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Flashover Characteristics of Basin-type Insulator with Metallic Particles on its Surface under Standard Lightning Impulse

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Abstract—**The basin-type insulator is one of the most important parts in SF_6 gas insulated switchgear (GIS). Flashover of basin-type insulators will cause serious harm to the electrical system. The fact that metallic particle attached to the surface cannot be detected in the delivery test under the standard lightning impulse (SLI) will pose potential threat to GIS. This paper studied flashover characteristics of the basin-type insulator with metallic particle contamination attached to its high voltage electrode in SF_6 under SLI. An 1800 kV lightning impulse generator and a specialized pulse-voltage divider were used in the study. The results show that the flashover voltage drops rapidly when the metallic particle is attached to its surface. At high pressure, the basin-type insulator will be more sensible to the metallic particle. The metallic particle may cause danger to the system even its size is small. The reduction of flashover voltage will become slow with the increase of the metallic particle's length. The gas pressure has little effect on the flashover voltage rate when the metallic particle exceeds a certain length. The flashover voltage under negative polarity of SLI is higher than that under positive polarity. Polarity effect will be obvious when the gas pressure is low. The discharge development process of basin-type insulator has been studied on the aspect of space charge accumulation at last.**

Keywords—basin-type insulator; SF_6; standard lightning impulse (SLI); metallic particle; flashover characteristic; space charge

I. INTRODUCTION

As a crucial part in GIS, the basin-type insulator serves as electrical insulation, mechanical support and gas chamber separation [1]. However, as is found in actual operation, some inevitable metallic particles are possibly produced in the production, assemblage and switching operations of GIS [2]. These particles may move in the electric field and be attached to the insulator surface, resulting in the accumulation of surface charge as well as the distortion of local electric field [3-5], and consequently the decrease of flashover voltage of the insulator[6-7]. Thus it is valuable to study the influence of metallic particle on flashover voltage of basin-type insulator under standard lightening impulse.

Numerous studies have been carried out regarding this subject. The study of S. Okabe from Tokyo Electric Power Co. indicates that the flashover voltage of supporting insulator decreases significantly as the metallic particle length increases [8]. Y. Qiu and Q. Zhang studied the flashover characteristics of supporting insulator with different waveform parameters in the presence of metallic particles, as well as the influence of space charge on the flashover voltage by means of rapidly changing the DC voltage pre-applied on the insulator to impulse voltage [9-11]. Their study indicates that in the presence of metallic particles, the flashover voltage under short wave-head impulse is much lower, and that the accumulation of space charge has an enormous influence on the flashover voltage.

Nevertheless, these studies mainly focus on the influence of metallic particles on small-size insulators, very few focuses on real-size insulators of GIS [12]. Besides, much research has been done under DC voltage while the flashover characteristics under standard lightening impulse are not evidently elaborate [13-16]. Therefore, the study of influence that metallic particles have on the flashover voltage has great engineering significance, and provides theoretical fundamentals to explore the flashover mechanism.

Previous studies have found that the flashover voltage of insulator is much lower when metallic particles are close to the high voltage conductor [17]. For this reason this paper sticks stainless needles of various sizes to the high voltage conductor to simulate metallic particles, and studies its influence on the flashover characteristics of an 110kV basin-type insulator under standard lightening impulse, including the length of particles, the voltage direction as well as the SF_6 gas pressure. This paper analyses in the end the flashover process of the basin-type insulator from the perspective of space charge accumulation.

II. THE EXPERIMENTAL DEVICE AND METHOD

Figure 1 shows the experiment system of this paper. An open-type 1800kV standard lightening impulse generator is used as the voltage source, producing LI waveform of 1.26 / 52.1μs shown in Figure 2.

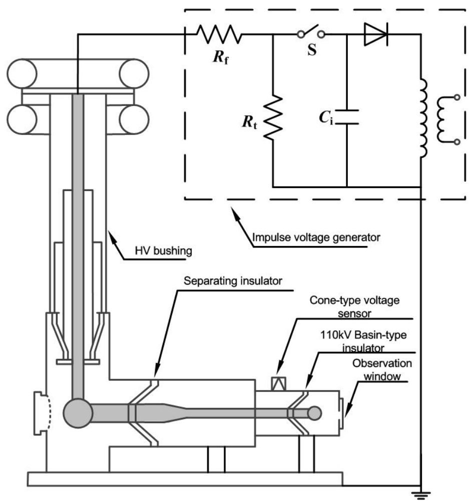

Fig.1. Structure of the experimental device

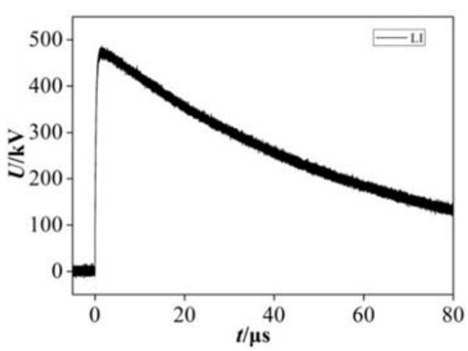

Fig.2. Output voltage waveform of SLI

In order to measure the voltage waveform, a cone-type voltage sensor is installed at the 110kV GIS switching section, along with appropriate integrators to obtain satisfying response. The structure of the cone-type voltage sensor is shown in Figure 3. By means of water resistance potential divider and metal film resistance divider, the measuring system is calibrated with a dividing potential ratio of 9251 and a measurement uncertainty of 2%. The oscilloscope used in this paper (Tektronix DPO4104) has a bandwidth of 1GHz and a sampling frequency of 5GHz, placed in shielding case to avoid electromagnetic interference.

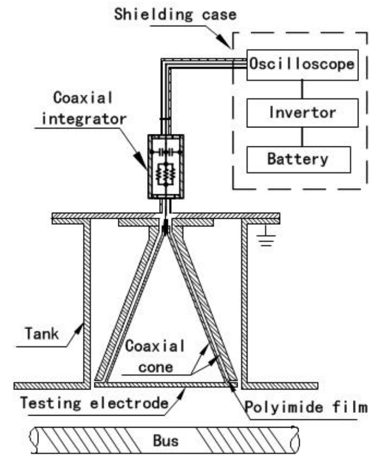

Fig.3. Output voltage waveform of SLI

The testing insulator is a typical 110kV basin-type. Stainless needles are stuck onto the insulator surface to simulate metallic particles. The diameter of the needles is 0.56mm, with different length of 2mm, 4mm, 6mm, 8mm and 10mm. Figure 4 shows the actual experiment insulator with stainless needle stuck to the high voltage conductor. During experiment the cavity is successively vacuumized, inflated with dry N_2, re-vacuumized and inflated with pure SF_6. The flashover voltage of the insulator is obtained by the lifting and lowering method, with the applied voltage variation of no more than 3% and a time interval of 15min. The flashover trace on the insulator surface is polished by fine emery paper so that the roughness of the surface maintains consistent. Research has found that for an epoxy resin insulator, the flashover voltage under impulse voltage does not have a significant change when the surface roughness increases. Therefore during the experiment the insulator surface is cleaned each time with ethyl alcohol after being polished, and for each statistic the effective experiment times exceed over 20.

Fig.4. Image of surface discharge model

III. EXPERIMENTAL RESULT

A. *Influence of metallic particle length*

The variation of flashover voltage of the basin-type insulator in function of the particle length is shown in Figure 5, where the 550kV line is the crest value of impulse withstand voltage for the 110kV GIS pre-delivery test. Positive and negative standard lightening impulse is respectively presented by +LI and –LI.

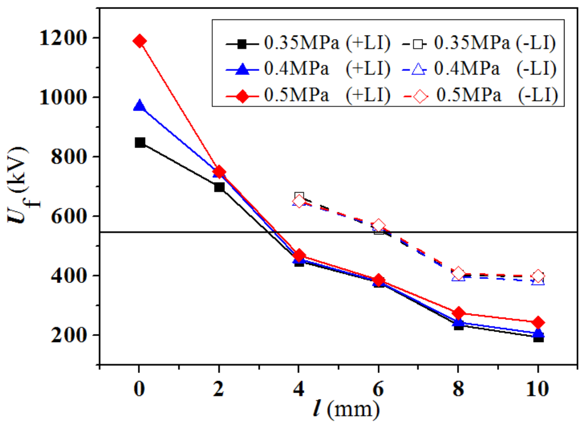

Fig.5. Flashover voltage vs. length of metallic particle

Figure 5 shows that in the presence of metallic particles close to the H.V. conductor, the flashover voltage under different gas pressure does not show any significant variety. What is more, the flashover voltage under negative impulse is much higher than that under positive impulse. In the case of 0.35MPa gas pressure, the flashover voltage of the basin-type insulator drops about 262.7kV when the particle length increases from 4mm to 8mm, while drops only 5.7kV when the particle increases from 8mm to 10mm. This shows that under negative impulse, the insulator is more sensitive to metallic particles less than 8mm, and that the flashover voltage does not decrease significantly when the particle length is over 8mm. The tendency for 0.4MPa and 0.5MPa gas pressure is the same as that for 0.35MPa. Besides, the flashover voltage under LI is more than 550kV when particles are less than 6mm, which means that in pre-delivery and delivery tests, particles less than 6mm could not be detected by traditional methods.

Under +LI, the flashover voltage of the clean insulator increases as the gas pressure augments, and shows the same tendency in function of the particle length. When the length of the metallic particle is less than 3.5mm, the flashover voltage surpasses 550kV, resulting in the fact that particles less than 3.5mm could not be detected in +LI withstand tests during pre-delivery and delivery, despite the enormous decrease of dielectric strength of the insulator. As is shown in Figure 5, the flashover voltage drops over 50% with particle length of 3.5mm in 0.5MPa SF_6 gas, which poses a grave potential threat to GIS in operation.

Metallic particles can easily lead to the concentration of local electric field. Simulation results show that in presence of particles the maximum value of surface electric field is approximately 10 times larger than that in normal cases. On the other hand, the complexion of the basin-type insulator surface shape results in the existence of normal component of electric field on the surface. With partial discharge or corona discharge near the metallic particles in strong electric field, the charged particles in SF_6 gas may eventually accumulate on the insulator surface. These accumulated charges lead to a huge decrease of the flashover voltage of insulator when they possess an opposite polarity against the applied voltage.

B. *Influence of polarity of the applied voltage*

In order to show the flashover voltage of the basin-type insulator under LI voltage of different polarities, a coefficient K is defined as follow:

$$K = U_{-\mathrm{LI}} / U_{+\mathrm{LI}}$$

Where $U_{-\mathrm{LI}}$ and $U_{+\mathrm{LI}}$ are respectively the flashover voltage under negative and positive lightening impulse.

Figure 6 shows the value of K in function of the particle length. As the particle length increases, the ratio of –LI and +LI grows correspondently, the polarity effect becomes more evident. Under +LI voltage the increase of particle length has greater influence on the flashover voltage than under –LI voltage, thus it is more effective to detect metallic particles under +LI rather than –LI.

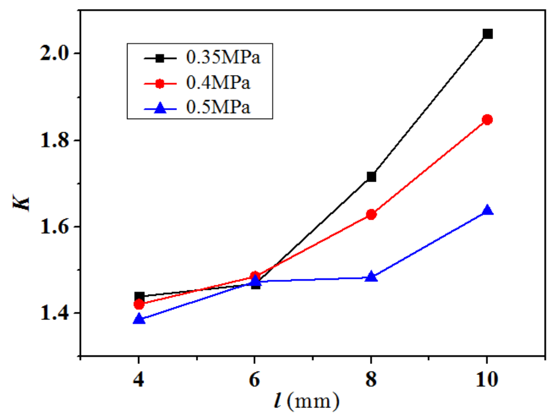

Fig.6. K vs. length of metallic particle

As the gas pressure increases, the value of K decreases and the polarity effect becomes less remarkable. Under high pressure, the corona stabilization effect becomes feeble so that when the corona begins at the end of the particle it is more likely for the insulator to flash over. Therefore there is not great difference in the flashover voltage under +LI and –LI.

C. *Analysis of the flashover process*

The flashover process of the basin-type insulator under +LI voltage in the presence of metallic particles will be analyzed below from the perspective of space charge accumulation and distribution.

The presence of metallic particles strengthens the local electric field, making it easy to produce effective initial electrons that results in electron avalanche and streamer. The streamer grows and produces streamer corona during its development. Ionization happens in the streamer corona area so that charged particles move in a certain direction to become electric doublets. In this process the charge injected into the streamer by the displacement current $i_d = C_s (du / dt)$ can be described as:

$$q_{\text{in}} = \int C_{\text{s}} \left(\frac{\mathrm{d}u}{\mathrm{d}t} \right) \mathrm{dt}$$

Where Cs is the equivalent capacitance of the streamer. The increase of electric field at the head of the streamer is:

$$\Delta E \approx \frac{q_{\text{in}} + Q_{\text{co}}}{4\pi\varepsilon_0 R^2}$$

Where ε_0 is the permittivity of vacuum, R is the radium of the streamer. Thus the total electric field before the streamer is:

$$E \approx \Delta E + (E / P)_{\text{cr}} \cdot P$$

Where (E/P) = 88.5kV/(cm • MPa), P is the gas pressure. The secondary streamer is formed when the total electric field forward is sufficiently high. The injection current rises the temperature inside the streamer until thermal ionization occurs in the gas tunnel, transforming the streamer into leade. New streamer corona appears at the head of the leader, thus resulting in the marching-type development of streamer and leader, until the leader reaches the other electrode and the discharge runs through the entire insulator surface.

IV. CONCLUSION

The investigations concerning the influence of metallic particles on the flashover voltage of basin-type insulator in SF_6 gas lead to the following conclusions:

1) The flashover voltage of the insulator decreases tremendously when metallic particles are located near the high voltage electrode. As the length of particles increases, the flashover voltage decreases much more slowly. The basin-type insulator is more sensitive to metallic particles under high gas pressure.

2) Considering their remarkable influence on the flashover voltage of the insulator, small-size metallic particles may cause danger to the system.

3) The flashover voltage of basin-type insulator under negative polarity impulse is higher than that under positive impulse, with the polarity effect being less evident as gas pressure increases and particle length becomes smaller.

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