

# The Preliminary Investigation of Needle Plate Electrode Discharge Characteristics in the Oil under Impulse Voltage

Liangliang Hua, Jidong Wei, Jun Zhang, Bo Kong, Mingchang Liu and Jianhong Guo

TongLiao Power Supply Company of Mengdong Electric Power Compang, No. 0097, Xinjian Rd., KeErQin District, TongLiao, NeiMengGu, China

**Abstract**—Partial discharge detection under impulse voltage is an effective method for monitoring the insulating properties and the aging of high-voltage electric equipment. It is of great practical significance for discovering potential safety hazard in time and ensuring the safe operation of equipment. In this paper, we set up an impulse voltage source with solid-state switch, the discharge signals of needle plate electrode in the oil are detected by using the photomultiplier. The results show that the measurement can successfully detect the discharge signal both in the wave head and the wave tail, the signals in the wave head usually have a long duration, intensely and constantly discharge; the signals in the wave tail usually have a short duration, weakly and discontinuity discharge. We make the analysis with a possible mechanism of physical aiming at this phenomenon.

**Keywords**—impulse voltage; solid-state switch; partial discharge; photomultiplier; streamer

## I. INTRODUCTION

Transformer work to bear the lightning or switching overvoltage is much higher than the power frequency voltage; multiple impulse voltage will cause damage to the cumulative insulation equipment [1]. Voltage test and partial discharge test of electrical equipment under AC voltage, the measurement method and technology have been relatively mature, and few studies have been done on partial discharge of equipment insulation under impulse voltage [2]. In the partial discharge test under the impulse voltage, it is easier to excite the insulation defect of the equipment. At the same time, the device used for the partial discharge test under the impulse voltage in practical application is easier to use on the equipment with larger capacity. The initiation and development process of partial discharge of internal insulation of electrical equipment under impulse voltage is revealed. To understand the electrical equipment insulation damage is helpful.

With the need of power network operation and maintenance, and the development of partial discharge measurement technology, the partial discharge characteristics of equipment insulation under the impulse voltage are gradually studied at home and abroad. Densley et al. (1971) [3] studied the partial discharge characteristics of Artificial porosity in polyethylene at impulse voltage, and discussed the relationship between the initial discharge voltage and the air gap diameter, and studied the discharge amplitude and time delay characteristics. Kamata et al. [4-5] studied the discharge breakdown characteristics of

several oil-immersed transformer insulation models when the AC voltage superimposed on the lightning impulse voltage; In order to classify the basic flashover phenomena in the transformer oil under the impulse voltage, the characteristics of flashover of the positive lightning impulse, the operating shock and the 50Hz alternating voltage were studied. Elisabeth Lindell et al. [6] developed a device to detect discharges at impulse voltages. The partial discharges at half-square-wave voltages at 2  $\mu$ s and 100  $\mu$ s rise times were measured for the typical needle-plate corona model, the motor winding solid insulation model, and the transformer turn-to-turn insulation model, while obtaining the key parameters of the partial discharge voltage. R. Clemence Kiiza et al. studied the partial discharge characteristics of transformer casing typical oil - paper insulation under impulse voltage. The experimental results show that impulse voltage has a great influence on the partial discharge characteristics of aging oil-paper insulation, but it has little influence on the insulation of oil-paper without aging. O. Lesaint et al. [7-9] studied the development of pre-breakdown of 5 to 20 cm transformer oil gap under square-wave voltage, and measured the transient current of the discharge under square-wave voltage using photoelectric measurement technique. JKNelson et al. [10] studied the impulse breakdown of transformer oil-paper insulation with different structures. By comparing the characteristics with the AC voltage, an equivalent factor was used to make the insulation structure design at the power frequency voltage used to evaluate the insulation capacity. And this study provides a reference for the design of composite oil-paper insulation structure under impulse voltage. Liu and Z.D. Wang et al [11] used high-speed cameras and photomultiplier to accurately measure the development process of streamer in the transformer oil insulation, to provide support for partial discharge measurement under impulses. Xi'an Jiaotong University, Sun Zhenquan and Zhao Xuefeng et al [12-13] found that oil-paper insulation air gap model in the lightning impulse voltage partial discharge impulses is divided into the first wave discharge time of the main impulse and the wave tail time multiple low-amplitude impulse, At the same time, the randomness of the impulse voltage waveform and the randomness of the partial discharge signal cause the partial discharge signal of the impulse voltage to be scattered and need to be analyzed by the statistical method. These conclusions laid the foundation for the insulation state evaluation of oil-paper insulation power equipment.

The paper, establish a set of low-noise impulse voltage generator means based on solid-state switch. On this basis, the partial discharge model of the needle plate in oil is detected by photomultiplier. The initial and development of discharge under impulse are analyzed.

## II. IMPULSE VOLTAGE PARTIAL DISCHARGE MEASUREMENT SYSTEM

### A. Impulse Voltage Generator Structure

The target waveform of the impulse voltage generator was lightning impulse voltage waveform, according to IEC and national standard. The wave front time  $T_f$  of lightning impulse voltage wave was  $1.2\mu s \pm 30\%$ , and the half-peak time  $T_t$  was  $50\mu s \pm 20\%$ .

At present, the partial discharge measurement power source of the impulse voltage all adopted the impulse source of the ball-gap switch. The ball gap discharge would cause large interference to the measurement system and cause insufficient stability. The paper applied solid-state switch to form the impulse of voltage generator which could reduce the interference to measurement system. The output voltage waveform was more stable. Figure 1 was the use of solid-state switch impulse voltage generator schematic diagram. the DC source charged the main capacitor through the protection resistance. The charging is triggered after connecting with solid-state switch. The main capacitor discharged the wave head resistance and the wave tail resistance. By changing the numerical value of wave head resistance and the wave tail resistance, the standard lightning impulse voltage was accomplished.

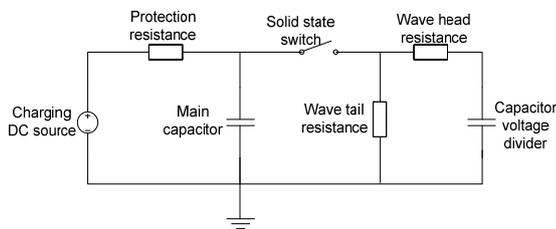


FIGURE I. PRINCIPLE DIAGRAM OF THE IMPULSE GENERATOR

Solid-state switch parameters for the withstand voltage 90kV, withstand current 100A, the main capacitor of 22nF, components of the other of the generator parameters were as follows in Table 1:

TABLE I. ELEMENT PARAMETERS OF IMPULSE SOURCE

Main capacitor (nF)	Wave head resistance (kΩ)	Wave tail resistance (kΩ)	Capacitor voltage divider (pF)
22	1.4	3.1	300

The impulse source was set up in the laboratory to test the impulse of voltage output. The voltage gradually increased

from 5kV to 30kV with lightning impulse voltage waveform under the different voltage levels, as shown in Figure 2. The wave head time and the wave tail time meet the specified deviation.

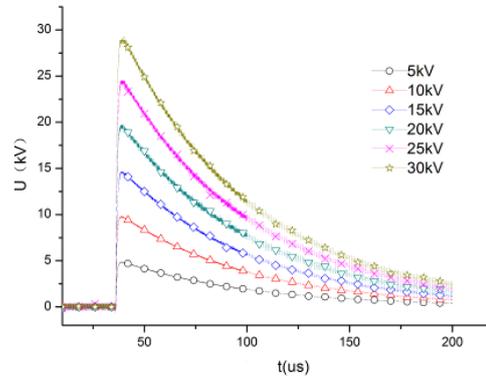


FIGURE II. EXPERIMENTAL WAVEFORMS OF SOLID-STATE SWITCH IMPULSE SOURCE

### B. Discharge Model

Partial discharge in the transformer types are many, such as: partial discharge air gap, corona partial discharge. This paper focused on the transformer oil in the needle plate electrode corona discharge.

The discharge apparatus of the needle plate electrode in oil was shown in Figure 3. High-voltage electrode was a copper tungsten needle with cone angle of 30 degrees, plate electrode diameter of 75cm and needle plate electrode spacing 25mm. Electrode was put into the sealed oil container with oil and the top covered with a seal. The high-voltage lead was equipped with an insulating casing, which was 250mm long. The edges of all components were chamfered to avoid tip-induced partial discharges.

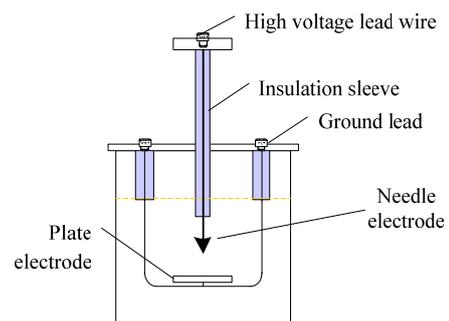


FIGURE III. DISCHARGE TEST APPARATUS

### C. Partial Discharge Measurement Means

When a partial discharge occurred, the optical signal was detected by a photomultiplier tube (PMT), and a corresponding current signal was obtained by the light intensity. PMT responded with a high sensitivity and fast by speed. Its

drawback was need for the experiment in an extreme dark environment.

**D. Experiments**

Figure 4 for the impulse voltage Partial discharge measurement system schematic. The photomultiplier was placed on the discharge electrode side, aligned with the tip electrode. Both the discharge signal and the impulse voltage signal from the capacitive were connected to the oscilloscope via a coaxial cable. The impulse voltage source was controlled by the solid state switch. DC-DC power supply;  $R_0$ -Protection resistance;  $R_f$ -Wavefront resistance;  $R_t$ -Wave tail resistance;  $C_0$ -Main capacitor;  $C_{load}$ -Load capacitance;  $C_1, C_2$ -Low damping capacitive divider high and low voltage arm capacitance;  $r$ -The weak damping resistance of the high voltage arm of the capacitive divider; The divider ratio of the capacitive divider was 2000: 1.

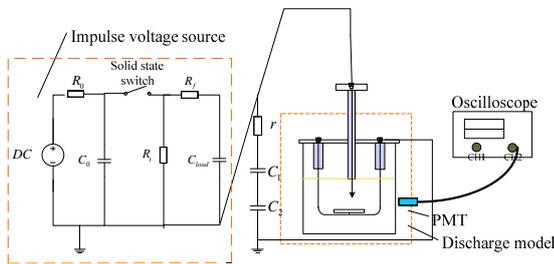


FIGURE IV. PARTIAL DISCHARGE MEASUREMENT SYSTEMS

In order to minimize the interference caused by the impulse of the source, the following methods were taken into practice:

- The impulse source and all components of the earth line are all connected with the earth through the copper skin, and to shorten the length of line and to ensure good grounding;
- The high voltage lead of the impulse source adopts smooth copper tube with diameter of 6mm, and the joint is handled smoothly;
- The oscilloscope connects to the power supply via an isolation transformer to protect the oscilloscope and isolate some of the interference.

In order to ensure the high repetition rate of the experimental, the following methods were used:

- Need to stop after an impulse for 5 minutes, and then next test, in order to eliminate the last test of the accumulation electronic;
- The use of new transformer oil and cardboard;
- The use of positive lightning wave, step-by-step boost, each voltage level under the impulse of three times, if the three shocks did not detect the discharge, can be considered that is not discharged.

**III. EXPERIMENTAL DATA AND ANALYSIS**

The partial discharge of the needle plate electrode under the impulse voltage was detected, and the amplitude of the impulse voltage was increased step by step, and recorded the start and progress of the discharge. The test waveforms curves are shown in Figs. 5 (a) to 5 (f).

When the voltage reached 20kV, PMT observed the beginning of the discharge, occurred in the impulse voltage near the end of the maximum. The voltage increased to 24.8 kV, and a strong discharge appeared in the wave head, and three weak discharges appeared in the wave tail, and the time of occurrence was after the half - peak time. As the voltage continues to raise, the discharge more and more intense at the head of the wave, the discharge time is gradually longer. And the frequency and amplitude of discharge are increasing gradually at the wave tails. The discharge signal of the initial discharge is obviously different from the discharge signal after the start, so that the two discharges may correspond to different mechanisms.

The initial discharge observed at 20 kV occurs near the peak of the voltage, the observed discharge signals at other voltages can be divided into near-wave head discharge and near-wave tails discharge. The duration of the light signal in the wave head part is long and the discharge is continuous and intense within a few tens of microseconds before the start of the voltage to the half-peak time. The discharge of the wave tail part is a short duration, a weak intermittent discharge, and even after the impulse voltage is reduced to near zero, discharge is observed.

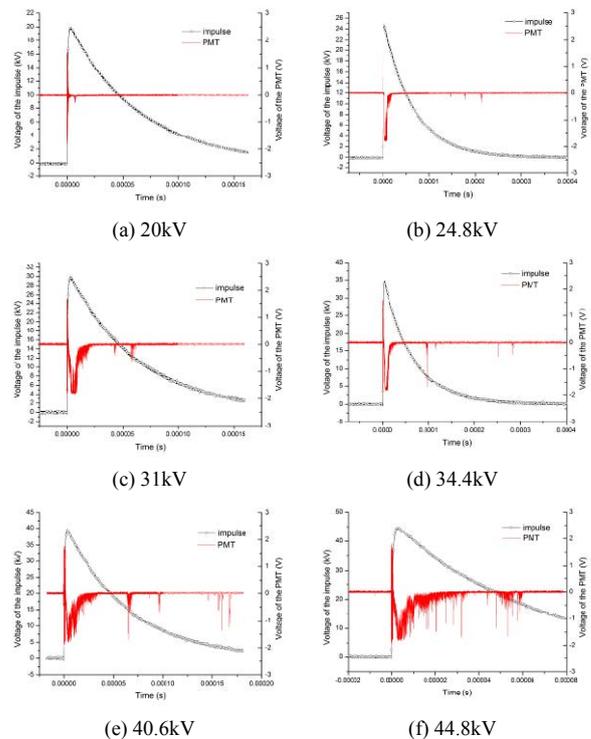


FIGURE V. MEASUREMENT CURVES IN THE TEST

The same time under the impulse of different characteristics of the discharge signal, leading to the phenomenon of possible mechanisms are as follows: During the period of wave head, with the rapid rise of voltage, near the tip electrode first ionization to produce the initial streamer, observed wave head part of the light signal is generated at this stage of discharge. This stage of the discharge of intense and longer duration, it may lead to the gas channel in discharge area, and the streamer is also developed in the channel. Streamer inside the electrons rapid movement and into the electrode, positive ions gradually spread out, gathered in the gas channel and the transformer oil interface. With the development of flow injection, the gas channel is expanding and the number of positive ions is increasing at the interface. The electric field strength of the gas channel decreases and the neutralization of the positive and negative charges and emits a lot of photons. As the added impulse voltage starts to decrease after reaching the maximum value and the increase of the positive ions in the channel interface leads to the decrease of the electric field strength, the start streamer is stopped. At the end of the start streamer, some positive ions are remained in the discharge gas channel. At this time, the voltage enters the wave tail, and the residual positive ions will accumulate near the tip electrode and generate reverse electric field. As the voltage drops further, the space charge may cause a reverse discharge, so a discharge signal will also be observed at the wave tail stage.

#### IV. CONCLUSIONS

The paper, a partial discharge measurement system based on solid-state switch impulse voltage is established, and the partial discharge of the needle-plate electrode model under the impulse voltage is detected. The results are as follows:

- At the impulse voltage, tip-plate electrode in the oil discharge from the voltage peak near the start.
- After the start of the discharge, the voltage is raised again, and the discharge signal can be detected at the wave head and wave tail under the impulse voltage. The signal of the wave head is longer and the discharge is continuous and more intense. The discharge of the wave tail is a weaker one with a short and intermittent.
- The discharge signal at the wave head may be due to the rapid development of the start streamer. The discharge signal at the wave tail may be caused by the reverse discharge of the residual space charge after the start streamer.

#### REFERENCES

- [1] Zhang Renyu, Chen Changyu, Wang Changchang, et al. High voltage testing technology[M]. Beijing: Tsinghua University Press, 2006.
- [2] Wang Changchang, LiFuqi, Gao Shengyou. On-line monitoring and diagnosis for power equipment[M]. Beijing: Tsinghua University Press, 2006.
- [3] R. J. Densley, B. Salvage. Partial Discharges in Gaseous Cavities in Solid Dielectrics Under Impulse Voltage Conditions[J]. IEEE Transactions on Electrical Insulation, 1971, 6(2): 54-62.
- [4] Y. Kamata, K. Endoh, S. Furukawa, et al. Dielectric Strength of Oil-immersed Transformer Insulation with Superimposed ac and Lightning Impulse Voltage[J]. IEEE Trans. on Electrical Insulation , 1990,25(4): 683-687.
- [5] Y. Kamata, A. Miki, S. Furukawa. A Singular Flashover Path Observed on the Surface of Synthetic-resin-bonded Paper Cylinders Immersed in Transformer Oil under Switching Impulse Voltage Conditions[J]. IEEE Transactions on Electrical Insulation, 1991,26(2): 300-310.
- [6] Elisabeth Lindell, Tord Bengtsson, et al. Measurement of Partial Discharges at Rapidly Changing Voltages[J]. IEEE Transactions on Dielectrics and Electrical Insulation, 15(3):823-831, 2008.
- [7] P. Rain, O. Lesaint. Prebreakdown Phenomena in Mineral Oil under Step and ac Voltage in Large-gap Divergent Fields[J]. IEEE Transactions on Dielectrics and Electrical Insulation, 1994, 1(4):692-701.
- [8] O. Lesaint, G. Massala. Positive Streamer Propagation in Large Oil gaps[J]. IEEE Transactions on Dielectrics and Electrical Insulation, 1998, 5(3):360-370.
- [9] L. Dumitrescu, O. Lesaint, et al. Study of Streamer Inception in Cyclohexane with a Sensitive Charge Measurement Technique under Impulse Voltage[J]. Journal of Electrostatics, 2001:135-146.
- [10] J.K. Nelson, C. Shaw. The Impulse Design of Transformer Oil-Cellulose Structures[J]. IEEE Transactions on Dielectrics and Electrical Insulation. 2006, 13(3):477-483.
- [11] Q. Liu, Z.D. Wang. Streamer characteristic and breakdown in synthetic and natural ester transformer liquids under standard lightning impulse voltage[J]. IEEE Transaction on Dielectric and Electrical Insulation, 2011, 18(1): 285-294.
- [12] Zhenquan SUN, Xuefeng ZHAO, et al. Experiment Investigation of Partial Discharges under Impulse Voltage[C]. Proceeding of the 9th International Conference on Properties and Applications of Dielectric Materials, 2009, E(31): 525-529.
- [13] Zhao Xuefeng, Sun Zhenquan, Yao Xiu. et al. Study on Partial Discharge Detection System under Oscillatory Impulse Voltage[J]. Chinese Journal of Scientific Instrument, 2010, 31(1): 188-193.