The Research of GIS Discharge Influence Based on Particle Properties in Installation Environment

Leicheng Lin¹, Dan Chen¹*

(¹. College of Electrical and Automation, Fuzhou University, Fuzhou, Fujian, 350108, China;)

*Corresponding author’s e-mail: T03019@fzu.edu.cn

Abstract: In order to explore the influence of atmospheric free particles that exit during GIS installation on the stable operation of GIS, the size, shape and inner properties of the particles contained in the air are analyzed. And based on 500kV GIS equipment, the GIS gas chamber model and the model of free particles were established. By using the finite element simulation software, the surface electric field distribution when the free particles remain on the insulator surface is solved. The results show that the electric field distribution of particles which exist along the surface of insulator is directly related to the relative permittivity of the material of the particles themselves, and the intensity of the electric field along the surface increases with the increase of the relative permittivity. With the fact that the relative permittivity of air particles is almost below 20, as a result, the existence of 10µm grade non-metallic free particles will not cause flashover discharge. But, when a small number of Fe₃O₄ particles which size over 1mm or when them accumulate regularly, it will lead to flashover discharge. Therefore, the suspended atmospheric particles in the installation environment have little impact on the stable operation of GIS. When considering the installation environmental conditions, the installation can be carried out on a clear, windless day which can save costs.

1. Introduction

The Gas Insulated Switchgear has been widely used in high voltage transmission system because of their good insulation performance, high reliability and small footprint[1]. However, it is inevitable that many equipment faults has turn up in the long run of GIS equipment. Of all the faults of GIS equipment, the rate of insulation faults is the highest which reaches 58%. Among them, the faults of basin-type insulator accounted for a large proportion, accounting for 26.6%[2]. A lot of researches on the simulated discharge caused by particles along the surface of basin-type insulators have been done and achieved fruitful results by scholars. Hongxin Ji studied the discharge behavior and discharge characteristics of linear and sheet metal particles, and proposed the conditions that different types of metal particles meet the runout under the operating voltage[3]. Youhua Gao established a three-dimensional finite electric field analysis and calculation model for basin-type insulators with metal particles above in 800kV GIS, and conducted surface flashover experiments accordingly. It is concluded that the maximum field strength on the surface of the basin-type insulator increases with the increase of the field strength along the surface where the metal particles are located before[4].

Studies have shown that the presence of particles along the surface of the basin-type insulator causes electric field distortion along the surface of the basin-type insulator, as a result, forming a through channel in the surface of basin-type insulator. Although insulation faults may not necessarily
be induced in the experiment, the amount of partial discharge changes greatly, and it is likely to cause surface flashover discharge after long-term accumulation[5]. The particles existing in the GIS mainly come from various particles which enter during the installation process and the metal particles generated due to abrasion during the operation of the equipment. On the premise of ensuring that the GIS products are qualified, the source of particles is mainly the particles that enter the cavity during the installation process. Considering that during the actual installation of the GIS, the installation steps such as vacuuming, standing, and injecting SF₆ gas are still required, so the number of particles remaining inside the GIS is still relatively small.

To explore the impact of the properties of free particles, which enter the GIS cavity in the installation, on the stable operation of the GIS, the finite element simulation software is used to simulate the flashover discharge of free particles existing along the basin-type insulator. The relationship between the particle properties of the installation environment and the discharge of the GIS is obtained.

2. Air free particles analysis
Researches shows that the sedimentation characteristics of free particles and dusts in the air are different due to the different particle size under the action of gravity. The free particles which has a small size less than 10μm can float in the air. While the particles with a great size more than 10μm that will settle on the ground quickly. Therefore, it can be considered that under no windy weather conditions, most of the atmospheric particles with a particle size greater than 10μm in the air have settled on the ground and have no affect in the installation process, while the size of most atmospheric particles floating in the air that will affect the installation process remain below 10μm. During the installation of the GIS, only particles smaller than 10μm may remain in the cavity of the GIS after installation.

Through the investigation and research, we can know that except for particularly inactive metals such as gold and silver, other metals generally exist as salts, oxides. According to the study of the morphology of atmospheric particles, we can know that the particles with the size less than 0.5μm accounted for 72.3%, the particles with the size between 0.5μm and 1μm accounted for 12.9%, the particles with the size between 1μm and 2.5μm accounted for 10.4% and the particles with the size between 2.5μm and 10μm accounted for 4.4%. Fossil fuel combustion, soil dust and motor vehicle exhaust were the main causes of atmospheric particulate pollution in Fuzhou city, and the effect of sea salt aerosol was less than the other three. The number of particles decreases with the increase of particle size and the shape of the main particles of PM10 include spherical, chain, cotton-shaped, strip, flake, irregular shape and special shape. And in Fuzhou, the main types of atmospheric particles are soot aggregate, fly ash particles, mineral particles, biological particles[6]. So on this basis, the simulation model of air particles and the relationship between air cleanliness and GIS internal discharge are established, and the mutual influence between them is discussed.

3. GIS gas chamber simulation model
The state Grid 500kV voltage level GIS equipment is selected as the research reference object in this study. Through Ansys software, a simple simulation model of GIS gas chamber and insulator is established. Through simulation, the relationship between airborne particulate matter and GIS stable operation during GIS installation is explored, the structure of GIS equipment is shown in Figure 1.

From Figure 1, it can be seen that the GIS is composed of six parts include center guide rod, basin-type insulator, gas chamber, the case, and the covers which are basin-type insulator actually. Considering the size of the actual equipment, the overall height and width of the GIS are set to 6m and 720mm.
4. Simulation about influence of discharge free particles exist on surface of insulator

4.1. Simulation parameter setting
Imported the established 3D Model of GIS gas chamber into Ansys software and set the materials of each component of the model. Among them, the materials of the central guide rod, the case and the basin-type insulator were metal aluminum, metal aluminum and epoxy resin. And 0.4MPa SF$_6$ gas was filled in the gas chamber. The relative permittivity distributions of aluminum, epoxy resin and SF$_6$ gas are infinity, 6.000 and 1.002.

In the simulation experiment, the rated short-time power frequency withstand voltage is used to carry out the simulation experiment. The central guide rod is loaded with 740kV voltage, the metal case is grounded.

4.2. The distribution of electric field along the insulator surface
Firstly, the distribution of surface electric field of basin-type insulators in GIS should be explored when GIS is in stable operation and the result of simulation is as the Figure 2 shown. When there are no particles on the surface of the basin-type insulator, the maximum creeping electric field appears near the central guide rod as the maximum is 4.7456kV/mm. And the minimum value appears at the edge of the basin-type insulator with the numeric about 0.2182kV/mm. The distribution of the electric field of the basin-type insulator is radial, and the intensity of the electric field decreases with the increase of the length of the surface.

According to literature[4], when particles exist in high electric field, they have the greatest influence on insulators. Therefore, according to Figure 2, location A of the high electric field area is selected.

4.3. Influence of particle type
It is considered that some atmospheric particles remain in the GIS and settle to the insulator surface. Explore the influence of particles existing in location A. Taking Fuzhou as a reference city, it is considered that the coarse particle size is 10μm and the fine particle size is 2.5μm. The types, shapes and particle sizes of each particle are shown in Table 1:
Table 1. Properties of different particles

| Types    | Property | Shape | Size               | relative permittivity |
|----------|----------|-------|--------------------|-----------------------|
| Fe₃O₄    | strip    | a=10µm, b=h=1µm | 20                  |
|          | flake    | a=b=10µm, h=1µm |                     |
| SiO₂     | strip    | a=10µm, b=h=1µm | 4.42                |
| CaSO₄    | strip    | a=10µm, b=h=1µm | 5.1                 |
|          | flake    | a=b=10µm, h=1µm |                     |
| C        | sphere   | r=2.5µm     | 5.87                |
| CaCO₃    | sphere   | r=2.5µm     | 8.67                |

Establish the 3D model of particles by using Ansys software, and divide the mesh was properly. The simulation results were obtained as shown in Figure 3:

![Figure 3: Effects of Fe₃O₄ particles on the electric field](image)

When different kinds of particles in Table 1 exist along the surface of the basin-type insulator, the variation of the electric field intensity along the surface of the insulator is shown in Table 2:

Table 2. The electric field strength of insulator in the presence of different particles

| Types    | Property | Shape | E_{max}/kV·mm⁻¹ |
|----------|----------|-------|-----------------|
| Fe₃O₄    | strip    |       | 6.3551          |
|          | flake    |       | 9.7000          |
| SiO₂     | strip    |       | 4.8006          |
| CaSO₄    | strip    |       | 4.8655          |
|          | flake    |       | 5.6183          |
| C        | sphere   |       | 4.7442          |
| CaCO₃    | sphere   |       | 4.7852          |

As is shown the table 2, in the process of GIS installation, the particles will impact on the electric field of insulator in different degrees. The presence of particles makes the charge along the surface accumulate in a small amplitude, and the electric field around the particles increases in a small range compared with that without the presence of particles. Metal oxide has the greatest influence on the surface electric field intensity of the insulator, but it does not reach the degree of flashover and will not cause the insulator to flashover.

4.4. Influence of particle relative permittivity

From Table 2, when particles exist along the surface of insulators, charge accumulates around the particles. Which is no only related to the shape and size of the particles to a certain extent, but also due to relative permittivity of the particles.
Select strip particles with length, width and height of 10μm, 1μm and 1μm placed it in location A. Change the relative permittivity of particles to explore the influence of the internal properties of particles on the electric field distribution along insulator surface. The simulation result is shown as Figure 4.

Figure 4. Relationship between $\varepsilon_r$ and $E_{\text{max}}$

As can be seen, with the increase of $\varepsilon_r$, the surface electric field strength of the insulator $E_{\text{max}}$ also increases, but the increasing amplitude is decreasing constantly, and finally there is a trend of convergence. On the premise that the strip particles are placed at position A, when the value of $\varepsilon_r$ reaches 80, the surface electric field strength of the insulator reaches the limit value which may lead to the damage of the insulator.

The relative permittivity of the conductor is infinity. Conduct a group of simulation experiments to verify the result above, the results are shown in Figure 5. When the granular material is metal, the maximum of the electric field along the surface of the insulator is 27.482 kV·mm$^{-1}$, which is consistent with the law in Figure 4.

4.5. Influence of particle size

In installation, sometimes in order to meet the deadline, the GIS equipment is installed in windy weather. As a result, the settled particles float into the air again and may makes the number of particles with large size increase in the air and thus enter the GIS during installation finally. Therefore, on the basis of Table 2, select Fe$_3$O$_4$ which has the greatest influence on the surface electric field strength of insulators as the research object to explore the distribution of the surface electric field strength of insulators when the particle size increases.

Establish 3D models of Fe$_3$O$_4$ with different sizes and set the length of the longest side of the strip and flake as $a$, maintain the aspect ratio of 10:1:1 for the strip and 10:10:1 for the flake particle. Through finite element simulation, the results are shown in Figure 6:

Figure 6. Effect of particle size on field strength

Figure 7. Effect of particle aggregation on field strength
As can be seen from Figure 6, when the shape of Fe₃O₄ is flake or approximately flake, it may exceed the surface electric field strength limit of insulators with the increase of particle size, leading to the occurrence of surface flashover discharge of insulators. Moreover, according to the simulation results, the particle size which may cause the flashover discharge is more than 1mm, while the number of this size is very little among the particles floating in the atmosphere.

4.6. The influence of particle aggregation

When the particles exist in GIS, the particles sedimentation may occur which may lead to particle aggregation because there is no gas flow. Therefore chose the Fe₃O₄ particle to analyse the influence of particle aggregation on the surface electric field strength.

The discharge condition of Fe₃O₄ particles clustered along radial and normal directions was simulated, and the results were shown in Figure 7:

As can be seen from Figure 7, the influence of Fe₃O₄ particle aggregation on the surrounding electric field is related to the shape of the particle itself. The flashover discharge of insulators along the surface will not occur if the strip particles gather, but when the flake particles are distributed along the normal and radial directions, the electric field strength around the particles will increase with the increase of the particles. When the number of particles is greater than 5, the electric field strength around the particle group will exceed the maximum allowable electric field strength limit along the surface of the insulator, leading to flashover discharge.

5. Conclusion

Taking GIS basin-type insulator as the analysis object, the 3D simulation model of GIS and free particles are established by using finite element analysis software. On this basis, the electric field distribution along the insulator surface when dust remains on the insulator surface is simulated, and the relationship between the presence of particles and the flashover discharge along the GIS insulator is explored. The specific conclusions are as follows:

(i) The distribution of the electric field of the basin-type insulator is radial, and the intensity of the electric field along the surface is within the limit value, and it can operate stably when there is no foreign matter.

(ii) When different kinds of non-metallic particles appear on the surface of the insulator, flashover discharge does not occur. It can be found that the influence of particles on the surface electric field distribution of insulators is related to the property, size and shape of particles. The maximum of electric field increases with the increase of relative permittivity and finally tends to be stable.

(iii) When the Fe₃O₄ particles which size is greater than 1mm exist on the surface of basin-type insulator or the particles gathered with the number over 5, the flashover discharge around the particles will occur and the stable operation of insulators will be damaged. When considering the installation environmental conditions, the installation can be carried out on a clear, windless day which can save costs.

Reference

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