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Study on Flashover Characteristics of Insulators in SF_6 under Combined Voltage of DC and Lightning Impulse

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***Abstract*—Insulators are under residual DC voltage after opening of disconnectors. When disconnectors reclose, overvoltage will be superimposed on the pre-existing DC voltage. As a result, insulators in GIS will be under combined voltage of DC and impulse. In this paper, flashover characteristics of insulators in SF_6 are studied under combined voltage of DC and lightning impulse. The results show that for non-contaminated insulators, pre-stressed DC voltage doesn't affect the flashover voltage if it is in the same polarity with the impulse voltage. When they are of the opposite polarity, flashover voltage decreases with increasing DC voltage. In the presence of metallic particles or powder around insulator, pre-stressed DC voltage will cause adhesion of the contaminants on the insulator surface. For the contaminated insulators, pre-stressed DC voltage will have big influence on the flashover voltage of insulators depending on its polarity. The results are analyzed from the perspective of surface charge accumulation. In addition, since combined voltage is found to be more sensitive to detect some insulation defects in SF_6, combined voltage test could be considered to serve as a supplement of field test to verify the insulation performance of GIS.**

Keywords—insulator; SF_6; flashover characteristics; combined voltage; DC; lightning

I. INTRODUCTION

Gas insulated switchgear (GIS) are increasingly used due to the excellent insulation ability of SF_6 gas. Operating experience shows that residual DC voltage of 0.6-1.0 p.u. remains in GIS bus bar for a long time after opening of disconnectors. This DC voltage will cause accumulation of contaminants and surface charge on the insulator surface, which will influence the flashover characteristics of insulators. When disconnectors reclose, impulse voltage could be generated in the bus bar and superimpose on the pre-existing DC voltage. As a result, insulators in GIS will be under combined voltage of DC and impulse. Various flashover accidents of GIS insulators are reported to have happened at the time of diconnectors reclosing. Therefore, it's necessary to study the flashover characteristics of insulators in SF_6 under combined voltage of DC and lightning impulse. In addition, for DC high-voltage equipment, impulse overvoltage is superimposed on the DC operating voltage, and combined voltage is a possible operating condition. Therefore this study is also beneficial for the insulation design of DC high-voltage equipment.

Some research has been conducted focusing on the flashover characteristics of insulators pre-stressed by DC voltage. For non-contaminated insulator, H. Fujinami and T. Nitta prove that DC voltage of the opposite polarity could cause decrease of impulse flashover voltage [1-2]. However, the research of H. Hasegawa shows that the influence of pre-stressed DC voltage is negligible [3]. For particle-contaminated insulator, it is experimentally demonstrated that impulse flashover voltage increases when pre-stressed DC voltage is in the same polarity with the impulse voltage, and flashover voltage decreases significantly when DC and impulse voltage are of the opposite polarity [4-7].

In this paper, flashover characteristics of insulators in SF_6 under combined voltage of DC and lightning impulse are studied. Pollutants such as metallic particles and powder, which are commonly found in GIS, are deposited near the insulator to simulate possible operating conditions. And the experimental results are analyzed theoretically.

II. EXPERIMENTAL CONDITIONS

A. Experimental Platform

Fig. 1 shows the experimental circuit. DC voltage is produced by a high-voltage DC source of ±50kV/2mA. Standard lightning impulse of 1.2/45μs is generated by a 600kV/3kJ impulse generator with 6 steps. A blocking capacitor of 50nF is used to isolate DC voltage from the impulse generator. And a protective resistor of approximately 1MΩ is used to protect the DC source from impulse voltage. In order to measure the combined voltage, a resistance-capacitance divider is adopted.

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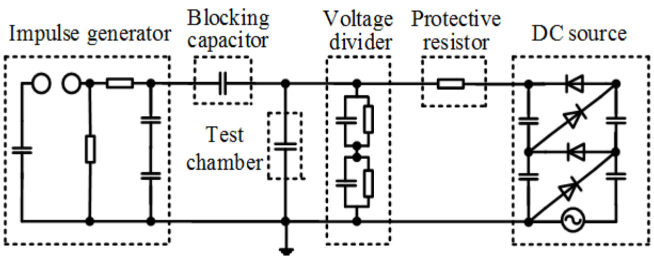

Fig. 1. Diagram of the experimental circuit.

An enclosed experimental chamber is specially designed, as shown in Fig. 2. The main body of the experimental chamber is of organic glass, with internal diameter of 160mm. Six nylon screws are used to fix the upper and bottom flanges. During the experiments, the chamber is filled with SF_6 gas of 0.4MPa. Rogowski electrodes of 156 mm in diameter are used and the distance between the electrodes can be changed by a distance adjustment device. Cylindrical insulators of epoxy resin filled with alumina are used as test samples. Each sample is 15mm in height and 25mm in diameter.

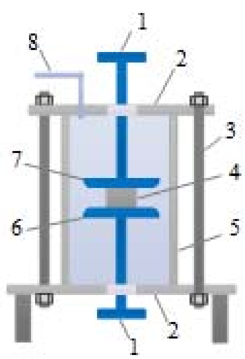

Fig. 2. Diagram of the experimental chamber.

1-distance adjustment device; 2-top and bottom flange; 3-nylon screw;

4-insulator; 5- organic glass cylinder; 6-ground electrode;

7-high-voltage electrode; 8-gas tube.

B. Experimental Method

In the experiment, DC voltage of positive/negative polarity is firstly raised to the required amplitude and kept for a given time. Then positive impulse voltage is generated and superimpose on the pre-existing DC voltage. 50% flashover voltage is obtained in a way similar to the up-and-down method. That is, the amplitude and application time of the DC voltage remains unchanged, while the amplitude of the impulse voltage is continually raised and reduced to get the 50% flashover voltage. Flashover voltage of insulators described in this paper refers to the peak value of the combined voltage relative to the ground potential. After each flashover, the insulator should be polished with abrasive papers and each experiment is repeated 20 times with the same condition.

III. Results and Discussion

A. Flashover Characteristics of Non-contaminated Insulator

The effect of pre-stressed time of DC voltage is first studied. DC voltage is applied to clean insulator for respectively 10, 30, 60 and 90min, then lightning impulse is generated. Fig. 3 shows the relationship between pre-stressed time of DC voltage and flashover voltage of insulators under the combined voltage. In the figure different colors represent flashover voltages with different amplitudes of pre-stressed DC voltage. Points with zero pre-stressed time are flashover voltage of insulators under LI voltage alone. It can be seen that with the increase of pre-stressed time, the change in flashover voltage becomes larger. The reason is that charge accumulation along the insulator surface becomes sever with longer time, thus having greater influence on the flashover voltage. When the pre-stressed time of DC voltage is longer than 60min, flashover voltages decrease slightly with longer application time. Based on the results, pre-stressed time of DC voltage is fixed to 60min in the subsequent experiments.

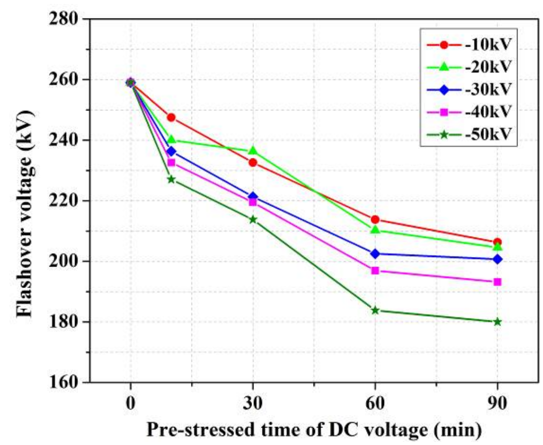

Fig. 3. Relationship between pre-stressed time of DC voltage and flashover votlage.

Flashover characteristics of non-contaminated insulators under combined voltage of DC and LI are shown in Fig. 4. The horizontal axis represents amplitude of pre-stressed DC voltage and the vertical axis represents flashover voltage of insulators under combined voltage. It can be seen that when DC voltage and LI voltage are in the same polarity, flashover voltage under combined voltage is nearly the same as the flashover voltage under LI alone. However, when they are of the opposite polarity, flashover voltage under combined voltage significantly decreases with increasing DC voltage. With pre-stressed DC voltage of -50kV, flashover voltage decreases by as much as 29%. This will cause a big threat to the insulation ability of GIS.

The decrease of flashover voltage is due to the charge accumulation on the insulator surface under pre-stressed DC voltage. When the insulator is pre-stressed by negative DC voltage, the insulator surface near the high voltage electrode will be electrified with charges of negative polarity [8-9]. when positive LI voltage is applied, negative charges will increase the electric field, making flashover easier to happen.

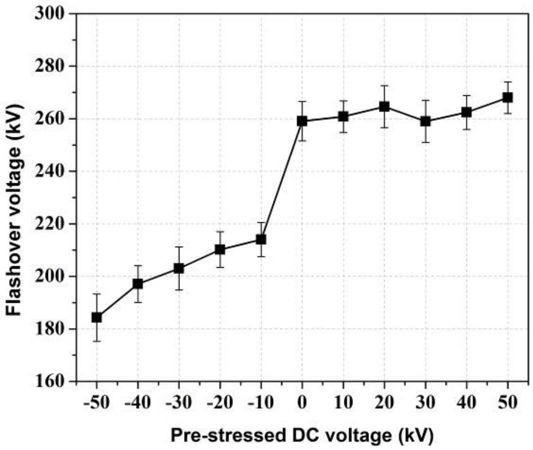

Fig. 4. Flashover characteristics of non-contaminated insulator under combined voltage of DC and LI.

B. *Flashover Characteristics of Particle-contaminated Insulator*

Free metallic particles can be inevitably produced in GIS during the process of production, transportation and assembling. To simulate metallic particle existing in GIS, an aluminum wire particle of 3mm in length and 0.5mm in diameter is deposited on the ground electrode. It is found that under pre-stressed DC voltage, particles tend to move towards the insulator and adhere to it. And if initial position of the particle is closer to the insulator, there is a greater possibility for it to be attached. In addition, once particle adheres to the insulator, it will remain adhered even the DC voltage is removed.

It is found that particles adhere to different positions of insulator surface under pre-stressed DC voltage in every experiment. Therefore, in order to facilitate the experiments, particle is artificially adhered to the top of the insulator and in contact with the high-voltage electrode. The effect of pre-stressed time of DC voltage is studied and the results show that for particle-contaminated insulator, pre-stressed time has little influence on the flashover characteristics. In the following experiments, the pre-stressed time of DC voltage is fixed to 10min.

Flashover characteristics of particle-contaminated insulator under combined voltage are summarized in Fig. 5. when DC and LI voltage are in the same polarity, flashover voltage under combined voltage increases with higher DC voltage. Conversely, when they are of the opposite polarity, flashover decreases significantly with increasing DC voltage. With pre-stressed DC voltage of 50kV, flashover voltage increases by 20%. With -50kV, flashover voltage decreases by as much as 47%. The change of flashover voltage under the combined voltage is due to the accumulation of charges on the insulator surface, especially at the end of particle. Under positive DC voltage, positive charges accumulate on the insulator surface and weaken the electric field of impulse voltage, resulting in an increase of the flashover voltage. While under negative DC voltage, accumulation of negative charges enhance the electric field, so flashover voltage decreases [10-11].

Compared with Fig. 4, it can be seen that that flashover voltages of particle-contaminated insulator are more largely affected by pre-stressed DC voltage. The reason is that for particle-contaminated insulator, the electric field is seriously distorted, and there will be much more charge accumulation on the insulator surface, which will greatly enhance the local electric field.

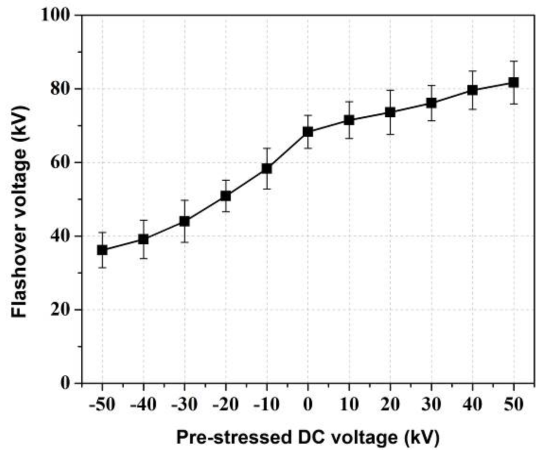

Fig. 5. Flashover characteristics of particle-contaminated insulator under combined voltage of DC and LI.

C. *Flashover Characteristics of Powder-contaminated Insulator*

Metallic powder is commonly found in GIS. The powder can easily lift off and adhere to the insulator surface. It will result in distortion of the electric field along the surface of the insulator, thereby threatening the insulation ability of GIS. In the experiment, 0.1g aluminum powder was arbitrarily deposited in the vicinity of the insulator. DC voltage is pre-stressed for 10 minutes, then LI voltage is superimposed to study the flashover characteristics of powder-contaminated insulator under the combined voltage.

It is found that some fine powder begins to lift off at several hundred volts. As the DC voltage increases, more powder moves and eventually adheres to the insulator surface. Even after the removal of the DC voltage, the powder still adheres to the insulator surface.

Flashover characteristics of powder-contaminated insulator under combined voltage are shown in Fig. 6. It can be seen flashover voltage of insulator decreases significantly under combined voltage of DC and LI. The reason is that once pre-stressed DC voltage is applied, metallic powder will adhere to the insulator surface and distort the electric field. Flashover voltages are in large dispersion, for the distribution of metallic powder on the insulator surface varies greatly in every experiment. With the increase of pre-stressed DC voltage, flashover voltage decreases because more powder is attached to the insulator surface. The most critical condition is found when DC and LI voltage are of the opposite polarity.

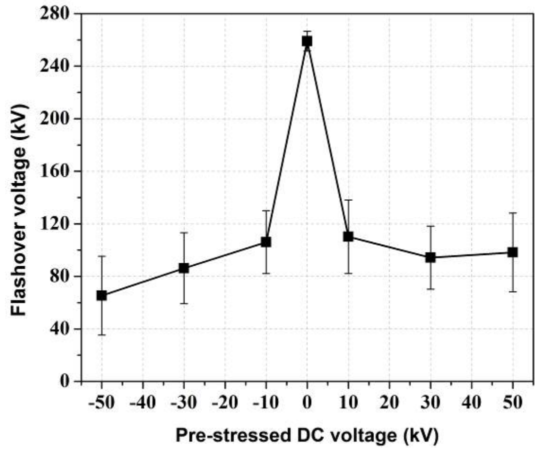

Fig. 6. Flashover characteristics of powder-contaminated insulator under combined voltage of DC and LI.

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IV. RESULTS AND DISCUSSION

In this paper, the flashover characteristics of insulators in SF_6 under combined voltage of DC and lightning impulse are studied. Test conditions include non-contaminated insulator, particle-contaminated insulator and powder contaminated insulator. The results are analyzed from the perspective of charge accumulation.

For non-contaminated insulator, change in flashover voltage becomes larger with longer pre-stressed time of DC voltage. When DC voltage and LI voltage are in the same polarity, flashover voltage under combined voltage is nearly the same as the flashover voltage under LI alone. However, when they are of the opposite polarity, flashover voltage under combined voltage significantly decreases with increasing DC voltage. For particle-contaminated insulator, when DC and LI voltage are in the same polarity, flashover voltage under combined voltage increases with higher DC voltage. Conversely, when they are of the opposite polarity, flashover voltage decreases significantly with increasing DC voltage. For powder-contaminated insulators, flashover voltage of insulator decreases significantly. With the increase of pre-stressed DC voltage, flashover voltage becomes lower because more powder is attached to the insulator surface.

According to the results, it can be seen that combined voltage of DC and impulse is found to be a critical condition for the insulation of insulators in SF_6. However, at present the insulation performance of GIS is only verified by impulse voltage test and power-frequency test. No test is performed to examine its insulation ability under the influence of residual DC voltage. For DC high-voltage equipment, impulse voltage test cannot guarantee its insulation ability under the combined voltage of DC and impulse. In addition, combined voltage is found to be more sensitive to detect some insulation defects in SF_6, so combined voltage test could be considered to serve as a supplement of field test to verify the insulation performance of GIS and DC high-voltage equipment.

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