Influence of Impulse Waveform Parameters on the Breakdown Voltage in SF_6 Highly Inhomogeneous Electric Field

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***Abstract*—Very fast transient overvoltages (VFTOs) generated during the routine operations of disconnector switch in GIS make great threat to the insulation of power equipment such as GIS. So far, the research results of the insulation characteristics of GIS under VFTO have big dispersion and poor comparability for the waveform parameters of VFTO have not been standardized. A generating system of double-exponential impulses with front times in the range of 0.08~1.2 μs and wave tail times in the range of 1.5~50 μs was established to simulate VFTO. Using this impulse generator, the influence of impulse wave front time and wave tail time on the breakdown voltage in SF_6 highly inhomogeneous electric field was studied. The results show that with the rise of gas pressure, the hump phenomenon occurs in the $U_{50\%}$-P curves. With the increase of impulse wave front time, the 50% breakdown voltages change significantly and the $U_{50\%}$-T_f curves tend to be U-shaped. The bigger the electric field factor f is, the more obvious the U-shaped trend is. Meanwhile, the 50% breakdown voltages decrease significantly with the increase of impulse wave tail time. Analysis reveals that the reasons for the phenomenon above may be explained by the differences of the migration and diffusion of space charges and discharge time delay under impulses with different waveform parameters.**

Keywords—impulse voltage; waveform parameter; SF_6; highly inhomogeneous electric field; 50% breakdown voltage; hump phenomenon; space charge; discharge time delay

I. INTRODUCTION

Gas insulated switchgear (GIS) is widely used today in electrical power systems because of its reliability, compaction, long maintenance cycle, and its small impact on the environment [1]. In its use, the normal operation of the disconnector sometimes generates very fast transient overvoltages (VFTOs) with frequencies ranging from 1 to 100 MHz [2] and amplitudes up to 2.5 p.u. [3]. For systems above 330 kV, the insulation strength of the GIS under VFTO is of concern as insulation failures caused by VFTO have exceeded those caused by lightning impulse (LI) [4]. This characteristic has attracted the attention of researchers worldwide and currently is a hot topic in the field of ultra high voltage (UHV) GIS insulation.

A series of investigations [5-16] have been conducted by researchers into discharge characteristics and mechanisms of SF_6 gas in GIS. But the research results of the insulation characteristics of GIS under VFTO have big dispersion and poor comparability for the waveform parameters of VFTO have not been standardized. The actual VFTO originates from multiple times breakdown process has many parameters, such as front time, oscillation frequency, oscillating coefficient and damping coefficient. Control variate method should be used to clarify the main influential parameters of VFTO on the breakdown in SF_6.

In this paper, based on the established impulse generating system, the discharge characteristics of SF_6 highly inhomogeneous electric field under impulses with different wave front times and wave tail times were studied, in order to obtain the insulation accidents causes under VFTO.

II. EXPERIMENTAL SETUP AND METHOD

A schema of the experimental set-up used in this work was shown in Fig. 1, which was designed by oil immersed Marx generator and simulation GIS bus, could generate double-exponential impulses with wave front time in the range of 0.08~1.2 μs and wave tail time in the range of 1.5~46.5 μs, as shown in Fig. 2.

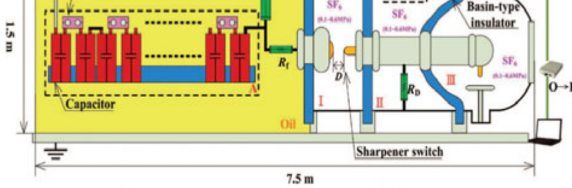

Fig. 1. Schematic diagram of double-exponential impulses generating system.

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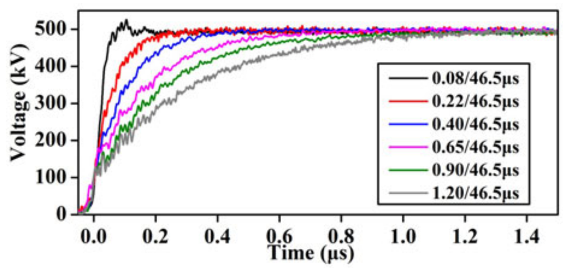
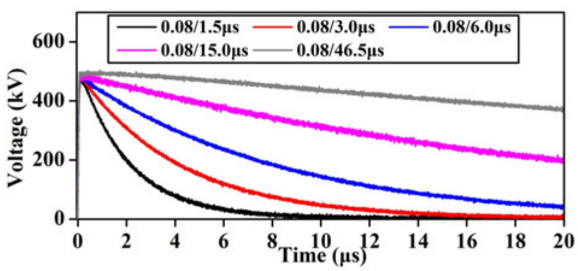


(a) impulses with different wave front times T_f



(b) impulses with different wave tail times T_t

Fig. 2. Typical voltage waveform of double-exponential impulses with different waveform parameters.

A newly developed conical voltage sensor was used for the measurement double-exponential impulses. 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 5 ns and the uncertainty of divider ratio was less than 3%. The 50% breakdown voltage ($U_{50\%}$) was obtained by using up-and-down method according to IEC 60060-1 [17].

The rod-plane electrode system shown in Fig. 3 was adopted to simulate local field enhancement in GIS. The high voltage electrode were hemispherically capped stainless steel rod with different curve radius *r*. The grounded plane was a 300-mm-diam Rogowski stainless steel electrode. The electrode gap *d* could be adjusted to 33 mm in the test. The field nonuniformity factor *f* calculated by [18] was shown in Table 1. The test setups were installed in the chamber filled with SF_6 up to absolute pressures from 0.1 MPa to 0.5 MPa.

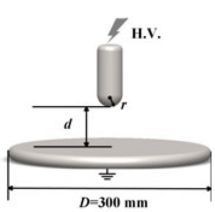


Fig. 3. Configuration of electrode.

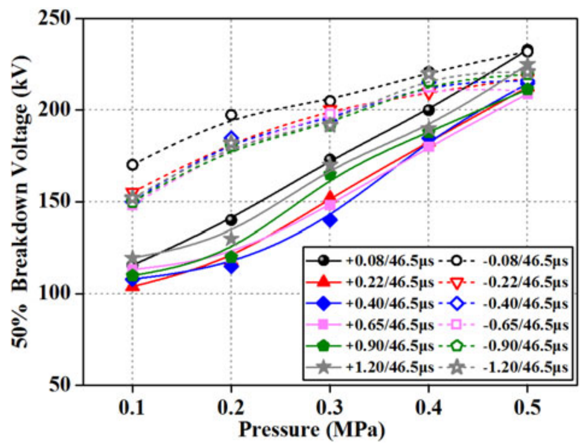
TABLE I. FIELD NONUNIFORMITY FACTORS OF SPHERE-PLANE AND ROD-PLANE ELECTRODES

Parameters	rod-plane electrodes	
r (mm)	15	2
d (mm)	33	
f	2.72	12.17

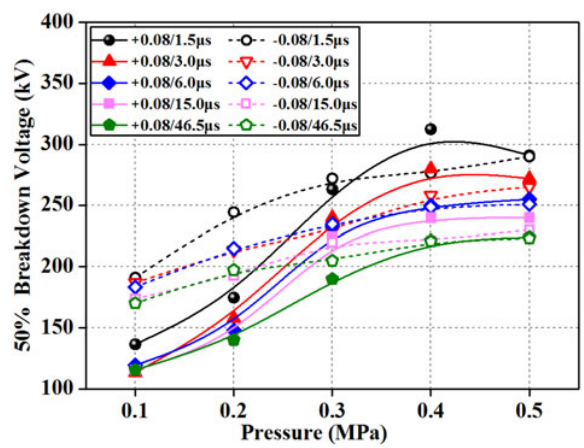
III. EXPERIMENTAL RESULTS AND DISCUSSIONS

A. Effects of Gas Pressure

In this paper, the 50% breakdown voltages of SF_6 under impulses with different waveform parameters at different gas pressures were studied. Fig. 4 shows 50% breakdown voltages of 2 mm rod-plane electrodes under impulses with different wave front times and tail times at five pressures.



(a) different wave front times T_f



(b) different wave tail times T_t

Fig. 4. 50% breakdown voltage vs. gas pressure for rod-plane gap under impulses with different wave front times and wave tail times (r=2 mm d=33 mm f=12.17).

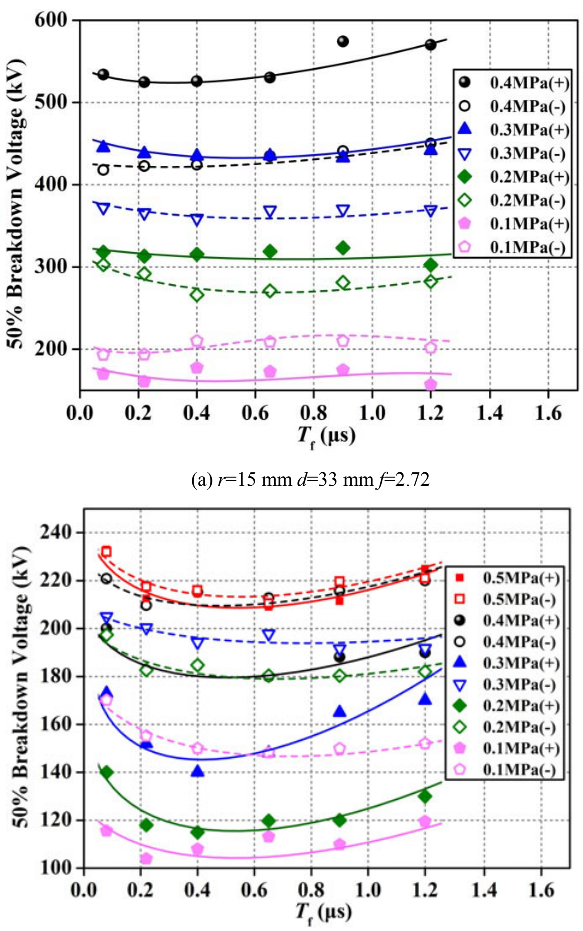
With the rise of gas pressure, the hump phenomenon occurs in the $U_{50\%}$-P curves, as shown in Fig 4(b).

B. *Effect of wave front time*

Fig. 5 shows the 50% breakdown voltage of rod-plane gas gaps under double-exponential impulses with different wave front times. It is not hard to find that with the wave front time T_f increase, the 50% breakdown voltages have remarkable change and the $U_{50\%}$-T_f curve tends to be U-shaped. For understanding of the U-shape, the statistical time lag, the corona formation time, the leader stepping time and the corona stabilization have to be considered. Compared r=15 mm with r=2 mm, it can find that the bigger the electric field factor f is, the more obvious the U-shaped trend is.

C. *Effect of wave tail time*

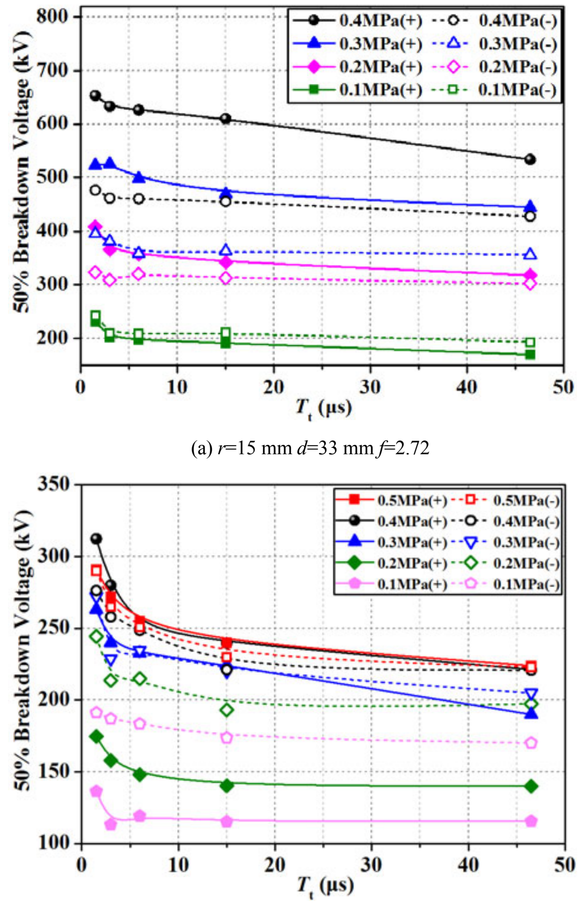
Fig. 6 shows the 50% breakdown voltage of rod-plane gas gaps under double-exponential impulses with different wave tail times. The 50% breakdown voltages decrease significantly with the increase of impulse wave tail time T_t, especially when T_t in the range of 1.5~15 μs, which could be explain by the area method. But the discharge voltages reduce gradually. Assumed that the discharge time lag is t_d, the static discharge voltage is U_0 (the corresponding time is t_0), the effective areas for the five impulses can be calculated by equation (1), where A_f is a constant that depends on the gap conditions and other factors. For the same impulse voltage U(t), the difference values of the adjacent two impulses are A_{21}、A_{32}、A_{43}、A_{54}. It can be



(a) r=15 mm d=33 mm f=2.72

(b) r=2 mm d=33 mm f=12.17

Fig. 7. 50% breakdown voltage vs. wave front times for rod-plane gaps at different gas pressures.



(a) r=15 mm d=33 mm f=2.72

(b) r=2 mm d=33 mm f=12.17

Fig. 5. 50% breakdown voltage vs. wave tail times for rod-plane gaps at different gas pressures.

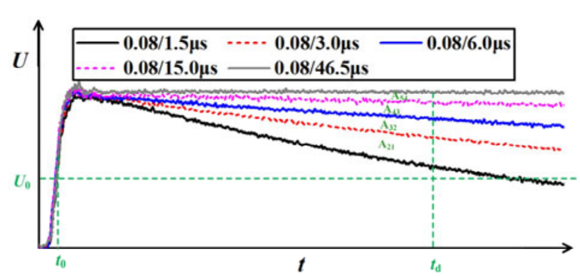


Fig. 6. 50% breakdown voltages decrease with the increase of impulse wave tails explained by the area method.

easily find that $A_{21} > A_{32} > A_{43} > A_{54}$. So with the wave tail time increases, the discharge voltage difference reduces.

$$\int_{t_0}^{t_d - t_0} \{U(t) - U_0\} dt = A_f \qquad (1)$$

IV. Conclusion

The discharge characteristics of SF_6 gas gaps under impulses with different front times and wave tail times were studied based on the enclosed impulse generating system. Experimental results show that with the rise of gas pressure, the hump phenomenon occurs in the $U_{50\%}$-P curves. With the increase of impulse wave front time, the 50% breakdown voltages change significantly and the $U_{50\%}$-T_f curves tend to be U-shaped. The bigger the electric field factor f is, the more obvious the U-shaped trend is. The 50% breakdown voltages decrease significantly with the increase of impulse wave tail time. With the wave tail time increases, the discharge voltage gradually decreases, which could be explained by the area method.

Acknowledgment

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