Pollution Accumulation Simulation of Composite Insulators in Western Inner Mongolia

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Abstract: To study the effect of pollution accumulation on flashover voltage for composite insulators in western Inner Mongolia, COMSOL software was used to simulate the impact of non-uniform pollution deposition, different particle sizes, varying pollution severity levels, and different wind directions on the amount of accumulated pollution and the flashover voltage of composite insulators. The results indicate that after passing through the composite insulator, pollution particles accumulate to varying degrees on the surface, mainly concentrated at the edges of the insulator shed and the ridges of the skirt. The larger the particle size, the more pollutants accumulate on the composite insulator, which leads to a higher degree of distortion in the surface electric field. The accumulation of pollutants under oblique wind conditions is higher than that under horizontal wind conditions, and the lower skirt position of composite insulators is more prone to accumulation. The non-uniform distribution of pollution on composite insulators leads to an uneven distribution of the surface electric field upon energization, thus reducing the flashover voltage of the composite insulator and making it more susceptible to flashover incidents.

Keywords: Composite Insulator; Flashover; Non-uniform Pollution Accumulation; Pollution Accumulation Simulation; Inhomogeneous Electric Field

1. Introduction

Composite insulators play a crucial role in electrical insulation and mechanical support in power transmission lines, serving as one of the essential components for the safe and stable operation of the power system [1-3]. Since the 1960s, countries such as the UK, USA, and Germany began to apply composite insulators in outdoor transmission lines successively. By 2011, China's usage of composite insulators had surpassed 5 million units [4], and by 2021, this number had exceeded 15 million, the highest in the world.

Over their long-term outdoor service, composite insulators are subject to aging from various factors including ultraviolet radiation, temperature, humidity, and pollutants as they age. When the insulation performance of composite insulators deteriorates to a certain extent, it may lead to flashover incidents [5-8]. Since the beginning of the 21st century, the rapid development of China's industry has resulted in an increase in atmospheric pollutants. As a result, the frequency of flashover accidents caused by aging and pollution on composite insulators has increased. In 2005, local heavy fog in the Pearl River Delta led to flashover and tripping of transmission lines [9]. In 2006, Tianjin experienced a pollution flashover incident due to dense fog [10]. In 2011, Shandong's Jiaodong region suffered a rare marine fog attack with visibility less than 10 meters. Due to low insulation configurations on some insulator equipment, 220 kV Ma-Li Line tripped and multiple 110 kV and 35 kV lines in Rushan city area tripped, causing large-scale pollution flashover incidents under the in-fluence of high-salt marine fog [11].

In summary, aging and the deposition of pollution on composite insulators are often the primary causes of flashover accidents. Aging reduces the physical and chemical properties of compo-site insulators themselves. At the same time, in areas with extreme pollution like

Mengxi, affected by industrial pollution and other factors, aged insulators will accumulate dirt and sediment, which, when encountered with light rain or dense fog, can easily trigger flashovers. To improve power quality and ensure the safety and stability of power supply, studying the aging and pollution flashover characteristics of composite insulators in western Inner Mongolia holds significant importance.

2. Simulation Model

The model was constructed using COMSOL software. The composite insulator employed adheres to GB/T 19519-2004 standards, specifically the FXBW-220/100 type composite insulator. The simulation model is illustrated in Figure 1. The relative permittivity of the materials is listed in Table 1, and the mesh refinement is depicted in Figure 2.

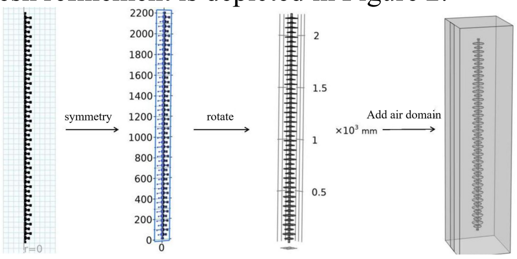

Figure 1. Composite Insulator Modeling Process Diagram

Table 1. The Relative Dielectric Constant of Composite Insulator Material

component part	Materials	relative permittivity
Air domain	Air	1.0
Fitting	CZ42	9.34×107
Mandrel	FR-4	8.0
Umbrella skirt	Silicone rubber	4.3

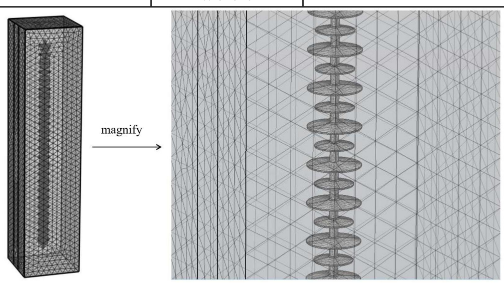

Figure 2. Composite Insulator and Air Domain Grid Subdivision Diagram

3. Simulation of the Non-uniform Pollution Accumulation Process on Composite Insulators

A composite insulator from a grid-connected installation at the Jilantai substation in the Mengxi region is shown in Figure 3. Its surface pollution distribution is non-uniform, with the majority of the contamination concentrated at the edges of the sheds and the ridges of the skirts. The non-uniform distribution of pollution on composite insulators leads to an uneven distribution of the surface electric field upon energization, thereby decreasing the flashover voltage of the composite insulator and making it more susceptible to flashover incidents.

Figure 3. Jilantai Substation Hanging Network Composite Insulator Surface Area Pollution Figure

Particles of haze and smog in the air are primarily influenced by drag forces from the fluid flow, electric field forces, and gravitational force. The initial velocity of the particles is set to 1 m/s. During the pollution accumulation simulation, three types of contaminant particles are considered. The specific properties of the contaminant particles are detailed in Table 2. Liquid drop-let particles are added, with the surface tension of the particles set to 0.0729 N/m.

Table 2. Properties of Filthy Particles

Particle numbering	Particle type	Particle size(μm)	Particle density(kg/m3)
Particle 1	droplet	1	1000
Particle 2	Solid particle	10	2200
Particle 3	Solid particle	5	2200

In the pollution accumulation calculation, once a contaminant particle comes into contact with the insulator surface, it is assumed that the particle will adhere to the insulator surface. To minimize the impact of the wall on the internal flow field, the outer wall is configured as a symmetry boundary. Contaminant particles are released from the inlet, and after passing through the composite insulator, some particles are adsorbed onto the surface while others reach the outlet. Particle tracking is performed at six distinct times: t = 0s, t = 0.2s, t = 0.4s, t = 0.6s, t = 0.8s, and t = 1s. This allows us to observe the pollution accumulation process on the composite insulator as illustrated in Figure 4.

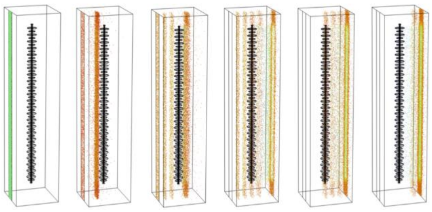

Figure 4. Composite Insulator Fouling Process Diagram

Utilizing the fpt.wall2.md1.delta function in COMSOL, the simulation diagram depicting the surface deposition mass of the composite insulator is obtained, as shown in Figure 5.

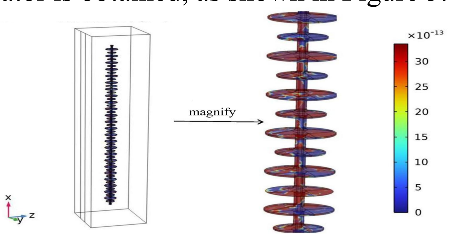

Figure 5. Composite Insulator Fouling Process Diagram

As can be seen from the figure, after the contaminant particles pass over the composite insula-tor, they accumulate to varying degrees on its surface. This accumulation is not evenly distributed but rather is concentrated primarily at the edges of the composite insulator's shed and skirt.

4. Impact of Different Contaminant Particle Sizes on Pollution Accumulation and Flashover Voltage for Composite Insulators

Under the condition of a uniform wind speed of 1 m/s, three particle size groups are set: small, medium, and large, as detailed in Table 3. Specifically, in the small-size group, the droplet diameter is set to 1μm, and the solid particle diameters are 10μm and 5μm; in the medium-size group, the droplet diameter is set to 1.5μm, and the solid particle diameters are 12μm and 8μm; in the large-size group, the droplet diameter is set to 2μm, and the solid particle diameters are 15μm and 10μm.

Table 3. Three Particle Sizes of Filthy Particles

Particle numbering	Particle type	Smaller size(μm)	Medium size(μm)	Larger size(μm)
Particle 1	droplet	1	1.5	2
Particle 2	Solid particle	10	12	15
Particle 3	Solid particle	5	8	10

Utilizing the function fpt.wall2.md1.delta_sum available in COMSOL, one can calculate the surface deposition mass of composite insulators. Relevant data is then exported and plotted using Origin software. As depicted in Figure 6, the simulation-derived data presents the surface contamination quantities on composite insulators under the same wind direction for particles of three different sizes.

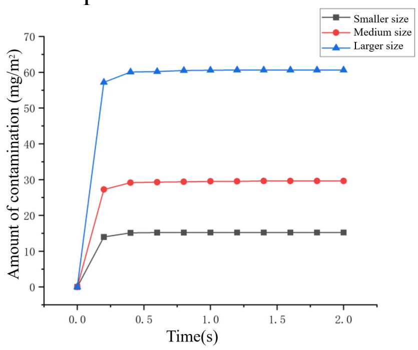

Figure 6. The Amount of Pollution Accumulation of Composite Insulators under Different Particle Sizes

As can be observed from the Figure 6, the larger the particle size, the greater the amount of pollution accumulated on the composite insulator. This is because when the particle size is larger, the wind has difficulty in removing the contaminants, leading to their deposition.

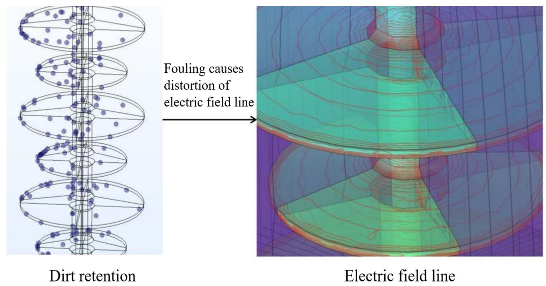

Figure 7. The Equipotential Line of Electric Field on the Surface of Composite Insulator After Contamination

Contamination can cause severe distortion in the voltage distribution along composite insulator strings, resulting in a decrease in the flashover voltage of the insulators. The equipotential lines of the surface electric field on the composite insulator after pollution accumulation are shown in Figure 7. It can be seen from the Figure 7 that after pollution buildup, the surface potential of the composite insulator is no longer uniformly distributed but rather experiences varying degrees of distortion due to the presence of contaminants. The higher the degree of pollution on the composite insulator, the greater the extent of distortion in the voltage distribution becomes.

5. Summary

In this paper, the modeling of silicone rubber composite insulators and the surrounding air do-main was carried out using COMSOL Multiphysics, simulating the non-uniform pollution accumulation process on the insulators under the influence of physical fields such as electrostatic fields, fluid flow, and fluid particle tracking. Through the simulation and analysis of the electric field distribution on composite insulators, the following conclusions were reached:

(1) After contaminant particles pass over the composite insulator, they accumulate to varying degrees on its surface. This accumulation is not evenly distributed but tends to concentrate at the edges of the composite insulator's shed and skirt.

(2) The non-uniform distribution of pollution on composite insulators leads to an uneven distribution of the surface electric field upon energization, which in turn decreases the flashover voltage of the composite insulator, making it more susceptible to flashover events.

(3) The larger the particle size, the greater the amount of pollution accumulated on the compo-site insulator. This is because when the particle size is larger, the wind has difficulty in removing the contaminants, resulting in their deposition. Contamination can cause severe distortion in the voltage distribution along composite insulator strings, leading to a reduction in the flashover voltage of the insulators.

Acknowledgments

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