Space Charge Accumulation Model of Multi-layer Oil-Paper Insulation under DC Electrical Field

Hao Jian¹,a, George Chen², Shuaiwei Liang³, Gong Lin¹, Yingkai Long¹, Huadong Pe¹, Shiling Zhangang¹

¹State Grid Chongqing Electric Power Co. Chongqing Electric Power Research Institute, Chongqing, China
²School of Electronics and Computer Science, University of Southampton, Southampton, UK.
³State Grid Zhejiang Electric Power Co. Ningbo Power Supply Company, Ningbo, China

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Abstract. Space charge could constrain and impact the electric strength of transformer oil-paper insulation. It is also the important factors that lead to oil paper insulation aging and insulation failure. For converter transformer oil paper insulation system, understanding the space charge accumulation behavior is particularly important for inhibit the space charge effect. In this paper, the space charge accumulation model of multi-layers oil-paper insulation was established based on the experiments. Results show that the polarity of the accumulation charge at the interface between oil gap and oil impregnated insulation pressboard is opposite with the other side of the oil immersed pressboard. Space charge accumulation behavior of the more complex insulation structure can be deduced according to the space charge accumulation model of oil impregnated insulation pressboard, two layers (oil + pressboard) and three layers (pressboard + oil + pressboard) oil-paper insulation.

Introduction

It is well known that space charge accumulation is easy to occur obviously in insulation materials under dc conditions [1]. The formation of space charge in insulation material can result in distortion of the electrical field distribution, i.e. enhanced electrical field in one region and reduced electrical field in the other [2-4]. The oil-paper insulation system is the ‘heart’ of a transformer, which is vital for the operation security of the transformer [5, 6]. Consequently, the understanding of space charge behavior of the oil-paper insulation system used in transformers is of significant interests from reliable operational viewpoint.

In this paper, the space charge dynamic characteristic of the multilayer structure of oil paper insulation mixed system was analyzed using the improved electro acoustic pulse system (PEA). The space charge accumulation model of multi-layers oil-paper insulation was established.

PEA Principle

The pulsed electroacoustic (PEA) technique opens a nondestructive way to make clear the charge behavior and understand physical processes taking place inside the dielectric materials, and makes it possible to select better materials and interfaces which can minimize the risks of partial discharge and electrical breakdown in HV applications.

The details of a PEA system can be found in literatures [7-9] and a schematic diagram is shown in Fig.1. Generally speaking, acoustic waves are produced at charge layers at both electrodes and internal charge when an electrical pulse is applied, and then, the acoustic signals are detected by a piezo-electric transducer. The electric signal obtained in the time domain represents the charge distribution [7-9]:

\[ V(t) = K \{ \sigma_1 + \sigma_2 \Delta T^* \rho(x=v_{sa} \Delta T^*) \} e_p \]  \hspace{1cm} (1)

Where \( \sigma_1 \) and \( \sigma_2 \) are the surface charges at the electrodes, \( v_{sa} \) is the sound velocity through the material, \( \Delta T \) is the width of the pulse, \( \rho(x) \) is the bulk charge and \( e_p \) is the amplitude of the pulse voltage.
Experiment

PEA experiments were performed on the oil impregnated insulation pressboard (Figure 1(a)), the mixed insulation with a combination of oil gap and oil impregnated insulation pressboard (Figure 1(b, c, d)). The thickness of the oil impregnated insulation pressboard is 200μm. The thickness of the mixed insulation with a combination of oil gap and oil impregnated insulation pressboard shown in Figure 1(b) is about 700μm (500μm for oil gap and 200μm for oil impregnated insulation pressboard). In Figure 1(c), oil gap is 500μm and oil impregnated insulation pressboard is 1000μm per layer. In Figure 1(d), oil gap is 270μm and oil impregnated insulation pressboard is 500μm per layer.

The oil impregnated insulation pressboard and mixed insulation with a combination of oil gap and oil impregnated insulation pressboard were stressed under the average dc electric field. The average dc electric field is 15 kV/mm in Figure 1(a)(b)(d), and Figure 1(c) is 12 kV/mm. Al electrode is cathode and Semi-conducting polymer is anode.
Results and Discussions

A. Oil Impregnated Pressboard

The space charge distribution of the pressboard impregnated with new oil under 15kV/mm is shown in Figure 3. The real line in the figure is the position of the electrode. Charge injection takes place quickly after the voltage was switched on. The amount of charges in the bulk of the samples increases with time initially. Homo-charge injection occurs at both electrodes and the positive peak moves towards the inner sample direction.

![Figure 3. Space charge distribution of the pressboard impregnated with new oil.](image)

B. “Oil+Pressboard” two layers mixed oil-paper insulation

Figure 4 is the space charge distribution of the new oil gap/oil impregnated pressboard (0.68% moisture content) under the average electric field 15kV/mm. The real line in the figure is the position of the electrode, the dot line in the figure is the interface between oil and pressboard. The space charge density at the cathode is gradually reduced with the voltage applied, which means the negative space charge injection and migration inside the sample. It can be clearly observed a large of negatives charges accumulated at the interface between the insulating oil and the pressboard. Its amount increases with voltage applied. A large of positive charges accumulated in the vicinity of the anode.

![Figure 4. Space charge accumulation behavior of the “oil+pressboard”.](image)

Figure 5 is the space charge accumulation behavior of three layers “oil immersed pressboard+oil gap+oil immersed pressboard”. It can be clearly observed that the charge polarity is opposite for the charge accumulated at the interface between oil and pressboard. The charge polarity is positive for the interface near to the cathode when the PB close to the cathode, while the charge polarity is negative on the other side of the oil gap.
Fig. 6 is the space charge accumulation behavior of four layers “oil gap+oil immersed pressboard+oil gap+oil immersed pressboard”. It can be clearly observed that the charge polarity is negative for the interface near to the cathode when the oil gap close to the cathode. The charge polarity is opposite on the other side of the PB or the oil gap.

Figure 5 and figure 6 show that the charge polarity for the charges accumulation at the interface between the oil immersed pressboard and oil gap is opposite to the charges on the other side of the oil immersed pressboard. If the oil gap without contacts with the electrodes, the charges at two sides of the oil gap is opposite polarity. If the oil gap contacts with the electrodes, the charges at two sides of the oil gap has the same polarity. The main insulation system of the transformer consists of cylindrical pressboard barriers in series with oil ducts and spacers, as shown in Fig. 1 [10]. Therefore, using this feature, the space charge accumulation model of multi-layers structure oil paper insulation mixed system can be deduced, as shown in Figure 8-10.
Figure 7. Section of main insulation in a core-type transformer.

(a) five layers
(b) six layers

Figure 8. Space charge accumulation model of five layer and six layer of oil-paper isolation.

(a) odd number layers (1, 3, 5, ....)
(b) even number layers (2, 4, 6, ....)

Figure 9. Space charge accumulation model of oil-paper isolation for odd number layers and even number layers (n is order number of the interface near to the cathode).
Conclusions

The polarity of the accumulation charge at the interface between oil gap and oil impregnated insulation pressboard is opposite with the other side of the oil immersed pressboard. Space charge accumulation behavior of the more complex insulation structure can be deduced according to the space charge accumulation model of oil impregnated insulation pressboard, two layers (oil + pressboard) and three layers (pressboard + oil + pressboard) oil-paper insulation.

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