Charge Transport Considering the Oil Flow Characteristics in zigzag oil-path

ZHANG Zhaoxiang[1], Yang Kai[1], YANG Fan[2], CHI Cheng[2], and HAN Longxiao[1]

[1] Chongqing University-University of Cincinnati Joint Co-op Institute, Chongqing University, Chongqing, China
[2] State Key Laboratory of Power Transmission Equipment & System Security and New Technology, Chongqing, China

***Abstract*—In order to study charge transport considering the oil flow characteristics of space charge, this paper has adapted an upstream finite element method to obtain the insulation state of zigzag oil-path. After the oil flow analysis of the converter transformer, these characteristics would be taken into consideration in analyzing charge distribution. Based on the experiments, with the oil velocity altering, the ion mobility would change as well. After calculations, it demonstrates that the result considering the oil flow is more complete. Meanwhile, this method can control the insulated margin.**

***Index Terms*—oil flow, space charge, transformer, upstream finite element.**

I. INTRODUCTION

The accumulation of space charge in the transformer would lead to the distortion of internal electric field and the reduction of the insulated performance. The researches on space charge by various institutions at home and abroad mainly focus on experimental research, such as PEA, TSDC and so on [1][2]. However, the oil velocity that has a great influence on the distribution of space charge is always ignored. Therefore, simulating the two-dimensional electric field distribution of the zigzag oil-path in the case of considering the space charge distribution under the oil flow effect of the converter transformer is vital for oil-paper insulation assessment and margin analysis. The upstream finite element method has been proposed in this paper to figure out the non-convergence problem of the final solution that is caused by the increase of the number of iterations in the calculation process. The method can be used to calculate the space charge distribution in the zigzag oil-path of the transformer model, so as to summarize the charge movement characteristics and electric field distribution law under the condition of polarity inversion. The research in this paper provides a valuable reference for the engineering preparation of oil-paper insulation materials and the optimization design of transformer insulation structures. In addition, a three-electrode experimental system has been constructed to obtain the nonlinear ion mobility under different oil flow velocity.

II. MATHEMATICAL MODEL

The equation of couplings is as follows:

$$\frac{\partial\left(\rho v_x c_p T\right)}{\partial x}+\frac{\partial\left(\rho v_y c_p T\right)}{\partial y}=S_T+\frac{\partial}{\partial x}\left(\lambda\frac{\partial T}{\partial x}\right)+\frac{1}{y}\frac{\partial}{\partial y}\left(\lambda \mathrm{y}\frac{\partial T}{\partial y}\right) \quad (1)$$

Where ρ is the density, v_x is the horizontal velocity and v_y is the vertical velocity, c_p is the heat capacity at constant pressure, S_T is the heat source, λ is the thermal conductivity and T is the temperature. The temperature can affect the oil flow velocity. According to the calculation, the distribution of the temperature and the oil flow velocity is shown in Fig.1, and the maximum oil velocity can reach 0.14m/s.

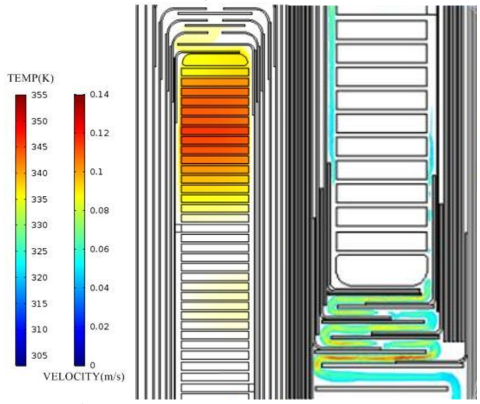

Fig.1. Distribution of the oil velocity and the temperature in the transformer.

Therefore, it is necessary to take the effect of the oil flow into consideration in studying the space charge in the zigzag oil-path.

The calculation of space charge is shown in Equations (2-3). Equation (4) reflects the mass transformation including diffusion, migration and convection [3].

Utilize (2) to calculate the electric field. According to the electric field, apply the upstream finite element method to calculate the total charge density of each point. Since carriers constantly migrate inside the medium after being emitted from the electrodes, the carrier densities of different nodes are always in the dynamic process.

$$\nabla^2\varphi(t)=\frac{-\rho(t)}{\varepsilon} \quad (2)$$

$$\frac{\partial C(t)}{\partial t}+\nabla j(t)=s(t) \quad (3)$$

$$j(t)=D\cdot\nabla C(t)+\mu(t)\cdot \mathrm{e}\cdot C(t)\cdot E(t)\text{-}\mathrm{C(t)}\cdot \mathrm{v(t)} \quad (4)$$

Where e is the elementary charge, ε is the dielectric constant, D is the diffusion coefficient, s is the recombination coefficient of four types of carriers, j is the current density, μ is the ion mobility, C is the concentration of the species and v is the oil velocity.

REFERENCES

[1] Keigo Matsubara, Satoru Ando, Hiroaki Miyake. Influence of Voltage Polarity on Space Charge Behavior in Multilayered Polyimide Films.

[2] Yin Pisheng (2017) Space Charge Measurement under Different Electrical Field Intensity and Temperature Gradient in Oil-paper insulation. Master thesis, Harbin University of Science and Technology.

[3] Liu, H., Liao, R., et al., “Calculation of Space Charge Density in Negative Corona Based on Finite-Element Iteration and Sound Pulse Method”, *IEEE Trans. Magn*., vol.54,no.3,2018.