Analysis of current characteristics of corona discharge in high voltage transmission

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Abstract. In order to study the current characteristics of corona discharge in high voltage transmission, the time-domain characteristics and volt ampere characteristics of corona discharge under different high voltage are tested and analyzed. The actual test results show that: in the whole process of corona discharge, with the increase of inter electrode voltage, the frequency of pulse current increases, and the duration of current remains unchanged; negative corona discharge is more likely to occur, and with the increase of voltage, the average current growth rate is higher than positive corona discharge. Under the same interelectrode voltage, the negative corona current is stronger than the positive one. The nonlinearity of equivalent resistance between positive corona discharge electrodes is stronger than that of negative corona discharge.

1. Introduction

In Up to now, the research on the gas discharge characteristics of high-voltage transmission has not stopped, involving many fields, and has made a lot of research results. For example, in engineering practice, people have obtained empirical formulas such as corona loss, corona field strength and synthetic electric field, as well as the influence law of air pressure, temperature and humidity on air discharge.

The research on the current characteristics of corona discharge is always one of the subjects that people study the air discharge of high voltage transmission. Pulse current will be generated in the discharge circuit. Scholars have explained the formation of positive and negative corona based on streamer theory and avalanche development theory respectively. Because of different mechanisms, positive and negative corona current show different characteristics. Compared with irregular positive corona pulse, negative corona pulse shows certain regularity under certain conditions, namely the so-called Trichel pulse, which has been widely studied. Due to the influence of medium, applied voltage, air pressure, temperature, humidity and other factors, the theory of corona discharge motor is more complex. Compared with other characteristics of corona discharge, the time-frequency characteristics and change rules of corona discharge current reflect the development process of streamer in the whole discharge process and the electrical characteristics of discharge circuit. Therefore, to study the micro mechanism of corona discharge and its electromagnetic radiation, it is necessary to study the current characteristics of corona discharge. [1-3]
2. Experiment
The experimental circuit of corona discharge simulation and current test is shown in Figure 1.

There are two types of DC high-voltage power supply used in the experiment, which can achieve positive and negative high-voltage output. The difference between the two is that the output voltage level, voltage resolution and load capacity are different. JDY-II electrostatic high-voltage generator can output 0-60 kV high voltage. GLOW28720 electrostatic high-voltage generator can output 0-35 kV high voltage.

If the total loop current in the circuit shown in Figure 1 is considered as \( i_d \), it will be composed of two components: corona current and displacement current. The corona current is mainly generated by the movement of electric charges (electrons and ions).

\[
i_{\text{corona}} = \frac{1}{U_c} \iiint (N_p \overline{W_p} - N_e \overline{W_e} - N_n \overline{W_n}) \cdot \overline{E_L} dv
\]

\( U_c \) is the voltage between the poles, \( E_L \) is the Laplacian field. The displacement current is mainly generated by the capacitance of the needle plate geometry. In the above circuit structure, if \( R \) is the external impedance and \( C_0 \) is the capacitance generated by the electrode gap, the total current of the circuit is the sum of displacement current \( i_{C_0} \) and corona current \( i_{\text{corona}} \)

\[
i_{C_0} = C_0 \frac{dV_{\text{corona}}}{dt}
\]

\[
\frac{dV_{\text{corona}}}{dt} = \frac{1}{RC_0} (V - Ri_{\text{corona}}) - \frac{1}{RC_0} V_{\text{corona}}
\]
$R_i$ current limiting resistance, to prevent excessive current in the circuit, plays a protective role for the instrument. There are two options in the experiment, 100 MΩ and 22 MΩ. This value is basically the external impedance $r$ of the circuit. It can be seen from formulas 1, 2 and 3 that the transient discharge current values at different positions in the circuit (such as point A and point B) are different in theory, and the measured values are related to the selection of test positions, but the actual test shows that the difference is not obvious. Therefore, the transient pulse current generated in the process of discharge is usually measured at the low voltage end of the grounding. There are two methods of measurement. One is the sampling resistance method. The sampling resistance is usually $R_0 = 50\,\Omega$. The ratio of sampling voltage to sampling resistance is the corona current generated by discharge. Another way is to use the current sensor to directly test the discharge current. The test frequency band of the sensor used in this experiment is 25 kHz-1 GHz.

In addition, to study the statistical characteristics of the pulse current in the corona discharge process, it is necessary to test the average current of the circuit. The average corona discharge current can be measured by the anti-static high-voltage micro ammeter BY2011, and the access point is generally selected at point A or point B in Figure 1.

3. Results and analysis

3.1. Time domain characteristics of corona discharge current
The as shown in Figure 1, the gap between steel electrodes is set to 5mm, and the radius of needle tip is 0.1mm. The protection resistance $R_i = 22\,\text{M}\Omega$ is selected. The pulse current generated by the discharge through the sampling resistance is measured. The micro ammeter is connected to point A and point B of the circuit respectively, and monitors the average current change during the discharge process. All test data are stored and read by oscilloscope, and the sampling rate is 2.5 GHz / s. According to the test results, the change characteristics of the current in the process of corona discharge are analyzed. [4-5]

Taking the negative corona discharge as an example, when the voltage between the electrodes reaches the corona voltage, the number of pulse currents that can be monitored is less and the amplitude is smaller in a quite long observation time. From the pulse current sequence shown in Fig. 2 (a), (b) and (c), we can draw the following conclusion: when the interelectrode voltage continues to increase, the peak value of a single pulse current increases with it, and the frequency of the pulse increases sharply. From the pulse current sequence shown in Fig. 2 (d), it can be concluded that when the voltage continues to rise to a certain threshold value, the pulse frequency continues to increase but the peak value of single pulse current detected at the same time decreases.
If the voltage between the electrodes is increased, the corona discharge will be converted into a stable glow discharge, and the pulse current will disappear; if the voltage is increased, the current beam discharge will be generated between the electrodes. It is found that although the positive and negative corona mechanisms are different, the frequency and amplitude of the pulse current vary with the voltage between the two electrodes in the same way.

In the same observation time, the phenomenon that the frequency of pulse current increases with the increase of interelectrode voltage is more obvious in the process of discharge, but the pulse width of single pulse current is the same, about 50ns. The results are shown in Figure 3, which shows that the duration of pulse current is independent of the applied voltage when other parameters of discharge remain unchanged.

The falling edge of the negative corona current pulse is equivalent to the time when the electron reaches the critical point from the cathode. The linearity of corona region is generally about 1mm, so the falling edge can be estimated to be about 5ns, which is consistent with the experimental test results in Figure 4.

As the voltage increases, the critical distance will decrease and the falling edge will slightly decrease, which is the same as the rule shown in Figure 4.

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**Figure 2** Currents for negative corona discharge

**Figure 3.** Duration time of the pulse currents under applied voltages
Figure 4. Decreasing time of the pulse currents under applied voltages

3.2. Analysis of volt ampere characteristics of corona discharge

The related characteristic parameters and changing rules of a single pulse current can reflect the physical process of gas discharge, but it has certain randomness. The characteristics of the pulse sequences alternating with the continuous discharge process will change with each other. The average current represents the statistical characteristics of electrode gap current, which can reflect the normal electrical characteristics in the process of corona discharge.

No matter what polarity of corona discharge, the number of pulse current is small and the amplitude is small in the initial stage of discharge. At this time, the average current measured is zero. If the voltage is slightly increased, the average current will no longer be zero. With the increase of applied voltage, the average current will continue to increase. When the corona discharge changes into a streamer, the average current will suddenly increase. The experimental results show that the average current values of point A and point B are the same.

In this experiment, the initial average current is several $\mu\text{A}$, and the average current is dozens of $\mu\text{A}$ when the corona discharge transits to streamer discharge. During the whole discharge process, the voltage at both ends of the electrode increases, and the average current in the gap increases accordingly. Because of the difference of the positive and negative corona discharge mechanism, the corona starting voltage of negative corona discharge is lower than that of positive corona discharge under the same condition, negative corona discharge is more likely to occur, and with the increase of voltage. The average current growth rate is higher than that of positive corona discharge. Under the same gap voltage, the negative corona current is stronger than the positive one. From the change curve of equivalent resistance of electrode gap, it can be seen that the nonlinearity of equivalent resistance of positive corona discharge electrode gap is stronger than that of negative corona discharge.

According to the formula, I-V characteristic curves of positive and negative corona discharge are fitted. The corresponding parameters are shown in Table 1.

| Table.1 Parameters’ value by fitting |
|-------------------------------------|
| parameter | value | standard deviation |
| Positive corona | $A$ | 3.60278 | 0.18767 |
| | $V_0$ | 4.9 | 0 |
| | $n$ | 1.24177 | 0.02836 |
| Negative corona | $A$ | 7.6253 | 0.25467 |
| | $V_0$ | 3.85 | 0 |
| | $n$ | 1.0465 | 0.01921 |
4. Conclusion
In this paper, the time-domain and I-V characteristics of corona discharge current are studied.

1. In the whole process of corona discharge, the change rule of positive and negative corona current is the same, that is, with the increase of interelectrode voltage, the frequency of pulse current increases, and the duration of current does not change, but the change rule of current peak value increases first and then decreases.

2. Negative corona discharge is more likely to occur, and with the increase of voltage, the average current growth rate is higher than positive corona discharge. Under the same interelectrode voltage, the negative corona current is stronger than the positive one. From the change curve of equivalent resistance of electrode gap, it can be seen that the nonlinearity of equivalent resistance of positive corona discharge electrode gap is stronger than that of negative corona discharge.

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