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Discharge Performance of Conductor Spikes in GIS under AC Voltage

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***Abstract*—Gas insulated switchgear (GIS) is widely applied in power systems due to its excellent insulation performance. The reliability of GIS will be influenced by various insulation defects generated during the manufacture, installation, adjustment, operation and maintenance of the apparatus. Some defects, including conductor spikes, free metal particles, etc., make local electric field higher. Due to the HUMP effect of SF_6 gas, the partial discharge inception voltage and the breakdown voltage of these defects are approximate to each other in non-uniform electric field under operating conditions. These defects cannot be effectively detected through partial discharge detection method as a result of this phenomenon. Different geometry of conductor spikes are used in this article, the partial discharge inception voltage and the breakdown voltage of these defects are measured by using ERA method, the results indicate that the breakdown performance is singular because of existence of space charge, and the partial discharge performance is closely related to the uniformity of gas gap.**

Keywords—Gas insulated metal-enclosed switchgear; HUMP curve; corona-stabilization

I. INTRODUCTION

SF_6 has been widely used in electric power system because of its high electric strength, strong arc extinguishing ability and good chemical stability.[1][2][3] The gas insulated enclosed switchgear with SF_6 has many advantages, such as high reliability, small covering area, convenient maintenance and small external influence. It is widely used in power network. But in the GIS equipment manufacturing, installation, commissioning and operation process, still inevitably occur some insulation defects, such as high-voltage conductor spikes. During GIS operation, sometimes insulation defects occurred, but partial discharge detection method did not play the expected role.[4][5][6][7] Some scholars believe that there is non-corona breakdown in the compressed gas when some insulation defects present. Thus, the use of partial discharge detection method cannot accurately assess the GIS equipment insulation statement. Therefore, it is very important to study the discharge characteristics of insulation defects in GIS in order to clarify the applicability of PD detection.

At present, it has been observed that the abnormal breakdown of SF_6 steady-state breakdown voltage with different gas pressure in inhomogeneous electric field, and this curve is described as HUMP curve, as shown in Fig.1. The key pressure of the HUMP curve includes the streamer breakdown pressure p_1, the breakdown voltage plunge pressure p_{pl} after the maximum breakdown voltage and the non-corona breakdown pressure p_c. When $p \leqslant p_1$, the corona forward the spikes is diffused ,there is no shielding effect on the electrodes. In the case of $p_1<p<p_m$, the breakdown mode is changed to the leader breakdown. At this time, space charge forward the spike tip in the high electric field strength to play a shielding effect, greatly increased the breakdown voltage. This phenomenon is defined as corona stabilization. When $p < p_c$, the stable corona and the leader discharge exist at the same time, this region is a transition region, corona stabilization is still existed, but its role is gradually weakened; when $p > p_c$, before the breakdown of corona is very weak, the region is called as non-corona breakdown.

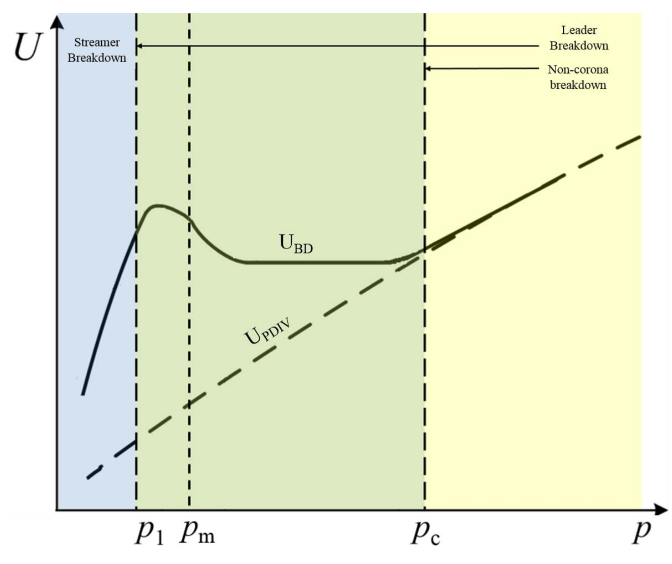


Fig. 1. Typical U-p curve under AC Voltage of SF_6 in non-uniform electric field (HUMP curve)

At present, for the study of HUMP curve, it's generally considered that corona stability depends on the uniformity of the electric field, the radius of curvature of the electrode, the pressure of gas and so on. In this paper, the breakdown characteristics and partial discharge characteristics of high voltage conductor spikes of different sizes are studied.

II. Experimental Setup and Methods

In order to study the discharge performance of conductor spikes in GIS under AC voltage, a 500kV GIS test power system was set up in the laboratory. The experimental system is shown in Fig.2.

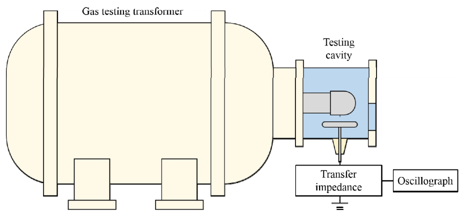


Fig. 2. Configuration of test system

The testing cavity and the gas testing transformer is connected directly through the basin insulator. The partial discharge of the test system can guaranteed less than 3pC when the output voltage is 350kV. Test voltage adjust by the column type voltage regulator, so that power-frequency waveform distortion is small, the output voltage and input voltage are same-phase. The test voltage is measured using a high-precision voltage transducer to measure the 1000:1 winding. In order to ensure high reproducibility of the test results, the test processes including boosting and measuring are under auto control.

The partial discharge signal is measured by using the coupling device series circuit method recommended in the standard IEC 60270:2000.[9] The stray capacitance of the transformer is used as the coupling impedance to obtain the pulse current on the single-point grounding line.

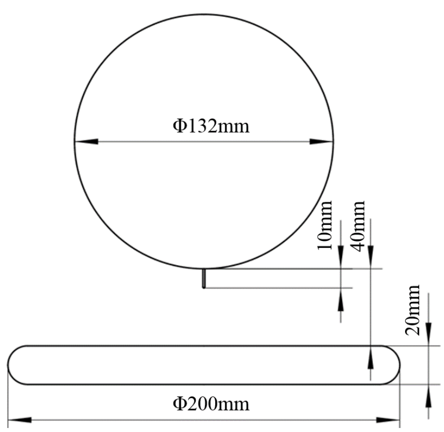


Fig. 3. Typical arrangement of electrodes used for test

The system can simulate GIS typical insulation defects, filled with different gas SF_6 gas to study the discharge characteristics. The high-voltage conductor spike electrode used as shown in Fig. 3. The distance between the poles is 30mm. The high voltage conductor is an aluminum bus bar with a diameter of 132mm. The spike is made by using round rod electrode and sharp rod electrode. The length of the spike can adjust according to experimental needs. The electrode is a flat electrode with a diameter of 200mm and the edge is chamfered.

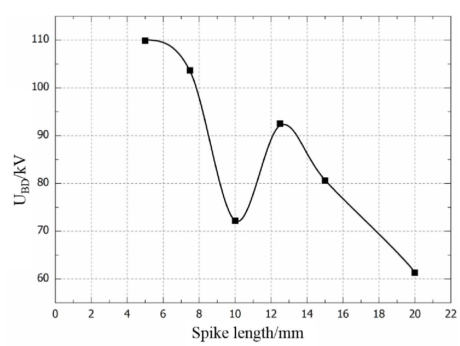
In the experiment, the experimental chamber was vacuumed, then the SF_6 gas was filled in the cavity with 0.1Mpa to 0.6MPa, and the experiment was carried out after standing for 12 hours. In order to reduce the influence of adjacent experiment, the interval between two experiments is 10min to ensure the recovery of the gas dielectric strength. The experiment is carried out with uniform boosting method, the boosting speed is 1kV/s. Partial discharge waveforms were acquired with a digital oscilloscope (Tektronix DPO4104). The oscilloscope simulated bandwidth is 1GHz and sampling rate is 5GS/s.

III. Experimental Results and Discussion

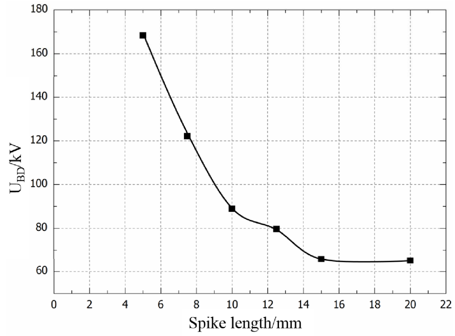
In the laboratory, the breakdown voltage of high voltage conductor spike electrode and the variation law of the critical pressure of HUMP curve with spikes were studied. The variation of partial discharge inception voltage with spikes size was studied.

A. Breakdown performance

Fig. 4 shows the relationship between breakdown voltage and the length of the spike. It can be seen that when the gas pressure is 0.1MPa, the breakdown voltage does not decrease monotonically with the length of the spike, but a maximum value appears when the spike length is 12mm. But there is no such phenomenon when the air pressure is 0.6MPa. This is because the distance between the plates decreases with the growth of the spikes length, the breakdown voltage decreases if the breakdown field strength is certain. However, with the increase of the spike length, the corona stabilization is enhanced. The corona stabilization could increase breakdown electric field. This two competition effects result in a maximum breakdown voltage at a certain spike length. At high pressure, there is almost no corona stabilization effect, so the breakdown voltage is only monotonically reduced due to the reduction of the distance of gas gap.



(a) p=0.1MPa



(b) p=0.6MPa

Fig. 4. Breakdown voltage as a function of spike length (d=40mm, Φ=1mm, round spike)

Fig. 5 shows the breakdown voltage as a function of curvature of spike. It can be seen that the breakdown voltage with the radius of curvature is not monotonous, too. This is because although the gap non-uniformity decreases with the increase of the radius of curvature, the breakdown field strength should be increased. However, due to the smaller radius of curvature of the spike stabilization strong corona, so the breakdown voltage is higher. For example, in this experiment, the tip rod electrode with a diameter of 1 mm still did not reach its non-corona breakdown voltage at 0.6MPa, so the corona stabilization still existed. The breakdown voltage-pressure curve is shown in Fig.6. Therefore, the breakdown voltage is not enough to clarify the breakdown characteristics of the high-voltage conductor spike defect. It is necessary to study the key gas pressure of HUMP curves.

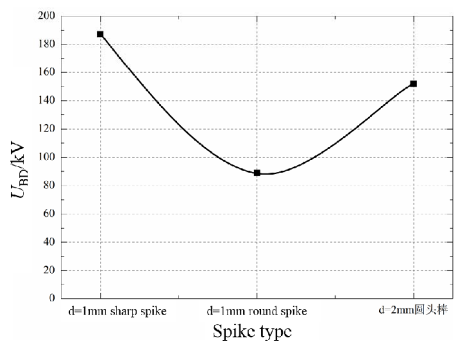


Fig. 5. Breakdown voltage as a function of the radius of curvature of spike (d=40mm, l=1mm)

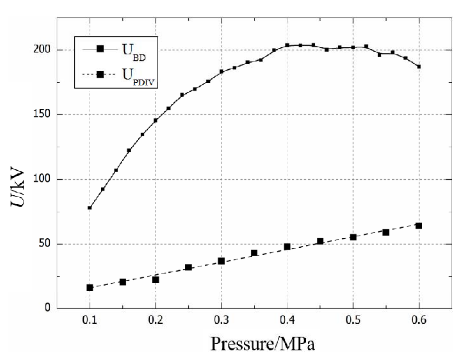


Fig. 6. Breakdown voltage and partial discharge inception voltage as a function of pressure (d=40mm, l=1mm, Sharp spike)

Fig. 7 shows the breakdown voltage plunge pressure p_{pl} and non-corona breakdown pressure p_{c} as a function of the spike length. It can be seen that breakdown voltage plunge pressure has an increasing trend with increasing spike length, that is, corona stabilization in the high pressure is not easy to maintain with shorter spike. The non-corona breakdown pressure is stable, both are distributed around 0.5MPa.

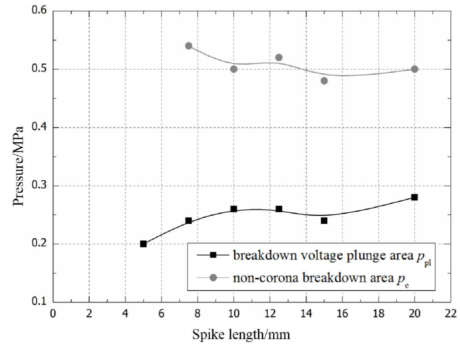


Fig. 7. Breakdown voltage plunge area and non-corona breakdown area as a function of spike length (d=40mm，l=10mm, round spike)

The variation of the breakdown voltage plunge pressure ppl with the radius of curvature is also studied, as shown in Fig. 8. It can be seen that breakdown voltage plunge pressure decreases with curvature radius increases, that is, the greater the radius of the spike curvature, corona stabilization at high pressure is not easy to maintain. In addition, the spikes with small radius of curvature at 0.6MPa have not reached the breakdown voltage drop point, indicating that it still has corona stabilization phenomenon.

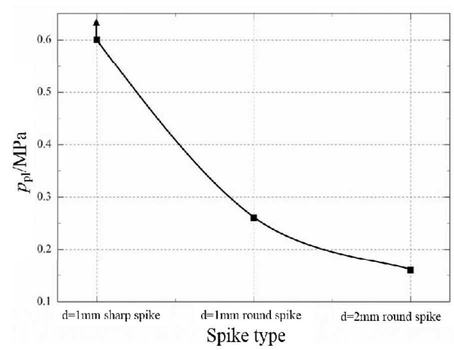


Fig. 8. Breakdown voltage plunge area as a function of the radius of curvature of spike (d=40mm，l=10mm)

B. Partial discharge performance

The partial discharge inception voltage of the high-voltage conductor spikes is linearly increasing with the pressure increases. This is because the nature of partial discharge inception voltage is the inception voltage of streamer. When electric field forward the spike tip reaches the SF_6 streamer inception electric field, the immediate voltage is the partial discharge inception voltage. Thus, this voltage linear growth with the gas pressure. The relationship between partial discharge inception voltage and gas pressure shown in Fig. 9.

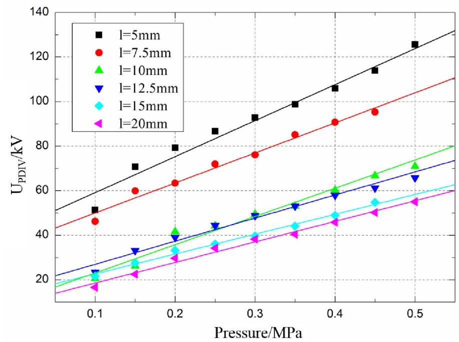


Fig. 9. Partial discharge inception voltage as a function of pressure (d=40mm , Φ=1mm, round spike)

Fig. 10 shows thse variation of the slope of the partial discharge inception voltage-pressure curve with the length of the spike extension. It's found that with the increase of spike length, the slope of the initial voltage-pressure curve of partial discharge decreases. This is because the slope reflects the non-uniformity of gap, longer spike means higher non-uniformity of the gas gap. For long spike, less voltage can maintain a stable partial discharge at a certain pressure increment.

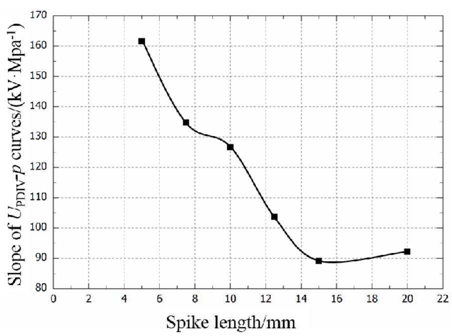


Fig. 10. Slope of U_{PDIV}-p curves as a function of spike length (d=40mm , Φ=1mm, round spike)

Similarly, Fig. 11 shows the relationship of the slope and the radius of curvature of spike also obey the above-mentioned discipline. It can be seen that the slope increases with the increase of the radius of curvature. This also satisfies the previous discussion about slope as a function of gap non-uniformity.

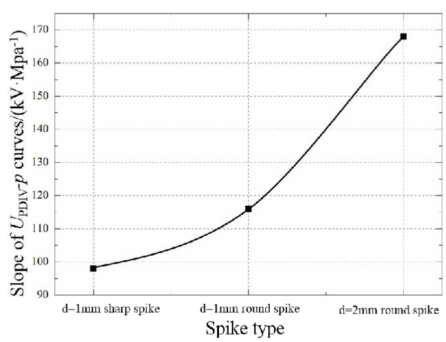


Fig. 11. Slope of U_{PDIV}-p curves as a function of the radius of curvature of spike (d=40mm, l=1mm)

IV. Conclusion

1) When the gas pressure is low, the breakdown voltage does not decrease monotonically with the growth of the spike length, but a maximum value occurs at a certain length, and the phenomenon disappears when the gas pressure is high. Similarly, the breakdown voltage decreases with the radius of curvature non-monotonically decreasing, and due to corona stabilization, breakdown voltage will rise when the radius of curvature is small.

2) The breakdown voltage plunge pressure has an increasing trend with increasing spike length, and decreases with curvature radius increases. That is, the shorter the spike length and the larger the radius of curvature, the more difficult corona stabilization is to be maintained under high pressure.

3) The nature of partial discharge inception voltage is the streamer inception voltage. When the maximum electric field strength in the extremely non-uniform electric field reaches the initial field strength of SF_6, the immediate voltage is the partial discharge inception voltage. The slope of U_{PDIV}-p curves reflects the non-uniformity of the gap.

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