopic model of zinc oxide crystals was established, the heat transfer performance of zinc oxide crystals was simulated, and the temperature field when the size of zinc oxide crystals and the area of the grain boundary layer was different were compared. In this paper, the mechanism for the thermal collapse of the MOA valve due to thermal stress was analyzed, and the reason why multiple lightning strikes are more likely to cause MOA energy overload than a single lightning strike was explained. This research provides reference for the selection and maintenance of MOA.

1. Introduction

Lightning is one of the main causes of power system failure. MOA is a kind of common lightning arrester. As an important equipment of power system lightning protection, MOA is responsible for absorbing and releasing lightning impulse energy. Line arresters protect electrical equipment by limiting over-voltage, but in the actual operation of the arrester, due to the long-term effect of lightning, the valve may be aging. When the lightning energy is too high, it may cause the arrester to thermal collapse and damage, and multiple lightning has higher energy than single lightning, which is more likely to cause the arrester damage[1]. At present, the material of MOA valve is mainly zinc oxide. Therefore, this paper simulates the temperature field of zinc oxide crystal from the micro point of view, analyzes the mechanism of MOA valve thermal collapse caused by lightning strike, and explains the reason why multiple lightning strikes have greater impact on MOA than single lightning strike.

2. Harm of lightning strike to power system

In the process of lightning discharge, it will produce strong electromagnetic effect, thermal effect and mechanical effect, which will cause great hidden danger to the safety and the stability of operation of electrical equipment. As mentioned above, for example, the induced overvoltage caused by lightning to ground discharge will cause flashover or breakdown of electrical equipment insulation. When the lightning current passes through the conductor, it will produce a lot of heat, which may lead to the broken strand of the transmission line. The mechanical effect of lightning cloud to ground discharge may lead to the splitting of line cross arm.
As an important lightning protection equipment, MOA can absorb overvoltage energy and limit overvoltage amplitude when lightning strikes. MOA is installed near the protected equipment in parallel with the protected equipment when in use. Because of the good non-linear volt ampere characteristics of ZnO, the current flowing through the arrester is very small under normal working voltage. When overvoltage acts, the resistance drops sharply, releasing the energy of overvoltage to achieve the effect of protection. After releasing the overvoltage energy, the arrester will automatically return to the normal working state with a non-conducting state[2].

However, due to the long-term effect of lightning, the zinc oxide valve of MOA will be aging. When the aging degree reaches a certain threshold, MOA may be damaged by thermal collapse when it is struck by lightning again. According to some data statistics, 80% - 85% of the lightning in lightning location system contain two or more return strokes, and the subsequent multiple return strokes with large amplitude will further increase the energy through MOA, and the influence of multiple lightning strokes on the aging and damage of MOA zinc oxide valve is more obvious[3].

3. Analysis of thermal collapse mechanism of MOA

The literature [1] shows that after the MOA zinc oxide valve is subjected to the impact current impulses, the ZnO crystal was observed by electron microscope that the ZnO crystal became smaller and the grain boundary layer became more than that before impulses. Therefore, we analyzed the thermal breakdown mechanism of MOA from the microscopic point of view.

3.1. Simulation of temperature field of ZnO crystal

The main component of MOA valve is zinc oxide. We established the micro model of zinc oxide crystal to study its heat transfer characteristics[5]. The crystal structure of ZnO is hexahedral, with cell parameters of 3.253nm and 5.207nm. When establishing the micro model of zinc oxide crystal, take one zinc oxide crystal as the center, extend four layers of zinc oxide crystal outward, a total of 61 zinc oxide crystals. The schematic diagram of the model is shown in Figure 1.

Due to the decrease of ZnO crystal size and the increase of grain boundary layer after lightning stroke, a thin layer is set between ZnO crystals to simulate grain boundary layer, and the crystals are separated to simulate the change of crystal size. The microscopic model of ZnO crystal after the impulses is shown in Figure 2.

When the MOA valve is struck by lightning, the current will concentrate on a few paths with high nonlinear coefficient of volt ampere characteristic of grain boundary layer, which will lead to local overheating of MOA valve. In order to study the difference of heat transfer performance of ZnO crystal with different crystal size and grain boundary layer area, the temperature of ZnO crystal in the center of Fig. 1 and Fig. 2 is set at 403.15K to simulate the overheating of some crystals caused by current concentration path, and the temperature of ZnO crystal in other positions is set at 293.15K as a
normal atmospheric temperature. Taking $1 \times 10^{-5} \mu s$ as the time interval, the heat transfer in $5 \times 10^{-4} \mu s$ of the models in Fig. 1 and Fig. 2 were studied respectively. And we have got the simulation result. For example, Fig. 3 and Fig. 4 show the temperature distribution of the two crystal models at the time of $2 \times 10^{-4} \mu s$ and $4 \times 10^{-4} \mu s$. It can be seen that there are differences in heat transfer between the two crystal models.

![Figure 3](image1.png)  
**a) Before the impulses**

![Figure 4](image2.png)  
**b) After the impulses**

Figure 3. ZnO crystal model’s temperature distribution at the time of $2 \times 10^{-4} \mu s$
Within $5 \times 10^{-3} \mu s$, with $1 \times 10^{-3} \mu s$ as the time interval, the maximum temperature changes of the two crystal models at each time are shown in Figure 5. It can be seen that after the impulses, the local temperature transfer is slower and the time of local heat concentration is longer than before in the crystal model of decreasing crystal size and increasing grain boundary layer area.
3.2 Thermodynamic analysis

From the microscopic point of view, the thermal stress $f$ between the two elements of ZnO crystal can be calculated by the following formula:

$$f = \frac{E\alpha}{1-\mu}(\Delta T_1 - \Delta T_2)$$  \hspace{1cm} (1)

Where $E$ is the elastic coefficient of the material, $\alpha$ is the coefficient of thermal expansion, $\mu$ is the Poisson ratio, $\Delta T_1$ and $\Delta T_2$ are the temperature rise of two adjacent units, which can also be understood as the temperature difference between the two ZnO crystals.

Because the research object is the micro crystal of MOA valve plate, the elastic coefficient, thermal expansion coefficient and Poisson ratio can be regarded as invariants. The temperature difference between the crystals directly determines the thermal stress. In the simulation model of 2.1, the central crystal simulates the current concentration path in the MOA valve. When lightning strikes pass through the MOA, the central crystal will generate a lot of heat higher than other crystals through a large amount of energy. Compared with the heat transfer characteristics before and after impulses, we found that the heat transfer between the crystals is slower when the crystal becomes smaller and the grain boundary area increases, which leads to the local high temperature not spreading in time. The value of $(\Delta T_1 - \Delta T_2)$ is larger. When the thermal stress inside the MOA valve reaches the threshold value, the thermal collapse occurs. Therefore, the decrease of ZnO crystal and the increase of grain boundary area can be regarded as the aging performance of MOA valve plate, because it makes the thermal stress inside MOA valve plate more easily reach the threshold of thermal collapse.

4. The influence of multiple lightning strikes on MOA

Compared with single lightning stroke, multiple lightning strokes are more likely to cause thermal collapse of MOA. Because multiple lightning strokes have multiple return strokes, although the amplitude of return stroke lightning current is not as large as that of the first lightning stroke, the time interval of multiple lightning current is millisecond level, and the rapid accumulation of energy generated by lightning current in a very short time is more likely to cause MOA energy overload, leading to valve deterioration or damage. The thermal collapse of MOA is very likely to occur when it occurs many times or the energy is overloaded seriously.
5. Conclusion
The main reason of MOA thermal collapse caused by lightning is that the local temperature of MOA zinc oxide valve is too high. When the local high temperature caused by lightning current is too late to diffuse, the thermal stress between crystal units reaches the threshold, and MOA thermal collapse occurs. However, MOA is affected by lightning current for a long time, which will lead to the decrease of ZnO crystal and the increase of the area of grain boundary layer. This is the performance of ZnO deterioration, which will make the local heat diffusion slower and the thermal stress between crystal units easier to reach the threshold. The energy generated by multiple lightning current is greater than that by single lightning, which is more likely to lead to energy overload or even thermal collapse of MOA valve.

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