Influence of Operating Voltage on Breakdown Characteristics of HVDC GIL under Impulse Voltage

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Abstract*-In HVDC GIL, impulse overvoltage is not generated alone but generally superimposed on the DC operating voltage. Therefore, it is of great necessity to study the influence of DC operating voltage on breakdown characteristics of HVDC GIL under impulse voltage. In this paper, breakdown characteristics of GIL under superimposed voltage of DC and impulse are studied. The results indicate that pre-stressed DC voltage of positive polarity has little effect on the breakdown voltage of gas gap. When DC voltage is in negative polarity, the influence of DC voltage is related to the polarity of impulse voltage. Under superimposed voltage of negative DC and negative impulse, breakdown voltage is higher than that under impulse voltage alone. Under superimposed voltage of negative DC and positive impulse, breakdown characteristics of GIL depend on the size of the fixed particle. With the increase of particle length and decrease of particle radius, the influence of DC voltage becomes larger. Moreover, the light signal proves that the space charge produced in corona discharge under DC voltage has significant influence on the discharge process of gas gap under superimposed voltage. The results of the experiments show that superimposition of DC operating voltage and impulse voltage can be a critical condition for HVDC GIL, therefore superimposed test of DC and impulse is proposed to be part of on-site test for HVDC GIL to ensure the insulation ability under the service condition. Since up to now there is no valid standard for HVDC GIL, this research can serve as reference for the future formation of test standards.

I. INTRODUCTION

The increasing demand of high power transmission over long distances will enhance the use of high voltage direct current (HVDC) transmission [1]. High voltage direct current gas insulated line (HVDC GIL) has attracted much attention due to its advantages of large transmission capacity, small electrical loss, high reliability, enormous space reduction, etc. It can be utilized to substitute overhead line in special conditions such as tunnels and connections between city load centers [2-3]. As a result, GIL will be an important component of future HVDC installations. In HVDC GIL, impulse overvoltage is not generated along but generally superimposed on the DC operating voltage [4-5]. Therefore, it is of great necessity to study the influence of operating voltage on breakdown characteristics of HVDC GIL under impulse voltage.

Some research has been conducted focusing on the breakdown characteristics of SF_6 under superimposed voltage of DC and impulse. In uniform and quasi-uniform electric field, breakdown voltage of SF_6 under the superimposed voltage is almost the same as that under impulse voltage alone [6-7]. In non-uniform electric field, if DC voltage is larger than the corona onset voltage, space charge will be produced in the corona discharge under DC voltage and thus influence the breakdown voltage. The research conducted by D. Berg and P. Arnold indicates that when DC and impulse voltage are of the same polarity, breakdown voltage of SF_6 will increase under the superimposed voltage [8-9]. When they are of the opposite polarity, breakdown voltage will decrease. However, the research of K. Siodla shows that breakdown voltage of SF_6 will increase regardless of the polarity of DC voltage [10]. Since the conclusions of existing studies differ greatly from each other and the effect of space charge is not clarified, further research should be conducted.

In this paper, the influence of DC operating voltage on the breakdown characteristics of HVDC GIL under impulse voltage is studied. Based on the results, the effect of space charge is theoretically analyzed.

II. EXPERIMENTAL CONDITIONS

A. *Experimental Platform*

An experimental circuit is specially designed to generate superimposed voltage of DC and impulse, as shown in figure 1. A high-voltage DC source of ±600 kV/10 mA and an impulse voltage generator of 1600 kV are connected in parallel. To isolate DC voltage from the impulse generator, a blocking capacitor of 30 nF is in series with the impulse generator. A protective resistor of 320 kΩ is placed between the DC source and GIL to protect the DC source from impulse voltage. A protective gap is connected in parallel with the block capacitor to protect the capacitor in case discharge occurs in GIL. A resistance-capacitance divider is used to measure the superimposed voltage.

Standard lightning impulse of 1.2/50 μs is generated by the impulse generator and superimposed on the pre-stressed DC voltage. Four waveforms of superimposed voltage can be generated by the circuit, namely superimposed voltage of positive/negative DC and positive/negative impulse.

Breakdown voltage described in this paper refers to the peak value of the superimposed voltage relative to ground potential.

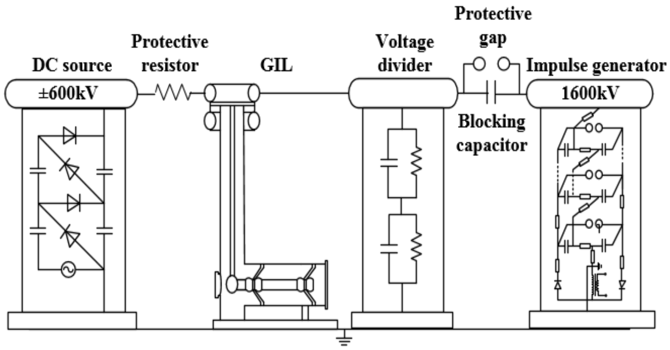


Fig. 1. Diagram of the experimental circuit.

The radiuses of high-voltage conductor and enclosure of the GIL test chamber are 170 mm and 550 mm, as shown in figure 2. The superimposed voltage is applied to the test chamber by a 500kV high-voltage bushing. To simulate the distortion of electric field in GIL, a metallic wire particle is fixed on the high-voltage bus bar.

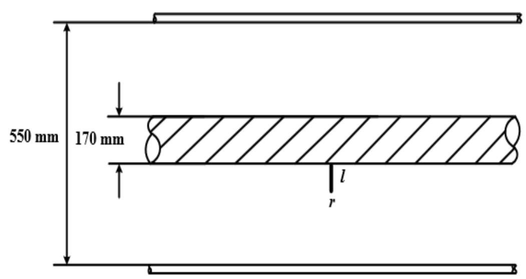


Fig. 2. Diagram of the experimental chamber.

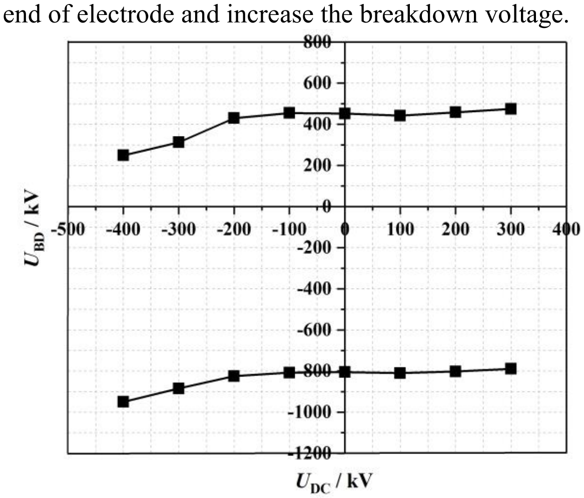
B. Experimental Method

In the experiment, DC voltage is firstly applied to GIL and kept for 5 min. Then impulse voltage is generated by the impulse generator and superimposed on the DC voltage. 50% breakdown voltage is obtained by the up-and-down method. The amplitude and pre-stressed time of DC voltage remain unchanged each time and the increment between successively applied impulse voltages should meet the rule of $\Delta U \leq 0.03U_{50\%}$. After a number of experiments, 50% breakdown voltage could be obtained. The fixed particle should be replaced after several breakdowns to eliminate the influence of erosion during the discharge. The amount of effective data in each condition is over 30.

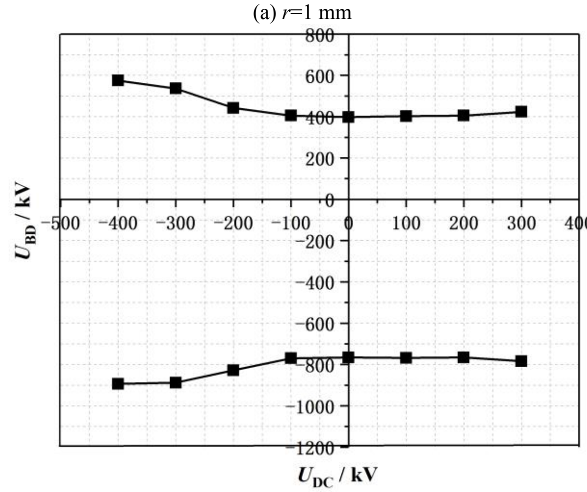
III. Results And Discussion

A. Influence of Particle Radius

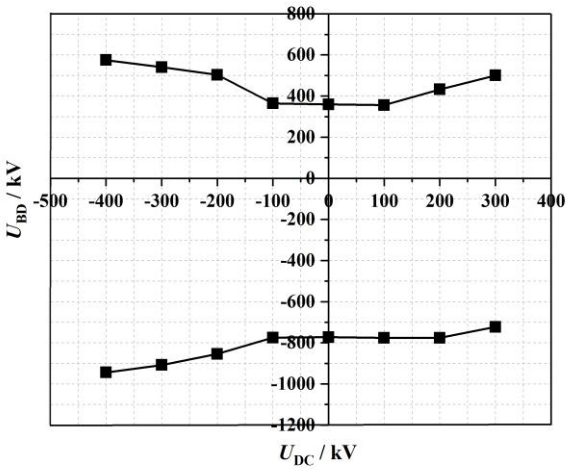
Particle of 1 mm, 0.5 mm, 0.25 mm in radius and 10mm in length is respectively fixed on the high-voltage conductor to study the influence of particle radius. Breakdown characteristics of GIL under superimposed voltage of DC and impulse are shown in figure 3. In the figure the horizontal axis represents the amplitude of pre-stressed DC voltage and the vertical axis is the amplitude of superimposed voltage. Breakdown voltages under impulse voltage alone are represented by points where DC voltage equals zero. From the figure it can be seen that pre-stressed DC voltage of positive polarity has little effect on breakdown voltage of gas gap. When DC voltage is in negative polarity, the influence of DC voltage is related to the polarity of impulse voltage. Under superimposed voltage of negative DC and negative impulse voltage, breakdown voltage is higher than that under impulse voltage alone. The reason is that under negative DC voltage, a mass of negative ions are formed due to corona discharge and accumulate near the particle. When negative impulse voltage is applied, the negative ions will weaken the electric field, and thus breakdown voltage will increase. However, under superimposed voltage of negative DC and positive impulse, breakdown characteristics of GIL depend on the size of the fixed particle. With the particle of 1 mm in radius, breakdown voltage decreases with the increase of DC voltage. The reason is that the electric field is enhanced by the negative ions produced in the corona discharge. With the particle of 0.25 mm and 0.5 mm in radius, breakdown voltage increases. Under negative DC voltage, a layer of plasma is formed in the area very close to the electrode due to massive electron avalanche and positive ions. It will weaken the electric field at the end of electrode and increase the breakdown voltage.



(a) r=1 mm



(b) r=0.5 mm



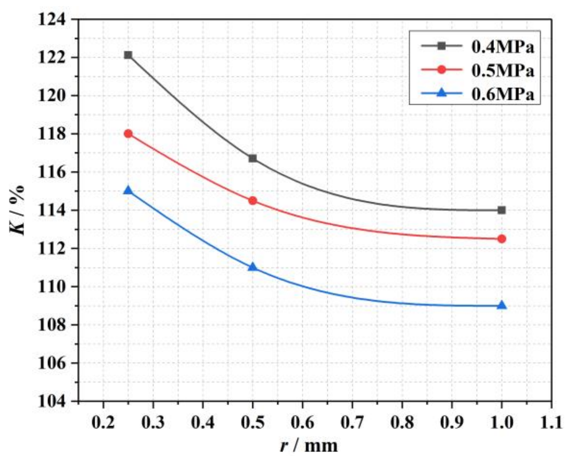
(c) r=0.25 mm

Fig. 3. Breakdown voltage of GIL under superimposed voltage of DC and impulse.

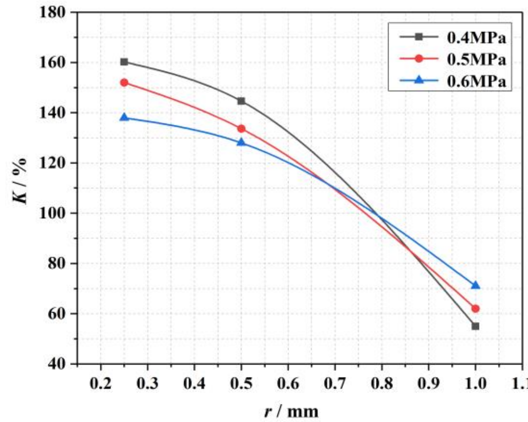
To analyze the influence of pre-stressed DC voltage on breakdown characteristics of GIL, the ratio of breakdown voltage under superimposed voltage to that under impulse voltage alone is defined as K. If K is close to 1, it means DC voltage has small influence on the breakdown voltage. The relationship between K and particle radius is shown in figure 4. It can be seen that with the increase of particle radius, the influence of DC voltage becomes smaller. The reason is that with the increase of particle radius, the intensity of corona discharge decreases. As a result, less space charge is generated and its influence on breakdown process is reduced. Moreover, with the increase of gas pressure, influence of DC voltage becomes smaller.

B. Influence of Particle Length

Particles of 3 mm, 5 mm in length and 1 mm in radius are used to study the influence of particle length on breakdown characteristics of GIL under the superimposed voltage. Relationship between K and particle length is shown in figure 5. It can be seen that with the increase of particle length, the intensity of corona discharge increases, and the influence of DC voltage becomes larger.

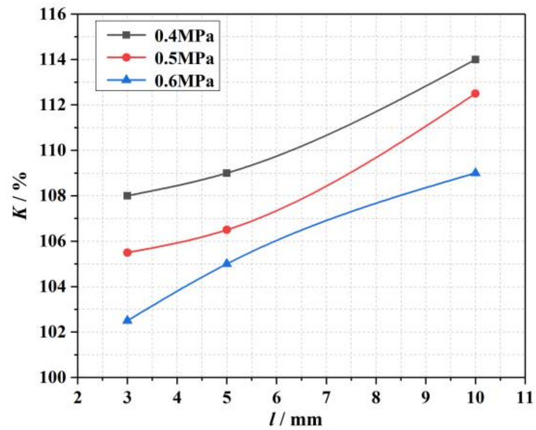


(a) –DC-LI

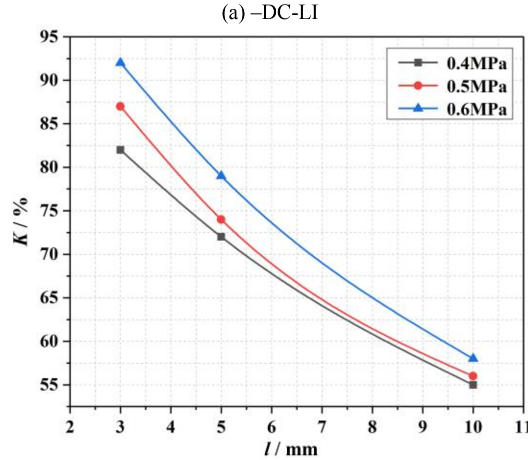


(b) –DC+LI

Fig. 4. Relationship between K and particle radius (U_{DC} = -400 kV).



(a) –DC-LI

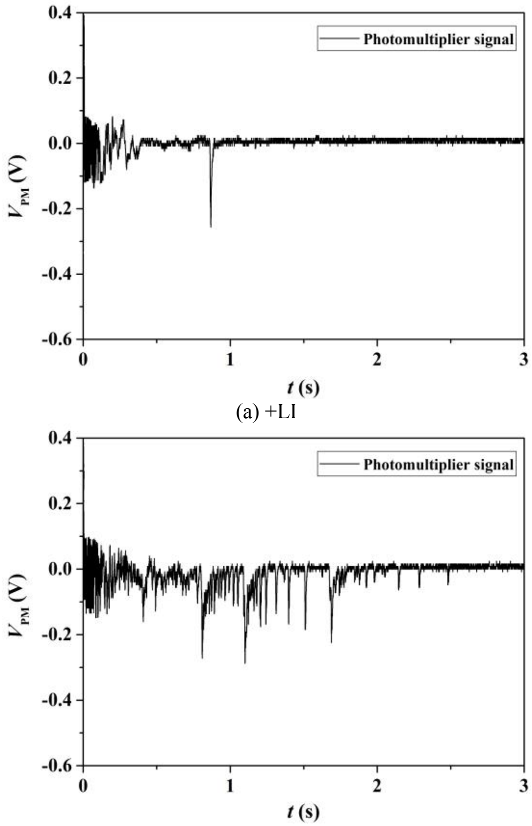


(b) –DC+LI

Fig. 5. Relationship between K and particle length (U_{DC} = -400 kV).

C. Light Signal

Light signal of the discharge process near the particle tip is measured with a photomultiplier tube (PMT). Typical light signal under impulse alone and under superimposed voltage is shown in figure 6. The light signal indicates that when the gap is pre-stressed by negative DC voltage, the level of corona activity increases, and corona inception voltage under positive impulse voltage decreases. On the contrary, corona inception voltage increases when the gap is pre-stressed by positive DC voltage. The light signal proves that the space charge produced in corona discharge under DC voltage has significant influence on the discharge process of gas gap under superimposed voltage.



(a) +LI

(b) -DC+LI

Fig. 6. Typical light signal under superimposed voltage (r=1mm).

IV. CONCLUSION

In this paper, the influence of DC operating voltage on breakdown characteristics of HVDC GIL under impulse voltage is studied. The results indicate that pre-stressed DC voltage of positive polarity has little effect on breakdown voltage of gas gap. When DC voltage is in negative polarity, the influence of DC voltage is related to the polarity of impulse voltage. Under superimposed voltage of negative DC and negative impulse voltage, breakdown voltage is higher than that under impulse voltage alone. Under superimposed voltage of negative DC and positive impulse, breakdown characteristics of GIL depend on the size of the fixed particle. With the increase of particle length and decrease of particle radius, the influence of DC voltage becomes larger. Moreover, the light signal proves that the space charge produced in corona discharge under DC voltage has significant influence on the discharge process of gas gap under superimposed voltage. The results of the experiments show that superimposition of DC operating voltage and impulse voltage can be a critical condition for HVDC GIL, therefore superimposed test of DC and impulse is proposed to be part of on-site test for HVDC GIL to ensure the insulation ability under the service condition.

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