Investigation on characteristics of arc extinguishing time of a new lighting protection gap for transmission lines

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Abstract. The present research envisages the development of a novel arc extinguishing lightning protection gap in pursuit of reducing the lightning trip-out rate and accident rate. In the developed setup, the jetting stream arc extinction lightning protection gap device was used for transmission line. When this transmission line was struck by lightning and the lightning surge was going to break down the gap, the arc extinguishing lightning protection gap immediately jetted out sufficient electronegative gas flow that quickly cut off the arc and effectively prevented the insulator from being damaged by the arc. Furthermore, when the line was attacked by lightning, the generated overvoltage instantaneously broke the gap that was parallel to the insulator string, so that the lightning current was oriented to the earth from the gap. Simultaneously, it triggered the gas generator and generated a high speed stream, then extinguished the frequency continuous current arc rapidly, thus effectively reducing the rate of line trip to ensure the reliability of power supply. We used a high-speed camera and ordinary camera that automatically captured the process of the jetting stream arc in the extinction lightning protection gap device, while extinguishing the 1kA power frequency arc. The image of the high-speed camera indicated that the power frequency arc of 1kA was quenched in 10 ms before the relay protection action of the test loop, which made that the overhead line lightning flashover but the circuit breaker did not trip. Thus, a reduction in the rate of lightning trip was observed by the developed setup, and it has an immense potential for application at the transmission lines of China.

1. Introduction

The southern part of China is located in the subtropical region, with a strong lightning activity. The annual average number of thunderstorm days in Guangxi is more than 80. In recent years, the overhead line of the power grid has been caused by lightning strikes, which affects the safe operation...
of the power grid. On an average, the 35 kV and below overhead lines of Guangxi Power Grid face more than 100 lightning strikes per year, resulting in a large number of line blackouts and a significant increase of the workload for repair and maintenance lines, thereby seriously affecting the reliability of power supply.

There are two main concepts employed in the protection from lightning strikes at home and abroad viz. the “intercept-type” and the “scatter-type”. At present, the developed countries like Japan, Germany, and France have generally adopted the “scatter-type” concept [1].

In the recent years, significant attempts were made by China for developing new lightning protection products based on concept of “scatter-type” device. Until now, China has developed the arcing horn and parallel gap which fit for different voltage levels, and some a few of these have been installed and are operational in actual line [2-11].

Ordinary insulator strings in parallel gap is known as arcing horn. The core idea is to allow the overhead transmission lines have a certain rate of lightning trip. The parallel gap fulfills the purpose of the priority breakdown of lightning by use metal electrodes to short circuit the insulator strings dry arcing distance. Through this the lightning energy is released by the discharge gap and eases the power frequency arc. Although it has a lightning flashover, auto reclosing can succeed, so it has no permanent fault. However, this method faces the following difficulties:

- This gap is adopted at the expense of the lightning trip rate with a low accident rate. It cannot self-extinguish the power frequency continuous current arc, which causes an increase in the lightning trip rate and the circuit breaker also gets a load to cut off short circuiting the arc that requires time. So, the overall reliability of power grid supply declines.
- When the auto reclosing is unable to move or it does not exist, the power frequency continuous current arc cannot be self-extinguished and continue to burn the gap. The useful time will shorten even more.

Therefore, this paper raises a new arc extinction lightning protection gap, which impulses a discharge path by the normal clearance with the function of fixed position lightning. Also, it can sense the lightning breakdown signal to trigger the stream generator in a short time. The stream generator device can jet high-speed airflow to extinguish the arc, so the transmission and distribution system cannot trip during the lightning flashover. Moreover, reduction in the lightning trip rate and protection of the insulator strings and transmission lines improves the power grid reliability.

The prototype of the arc extinction lightning protection gap developed in the present work successfully accomplished the interrupter test verification of 1kA, 5kA, 10kA short circuit arc in a large capacity testing laboratory of Xi’an high-voltage apparatus research institute.

2. Rapid quenching experiment of the arc by extinction lightning protection gap

2.1. Experimental

This jetting stream arc extinction lightning protection gap device was used for transmission line. When the line was attacked by lightning, the generated overvoltage led to a priority breakdown of the gap which was parallel to the insulator string. Hence, the lightning current was oriented to the earth from the gap. Simultaneously, it triggered the gas generator and generated a high speed stream that extinguished the frequency continuous current arc rapidly, thus effectively reducing the rate of line
trip to ensure the reliability of power supply. During recent years, the theoretical basis for this lightning protection gap has been extensively studied [12-17]. The test run in several power supply bureaus of Guangxi Power Grid has achieved good operating results.

This device included: wire connector, high voltage electrode, ground electrode, gas generator, signal pickup assembly, and earth connector. The arc extinction lightning protection gap as shown in Figure 1.

The whole device through wire connector-1 and earth connector 5 tied with the insulator string, simulated the real situation of the clearance installed in the overhead line insulator string. During the test, the high voltage electrode-2 was connected to the generator outlet conductor, and the ground electrode-3 was connected with earth metal. Since, the parallel clearance located the path of lightning impulse flashover, the clearance between the high-voltage electrode and the ground electrode short circuited by 0.8 mm fuse, to ensure the burning of the frequency continuous current arc in the ends of gap after the lightning stroke. The signal pickup assembly-6 triggered the gas generator-4 after the detection of the current signal. The gas generator-4 generated a high speed stream to extinguish the arc. If the working succeeds, the arc gets extinguished in 0 - 15 ms.

**Figure 1.** Schematic drawing of the arc-quenching lightning protection gap

2.2. *Test for rapid extinguishing of the power frequency arc*

The test for the rapid extinguishing of the arc by the lightning protection gap was conducted in the large capacity testing laboratory of the Xi’an high-voltage apparatus research institute. A voltage of 12 KV and 50 Hz power frequency current was provided using a short circuit generator to adjust reactor.

The gap sample was pre-commissioned in the order of 200 ms without the replacement of any other components, except the gas generating device, and the current RMS value was 1 kA, 5 kA, 10 kA for 3 arc-extinguishing tests. Therefore, when the effective value of the arc flowing through the gap was 1 kA, the current waveform was collected, and the arc was extinguished at 7.5 ms, and the waveform is as shown in Figure 2 and 3.
In addition, in the arc-extinguishing experiment conducted at 5 kA and 10 kA, because the sample was sensitive, the arc was extinguished, the current was in ampere level, and the measurement system failed to collect the current waveform. After the test, the appearance of the sample gas generating device was intact, and the gas generating device operated successfully, which was judged from the successful extinguishing of the sample. The pre-commissioning and extinction waveforms of the 10 kA arc are shown in Figure 4 and 5. The pre-commissioning and extinction waveforms of the 10 kA arc are shown in Figure 6 and 7.
Figure 6. Voltage and current waveforms of 5kA arc before the rapid arc-quenching test

Figure 7. Voltage and current waveforms in the rapid arc-quenching test

At the test site, the ordinary camera was used to record the extinguishing of the power frequency arc by the lightning protection gap, and the visual effect of the extinguishing the power frequency arc in the gap is shown in Figure 8.

Figure 9 shows the microscopic process of the high-speed airflow captured by a high-speed camera at a speed of 6 000 s/s. It shows the guidance of the arc-free lightning protection gap gas generating device with the gap current. On its activation, the high-speed airflow acted on the power-frequency freewheeling arc to extinguish it.

Figure 8. Arc screens extinguish process using ordinary camera: (a) Before the device act; (b) Switch was closed and device in operation; (c) Airflow expands the arc; (d) Arc cracks began to appear; (e) Arc cracks was obvious; (f) Arc began to cease; (g) Arc continues to weaken; (h) Extinguishing of arc

3. Analysis of extinguishing of the rapid frequency continuous arc by the lightning protection gap

The jetting stream lightning protection gap was through the acquisition of current pulse signal and then instantly triggered the gas generator. After 200 µs of the acquisition signal, a high speed stream was generated to role on the earlier arc and strongly interposed the clearance of the built arc process.
The moment when the frequency continuous current arc just rises (the extinguished instantaneous value is only a few percent of frequency current amplitude), it gets extinguished out. The success of this device in extinguishing the arc is because of “fast rule strong”, and does not impacted by the current steady-state magnitude and closing phase angle.

The arc-extinguishing lightning protection device was already tested for its response time for generating gas before the studies at the Xi'an High-voltage Electrical Apparatus Research Institute. In this test, only a small arc was used as a trigger power source. Figure 10 shows the measured jet airflow response time, which is about 200 μs. The test results were consistent with the assumptions. The rapidly generated jet airflow was the main reason for the rapid extinguishing of the arc-frequency lightning protection power frequency arc. It strongly impacted the arc and interrupted the arcing process when the arc current did not yet develop into a steady state.

![Figure 9. Arc extinguishing process captured by the high-speed camera](image)

In the present work, we tested the arc-proof lightning protection gap for 3 times, and the steady-state amplitude was 1, 5, 10 kA in the 3 arc-extinguishing tests. The short-circuit arc waveform with 7.5 ms was collected at 1 kA, and the other 2 times. The reason is that the occurrence time of the gas flow of the gas generating device was related to the current power flowing through the signal collecting device. Once the current power met the requirements, the gas generating device was triggered to generate a high-speed air flow. It was expected that the power frequency arc of 5 kA, 10 kA triggered the gas generating device in a shorter time than the 1 kA power frequency arc, as the arc of the high-speed air current was faster for 1 kA power frequency arc. Hence, the arc current in these two tests (5 and 10 kA) and the existence time was extremely short, which was outside the scope of the system test, resulting in the system not collecting the relevant waveform.

The test result of Xi’an high-voltage apparatus research institute was consistent with our envisaged results. This is the reason why the arc extinction lightning protection gap frequency current arc was extinguished rapidly, when the arc current was just created, and did not develop into a steady state due
to the strong gas stream that interrupted its built-arc process.

![Figure 10. Measured jet airflow response time (yellow trigger pulse, blue for the air to produce time; response time ~ 0.2ms)](image)

During the test, we performed the arc extinction lightning protection gap test with expected commission steady-state amplitude of 1kA. It was only collected short arc waveform in 1kA level, whose duration was 7.5 ms. The occurrence time of gas generator device and the jetting stream have a relationship with short current power which pass through signal acquisition device. Once the short circuit current power met the requirements, it triggered the gas generator device to generate a high speed gas stream. Since, the short circuit power was proportional to the power frequency arc, thus, the greater the power frequency electric arc, the shorter the trigger time was needed to generate the gas by the gas-generator. If the expected frequency current arc in the test was 5 kA or 10 kA, the trigger time of the gas generator device would be earlier than that needed for 1 kA. The high-speed gas generated by the gas generator affected the power frequency electric arc depending on the time needed to trigger, which was more conducive to rapid arc extinguishing.

The triggering of the gas generating device is shown in Figure 11. t10, t5, and t1 correspond to the triggering time of the gas generating device when the power frequency short-circuit current amplitude was 10, 5, 1 kA, and t10 < t5 < t1. When the device was actually installed on the transmission line, the gas generating device was directly triggered by the lightning pulse, which was earlier than the triggering of the short-circuit current in the test, and the airflow was applied to the instantaneous value of the short-circuiting arc, so that the probability of the device cutting off the arc was more high. The time for the lightning current to reach the peak was about 1~5 µs, and the required grooming time was extremely short, much less than 100 µs. The inherent reaction time of the arc extinguishing device ensured that the lightning current was smoothly introduced into the earth.
Figure 11. Trigger time map of gas generating device under different amplitude of current

The process of extinguishing the arc from the gap can be further analyzed from the image recorded by the high-speed camera in Figure 8. The essence of power frequency arc is the plasma. The plasma gap arc exhibits the force of contracting to the center of the arc column under the action of its own magnetic field force [18], and the temperature is very high. Therefore, the shape is fine and the color is blue. We observed that shape of the light generated by the arc extinguishing device was relatively thick and the color is white, so the thick white point at both ends of the gap was the light when the arc extinguishing device exploded. It can be seen from Figure 7 that the gas generating device already operated when the gap was just turned on and the gap arc was not completely formed. The high-speed airflow of the explosive jet followed the power-frequency freewheeling arc and rapidly elongated the freewheeling arc that caused the arc diffusion coefficient to increase rapidly, and the deionization process quickly returned the gas to a neutral insulating state. At the same time, the gas carried a lot of energy through heat conduction and convection, so that the arc temperature was suddenly reduced and the thermal ionization could not be maintained. The final gap arc was quickly extinguished because the insulation recovery strength was greater than the breakdown recovery voltage, and the energy supply was cut off.

4. Conclusion

- The nature of power frequency arc was the plasma, which exited for a very short time. The high-speed camera was used to study the arc shape and the arc development process, which recorded the arc quenching process automatically and clearly.
- The speed of gas generator device in response to the lightning pulse jetting stream and the speed and pressure were the main reasons of the extinguishing of the power frequency continuous current arc. Furthermore, shorter response time of gas generator device, and a higher speed and pressure of the jetting stream can lead to faster extinguishing of the arc.
- Because of its speed, the arc extinction lightning protection gap extinguished the arc. Although, the ends of frequency continuous current arc were burned, but the instantaneous value of extinguishing the arc was small and with a very short time, so it did not exhibit a
great influence on its clearance.

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