Polarization and depolarization characteristics of different structure oiled paper composite insulation under high applied voltage

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Abstract. Transformers are an important part of the power transmission and distribution process of power systems. Designing and manufacturing a stable transformer is essential for the stable operation of the entire power system. Accordingly it is critical for the stable operation of the entire power system to design and manufacture a stable transformer. In order to improve the composite insulation performance of the oil-paper in power transformer, studying the polarization characteristics of oil-paper composite insulation is essential. In this paper, the polarization characteristics of high external applied voltage and different oil-paper composite insulation structures are studied. In the three-electrode system, the cardboard has obvious polarization characteristics at the two poles, and the polarization characteristics are most obvious when the cardboard is at the high pressure pole. The initial value and the attenuation function of the polarization and depolarization current do not match the laws determined by the RC circuit. When the voltage is at a higher level, the difference between the initial values of the polarization and depolarization currents at different positions of the cardboard at the same voltage level is greater, and the polarity effects are more obvious. the above rules still exist when the distance between the electrodes is changed.

1. Introduction

Power transformers play a critical role in the normal operation of power systems, and hence the reliability and durability of transformer are directly related to the long-term safe operation of the entire system. In the event of a serious accident in a power transformer, it not only causes damage to itself, but also disrupts the power supply and causes significant economic losses. For reducing the failure rate of power transformers in operation and improve the composite insulation performance of power transformers, it is necessary to study the polarization characteristics of oil-paper composite insulation [1-3]. In 2007, Sarkar used a combination of polarization and depolarization current and recovery voltage to study the effect of micro water content on insulation paper of power equipment [4, 5]. In 2014, Nie Dexin and Tsinghua University Sha Yanchoao et al. used the partial discharge method to study the basic characteristics of various discharge periods of oil-paper insulation, and initially perfected the insulation discharge theory of converter transformers [6, 7]. In the same period, Zhou Yuanxiang and Huang Meng of Tsinghua University used electro acoustic pulse method to study the space charge and interface charge characteristics of oil-paper insulation [8, 9]. At present, the literature mainly focuses on the polarization and depolarization characteristics of low-voltage grade oil-paper
composite insulation, which is quite different from the actual transformer working state. This paper is aimed at the polarization and depolarization characteristics of thick cardboard at different positions of high voltage level, which is closer to the actual working status of transformers. According to the structural characteristics of oil-paper composite insulation of a power transformer, a test model and a three-electrode system were built, and a test platform for oil-paper composite insulation polarization characteristics was established. By changing the distance between the gap of the oil-paper composite insulation structure and the position of the cardboard, the polarization current and the depolarization current were measured by the current collecting system at different voltage levels, respectively. Through the fitting of the current curve, the polarization characteristics of the oil-paper composite insulation structure at different distances and high voltage levels were obtained with statistical analyses between the raw data and the fitted data.

2. Standardized processing and test platform for test samples

2.1. Sample preparation and pretreatment

The purpose of the sample pretreatment is to prevent deviations in the experimental results due to differences in environmental conditions experienced by the test sample before the test. In this test, it includes two aspects of pretreatment of transformer oil and pretreatment of insulating paperboard.

(1) Oil-impregnated cardboard pretreatment

Cardboard selected from Weidman’s platen with a thickness of 1 mm. The standard water content of oil-impregnated paperboard treated in accordance with national standards shall be less than 0.4%. The pretreatment of the oil-impregnated paperboard consists of two processes, vacuum drying and paperboard immersion. According to the standard pretreatment process of the oil-impregnated paperboard, the treated sample should be placed in a drum and sealed in a vacuum to avoid contact with air. After that, it is necessary to test the moisture content of the paperboard according to the national standard DL-449-91 Determination of water content of oil-impregnated fibrous insulation before each test. If the test result does not meet the standard, the sample should be vacuum dried again. After testing, the moisture content of the oil-impregnated paperboard used in the test was 0.38%.

(2) Transformer oil pretreatment

Since the transformer oil generates a variety of impurities during storage and breakdown, it has a great influence on the polarization and depolarization current. The pretreatment of transformer oil mainly involves three processes, dehydration, degassing and filtration. The required testing equipment includes the Karl Fischer micro water tester, the insulating oil dielectric strength measuring instrument, and the oil dielectric loss measuring instrument. Referring to SH-T0207-92 Insulation Oil Water Content Determination Method for moisture content in oil, transformer oil is standardized in accordance with standard procedures. In this paper, Kunlun No. 45 transformer oil is selected and required to have a water content of less than 10 ppm, a dielectric loss of less than 0.4% at 90 °C, and an AC breakdown voltage greater than 60 kV (2.5 mm gap). The treated transformer oil should be stored in a vacuum tank [10]. The sample treated above has good consistency during the test.

2.2. Measuring experimental platform construction

The test platform device mainly consists of DC reverse voltage generator, 30MΩ protection resistor, test tank car, current collecting system, single pole double throw switch, positive polarity regulator and upper computer.

The three-electrode system is shown in the Figure 1. The high-voltage electrode has a diameter of 90 mm, a chamfer radius of 15 mm, and a height of 50 mm. The function of the roller is to fix the cardboard and adjust the position of the cardboard.

The DC high voltage cascade generator is connected in series by multiple voltage doubler circuits. The schematic diagram and actual structure are shown in Figure 2 and Figure 3. The rated output voltage is 400kV and the rated output current is 5mA. The motor controls the rotation of the motor
through a single-pole double-throw switch, thereby driving the rotation of the protection resistor to ground the high-voltage pole.

![Diagram of electrode system]

1-High voltage electrode 2-Samples of the cardboard 3- Fixed roller 4- Insulation support 5- Low voltage electrode 6- Shielding electrode

**Figure 1.** Three-electrode system structure.

![Measuring system schematic]

**Figure 2.** Measuring system schematic.

![Actual structure chart of measuring system]

**Figure 3.** Actual structure chart of measuring system.

The current detecting system uses the I-PR-1 type current collecting unit, which converts the collected current signal into a voltage signal, which is converted into a digital signal after signal processing to remove high frequency interference, and transmitted to the signal of the upper computer through the optical fiber. The acquisition card is programmed on the host computer to convert the transmitted digital signal into an analog signal and save it in the host computer.

Considering that the oil-paper composite insulation sample is a series-connected composite dielectric structure, and polarization-depolarization is a slow process, the longer the test time, the better the analysis of the data. Therefore, both the polarization time and the depolarization time are set to 3600s.
3. Test results

3.1. Test results of 8mm oil-paper composite insulation structure

The polarization-depolarization measurement current curves of the 8mm paperboard centred oil-paper composite insulation structure at 50kv, 60kv, 70kv, 80kv, and 90kv voltage levels are shown in a, b, c, d, and e of Figure 4, respectively:

![Figure 4](image)

**Figure 4.** 8mm oil-paper insulating oil-impregnated composite board centrally polarization and depolarisation current curve.

It can be seen from Figure 4 that the polarization and depolarization current increases with the increase of the voltage level, but it is quite different from the polarization and depolarization current law of the general RC model. It shows that the insulation resistance of the 8mm oil-paper composite insulation structure is nonlinear during the process of polarization-depolarization. When the paperboard is centered, it can be clearly seen that the polarization and depolarization current curve is basically symmetric and the polarity effect is weak. It can be confirmed from the following test data as well.

The electrode gap is unchanged, and the position of the adjustment cardboard is placed at the high voltage extreme and the low voltage extreme respectively. The polarization and depolarization...
measurement current curves of the oil-paper composite insulation structure at 50kv, 60kv, 70kv, 80kv, 90kv voltage are respectively shown in Figure 5 and Figure 6.

It can be seen from Figure 5 and Figure 6 that the variation law of polarization and depolarization current does not change with the change of the position of the cardboard. The polarization current is still attenuated with the exponential function of the exponent of the variable, which is inconsistent with the polarization depolarization current law of the traditional RC model. As is shown in the figure that there is no obvious symmetry between the polarization and depolarization currents of the oil-impregnated paperboard placed at the high and low poles, and the polarity effect is more obvious.

Figure 5. 8mm oil-paper insulating oil-impregnated cardboard composite electrode polarization and depolarisation high voltage current curve
Figure 6. 8mm oil-paper insulating oil-impregnated composite board low voltage electrode polarization and depolarisation current curve

3.2. Test results of 6mm and 10mm oil-paper composite insulation structure

In order to investigate the law of the polarity effect, the electrode gap is adjusted to 6mm and 10mm respectively, and the oil-impregnated paperboard is centered at the voltage level of 50kv, 60kv, 70kv, 80kv, 90kv, placed on the high voltage pole and placed. Under the low voltage pole, the initial values and fitting curves of the obtained polarization current and depolarization current are shown in a, b in Figure 7, Figure 8 and Figure 9.

It can be seen from the statistical data of Figure 7, Figure 8 and Figure 9 that the oil-impregnated paperboard has obvious polarity effects when placed at the high voltage and low voltage extremes, and the polarization effect still exists after changing the gap of the oil-paper composite insulation. From the initial value of the polarization current and the absolute value of the initial value of the depolarization current, it can be seen that the polarization and depolarization current of the cardboard placed at the high voltage pole is significantly higher than that of the cardboard placed at the low
pressure pole and the paperboard is centered, and the polarization and depolarization current placed in the center of the cardboard is the smallest.

![Figure 7. 6mm oil-paper insulation composite polarization and depolarisation current initial value.](image)

![Figure 8. 8mm oil-paper insulation composite polarization and depolarisation current initial value.](image)

![Figure 9. 10mm oil-paper insulation composite polarization and depolarisation current initial value.](image)

It can be seen from the above data that the closer the two plates are to the two poles at the same voltage level, the more obvious the polarity effect. Under the action of high voltage, the higher the voltage level, the greater the difference between the initial values of the polarization and depolarization currents at different positions of the cardboard at the same voltage level, indicating that the higher the voltage level, the more obvious the polarity effect.
4. Conclusions

Under the condition of high applied voltage and different oil-paper composite insulation structure, statistical analysis of the polarization and depolarization current of oil-paper composite insulation can obtain the following conclusions:

(1) Under DC voltage, the initial value and attenuation function of the polarization and depolarization current do not match the laws determined by conventional RC circuits. But the steady state current still conforms to Ohm's law. When the gap between the electrodes is increased, the electric conduction current decreases at the same voltage level due to an increase in the insulation resistance of the oil.

(2) At the same voltage level, the closer the cardboard is to the two poles, the more obvious the polarity effect is. When the cardboard is close to the high voltage pole, the polarity effect is most obvious.

(3) As the voltage level increases, the difference between the initial values of the polarization and depolarization currents at different positions of the cardboard at the same voltage level is greater, indicating that the higher the voltage level, the more obvious the polarity effect. And changing the distance between the electrodes, the above rule still exists.

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