Investigation on the Characteristics of Nano-modified Vegetable Insulating Oil

Xiyan Wei[1], Xinyu Xu[1], Jingsong Li[1, 2]*, *Member IEEE,* Guofeng Li[1], Nianfeng Zheng[2], and Zhongqing Wang[2]

1.School of Electrical Engineering, Dalian University of Technology, Dalian 116024, China
2. R & D, LUTE Electric Co., Ltd., Jining 272200, China
*Email: lijingsong2019@dlut.edu.cn

Keywords: Vegetable insulating oil, nano-doping modification, insulation characteristics, thermal performance

Abstract

Under the premise that the global is advocating low-carbon development, vegetable insulating oil has attracted widespread attention as a green and clean material. Compared with traditional mineral insulating oil, vegetable insulating oil have the disadvantages of poor fluidity and insufficient insulating performance. Nano-doping modification is a commonly used insulating oil modification method. The vegetable insulating oil models with different doping mass fractions of nano-silicon dioxide, nano-aluminium oxide, nano-silicon dioxide modified with silane coupling agent (KH550) and nano-aluminium oxide modified with silane coupling agent (KH550) were established using Materials Studio simulation software to explore the optimal conditions for nano-modified vegetable insulating oil. By analyzing the non-bonded interaction energy between nanoparticles and vegetable insulating oil molecules, the Mean Square Displacement (MSD) and the DC breakdown voltage of the modified system, it was explored whether the modified vegetable insulating oil could stably exist and the modified conditions with the best heat dissipation and insulation characteristics. Finally, the optimal conditions for nano-doping modified vegetable insulating oil were comprehensively analyzed, including the type and doping concentration of nanoparticles.

1 Introduction

Oil-immersed transformer's insulating oil mainly plays the dual role of heat dissipation and insulation [1]. Compared to traditional mineral fluids, vegetable insulating oil has the properties of long carbon chain, high freezing point, poor low temperature fluidity and poor heat dissipation due to large kinematic viscosity [2]. Improving the heat dissipation performance and insulation performance of insulating oil is of great significance to extend the service life of valuable equipment such as transformers.

2 Characterization of the performance of the modified system

2.1 Performance of heat dissipation

Mean Square Displacement (MSD) and the diffusion is used to describe the velocity of particle motion to reflect the diffusion flow of vegetable insulating oil molecules.

2.2 Characterization of insulation properties

a. Molecular electrostatic potential

Atoms in the negative electrostatic potential region tend to lose electrons. Atoms in regions with positive electrostatic potential tend to gain electrons. The electrostatic potential calculation is given as follows

$$V(r)=\frac{1}{4\pi\varepsilon_0}\left[\Sigma\frac{Z_A e}{|R_A - r|} - e\int\frac{\rho(r')\mathrm{d}r'}{|r' - r|}\right] \tag{1}$$

b. The relationship between electric field and molecular electrostatic potential

The influence of nanoparticles on the pace electric field is derived from Eq. (2).

$$Q_{ab(r=r_0)} = \frac{d^2}{dr_a dr_b} V(r) \quad (2)$$

Therefore, the electrostatic potential around these nanoparticles is used to reflect to the influence of the nanoparticles on the mixed system with the external electric field applied.

3 Establishment of nanoparticles models

Establish the nano-silicon dioxide (NSD) models, nano-aluminium oxide (NAO) models, the NSD modified with silane coupling agent (NSDS) model and nano-aluminium oxide modified with silane coupling agent (NAOS) model.

4 Analysis of stability

The energy of the four systems has a similar tendency to change with the doping mass fraction. There is a significant linear correlation between E_b and doped mass fraction.

5 Analysis of heat dissipation performance

The simulation temperature is set to 50 °C with NVT system. The heat dissipation capacity of all four systems is higher than that of pure oil under most conditions. Respectively, the diffusion coefficient is increased by 60.86%, 79.42%, 249.09% and 130.88% compared with pure oil. The diffusion coefficient of the mixed system is basically consistent with the trend of nanoparticle diffusion coefficient.

6 Analysis of insulation properties

Since the electrostatic energy between molecules changes significantly when the applied voltage is changed, the applied voltage when the electrostatic energy between molecules is abruptly changed is used as the DC breakdown voltage of the system, and the results are shown in Fig. 1.

Comparing the four modified systems, the performance of the NSD modified system is higher than the other systems, the doped mass fraction is 3.50%, and the DC breakdown voltage is 28 kV/mm.

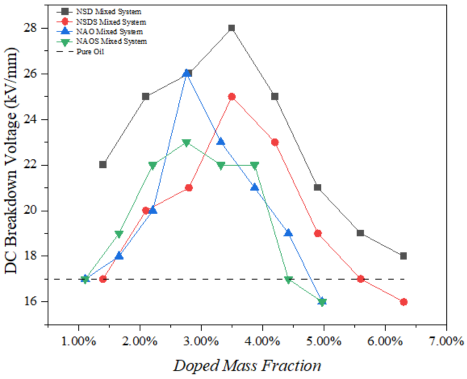

Fig. 1: Relationship between mass fraction of different nanoparticles and breakdown voltage.

The highest DC breakdown voltage of NAO mixed system，NSDS mixed system and NAOS mixed system appears at the doping mass fraction of 2.76%, 3.50%, 2.76%, and the corresponding breakdown voltage is 26 kV/mm, 25 kV /mm, and 23 kV/mm.

7 Conclusion

1) Under most conditions, the heat dissipation capacity of the doping system is ranked from high to low as follows: NAO mixed system, NAOS mixed system, NSDS mixed system and NSD mixed system.

2) The potential well in the mixed system generated by the electrostatic potential of nano particles attract charges in space to improve the insulation performance of mixed systems.

3) The vegetable insulating oil modified by doping nano aluminum oxide has the best modification effect after taking into account the improvement of the heat dissipation performance of insulation performance.

Reference

[1] T. V. Oommen, C. C. Claiborne, J. T. Mullen, “Biodegradable electrical insulation fluids”, *Proceedings of the Electrical/Electronics Insulation Conference,* 1997. Rosemont: *IEEE,* 2002.

[2] L. J. Yang, R. J. Liao, H. G Sun, “Investigation on properties and characteristics of oil-paper insulation in transformer during thermal degradation process”, *TRANSACTIONS OF CHINA ELECTROTECHNICAL SOCIETY,* vol. 24, no. 8, pp. 27-33 (2009)