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Recording the breakdown phase of a 4 m rod-plane air insulation under positive standard switch impulse voltages

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Abstract: *Air insulation is widely used as the external insulation of power transmission lines. The performance of air insulation is a concern. The breakdown voltage of rod-plane air insulation with a certain length is often used to evaluate the performance of the air insulation with the length. The breakdown voltage of rod-plane air insulation is determined by the discharge phase termed breakdown phase. The breakdown phase of a 4 m rod-plane air insulation under positive standard switch impulse voltages was recorded by a high-speed camera and reported in this paper. The breakdown phase would help to deepen the understanding of air insulation.*

Keywords: *High voltage, air insulation, discharge, breakdown phase*

1. Introduction

Air insulation (gap) is the most widely used form of external insulation of power transmission lines. With the increase of the voltage level of power transmission lines, the length of air gaps also increases. For Ultra-high-voltage (UHV) transmission lines, the length of air gaps, which are used as the external insulation, is up to 10 m. The knowledge of the performance of air gaps with a certain length is the basis for the insulation coordination design of power transmission lines and is concerned by electric engineers [1]. The breakdown voltage of air gaps under standard switch impulse (SI) voltages is often selected as the parameters for evaluating the insulation air gaps. As the external insulation of the power system, the air gap mainly has two forms: rod-plane and rod-rod. Under standard switch impulse voltages, the breakdown voltage of rod-plane air gaps is smaller than that of rod-rod air gaps. On the other hand, the breakdown voltage of rod-plane air gaps under positive standard switch impulse voltages is lower than that under negative standard switch impulse voltages. As a result, the breakdown voltage of rod-plane air gaps under positive standard switch impulse voltages is generally used as a reference for the insulation coordination design of power transmission lines [1].

For meter-scale rod-plane air gaps under positive standard switch impulse voltages, the breakdown phase is dominated by the discharge termed positive leader discharge. A hot and positively charge plasma channel is first incepted near the positive rod and then propagates toward the negative or grounded plane. When the leader corona discharge region ahead of the positive leader tip attaches the plane, the breakdown occurs [2]. That is to say, the breakdown voltage is determined by the breakdown phase termed leader discharge. Some researchers have studied the breakdown phase of rod-plane air gaps in detail [2-6], but there are still many air gaps whose breakdown phase is not clear.

In this paper, we recorded the breakdown phase of 4 m rod-plane air gaps under standard switch impulse voltages, using the high-speed video camera. The results are reported here.

2. Methods

The experiments were conducted at the Ultra-High Voltage Laboratory affiliated with the State Grid Corporation of China (SGCC) in Hefei, China. The experimental setup is shown in Figure 1. A rod-plane air gap was constructed. We applied positive standard switch impulse voltages (250/2500 μs) to the rod electrode. The peak value of the applied voltage waves was set as 1.2 U_{50}.

The applied voltage impulses were measured by a capacitor voltage divider The frames showing the

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dynamic process of leader discharge (breakdown phase) were captured by a high-speed video camera with an aperture lens (8-48 mm, 1:1.0) at a frame rate of 150000 frames per second (6.67 μs exposure time per frame). The frames recording by the high-speed video camera is gray.

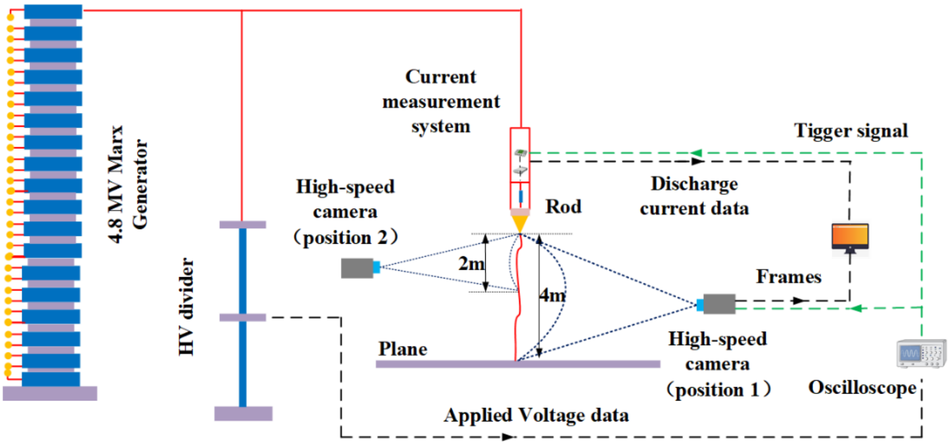

Figure 1: The scheme of the experimental setup

The humidity and the air pressure may also influence of the breakdown phase of the 4 m rod-plane air gap under positive standard switch impulse voltages. The experiments were conducted in winter, 2019. The atmospheric conditions during experiments are given as follows: temperature, 279 to 280 K; absolute humidity, 4 to 6 g/m^3; air pressure, 1 atm.

3. Results

The typical result is shown in Figure 2. Figure 2 shows the breakdown phase of a 4 m rod-plan air gap, recording by a high-speed video camera. In order to show the discharge process more clearly, these frames are enhancement processed.

As shown in Figure 1, the rod is connected with the high voltage and the plane is grounded. As can be seen in the 13th frame, the leader corona region ahead of the leader tip attaches the grounded plane, indicating the breakdown phase occurs at the exposure time of this frame.

From Figure 2, it can be seen that the positive streamer discharge was first incepted at the surface of the rod tip. Then a dark period appeared and lasted about 6.67 μs. After the dark period, a luminous plasma channel (leader) is incepted and propagated toward the plane.

Notice that the leader had two main branches in its development process. The discharge measured inner the rod electrode with positive high voltage was contributed by the two leader branches. The propagating velocity of the two branches was almost the same. The development process of the branched leader channel was recorded by 12 frames, indicating the process lasted about 80.4 μs. Before the leader corona region ahead of the leader tip attached the grounded plane, the 2D length of the leader channel is about 2 m. Then it is can be estimated the average propagating velocity of each branch of the leader channel is about 2.5×10^5 m/s. During the propagating process, the velocity had hardly changed.

The average propagating velocity of propagating leader may also be affected by the humidity and other factors.

Modeling the positive leader discharge phase shown in Figure 2 could help to predict the breakdown voltage of the air insulation, which is critical to the insulation coordination design of power transmission lines.

For modeling the positive leader discharge phase, the ratio between the leader discharge current and the propagating velocity of the leader channel need first get through experiments. In terms of physical meaning, the ratio represents that the amount of charge required to advance the pilot channel per unit length. From the result shown in Figure 2, the propagating velocity of each branch of leader channel can be get. But the discharge current measured inner the high voltage rod in previous researches [5] is contributed by two branches. As a result, the ration cannot be direct got. That need to be noticed!

During the breakdown phase of the 4 m air gap under positive standard switch impulse voltages, shown in Figure 2, the luminosity of the leader channel is roughly unchanged. The luminosity of leader

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channel corresponds to the discharge current flowing through the leader channel. On the other hand, the luminosity of two branches is almost the same, indicating that the discharge current flowing the leader channel is almost the same. When extracting the ratio between the leader discharge current and the propagating velocity of the leader channel, the discharge current could be divided by a factor (=2).

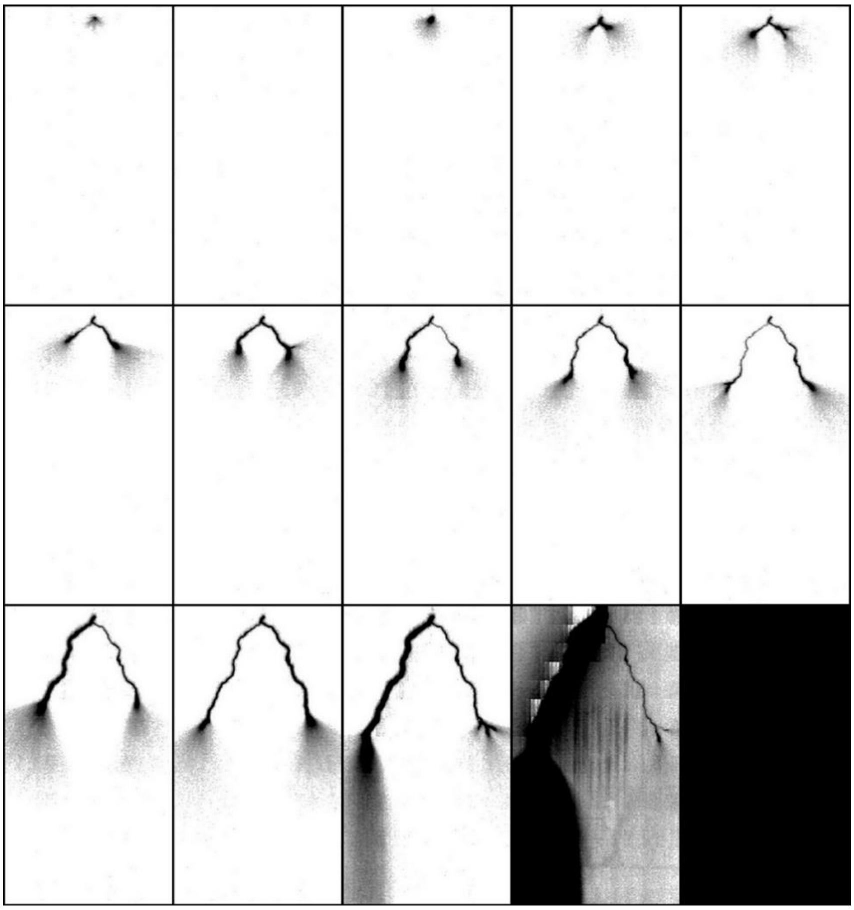

Figure 2: The typical breakdown phase

There were 20 breakdown phases of the 4 m rod-plane air gap under negative standard switch impulse voltages recording by the high-speed video camera. In most phases, the leader channel has two branches. The results reported here could help to extract the ratio between the leader discharge current and the propagating velocity of the leader channel, which is critical to model the positive leader discharge.

There were only few breakdown phases that the leader channel containing only one branch. Humidity may correspond to the phenomenon.

4. Conclusions

In this paper, the breakdown phase of a 4 m rod-plane air insulation under positive standard switch impulse voltages recording by the high-speed video camera. The results indicate that the positive leader causing the breakdown of air gaps may have many branches during the breakdown phase. The developing velocity of these branches are almost the same. The luminosity of each branch is also almost the same, indicating the leader discharge current flowing each branch is almost the same. When extracting the ratio between the leader discharge current and the propagating velocity of the leader channel, the discharge current could be divided by a factor.

The results reported in this paper could guide the modeling of positive leader discharge and deepen our understanding of air insulation for power transmission lines.

References

[1] Beroual A, Fofana I. Discharge in Long Air Gaps - Modelling and applications[M]. 2016.

ISSN 2616-5767 Vol.4, Issue 4: 16-19, DOI: 10.25236/AJETS.2021.040404

[2]T Ronald. Positive discharges in long air gaps at Les Renardières. 1977.
[3] Group L R. Positive discharges in long air gaps[J]. Electra, 1977, 53.
[4] Diaz, Oscar, Hettiarachchi, et al. Experimental Study of Leader Tortuosity and Velocity in Long Rod-plane Air Discharges[J]. IEEE Transactions on Dielectrics & Electrical Insulation, 2016.
[5] Li Z, Huang S, Gu J, et al. A Contribution to the Investigation of Leader Tortuosity in Positive Long Rod-Plane Air Discharge[J]. IEEE Access, 2019, 7:170442-170447.
[6] Xie Y, He H, Wu C, et al. An experimental and numerical study of leader development in rod-rod gaps under positive switching impulse voltage[J]. European Physical Journal Applied Physics, 2013, 64(1):10802.