Insulation Defect Detection of Solid Insulating Material Based on Nanosecond Pulse Voltage

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Abstract. In this paper, a partial discharge detection platform with repeated frequency nanosecond pulse voltage is built. Its output voltage is 30kV, the pulse front is 100ns, the half-width of the voltage is 120ns, and the maximum repetition frequency is 10 kHz. Under the excitation of nanosecond pulse voltage, the defects in the test sample produce partial discharge, the number of partial discharge is consistent with the number of applied pulses, the repeatability of discharge is good, the discharge quantity and the initial discharge voltage are easy to be counted, the partial discharge parameters are easy to be extracted. Under continuous pulses excitation, the development of defect of the sample can be judged by the change process of the discharge amount. Therefore, the nanosecond pulse voltage can be used to detect the insulation defect of the sample, and it is helpful to study the destruction process and mechanism of the solid insulating material under partial discharge.

1. Introduction

In recent years, solid insulation materials have made great progress, and a variety of polymer and ceramic materials with excellent performance have been widely used in power system equipment. However, the processing and assembly process inevitably leads to defects on surface and inside in the material. Under the action of electric field, partial discharge occurs in the defects. Partial discharge exists for a long time, which will lead to the deterioration of material insulation and ultimately lead to the breakdown of the body breakdown insulation. Solid dielectric partial discharge detection is a kind of defect detection method widely used in power system. In order to prevent and control accidents better, partial discharge detection of insulating parts is very important. The defect detection of solid media can be carried out under a variety of power supply operating environments. At present, the research on defect detection characteristics under normal voltage such as DC and AC (power frequency voltage) is in-depth, and various detection and evaluation systems are mature[1-4]. Under the condition of the same voltage level, partial discharge under pulse voltage causes much less harm to insulation than power frequency voltage and dc voltage[5]. There are few researches on the application of pulse voltage to defect detection, and the application of nanosecond pulse voltage to defect detection has not been seen yet.

The nanosecond pulse source based on semiconductor opening switch (SOS) has the advantages of high repetition rate, high reliability, long life and so on[6], in the process of exploring the field of civil...
applications, it has been successfully applied to the production of industrial ozone [7], the research on the biological effects of electromagnetic pulse [8], SOS nanosecond pulse source has a huge development potential in the field of civil. Based on SOS nanosecond pulse source, this paper explores its application in partial discharge detection. The nanosecond pulse voltage partial discharge detection platform was built, and the output voltage of the pulse source was applied to the solid insulation samples of different defect types. By changing the output voltage amplitude and frequency of the pulse source, the defect detection of the insulation samples was carried out, and the characteristics of the nanosecond pulse voltage in detecting the defects of solid insulation materials were studied.

2. Principle and structure of nanosecond pulse source
Nanosecond pulse source is composed of primary charging unit, magnetic pulse compression unit and SOS. The principle is shown in figure 1. The primary charging power supply Udc charges the primary energy storage capacitor C1 through IGBT-1, diode VD1, inductance L1 and the primary winding of the pulse booster transformer PT. The charging current simultaneously excites the magnetic core of the pulse transformer. Charging is completed, the main switch IGBT-2 is closed, C1 is discharge, the high voltage capacitor C2 is charged by the PT, the charging current is pumped semiconductor opening switch (SOS), after the completion of the charging PT core saturation, C2 discharges through the secondary side of the PT and reversely pumping SOS, when reverse current maximum, SOS truncation quickly, because the PT vice winding inductance current can’t mutations, the reverse current is transferred to the load resistance, produces high voltage pulse output load resistance R [9-10].

Pulse booster transformer PT undertakes the functions of pulse booster and pulse compression in the working process. The time-sharing trigger circuit controls the on-off timing sequence of IGBT-1 and IGBT-2, and completes the pulse output on the circuit charge and discharge and load resistance. Udc control pulse source output pulse amplitude, The trigger signal controls the output pulse frequency.

![Figure 1. Schematic Diagram of Pulse Source Circuit](image)

3. Test platform and test method
The platform for detecting partial discharge of repetitive frequency nanosecond pulse voltage is shown in figure 2, including Trigger Supply, Nanosecond Pulse power Source, HV probe, Rogowski Coil, Oscilloscope, Column-column electrode, Current-limiting R and Test sample. The test sample was organic film, which was closely connected with the Column-column electrode through the Pte-support, and the pulse source output was respectively connected to the upper and lower electrodes of the Column-column electrode. The diameter of the upper electrode of the column-column electrode was 6mm, and the diameter of the lower electrode was 25mm.
A trigger is used to trigger a repeated frequency nanosecond pulse source and to output a specific frequency, continuous or a specific number of triggering signals. Tektronix P6015A, 75MHz bandwidth, partial pressure ratio 1000:1, can be used to measure the peak pulse of 40kV. The coil is Pearson 6595, with a sensitivity of 0.5V/A and a bandwidth of 150MHz. SOS heavy frequency nanosecond pulse source is developed by ourselves, and its output waveform has excellent stability, high reliability and no local discharge. When Udc is determined, the output voltage amplitude of the pulse source varies with the change of the load resistance. The resistance load can choose different resistance values to adjust the output pulse amplitude. The maximum output voltage of the developed pulse source is 30kV. Figure 3 shows the output voltage amplitude of the pulse source, with the amplitude ranging from 10kV to 30kV. Figure 4 shows the waveform record under continuous operation of 1 kHz, and figure 5 shows the envelope of 30,000 pulse waveforms after 5min operation at 100Hz heavy frequency.
4. Defect partial discharge experiment

As shown in figure 7, the organic film of zero defect and defective sample(s) have been made: (a) two pieces of sound insulation film, (b) two pieces of insulation film, the upper insulating film in good condition, the lower groove, (c) two pieces of insulation film, the upper insulating film in good condition, the lower disconnect, (d) three pieces of thin film, insulation on the lower layer insulation film in good condition, the middle tier disconnect. The thickness of a single film is 0.5mm.
Pulse voltage was applied to the sample, and the current waveform on the sample (a) and (b) was the same, without current mutation. When the voltage amplitude increased to 30kV, there was still no obvious discharge phenomenon, as shown in Figure 8. When the pulse voltage is 25kV, the discharge pulse superimposed on the charging current can be seen on sample (c), as shown in Figure 9. When the pulse voltage is 23kV, obvious discharge pulses can also be seen on the sample (d), as shown in Figure 10. Therefore, the pulse voltage can clearly detect the fracture defects in the sample.

Figure 8. Two Intact Insulating Films

Figure 9. Two Insulating Films, the Lower Layer Disconnected from the Middle

Figure 10. Three-layer Insulation Films with Middle Layer Disconnected from the Middle

At the same pulse voltage, 50Hz continuous repetition frequency experiment was carried out on the sample (c). The change of sample discharge current in the process of pressurization is shown in Figure 11. At the beginning, the defects of the sample were small, and there were small spike pulses in the current waveform of the sample. After the pulse voltage is continuously applied for a period of time, the spike on the current waveform will increase and become severe at the same time, indicating
that the defect of the sample becomes larger. After aging for a long time, the circuit current surges, and the sample is broken down, and the insulation cannot be restored. It can be seen from the above experiments that the defects in the insulation wafer can be detected by using pulse voltage excitation, and the partial discharge will become more severe with the increase of defects.

![Figure 11. Partial Discharge Waveforms of Defective](image1)

Different amplitude voltages are applied to the sample (d). With the gradual increase of pulse amplitude, the sample generates discharge current, reduces voltage amplitude, and the sample discharge disappears. As shown in Figure 12, during the voltage rise, the position of discharge pulse gradually moves forward. When the voltage amplitude reaches about 19kV, the discharge pulse position is at the peak voltage of 50%. With the decrease of voltage, the position of discharge pulse gradually moves backward, and the discharge pulse appears at the drop edge of voltage when it is lower than a certain value. The discharge disappears when the voltage continues to drop to about 13.5kV.

The discharge quantity produced by partial discharge of the same sample under different voltages is stable, and the discharge location is different, but the corresponding initial voltage of partial discharge is the same.

![Figure 12. Pulse Positions of Partial Discharge](image2)

In order to mark partial discharge signals more accurately, coupling capacitance was added to the original measurement circuit. Two Rogowski Coil were used to measure the pulse current signals of the sample circuit and coupling capacitance circuit respectively. The circuit principle is shown in Figure 13. When the sample (c) is applied with voltage, the polarity partial discharge pulse signal of the sample loop is opposite to the current signal of the coupling loop, so the determined partial discharge signal can be distinguished by the direction of the pulse current, as shown in Figure 14, the discharge pulse in the opposite direction can be clearly seen.
5. Experimental results

(1) Nanosecond pulse voltage experiments were carried out on organic films with different defects. By measuring the changes of current waveforms in the circuit, the defects of organic film materials could be judged.

(2) When the defective sample is under continuous high frequency voltage, its insulation will gradually age, leading to the gradual increase of defects and the gradual increase of local discharge. The change of local discharge can reflect the deterioration process of insulation material defects. The severity of defects can be judged by the local discharge.

(3) Under different voltage amplitudes, the same defect has good repeatability of partial discharge and stable discharge, so the initial voltage of partial discharge of the sample can be determined.

(4) A pulse voltage corresponds to a discharge, the charging current and partial discharge current signals are easy to distinguish, the experimental results can be observed in real time, and the discharge is easy to be counted.

6. Conclusion

Nanosecond pulse voltage testing platform is simple and can be used to detect defects in insulating materials. The defects of insulating materials and the severity of defects can be judged by the current waveform of the test circuit. The pulse width and width of nanosecond pulse voltage enable it to run at high frequency and repeat frequency. The discharge times and discharge quantity of samples under continuous pulse can be accurately captured and the initial discharge voltage can be highly accurate. Under continuous pulse, the changing process of sample discharge can be observed and recorded in real time, which is helpful to study the failure process and mechanism of solid insulation under partial discharge.

Acknowledgment

Project supported by science and technology project of Inner Mongolia Power(Group) Co., Ltd.(20170106, 201801024).
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