Influence of typical composite insulators defects on axial temperature based on simulation analysis

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Abstract. In this paper, the finite element analysis software comsol is used to design two different defect models on the short-string composite insulator model, namely, the air gap defect and the mandrel-damp defect. The thermal field of composite insulators with two kinds of defects is simulated, and comparing the axial temperature gradient changes of mand-sheath interface under normal condition and under the condition of defects. The results show that local heating does not occur when the composite insulator contains an air gap defect without partial discharge.

Keywords: Composite insulator, Insulator defect, Thermal field simulation.

1. Introduction

With the wide application of composite insulator in power industry, the loss caused by its failure cannot be ignored. The internal defects of the composite insulators in some transmission lines lead to some breakdown and brittle break accidents, which seriously affect the transmission safety of the lines. Existing studies have shown that most of the composite insulators in these accidents have abnormal heating [1-4]. According to the research of North China Electric Power University [5], the causes of insulator heating can be roughly divided into the following three categories:

1) Long-term partial discharge causes fever.
2) Loss and heating caused by repeated polarization of water molecules in alternating electric field.
3) Joule heating caused by declining resistance due to aging of insulating medium.

The above three types of heat release mainly correspond to three different defects of composite insulators, which are poor mandrel-sheath bonding (air gap), mandrel dampness, and aging of insulating medium. In this paper, the heat transfer model is used to simulate the air gap defects without local discharge, and the Joule thermophysical field simulation is added into the model.

2. Simulation and Analysis of Axial Thermal Field of Composite Insulator without Partial Discharge Gap Defect

2.1. Axial thermal field simulation design of composite insulator without partial discharge gap defect

Local heating will seriously affect the insulator insulation performance in the long-term operation of composite insulators. According to the experimental study conducted by Cheng Yangchun [6] of North China Electric Power University, it is found that there are various causes of fever. When partial discharge occurs in the air gap of insulation material, heat accumulation is most likely to lead to local...
temperature rise of insulator. In this paper, the thermal field of composite insulators without partial discharge with air gap defects is simulated in the quasi-static domain to study the effect of air gap distortion on the axial temperature of the insulator.

The main parameters of short-string composite insulator are shown in Figure 1 and Table 1:

| Table 1. Three Scheme comparing. Short string composite insulator parameters. |
|-----------------------------|-----------------|-----------------|----------------|
| Length of mandrel          | Total length of fittings | Length of silicone sleeve | Length of insulator string |
| 376.8mm                    | 261.1mm          | 260.1mm          | 471.8mm          |

This paper applies 25kV voltage to the high voltage end of the fittings, zero potential to the low voltage end of the fittings. The intact short-string insulator models are processed when the interface air gap defects are designed. The insulator models are numbered as 1, 2. There is an air gap at the interface of insulator 2. The air gap positions of insulator 2 starts from the position of the first small umbrella at the high voltage end. The air gap data are shown in Table 2:

| Table 2. Material parameters. |
|-------------------------------|-----------------|-----------------|----------------|
| Insulator number             | The interface condition | Length of air gap | Diameter of air gap | Position of air gap |
| 1                             | Good condition   | 0mm             | 0mm             | -               |
| 2                             | Air gap          | 10mm            | 1mm             | 168.9mm         |

At the same time, the material parameters of each part of the composite insulator are modified to keep the dielectric constant of each part unchanged. According to the material warehouse parameters of COMSOL, other material parameters are shown in Table 3:

| Table 3. Interfacial air gap parameters. |
|-----------------------------|-------------------|-----------------|-------------------|
| Name                        | Electrical conductivity (S/M) | Coefficient of thermal conductivity (W/(m·K)) | Density (g/cm³) | Heat capacity at constant pressure (J/kg·K) |
| Silicone rubber             | 0.2*10⁻¹²         | 0.27            | 1.1              | 1700             |
| Epoxy resin                 | 0.71*10⁻¹²        | 0.2             | 2                | 1000             |
| Carbon structural steel     | 0.125*10⁻⁸        | 45              | 7.85             | 470              |
| Air                         | 0.2*10⁻¹²         | 0.0267          | 0.0013           | 1003             |
Adding the boundary conditions of the solid heat transfer module and the initial temperature of all subdomains and boundaries in the domain is set at 293.15K (20°C). It was assumed that the convective heat transfer coefficient between the insulator and the external air was a fixed value, \( h = 5 \text{W/(m}^2\text{*K)} \).

### 2.2. Simulation of axial thermal field of composite insulator with air gap without partial discharge

Conducting the temperature simulation on No.1 insulator, the temperature cloud image and the temperature gradient at the mandrel interface were obtained as shown in Figure 2:

![Temperature Cloud Image and Temperature Gradient](image)

(a) The overall temperature

(b) Interfacial axial temperature gradient

**Figure 2.** Normal composite insulator interface temperature

Under normal operation, the axial temperature gradient of the mand-silicone rubber sheath interface of the non-defective composite insulator presents a roughly U-shaped distribution, and the temperature gradient in the middle of the interface has a peak-valley curve due to the existence of insulating skirt. From the order of magnitude of the overall temperature gradient, it can be found that the temperature gradient of the composite insulator without defects in operation is about \(10^{-6}\), that is, there is almost no temperature rise. Therefore, it can be understood that if the composite insulator has a large temperature rise, it is likely to have some defects.

The temperature cloud diagram of No. 2 air-gap insulator and the temperature gradient at the mandrel interface are simulated, as shown in Figure 3:

![Temperature Cloud Image and Temperature Gradient](image)

(a) The overall temperature

(b) Interfacial axial temperature gradient

**Figure 3.** Interface temperature of composite insulator with air gap (no PD)
It can be seen from the figure that the existence of air gap does have a great distortion effect on the axial temperature gradient of the composite insulator interface, which will make the axial temperature gradient appear a peak and a trough. Under the condition of no partial discharge, the overall temperature rise of the insulator is not high, and the temperature gradient of the interface is of order of $10^{-6}$. Therefore, even if the distortion is large in the image, it has no great influence on the actual operation of the insulator. This also proves that the new insulator with air gap defects in the experiment does not show the phenomenon of temperature rise when pressurized. This is because the new insulator does not have partial discharge although it contains air gap.

3. Short string composite insulators temperature measurement with air gap defects by infrared imaging

In this paper, a new composite insulator with short string and air gap defects in equal proportion to the established model is used for temperature measurement. The air gap parameters are the same as that of No. 2 insulator (length 10mm, diameter 1mm). The actual experimental images are shown in Figure 4. Infrared imaging method was adopted, and the instrument used Maison R series research thermal imager.

![Figure 4. Infrared imaging method to measure the temperature of insulator](image)

25kV AC voltage was applied to the high voltage end of the composite insulator at room temperature (24.7°C), the low voltage side was grounded, and the overall temperature of the insulator was measured after 40min of pressure, as shown in Figure 5.

![Figure 5. Infrared imaging method to measure the temperature of insulator](image)
From the imaging data, it is found that there is almost no temperature change in the axial direction of the composite insulator, and the temperature value is always about 24.7°C at room temperature. Trying to increase the voltage to the high voltage end, until the pressure to 40kV and extend the pressure time, the insulator has no obvious temperature rise. In addition to testing the defective insulators with 10mm air gap, this study also tested the insulators with 20mm, 40mm and 60mm air gaps, but the results still did not find that their temperature rose significantly after operation.

It shows that even if the new insulator contains air gap, local heating phenomenon will not appear in a short time, which will not temporarily affect its operation, which is also consistent with the simulation results. This also means that even if air gap defects occur during insulator production, if the insulator can be detected and found in a short time after operation, and the insulator can be replaced in time, there will be no adverse effects on insulators and transmission lines due to local heat accumulation.

4. Using infrared imaging to measure the temperature of new composite insulator in short string with whole mand-rod damp

In this test, all the insulators affected by moisture are boiled with mandrel-rod, and the degree of moisture is determined according to the different boiling time. The sample (dielectric constant is about 10) boiled with mandrel for 4 days was used for the test. At room temperature (24°C), 25kV AC voltage was applied to the high voltage end of the composite insulator, the low voltage side was grounded, and the overall temperature of the insulator measured by the thermal imager after 40min of pressure was shown in Figure 6:

![Figure 6. Infrared image of damp composite insulator](image)

The whole insulator basically has no temperature rise, and the axial temperature of the insulator basically keeps about 24°C. Trying to increase the voltage to extend the pressure time and using DC high voltage, the sample temperature is still basically unchanged. Then the sample boiled in mandrel water for 8 days was used again, and the results were similar to those obtained in this experiment.

According to the experimental study conducted by Cheng Yangchun [7] of North China Electric Power University, the causes of composite insulator heating include the polarization loss of water molecules under alternating current field. Compared with normal insulators, the electric field of insulator mandrel of the test sample reduces uniformly and does not have distortion after the whole hygroscopic process, which eliminate the influence of electric field. According to the measured dielectric spectrum, the dielectric constant of the mandrel increases significantly, which proves that the mandrel absorbs water after boiling. However, in the test, the insulator still has no temperature rise under AC and DC voltage, which indicates that the polarization loss of water molecules in the mandrel is not large in the electric field.
According to the study of Shen Rui [8] from North China Electric Power University, the degree of moisture of mandrel after wet and heat aging in engineering is often greater than that of new sample, which may be due to the influence of material structure after aging of mandrel and the generation of water molecular diffusion channels. Insulator heating due to damp in actual operation is often accompanied by the aging of mandril and silica gel sheath. Therefore, the composite insulator in this test with damp mand-rod basically has no temperature rise, possibly because the sample insulator mand-rod runs for a short time, and the mand-rod does not appear aging. Even if water molecules are contained in the mandolin, the polymer of epoxy resin is closely arranged so that the polarization speed of the water molecules absorbed in it is relatively slow under the action of electric field or the loss generated in the polarization process is very small, and the energy released is not enough to lead to the accumulation of heat, so there is no temperature rise.

5. Conclusions
(1) For the new composite insulator without defects in normal operation, there is almost no temperature rise of the insulator. If the composite insulator interface contains an air gap, there is almost no temperature rise at the insulator interface in the absence of partial discharge.
(2) For the new composite insulator with damp mandril, heating phenomenon will not occur after a short period of pressurized operation.

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