Research on Shielding Effect of Background Electric Field for GIS Bus with a Conductive Protrusion Under Impulses

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Abstract- **Gas-insulated metal-enclosed switchgear (GIS) is an important switching equipment in modern power system. The lightning impulse (LI) test is particularly sensitive to abnormal field configurations and is recommended in IEC 62271-203 and GB 7674-2008 for voltage classes of 245 kV and above. Usually, the rod-plane electrodes system with different geometric parameters are adopted to simulate local field enhancement in GIS. But for GIS, the defects may occur in the high voltage bus. In this situation, it's not just the rod-plane electrode can be represented. In order to research the shielding effect of background electric field for GIS bus with a conductive protrusion under impulses, coaxial cylinder structure with conductive protrusion electrodes was used. Meanwhile, the classical rod-plane gap was also used to make a comparison. A generating system of double-exponential impulses with front times in the range of 0.08~15 μs and wave tail times around 50 μs was established to simulate different impulse test waveforms based on a fully enclosed oil-immersed Marx generator. The results show that when the gap distance is fixed, with the length of the needle increase, the 50% breakdown voltage decreases. Discharge characteristics under different electrode configurations are compared. It is found that the shielding effect of the bus on the defect changes the electric field distribution of the gap. The $U_{50\%}$-T_f curves of the bus with needle defects thereafter no longer show the U-shaped as the rod-plane electrode, but increase with the increase of wavefront time.**

Keywords—Gas-insulated metal-enclosed switchgear (GIS); shielding effect; impulse; wavefront time; 50%breakdwon voltage

I. Introduction

Gas-insulated metal-enclosed switchgear (GIS) is an important switching equipment in modern power system [1-3]. Since GIS equipment has a fully enclosed structure, once failure occurs, it will always be followed by a huge economic loss and an adverse social impact. However, increased operating voltages and more extensive power grids have given rise to increased GIS failure rates [4-5]. The lightning impulse (LI) test is particularly sensitive to abnormal field configurations and is recommended in IEC 62271-203 and GB 7674-2008 for voltage classes of 245 kV and above [6-7]. Therefore, the discharge characteristics of GIS, especially when it with insulation defects, are important for the designing and testing. Usually, the rod-plane electrodes system with different geometric parameters are adopted to simulate local field enhancement in GIS [8-11]. But for GIS, the defects may occur in the high voltage bus. In this situation, it's not just the rod-plane electrode can be represented.

In this paper, in order to obtain the shielding effect of background electric field, the insulation characteristics of GIS bus with a conductive protrusion under impulses with different waveform parameters were studied. And the classical rod-plane gap was also used to make a comparison.

II. Experimental Setup and Method

An impulse generating system based on a fully enclosed, oil-insulated Marx generator and a simulated GIS bus is established, as shown in Figure 1. The Marx generator and simulation GIS bus are separated by dielectric spacers and a basin-type insulator. By immersing the Marx generator in oil, the generator can be made very compact, thereby lowering inductance, which affects the front time of the output wave. The generator could generate double-exponential impulses with wide range T_f in the range 0.08 ~ 15 μs and wave tail time around 50 μs, as shown in Figure 2.

In order to research the shielding effect of background electric field for GIS bus with a conductive protrusion under impulses, a special test electrode was designed, as shown in Figure 3(a). In the test electrode, the high voltage electrode was a GIS bus with a conductive protrusion. The diameter of the bus was 72 mm. The conductive protrusion was a needle with a diameter of hundreds of μm. The needle was perpendicular to the bus surface and the length of it L could be adjusted form 3 mm to 40 mm. The ground electrode was a 300-mm-diam Rogowski stainless plane. The distance from the tip of the needle to the plane was fixed to be 33 mm by the adjusting the plane. Meanwhile, the classical rod-plane gap with curve radius r = 0.5 mm and gap distance d = 60 mm was also used to make a comparison as shown in Figure 3(b). The waveforms were recorded using an oscilloscope (Tektronix

DPO4104) with a bandwidth of 1 GHz and a sample rate of 5 Gs/s. Calibration results demonstrated that the response time of the measuring system was less than 7 ns and the uncertainty of divider ratio was less than 3%. The 50% breakdown voltage by using the up-and-down method described in IEC 60060-1 was the prospective voltage value which has a 50% probability of producing a disruptive discharge on the test object. When calculating the 50% breakdown voltage, it should use the prospective voltage value, not the recorded breakdown voltage values.

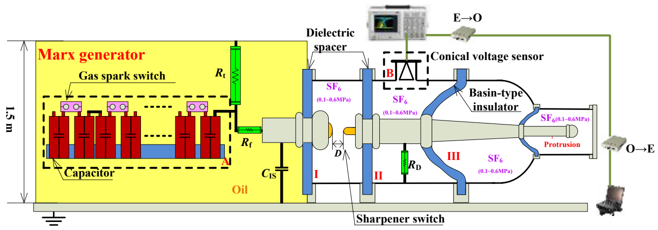


Fig. 1. Schematic diagram of impulse generating system

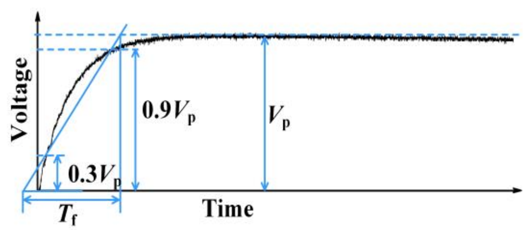
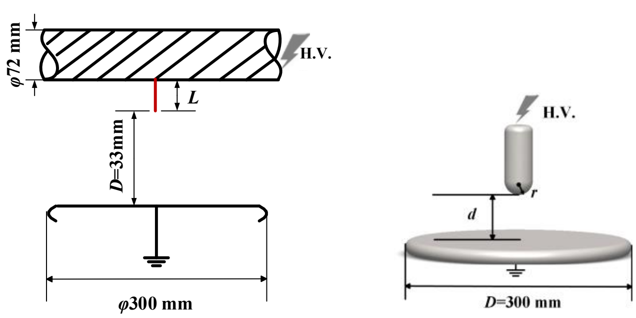


Fig. 2. Output impulse voltages with different waveform parameters



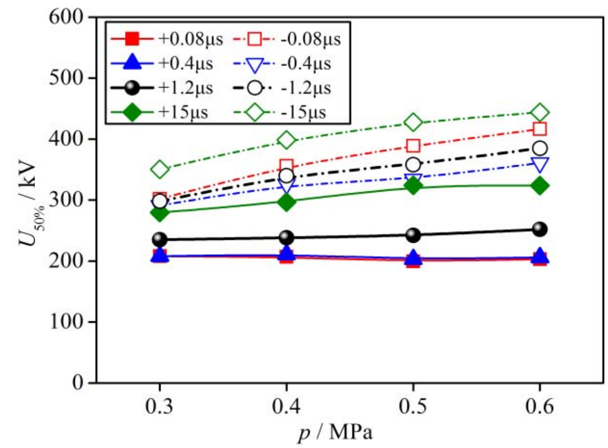
(a) Coaxial cylinder structure with protrusion (b) Rod-plane electrode

Fig. 3. Configuration of test electrodes

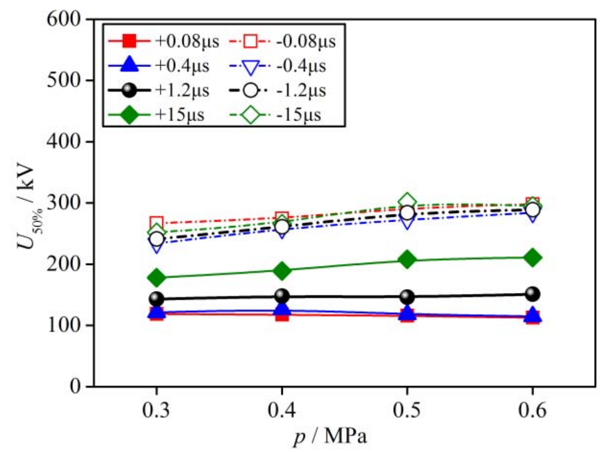
III. Experimental Results and Discussions

A. Effect of Gas Pressure

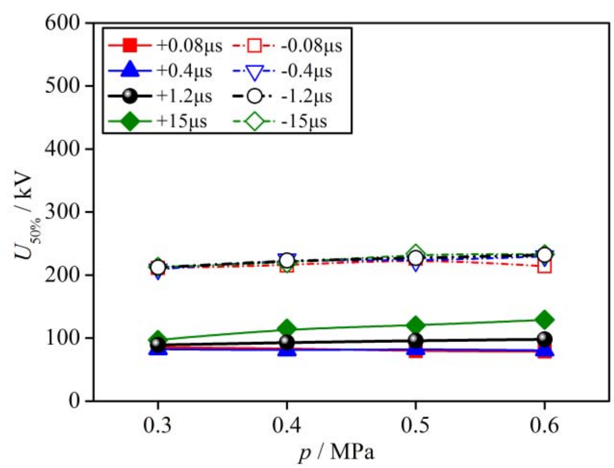
Figure 4 shows the 50% breakdown voltage vs. gas pressure under impulses with different T_f for coaxial cylinder structure with different needle length L. It can be seen from Figure 4 that the polarity effect is very significant for the needle electrode with extremely small curvature radius. Within the pressure range of 0.3 MPa to 0.6 MPa, the negative discharge voltage is higher than the positive polarity. The reversal of polarity effects [12] has not yet appeared. Comparing positive and negative $U_{50\%}$-p curves, it can be found that positive discharge voltage is less influenced by gas pressure. Meanwhile, the discharge voltage at T_f = 15 μs increases more significantly with the gas pressure than that at T_f = 0.08 and 0.4 μs. It can be explained that the long wavefront time enhances the effect of space charge on the electric field.



(a) L = 3 mm, D = 33 mm



(b) L = 10 mm, D = 33 mm



(c) L = 40 mm, D = 33 mm

Fig. 4. 50% breakdown voltage vs. gas pressure under impulses with different T_f for different needle length L

B. Effect of Needle Length

Figure 5 shows the 50% breakdown voltage vs. needle length L under impulses with different T_f.

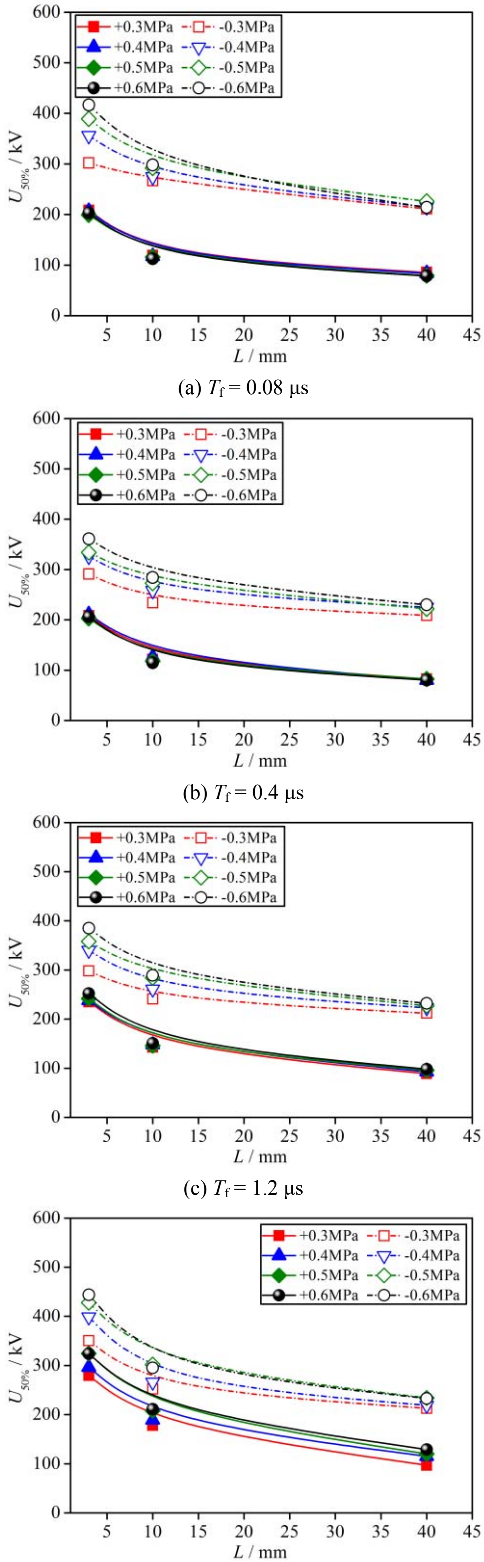


Fig. 5. 50% breakdown voltage vs. needle length L under impulses with different T_f

When the gap distance is constant, the longer the defect length, the lower the discharge voltage. This phenomenon fully shows that when the gap distance and the defect scale are consistent, the discharge voltage of the SF_6 gas gap is greatly influenced by the shielding electrode. The influence effect is basically determined by the gap electric field distribution. When L increases from 3 mm to 10 mm, the discharge voltage drops obviously. When L is further increased, the discharge voltage decreases slowly. The gap electric field distribution under different defect lengths is obtained by simulation. And the electric field nonuniformity coefficient is calculated, as shown in Figure 6. The discharge initial conditions of SF_6 highly inhomogeneous electric field are closely related to the electric field strength near the sharp electrode. With the increase of L, the non-uniformity coefficient of the gap electric field rapidly increases and becomes saturated, causing the discharge voltage to drop rapidly and become saturated.

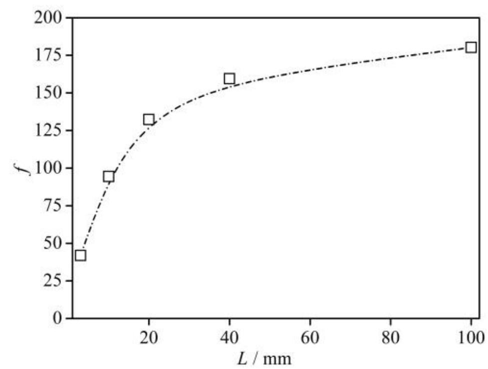


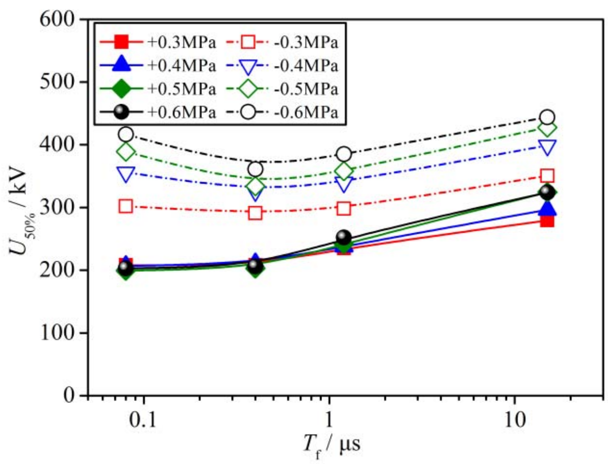
Fig. 6. Electric field nonuniformity coefficient under different L

C. *Effect of Wavefront Time*

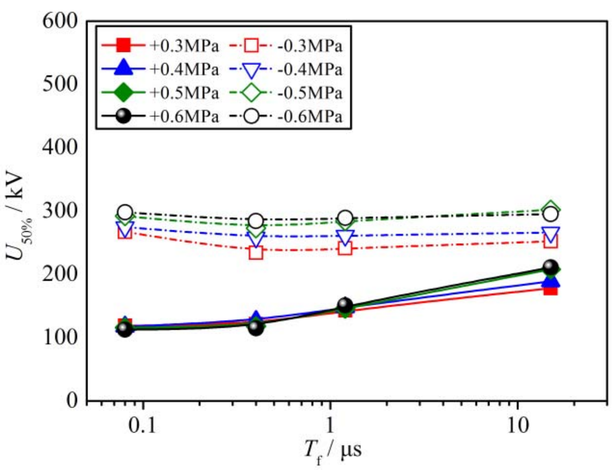
Figure 7 shows the 50% breakdown voltage vs. T_f for different needle length L. Compared with the negative polarity, the gap discharge voltage with positive polarity impulse voltage changes more obviously with the wavefront time increase. With the increase of wavefront time, the discharge voltage of the gap increases, which is different from U-shape of $U_{50\%}$-T_f curve for rod-plane gap as shown in Figure 8 [13]. The U-shaped trend of the $U_{50\%}$-T_f curve for coaxial cylinder structure is not obvious. The discharge voltage decreases with the decrease of wavefront time and does not increase at short wavefront. It is because the shielding effect of the background electric field increases the discharge voltage and the critical volume of $E \geq E_{cr}$ near the needle electrode. The effective initial electron is easier to generate, then reducing the statistical delay of discharge. The effect of space charge on electric field during discharge is stronger than the statistical delay on discharge voltage. So the discharge voltage is not significantly improved.

IV. CONCLUSION

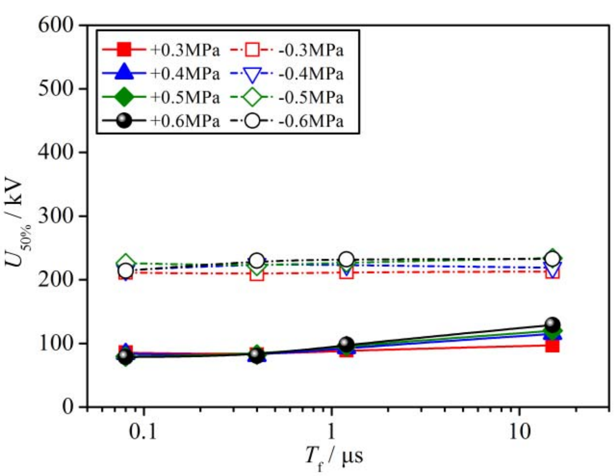
The insulation characteristics of GIS bus with a conductive protrusion under impulses with different waveform parameters were studied based on the enclosed impulse generating system. Experimental results show that the electrode structure has a great influence on the discharge characteristics. For the GIS bus with a conductive protrusion, the shielding effect of the bus on the defect changes the electric field distribution of the gap, so that the $U_{50\%}$-T_f curves no longer show the U-shaped as the rod-plane electrode. The 50% discharge voltage of the bus with needle increases with wavefront time increase. The field simulation results also show that with the increase of the needle length, the field nonuniformity factor increases. Therefore, when studying the discharge characteristics of GIS with defects, the shielding effect should be considered.



(a) $L = 3$ mm, $D = 33$ mm



(b) $L = 10$ mm, $D = 33$ mm



(c) $L = 40$ mm, $D = 33$ mm

Fig. 7. 50% breakdown voltage vs. T_f for different needle length L

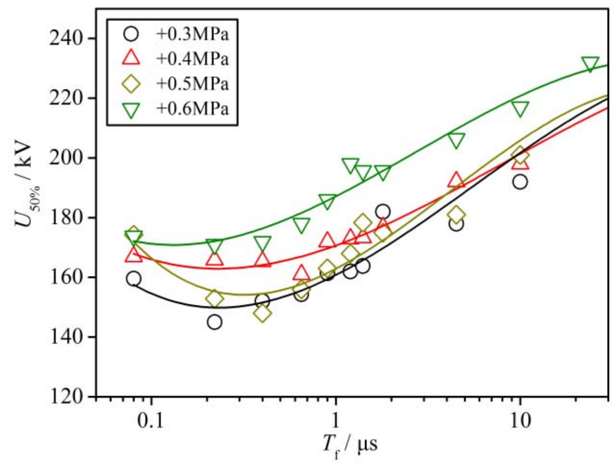


Fig. 8. 50% breakdown voltage vs. T_f for rod-plane gap [13]

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