Space Charge Behavior in Multi-layer Oil-paper Insulation under Different DC Voltages and Temperatures

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ABSTRACT

Oil-paper as a reliable insulation system is widely used in power transformers and cables. The dielectric properties of oil-paper insulation play an important role in the reliable operation of power equipment. However, the formation and dynamics of space charge can affect the performance of insulation material. In this paper, space charge in oil-paper insulation system has been investigated using the pulsed electroacoustic (PEA) technique. A series of measurements were carried out when the insulation system was subjected to different applied voltages at different temperatures. Charge behavior in the insulation system has been analyzed and the influence of temperature on charge dynamics was discussed. The test results show that homocharge injection takes place under all the test conditions, the applied dc voltage mainly effect the amount of space charge, while the temperature has greater influence on the distribution and mobility of space charge inside oil-paper samples.

Index Terms — **Space charge, oil-paper, DC voltage, multi-layer, pulsed electroacoustic (PEA).**

1 INTRODUCTION

OIL-PAPER insulation has been used in power transformers, power cables and HVDC equipments for quite a long time because of its low cost and desirable physical and electrical properties. But it degrades under a combined stress of thermal, electrical, mechanical, and chemical stresses during routine operations. This will affect the lifetime of power equipment significantly. On the other hand, space charge in dielectric materials has a close relation to the electrical performance of a material. For example, trapped or low-mobility electrically charged species within the bulk can give rise to space charge, resulting in localized electrical stress enhancement. This can cause further concentration of charge and lead to premature failure of the material [1, 2]. Therefore, a better understanding of charge dynamics, in accordance with the specific variation of the charge distribution in multi-layer insulation system becomes increasingly important and needs a careful investigation.

The pulsed electroacoustic (PEA) technique was first developed in 1980s, it has been widely used in space charge research area because of its low cost and ease of implementation. The PEA method can allow space charges to be observed during poling, i.e. under electric field, and after electric field removal, i.e. during depolarization, thus providing thorough information on space charge dynamics [3]. Such method opens a way to understand physical processes taking place inside the dielectric materials, and makes it possible to select materials and interfaces which minimize the risks of breakdown in HV applications.

Most of the space charge measurements have been carried out upon polymeric insulating materials, such as XLPE, LDPE and PE. From the year 1997, a few studies have been performed on oil-paper insulation. Morshuis and Jeroense [4, 5] made some space charge tests on oil impregnated insulation paper, concluded from the test results that whatever the combination of paper and oil, three general trends were observed. Firstly, homocharge is always observed, both at the anode and the cathode. Secondly, specific charge growth/decay pattern occurs. Thirdly, the growth and decay of the charge profiles can be described by roughly two time constants. This is the first time that results have been published on space charge measurements on HVDC cable paper insulation [4, 5]. However, the influence of temperature has not been discussed. Ciobanu et al, analyzed the space charge evolution in oil-paper insulation, and associated the mobility phenomena with the mineral content of cable paper. They concluded that the charges parameters derived from the

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PEA measurements, such as, charge density, apparent trap-controlled mobility and variation of trap depth distribution, can be successfully used towards promoting criteria for the best choice of oil-paper insulation technology for dc cables application [6].

In this paper, based on the PEA technique, a series of measurements were carried out when the oil-paper insulation system was subjected to different applied voltages and temperatures. Charge dynamics in the insulation system during the volts-on, volts-off and decay have been analyzed, and the influence of temperature on charge dynamics discussed.

2 EXPERIMENTS

In this study, the measurements were carried out on oil immersed insulation paper. The insulation paper which is made by Croylek Ltd., has a thickness of ~60 μm for single layer. The parameters of the paper meet the international standard IEC 554.2.

The insulation oil used in this experiment was Nytro 10X transformer oil, which was provided by Nynas Oil Company. Nytro 10X is an inhibited transformer oil with good electrical properties and oxidation stability, it has a widely industrial application as well.

Before PEA tests, several pretreatment steps were carried out upon samples. Firstly, the new insulation paper was cut into round shape with a diameter of ~2 cm. Then the paper samples were kept in a vacuum oven at 393 K (120 °C) for 30 min, in order to make the moisture content less than 0.2%. After that, the paper samples were impregnated by fresh degassed insulation oil in a sealed oven. As thin paper was used, the sample can be fully impregnated after 1 day. All oil-paper samples used in these tests are thought to be uniform as that both the oil and paper sample are in the same size respectively, and the same pre-treatment are performed.

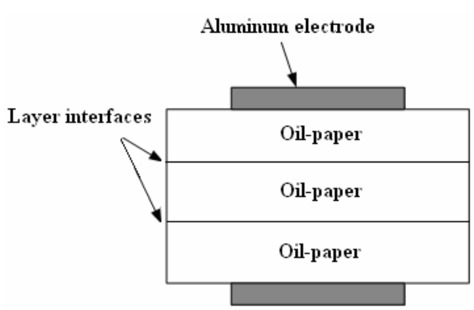

Figure 1. Schematic diagram of sample arrangement.

In practical application, oil-paper is usually used as multilayer insulation. Therefore, in this experiment, the PEA tests are performs on three layers oil-paper samples (~120 μm after oil immersed and being pressed by electrodes, in Figure 1). The samples were stressed at three different dc voltage levels (4 kV, 6 kV, 8 kV) and three temperatures (20 °C, 40 °C, 60 °C). Each time, an electrical stress time of 1 h was tested. In addition, space charge evolution after the removal of the applied electric field was also measured.

The space charge measurements were taken at various times during the periods of both volts-on and volts-off (short-circuit condition) using the PEA technique (Figure 2). In the PEA technique, acoustic pressure waves are generated due to the interaction of pulsed electric field and charge layer. Detection of acoustic pressure waves allows one to determine charge distribution across the sample. The principle of the PEA can be seen in many literatures [7, 8]. The PEA system (PEANUT, made by Five Lab) used in this study has a pulse width of 5 ns. The bottom electrode is made of 10 mm thick aluminum plate and the top electrode is semiconducting polymer to achieve a better acoustic match. The piezoelectric sensor used was a 9 μm thick LiNbO3 material that enables the system to be heated up to 90 °C although this was not utilized in the present study.

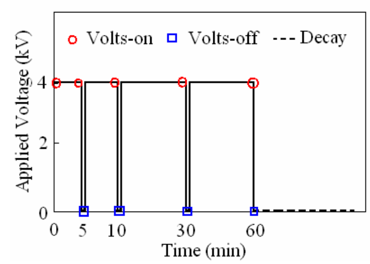

Figure 2. Illustration of experimental measurement points.

3 RESULTS AND DISCUSSION

3.1 STEP VOLTAGE TEST

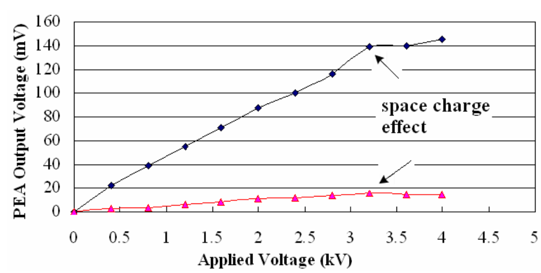

Figure 3. Step voltage test (under 20 °C).

First, a step voltage test was conducted to determine the threshold voltage/stress at which the space charge effect is initiated in the samples [9]. The amplitude of charge peaks on both the anode (red line) and the cathode (dark line) were recorded. As seen from Figure 3, the homocharges initiate when the applied voltage is about 3.2 kV (under 20 °C). It indicates that no obvious space charge should exist in oil-paper sample below this level, at least for a short period of voltage applied. Hence a suitable signal measured at 2 kV was selected as a calibration signal [10].

It is noteworthy that both the applied voltage and pulse voltage make a contribution to the output signal. The contribution from the pulse voltage is often neglected. Based on the study in paper [10], under the combination of an applied voltage of 10 kV and a pulse voltage of 100 V, the error introduced by neglecting the