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Effect of Permittivity on Breakdown characteristic of Transformer oil based Nanofluid

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ABSTRACT

The expansion of forthcoming high voltage network and smart grid has upraised the desires on reliability and performance of insulating materials used in electrical power system to deal with more vigorous and volatile operating conditions. Since from long decades, in conjunction with paper the mineral oil or synthetic oil is mainly being applied as an insulating medium in many of the high voltage apparatuses. Concomitant development of advanced new materials with high insulation and thermal gains will ensure a significant upgrade in the reliability of liquid-filled power equipment and hence the electrical network. These novel specific desires have brought the challenges to the transformer manufacturing companies to design the transformers with enhanced electrical and thermal properties. The transformer oil modified by nanotechnology has the potential to switch mineral oil base products in the marketplace due to its superiority in function and definite insulating and thermal properties. This paper discusses on the influence of nanoparticle's permittivity over the electrical performance of transformer oil.

Keywords: *Transformer oil,Nanofluid, Nanoparticle, COMSOL Multiphysics*

I. INTRODUCTION

The incessant growth of high voltage network [HVAC and HVDC] has provoked the researchers to direct their attention onto insulation system which can abide the intensifying levels of high voltage to make electrical transmission and distribution network more efficient and reliable. Power transformers, the most important electric apparatus for providing the reliable energy flow are critical and costly assets in electric power system beginning with the grid, transmission, and down to the plant. As an asset class, transformers constitute one of the largest investments in a utility's system or in an industrial complex [1]. The political and media attention has remarkably addressed the surrounding blackouts at various locations around the world was due to the potential consequences of transformer failure [2]. The functioning consistency and lifespan of transformers predominantly rely on characteristics and grade of dielectric material [3].

One of the potential issues with existing liquid-solid insulation system in power transformer that limits the compactness in design of a transformer is the incompatibility in permittivities between them. Because of inferior properties of liquid insulation, it was stressed much more than the solids at ac and/or impulse voltages which might results in explosive operation of transformers. [4]. Apart from the key functions such as protecting solid insulation, arc quenching media and dissipating heat, liquid insulations can also act as acoustic dampening media in transformers [5]. So, to survive with the increasing demand of high voltage rate with compact design for transformers, the advancement of transformer oil with promising dielectric and thermal characteristics is extensively required [3].

After the first conceptual introduction of nanotechnology, the Nano dielectrics gained the notable devotion in improving the service life of insulations. Nowadays in dielectric society, the term nanofluid becomes renowned and prominent term that brings the challenges and opportunities to the investigators over the past decades. The terms "nanofluids" and "Nano-liquids" are used mutually to refer to transformer oil/nanoparticle combination for insulating and cooling interest [3]. Nano structured particles dispersed homogeneously within the liquid with a few concentration forms the nanofluid. The term 'nanofluids – a two-phase mixture' was introduced by researchers at the Argonne National Laboratory containing a matrix liquid, and dispersed nanoparticles in suspension [6].

In recent years, nanofluids have concerned more attention because of their outstanding and exceptional characteristics [3]. This paper discusses about the influence of nanoparticle's permittivity over the electrical performance of transformer oil.

II. Nanofluid

The restricted electrical performance of the existing electrical insulation system has forced the electrical engineers to develop up-to-date electrical insulation that have fitness to withstand high voltage levels. The evidences show that the Nanofluids produced by dispersing the nanostructured particles have distinct dielectric characteristics as compared to the conventional liquid insulation. A lot of research work has been initiated to analyse the potential of nanofluid for ultrahigh voltage AC and DC power transmission system.

III. Synthesis and Preparation of Transformer oil based Nanofluid

A. Nanoparticles

One of the most significant concerns in preparation of the nanofluid is the selection of the nanoparticle. With the aim of enhancing the dielectric properties of liquid insulations, several nanoparticle additives have been examined till date [11-41]. These additives can be categorized according to conductivity and permittivity into three major groups:

- Conducting Nanoparticles: Fe_3O_4, Fe_2O_3, ZnO, SiC
- Semiconducting Nanoparticles: TiO_2, CuO, Cu_2O, CdS
- Insulating Nanoparticles: Al_2O_3, SiO_2, BN

B. Method of Dispersion

One of the preliminary tasks is the preparation of the sample to make it ready for the experimentation once the nanoparticle is selected. Ideally, the methods of dispersion can be classified as one-step or two-step methods.

One step Method: In this technique, the nanoparticles are dispersed traditionally into a host fluid to minimize the chances of agglomeration with enhanced stability [3, 11]. One of the key weaknesses of this procedure is the formation of clusters during mass production. The difficulty of grouping can be squeezed by using evaporation-condensation method.

Two-step Method: The extensively used technique for formulating the nanofluids is two-step method. In first step of formulation, the particles, tubes, fibres or any other non-metals of nano scale are primarily fashioned as dry powders via physical and chemical processes. In second step, these powders will be spread in the matrix fluid by magnetic stirrer or ultrasonic bath to get stable dispersion. The inert gas condensation process is used for mass production of nanoparticles which makes this technique more expensive to generate nanofluids in a big scale.

III. Development of Model

A. COMSOL Multiphysics

COMSOL Multiphysics originates from PDE Toolbox of MATLAB.COMSOL Multiphysics software is universally adopted computer aid engineering software which works on finite element analysis.It has a large set of functions for analyses and solution. This software includes electrostatic module, heat transfer module, electromagnetic module, plasma module, chemical engineering module and many more. It also has many pre- and post- processing functions, which provides a friendly working environment for solving both complex scientific problems and large-scale engineering problems. The other advantage of COMSOL Multiphysics is that it can solve coupled multiphysics phenomena simultaneously. Owing to these advantages, it is referred to as the first class software package for any number of coupled multiphysics fields [12].

B. Experimental Analysis

Figure 1 shows the model developed in COMSOL Multiphysics software to study the influence of nanoparticle's permittivity over the electrical performance of transformer oil.

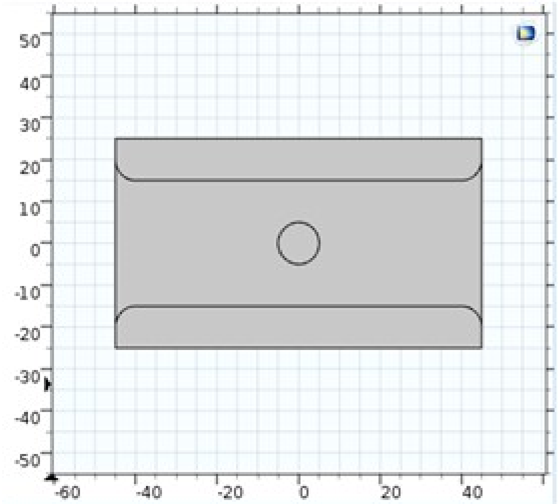

Fig. 1 Modeling of Transformer oil with Nanoparticle using COMSOL Multiphysics

Table 1 shows the specifications of transformer oil used for the simulation.

TABLE I. SPECIFICATIONS OF TRANSFORMER OIL [13]

Property	Specification
Density at 20°C	875 kg/m^3
Flash point	140°C
Kinematic Viscosity at 40°C	9.4 mm^2/s
Pour point	-57°C
Neutralization Value	<0.01 mg KOH/g
Dissipation factor at 90°C	0.002
Relative Permittivity	2

IV. RESULTS & DISCUSSION

A. Nanoparticle Charging Mechanism

As shown in figure 2, the electric field distribution inside the transformer oil gets deformed when nanoparticle of different permittivity values (usually higher than the permittivity of base liquid) is dispersed in the base oil [13].

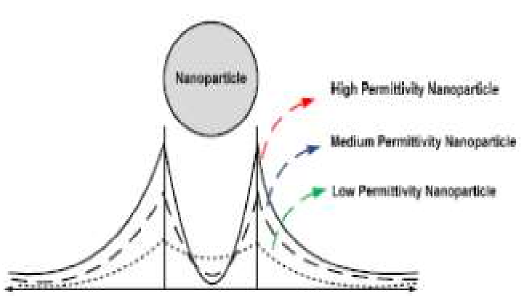

Fig. 2 Effect of Nanoparticle Permittivity on Electric Field

It can be observed that, the electric field strength at the surface of nanoparticle i.e. nanoparticle-oil interface is maximum. The value of electric field intensity would increase with increase in dielectric constant of nanoparticle. This is validated using COMSOL Multiphysics.

B. Simulation using COMSOL Multiphysics

The relative permittivities of nanoparticle considered for the simulation are 5.7, 10.9 and 43.3 [13].

Figures 3 to 6shows the electric field distribution with and without nanoparticle inside the transformer oil.

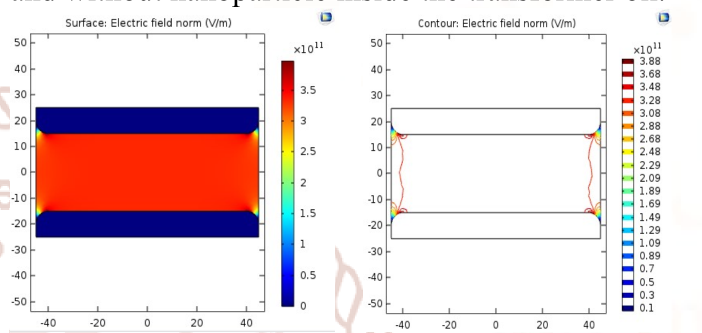

Fig. 3 Electric Field distribution in transformer oil without Nanoparticle

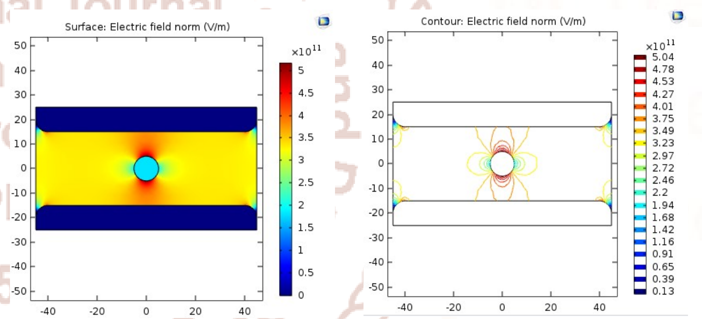

Fig. 4 Electric Field distribution in transformer oil based nanofluid (Relative permittivity of Nanoparticle is 5.7)

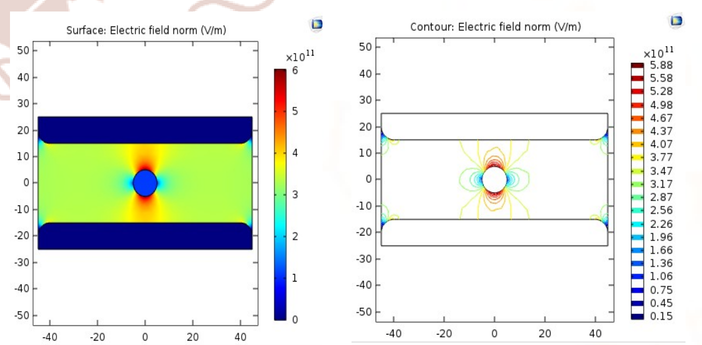

Fig. 5 Electric Field distribution in transformer oil based nanofluid (Relative permittivity of Nanoparticle is 10.9)

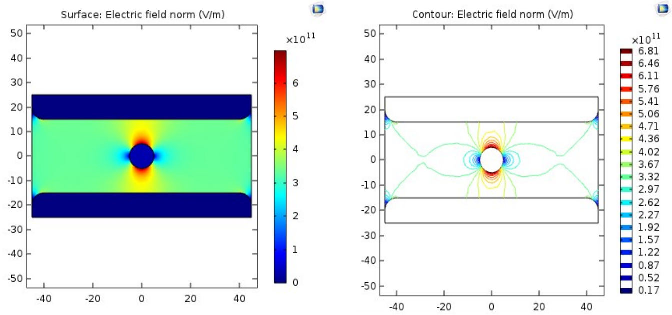

Fig. 6 Electric Field distribution in transformer oil based nanofluid (Relative permittivity of Nanoparticle is 43.3)

According to the law of electrostatics, the ionization takes place in a given dielectric when the electrical potential is applied between two electrodes. Because of the ionization process the electrons and positive ions are released in the insulation. The electrical force F = qE, where, F is the force in Newton, q is the charge value in Coulomb and E is the electric field strength in V/m is exerted between negative and positive charges [13]. In case of nanofluids the electrical force is exerted on the nanoparticle dispersed in mineral oil. The electrons produced due to ionization of liquid are attracted towards the nanoparticles and leave the positive ion behind them because of their heavy weight as compared to free electrons. These attracted electrons are distributed over the nanoparticle surface.

It has been claimed that the dispersion of nanoparticles influences the ionization process inside the liquid and hence the breakdown physics of the oil [14, 15].The mechanism of augmenting the electrical strength of transformer oil based nanofluid with high relative permittivity of nanoparticles can be clarified by trapping properties of interfacial surface between host oil and nanoparticles.

The electrons produced at high electric stress are largely responsible for ionization and hence breakdown in oil. These electrons gain the sufficient kinetic energy from the applied electrical stress and accelerated very fast within the liquid. The ionization efficiency can be reduced by reducing the force exerted between the electrons and neutral atoms of the base oil. This could be achieved by enhancing the relative permittivity of the base oil.

The augmentation in dielectric constant can be brought up by dispersing the nanoparticles of high relative permittivity. The dispersed nanoparticles with high dielectric constant have a tendency to trap and de-trap the electrons accelerated at high speed in the ionization region. The trapping and de-trapping process will cause a reduction in transformation of energy and velocity of the electrons moving in the base oil. Because of reduction in the speed of the electrons the ionization efficiency will reduce which delay the breakdown until the electrical stress is increased.

On contrary, the nanoparticles with relatively low dielectric constant do not have property to trap the electrons moving at a high speed. Hence, the exerted force from the external magnetic field doesn't have the ability for electron attraction and hence the mechanism of trapping and de-trapping will not justify the breakdown mechanism in nanofluid with low relative permittivity. The breakdown mechanism for such type of fluid can be explained based on the polarization mechanism [15].

V. CONCLUSION

It has been conclude that nanoparticles with high relative permittivities tend to positively charged when exposed to an external electric field, but the nanoparticles with low relative permittivities tends to be polarized and negatively charged. The electrons produced at high electric stress are largely responsible for the ionization and hence breakdown in oil. These high speed electrons will be trapped and de-trapped by the interface between oil and nanoparticle. Due to this trapping and de-trapping process, the energy transfer and velocity of these electrons will reduce. The fast electrons will become slower ones by this process of trapping and de-trapping in the interface and breakdown will occur at high voltages than that of base oil.

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