Experimental Study on High Frequency Pulse Current Variation Characteristics of Pollution Discharge of Insulators

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Abstract: Pollution flashover of insulators is an important factor causing trip of transmission lines and even large-scale blackouts of power grids. At present, the research on pollution discharge of insulators mainly focuses on leakage current monitoring, while leakage current detection mainly focuses on the low-frequency components of the discharge process, and the research on high-frequency discharge characteristics is rare. In this paper, the voltage is monitored based on the coupling capacitance partial voltage method. The high-frequency current is monitored based on the Rogowski coil principle. The characteristics of high frequency pulse discharge in safety zone, forecast zone and danger zone are analyzed. The results show that the pulse amplitude and repetition rate increase significantly with the increase of discharge. The statistical law of high frequency pulse current can reflect the severity of pollution discharge and realize early warning.

1. Introduction

With the increasing industrial emissions and chemical pollution, insulator pollution flashover causes large-scale blackouts from time to time [1-3]. According to statistical data, the number of pollution flashover accidents in a national power grid occupies the second place in the total number of power grid accidents, only second to lightning accidents, but the losses caused by pollution flashover accidents are 10 times as much as those caused by lightning accidents [4-6].

In order to reduce and prevent insulator pollution flashover fault, a long time of research has been carried out at home and abroad [7]. At present, the research on insulator pollution discharge mainly focuses on exploring the mechanism of arc extinguishing and reburning during the development of pollution flashover, and some achievements have been made in anti-pollution flashover [8-10]. At present, the common detection methods of insulator contamination include equivalent salt deposit density (ESDD), current pulse counting, flashover voltage gradient, surface contamination layer conductivity, leakage current, etc. Leakage current method combines pollution with environmental temperature, humidity and other factors, which can fully reflect the contamination status of insulators [11]. In paper [6], the development process of the pollution discharge is divided into three sections according to the effective value of the leakage current, namely the safety zone, the forecast zone and the danger zone, and the boundary values are 50 mA and 150 mA. In paper [8], it is proposed that the leakage current will increase in the process of pollution flashover, mainly the fundamental wave, the
third harmonic and the fifth harmonic.

The existing research on leakage current monitoring is mainly for low frequency components in the discharge, and the detection frequency is generally lower than 10 kHz. At present, there is no research on the high-frequency discharge characteristics of pollution discharge. In this paper, the characteristics of high-frequency discharge current waveforms in different discharge stages are studied through experiments.

2. Current and Voltage Monitoring Method

In this paper, a monitoring terminal is installed on the test wire, and the waveforms of voltage and high frequency current are collected directly from the wire. Its components include sensor unit, power unit, GPS unit, wireless communication unit and acquisition and processing unit, etc. The sensor unit includes a current sensor and a voltage sensor. The current sensor uses a Roche coil with good high frequency performance. Its output and input satisfy the following relations:

\[ e(t) = -M \frac{di_1(t)}{dt} = L_0 \frac{di_2(t)}{dt} + (R_0 + r)i_2(t) \]  

In the formula, \( i_1(t) \) is the current of the conductor, \( M \) is the mutual inductance between the Roche coil and the conductor; \( L_0, R_0, C_0 \) and \( R \) are the self-inductance, internal resistance, distributed capacitance and integral resistance of the coil, respectively; \( i_2(t) \) is the current on the integral resistance. Since \( R_0+r \) is very small in self-integration, it satisfies \( wL_0 \) for high frequency signal, then:

\[ e(t) = i_2(t) r \approx -\frac{M r}{L_0} i_1(t) \]  

Formula (2) shows that the output voltage of the self-integrating Roche coil has a linear relationship with the measured current. The current to be measured in the test circuit can be obtained by collecting the output voltage of the sensor. The sensor model used in this project is ETA5315, whose - 3dB cut-off frequencies are 20Hz and 60MHz. In order to avoid the influence of low-frequency harmonic interference in leakage current, the frequency band of conditioning circuit is set to 2 kHz~40 MHz, so the measurement bandwidth of the whole monitoring terminal is 2 kHz~40 MHz, which meets the requirements of high-frequency discharge measurement.

Distributed capacitance voltage divider technology is used to measure conductor voltage. By applying a thin metal sheet outside the monitoring terminal, the capacitance \( C_1 \) between the metal sheet and conductor and the capacitance \( C_2 \) between the metal sheet and the earth are made up of capacitance voltage divider system, in which \( C_1 \) is the low voltage arm of capacitance divider and \( C_2 \) is the high voltage arm.

![Schematic diagram of voltage monitoring](image)

1-wire, 2-metal sheet, 3-signal cable, 4-signal acquisition system, 5-earth

Figure 1. Schematic diagram of voltage monitoring

The metal sheet is an arc sheet with a width \( a \), a radius \( R \), and an arc angle of \( a \). According to paper [3], the coupling capacitance \( C_1 \) between the metal sheet and the conductor can be calculated by the following formula:
In the formula, \( R \) is the radius of the conductor. When \( R = 8 \text{cm} \), \( r = 1.1 \text{cm} \), \( a = 5 \text{cm} \), \( \alpha = 60 \) degrees, \( C_1 = 0.465 \text{pF} \) can be calculated. \( C_2 \) is estimated in reference [3], and its size is about 1-3 pF. In order to meet the requirement of input processing of hardware conditioning circuit, a capacitor of 0.1 \( \mu \text{F} \) should be connected in parallel at both ends of \( C_1 \). At this time, the ratio of voltage sensor is about 5000:1. Voltage sensor is a pure capacitive sensor, and its measurement frequency band is very wide. In paper [3], the power frequency and standard lightning impulse voltage measurement experiments of the sensor are carried out, and its waveform restoration meets the needs of power frequency to high frequency transient voltage monitoring.

3. Experimental research

3.1. Test arrangement

The experimental wiring principle is shown in Figure 2. In Figure 2, the test power supply is an AC contamination test power supply consisting of a coil-shifting voltage regulator named TDJY 1000/10 and a test transformer named YDJ 900/150. The rated current of the test transformer is 6A, and its maximum short circuit current can reach 30A, which meets the requirements of IEC 60507 and GB/T4584 2004 for AC pollution test power supply. The test power supply is introduced into the artificial fog chamber through the wall sleeve. The high voltage terminal is connected to the voltmeter through SGB200A AC capacitive voltage divider. The divider voltage ratio is 1:1000. Leakage current detection system is used to record the leakage current and applied voltage in the process of pollution discharge. On the other hand, the monitoring terminal installed on the conductor realizes synchronous monitoring of voltage and high frequency current.

![Figure 2. Experimental layout schematic diagram](https://example.com/figure2)

This test simulates pollution discharge of 110kV voltage grade insulators. The number of insulators in the test is 7 and the type is XP-70. Considering the grade III pollution, the equivalent salt density ESDD is 0.2 mg/cm\(^2\) and the equivalent gray density NSDD is 2.0 mg/cm\(^2\).

3.2. Test method

The test was carried out in accordance with the steps prescribed by IEC 60815-1:2001. Place the polluted insulator in the fog chamber and arrange the test circuit according to Figure 2. The cleaning spray method was used to slowly and continuously fog the fog chamber and control the relative humidity of fog room air gradually increased until saturation. The air humidity in the fog chamber was measured by a temperature and a humidity meter. Slowly raise the voltage until the insulator discharges obviously. The data of the leakage current detection system is read in real time, and the voltage is adjusted so that the leakage current of the insulator is in three ranges: less than 50 mA, 50 mA to 150 mA, and more than 150 mA. At least 40 minutes of discharge are maintained in each range.

3.3. Test results

With the increase of applied voltage, the surface of insulator is discharged and shows an increasing trend, in which the arc becomes brighter and the leakage current amplitude is rising steadily. When the voltage remains unchanged, the surface arc of insulator alternately transforms in bright and dim,
forming a stable discharge along the surface. The discharge phenomena corresponding to different discharge stages are monitored as shown in Figure 3 below.

Figure 3. Discharge phenomena at different discharge stages
Figure 4. High frequency discharge waveform and applied voltage waveform at different discharge stages

(c) danger zone

Figure 5. Partial amplification of high frequency discharge waveform in different discharge stages

It can be seen from Figure 4 that the maximum amplitude of discharge pulse increases gradually with the increase of discharge degree. The amplitude of discharge pulse in safety zone, forecast zone and danger zone is 110 mA, 215 mA and 1820 mA respectively, while that in flashover time, it is as high as 17.5 A. By comparing the pulse discharge waveform with the synchronous acquisition of power frequency voltage waveform, it can be seen that the pulse discharge mainly occurs near the positive and negative peaks of power frequency voltage, and when the voltage is positive, the discharge amplitude is larger and the pulse is more intensive.

During the experiment, the current of each discharge stage is collected 1400 times, and the sampling time of each discharge is 40 ms. One group of waveforms contains 8 to 20 discharge pulses. Then the number of discharge pulses in each discharge stage is 11200 to 28000, which can reflect the statistical characteristics of discharge pulses.

In this paper, the average value, rise time, half-peak time, duration, phase interval, and pulse
frequency are used to count the discharge pulse. The rise time represents the time required for the current waveform to rise from 10% of the peak to 90%. The half-peak time is the time between the 10% peak of the rising segment of the waveform and 50% of the falling segment. The duration is the time between the current waveform from the 10% peak of the rising phase to the 10% peak of the falling phase. The above several time indicators are average values. Pulse phase synchronization is realized by monitoring the power frequency voltage. The lower limit of phase interval is the minimum phase of all pulse phases, and the upper limit is the maximum phase of all pulse phases. The pulse frequency is the average of the number of pulses per second of discharge. The statistical analysis software is compiled by matlab, and all the pulses monitored in the experiment are analyzed. The statistical data in Table.1 are obtained as follows:

Table 1. Statistical results of high frequency pulse waveform parameters at different discharge stages

| Discharge stage | Average amplitude /mA | rise time /μs | half-peak time /μs | Frequency | Phase interval /° |
|-----------------|-----------------------|---------------|--------------------|-----------|------------------|
| Safety Zone     | 33.22                 | 0.24          | 2.52               | 252.31    | [82,97]∪[254,286] |
| Forecast Zone   | 168.61                | 0.28          | 1.79               | 344.52    | [79,118]∪[256,297] |
| Danger zone     | 352.95                | 0.21          | 3.25               | 376.52    | [45,127]∪[251,288] |

It can be seen from the data in Table.1 that there are differences in the statistical results of the pulse parameters in different discharge stages, in which the difference between the rise time and the half-peak time is small, and the statistical results of the average value, the discharge frequency and the phase interval are quite different. This indicates that as the leakage current gradually increases, the amplitude of the high-frequency pulse increases significantly, and the discharge becomes more frequent, indicating that the discharge becomes more intense. For danger zone, discharge is not limited to occur at voltage peaks, but occurs in larger neighborhoods near the peak.

4. Conclusion
1) The synchronous monitoring of voltage and high frequency discharge is realized based on the coupled capacitance voltage dividing method and the principle of Roche coil. The bandwidth of current monitoring is 2 kHz~40 MHz, which meets the need of high frequency current monitoring of pollution discharge.

2) The discharge test and monitoring data at different stages show that with the increase of leakage current, the discharge degree increases gradually, the amplitude and frequency of pulse current show a significant upward trend, and the phase interval also increases. The statistical characteristics of high frequency discharge pulse parameters can reflect the variation of leakage current, and further reflect the severity of pollution discharge of insulators.

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