

Electric Insulation Detection Method for High-voltage Insulators

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Abstract

The principle of partial discharge detection is that through partial bridged discharge under high voltage electric field, it detects the inner air-filled cavity of high-voltage insulators. And it is a nondestructive detection method based on discharge magnitude to judge the insulation quality. The detecting system that adopts the partial discharge detection is more rigorous than testing system for electricity products, which must have small discharge capacity and higher sensitivity. This paper describes the principles of partial discharge detection and analysis insulation detection.

Keywords: vacuum pressure potting, potting quality inspection, insulation detection, partial discharge detection, electric insulation detection, bubble detection

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1. Introduction

Insulation quality testing methods of electrical components include Withstand Voltage Test, Ultrasonic Detection and Partial Discharge Detection [1, 2].

Electrical components adopting vacuum potting have complex internal structure and commonly higher reliability requirements for insulation. At the same time, the sizes are very small. Withstand Voltage Test easily damages the insulating properties of electrical components, and Ultrasonic Detection often cannot show the internal potting defects of electrical components due to lack of precision [3-5]. There, Potting Quality Inspection must use partial discharge detection method.

Conventional partial discharge detection method and equipment are matched with the electrical equipments. Generally, AC voltage is used as the discharge voltage source. High-Voltage Insulators, especially in Space Application (for example traveling wave tube amplifier), features high operating frequency, small volume and unique high voltage generator [6]. So, partial discharge detection for High-Voltage Insulators is more rigorous than testing system for electricity products. The system also has small discharge capacity and higher sensitivity. Therefore, the AC/DC Parallel Superposition Pulse Testing method is proposed for the partial discharge testing of high voltage components. This testing method is capable of simulating the real working conditions of high-voltage insulators through accurate and reliable assessment of authentic test data.

2. Detection Principle and Detection Model

The basic principle of partial discharge detection method is depicted as follows[7-8]: when partial discharge occurs, the dielectric between A and B is expressed by equivalent model. As shown in Figure 1, C_x is the capacitor between A and B, U_g is the capacitor of dielectric partially occurring discharge, C_b is the serial capacitor with U_g and C_a is the capacitor unaffected by partial discharge. Acting under AC voltage, U_g occur partial discharge, and it is represented by discharge gap G parallel with U_g . When G discharge under AC voltage, U_g generated voltage between two terminals of G which represents the relation between discharge pulse current I_g and hold time t .

U_g is the voltage waveform of C_g when G does not discharge. U_1 is the starting discharge voltage of G and U_2 is the discharge extinction voltage. For each partial discharge pulse, a certain amount of electric charge q_g of C_g will be neutralized. Its discharge can be expressed as

$$q_g = \int i_g dt = C_g(U_1 - U_2) \quad (1)$$

There is a mutation voltage ΔU_x between A and B electrodes of equivalent model. It is expressed as:

$$\Delta U_x = \frac{C_b q_g}{(C_b + C_g) C_x} \quad (2)$$

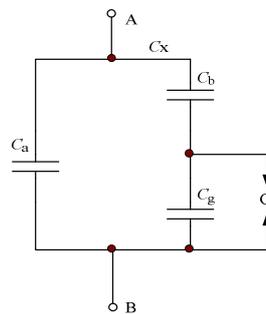


Figure 1. The principle diagram of partial discharge detection

So, internal partial discharge of dielectrics can be expressed through waveform test method. The traditional partial discharge detection, matching a large number of electrical equipments, generally uses AC voltage source as the discharge voltage.

In Figure 1, q_g cannot be measured, but mutation voltage ΔU_x between A and B terminals can be measured. Therefore, when the instantaneous input electric charge across the coil of high-voltage insulators, it makes the change of terminal voltage same with the change of terminal voltage caused by partial discharge. The input electric charge is the apparent partial discharge and usually represented as pC. If q is defined as the amount of the charge, its expression is discharge magnitude

$$q = C_x \Delta U_x = \frac{C_b q_g}{C_b + C_g} \quad (3)$$

From formula 3-3, it can be seen that a linear relationship holds between q and q_g . So, the electric charge of the coil will be measured by q .

3. Detection System

Partial discharge detection system of high-voltage insulators is shown in Figure 2. T_1 high-pressure components for the exchange of non-corona, T_2 is DC power without corona, C_k is the coupling capacitor, C_x is high-voltage insulators for testing, Z is the high-voltage limiting resistance, Z_{mi} is the coupling impedance, and C is the filter capacitor.

The voltage signal is transmitted into the IF amplifier through the coupling impedance isolation and be amplified. According to the phase relationship between the peak of output voltage and AC signal, the discharge amount can be calculated and it's compared with the specified value to determine whether there is potting defects in secondary coil of high-

voltage insulators. In the test, $C_x=100\text{pF}$, $C_k=1000\text{pF}$, $C_g=1\text{pF}$, $C_b=5\text{pF}$ and $Z_{mi}=50\Omega$. Its equivalent circuit is shown as Figure 3.

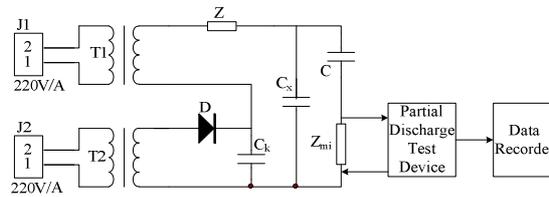


Figure 2. Test system diagram of partial discharge detection

It can be seen that it is equivalent to produce a partial discharge between the two layers of windings of the high-voltage insulators and re-allocate the charge capacitance in the equivalent circuit model, as shown in Figure 3. The voltage pulse in 50 ohm sense resistor caused by the coupling capacitor is really wanted. The peak voltage waveform of the partial discharge for 100pC coupling capacitor is shown in Figure 4. It can be seen that greater than 0.2V discharge signal is detected in the sense resistor. When the coupling capacitor is 1pC, about 2mV discharge voltage can be detected in the sense resistor. After amplified by partial discharge device, it can still get the partial discharge signal which noise ratio is greater than 3dB.

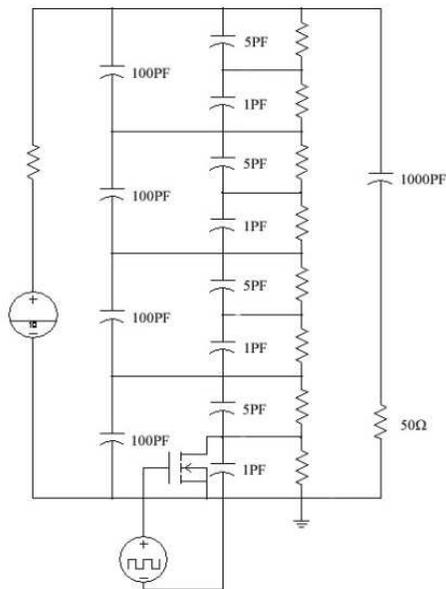


Figure 3. The equivalent circuit for partial discharge detection

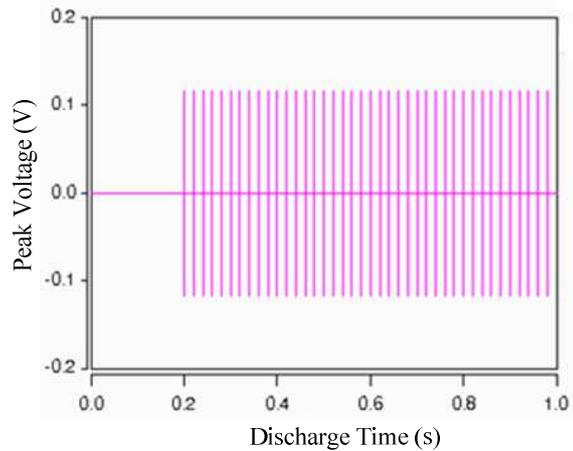


Figure 4. The waveform of the discharging peak voltage when the coupling capacitance is 100pC

Results and Analyses of Detection: After preliminary on-off test and temperature cycling test, qualified insulators are detected by partial discharge detection. Its technical specifications are as follows:

- 1) Test environment: normal temperature and pressure;
- 2) Applied voltage between two groups: 1200V;
- 3) Test time: 1min;

4) Temperature cycle test conditions: low temperature: -35°C , high temperature: $+85^{\circ}\text{C}$, high-low temperature hold time: 30 min, the temperature change rate: $5^{\circ}\text{C}/\text{min}$ (the average value of the whole temperature change), 10 cycles.

In order to prove partial discharge detection, we use the same material to pot these samples through different processes. First: a preliminary test, these samples are qualified. Second: first partial discharge inspection, the result shows that samples A and C do not discharge, but sample B produces a large number of discharges. Third: temperature cycling test, the result shows that the appearance of the samples A and C does not change. Finally: second partial discharge inspection, the results show that sample C has a micro-discharge, but sample A still does not discharge. The test results are shown in Table 1.

Table 1. Test results of partial discharge detection

Sample	A	B	C
Potting environment	Vacuum and pressure	Atmospheric	Vacuum
Preliminary test	Normal	Normal	Normal
First partial discharge detection	No discharge	A large number of discharge	No discharge
Temperature cycling test	No Change in appearance	—	No Change in appearance
After partial discharge detection	No discharge	—	Micro-discharge
Test results	Normal	—	Normal

Sample A is potted under vacuum and pressure environment, Sample B under Atmospheric environment and Sample C under vacuum environment. Partial discharge waveform of sample C is shown as in Figure 5(b) and sample A as in Figure 5(a). CH1 is discharge voltage waveform between two groups of secondary coil, CH2 applied voltage waveform between two groups of secondary coil and M is the discharge time.

Compared with the calibration signal, the discharge is about 50pC . So from Figure 5(a) and Figure 5(b), it can be seen that there is a bubble defect in sample C. Then, sample A, potted under vacuum and pressure environment, doesn't detect partial discharge (i.e. its discharge is 2pC). In summary, it proved that the new technology has played a crucial role in improving potting quality.

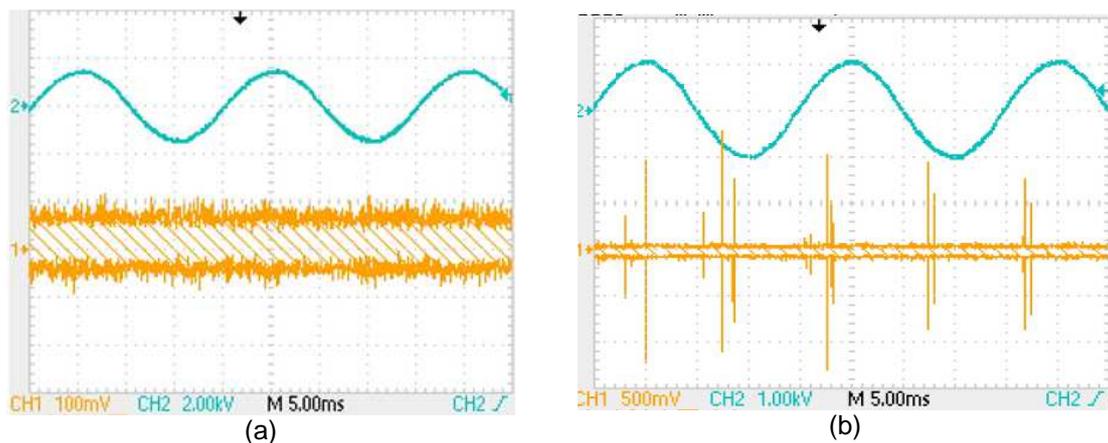


Figure 5. Partial discharge waveform of sample A and C

To take voltage and temperature as variables, we use DC partial discharge detection to test electrodes of the sample potting in order to result the relationship between partial discharge and insulation life. And test results are shown in Table 2.

Table 2. the results of DC partial discharge detection for electrodes of the potting sample

Applied voltage (kV)	Temperature (°C)	Discharge frequency (/s)	Discharge magnitude (pC)	Hold time (h)
-5	20	No discharge	0	0.1
-5	105	0.3	2000	24
-5	105	0.4	16000	48
-5	22	0.15	4000	24
-5	105	0.5	16000	72

As can be seen from Table 2, at the beginning of the test, the potting samples almost don't occur partial discharge under normal temperature and pressure. Under the effect of high temperature and high voltage, discharge magnitude increases rapidly and it reaches 16,000 pC after 72 hours. At this case, the discharge magnitude is 4,000 pC if returns to normal temperature. Then test under high temperature and high voltage for 72 hours, the discharge magnitude remains unchanged but discharge frequency increases by 25%. If it returns to normal temperature again, the discharge magnitude will reach 8,000 pC, which is 2 times of its original value. This test fully proves that high temperature and high voltage can rapidly damage high-voltage insulators by partial discharge and it's irreversible

4. Conclusion

In accordance with the problem of bubble defects of high-voltage insulators, partial discharge detection (i.e. AC/DC Parallel Superposition Pulse Testing method) is developed. Compared to ordinary partial discharge test system, this detection method can detect a lower discharge magnitude and have a higher sensitivity. At the same time, the testing method is capable of simulating the real working conditions of high-voltage insulators through accurate and reliable assessment of authentic test data. Through testing potting samples through different potting process, we can complete potting quality inspection and control.

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