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Enhancement of Electrical Breakdown Voltage Properties of Transformer Oil Using Nano Particles

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ABSTRACT

Transformer oil is widely used in electric transformers serving the dual functions as insulating medium and cooling material. However, safety and stability of power system is interrupted due to the operation failure of electric transformers in certain case. Therefore, efforts should be focused on improving the property of transformer oil for the stable operation of insulating system. The purpose of this work is to obtain a new type of nano-modified transformer oil with improved dielectric and thermal properties. In this work, ceramic nano particles like Zro_2 and Ceo_2 are chosen because of their electrical insulating property and higher relative permittivity and good thermal characteristics. The breakdown voltage property of the prepared nano-fluid is measured for different samples. Finally, the optimal content (%wt) of nanoparticles are chosen based on the measured nanofluids thermal and electrical properties.

Keywords : Electrical Breakdown Voltage, Transformer, Nano Particles, Mineral Oil, X-Ray Powder Diffraction

I. INTRODUCTION

Electric transformers form a critical part in power system. The transformer operation failure can severely hinder the stability of power system. The oil applied in transformers is highly refined mineral oil which performs dual functions of insulating and cooling materials. This oil is customarily a highly refined mineral oil (MO) and employed in transformers as a cool and because of its high stability at elevated temperatures and excellent electrical insulating properties.

Insulation is essential as the winding inside has to be separated to prevent voltage from leaking or shorting. As the thermal conductivity of MO is low, it is not uncommon to experience thermally driven failures from instantaneous overload. Therefore, to achieve significant extension in transformer lifetime and increment in load/cooling capacity, it is pertinent to increase the insulation break down strength and thermal conductivity of the transformer oil.

Suspensions prepared by dispersing nanometre-sized solid particles, rods or tubes in the base fluids are called nanofluid. These are found to possess enhanced physical properties such as thermal conductivity, thermal diffusivity and convective heat transfer coefficients compared to those of base fluids. In many cases the viscosity of the nanofluidsis also considerably reduced. The presence of nanoparticles with large surface are cannot only be expected to enhance the heat-transfer, but also to increase the stability of the suspension.

Moreover, the size and the weight of the transformer and the current density of the transformer windings depend on the amount of oil and the rate of heat transfer. Thus, any work related to transformer oil must take into account both its dielectric and thermal characteristics.

The base concept of dispersing solid particles in fluid to enhance the thermal conductivity is not new. It can be traced back to 1873, when Maxwell presented a theoretical basis for predicting the effective thermal conductivity of liquid/solid suspension [3]. Solid particles are added because they conduct heat much better than liquids. For more than 100 years, scientists and engineers have made great efforts to enhance the inherently poor thermal conductivity of traditional heat transfer liquids, such as water, oil and ethylene glycol [1]. Numerous theoretical and experimental studies of the effective thermal conductivity of suspensions that contain solid particles have been conducted. However, all of the studies have been confined to millimeter- or micrometer-size particles. The major problem with the use of millimeter- or micrometer-size particles is the rapid settling of the particles in fluids [1]. The large size particles and the difficulty in production of small particles are the limiting factors for liquid/solid suspension to be investigated for practical applications.

Nanotechnology helps to overcome these problems by stably suspending in fluids nanometer-sized particles instead of millimeter- or micrometer- sized particles [2]. An important step in the development of nanoscience was the assessment of the nano-meter size of molecules in the beginning of the 20th century. The concept of nanotechnology was introduced in the famous lecture of Richard Feynman “There is enough space at the bottom” in 1959 [9]. The invention of the scanning tunneling microscope triggered the growth of nanotechnology in the 1980’s. In 1995, Stephen Choi from Argonne National Laboratory presented at the annual winter meeting of the American Society of Mechanical Engineers “the remarkable possibility of increasing the convection heat transfer coefficients by using high-conductivity nanofluids instead of increasing pump power” [2]. After that, Choi and Eastman have tried to suspend various metal and metal oxides nanoparticles in several different fluids. The results showed that nanoparticles stay suspended longer than larger particles and nanofluids exhibit excellent thermal properties and cooling capacity Since then numerous research groups have investigated thermal conductivity, convective heat transfer and breakdown strength of nanofluids. The nanofluid technology is still in its early phase and scientists are working now to help using nanofluids as a tool to solve technological problems of industry.

Nanofluids have some potential features which make them special for various engineering applications. A large number of research groups focused on the drastically enhanced thermal properties of nanofluids, especially the thermal conductivity and convective heat transfer.

II. NANOSCIENCE AND SYNTHESIS OF NANOFLUIDS

Synthesis Procedure

A sol is a stable dispersion of colloidal particles or polymers in a solvent. The particles may be amorphous or crystalline. A gel consists of a three-dimensional continuous network, which encloses a liquid phase. In a colloidal gel, the network is built from agglomeration of colloidal particles. In a polymer gel the particles have a polymeric sub-structure made by aggregates of sub-colloidal particles. Generally, the sol particles may interact by van der Waals forces or hydrogen bonds. A gel may also be formed from linking polymer chains. In most gel systems used for materials synthesis, the interactions are of a covalent nature and the gel process is irreversible. The gelation process may be reversible if other interactions are involved.

The idea behind sol-gel synthesis is to "dissolve" the compound in a liquid in order to bring it back as a solid in a controlled manner.

Multi component compounds may be prepared with a controlled stoichiometry by mixing sols of different compounds. For the nanofluid preparation in this study, the two-step method is used. The nanofluid dispersion process is shown in Fig.2.4. All the preparations were done under a fume-hood. The preparation of nanofluids starts with the weighing of nanoparticles in a glove box. Then the nanoparticles are mixed with mineral oil and surfactant if necessary. After this, the mixture is stirred with a magnetic stir at ambient temperature for 30 minutes. Finally the mixture is put under ultra-sonication for 8 hours to get a well dispersed nanofluid. The magnetic stirring helps to disperse the nano powders evenly in the base fluid, but the energy is not enough to break any agglomeration of nanoparticles. So an ultrasonic bath is used to break the agglomerations of nanoparticles.

III. EXPERIMENTAL

Dielectric strength of transformer oil is also known as breakdown voltage of transformer oil **or** BDV of transformer oil. Break down voltage is measured by observing at what voltage, sparking strands between two electrodes immerged in the oil, separated by specific gap. Low value of BDV indicates presence of moisture content and conducting substances in the oil. For measuring BDV of transformer oil, portable BDV measuring kit is generally available. In this kit, oil is kept in a pot in which one pair of electrodes are fixed with a gap of 2.5 mm between them.

Now slowly rising voltage is applied between the electrodes. Rate of rise of voltage is generally controlled at 2 KV/s and observe the voltage at which sparking starts between the electrodes. That means at which voltage dielectric strength of transformer oil between the electrodes has been broken down. Generally this measurement is taken 3 to 6 times in same sample of oil and the average value of these reading is taken. BDV is important and popular test of transformer oil, as it is primary indication of health of oil and it can be easily carried out at site.

IV. RESULTS AND CONCLUSION

SEM Characterization

The scanning electron microscope (SEM) is one of the most widely used instruments in materials research laboratories and is common in various forms in fabrication plants. Scanning electron microscopy is central to micro structural analysis and therefore important to any investigation relating to the processing, properties, and behavior of materials that involves their microstructure. The SEM provides information relating to topographical features, morphology, phase distribution, compositional differences, crystal structure, crystal orientation, and the presence and location of electrical defects. The SEM is also capable of determining elemental composition of microvolumes with the addition of an x-ray or electron spectrometer and phase identification through analysis of electron diffraction patterns. The SEM images of synthesized nano-materials ceria and zirconium at different resolutions are shown in the figures 1 and 2.

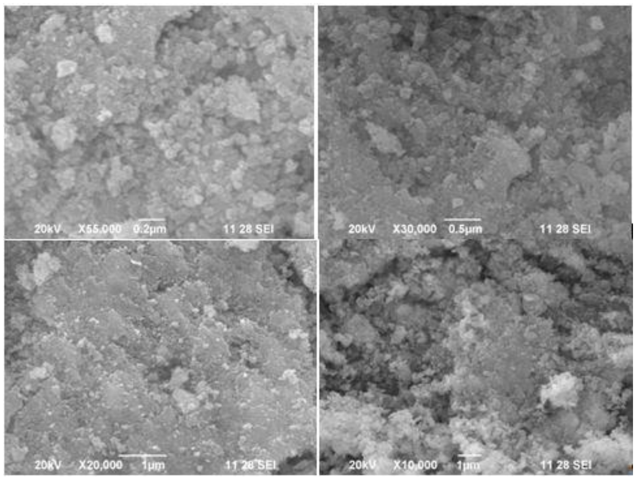

Figure 1. SEM images of Ceria nonmaterial

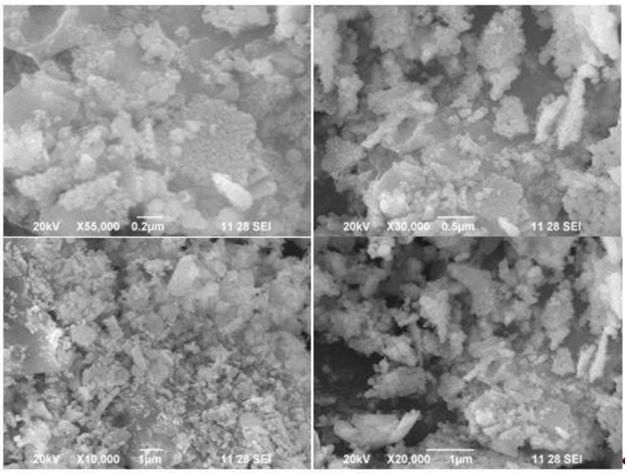

Figure 2. SEM images of Zirconium nonmaterial.

XRD Characterization

X-ray powder diffraction is most widely used for the identification of unknown crystalline materials (e.g. minerals, inorganic compounds). X-ray powder diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The analyzed material is finely ground, homogenized, and average bulk composition is determined, other applications include characterization of crystalline materials identification of fine-grained minerals such as clays and mixed layer clays that are difficult to determine optically Determination of unit cell dimension measurement of sample purity. The XRD characterization of synthesized ceria and zirconium are shown in the figures 3 and 4. The particle can be determined by using Scherrer formula $\boldsymbol{L} = \frac{\mathbf{0.94}\ \boldsymbol{\lambda}}{\boldsymbol{B}\ \mathbf{cos}\ \theta}$. From the intensity curves of ceria, the value of B is determined as 0.9deg or 0.01571 rad and θ = 14.4302 deg. Substituting the values, the particle size of ceria is determined as 16.55nm.

Similarly from the intensity curves of zirconium, the value of B is determined as 1.5 deg or 0.0261 rad and θ = 15.25 deg. Substituting the values, the particle size of zirconia is determined as 26.2233nm.

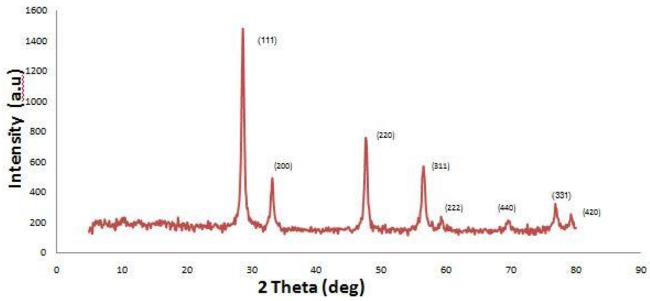

Figure 3. XRD of Ceria nanoparticles

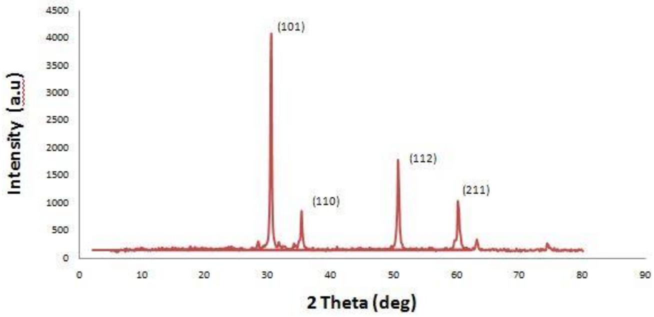

Figure 4. XRD of Zirconium nanoparticles

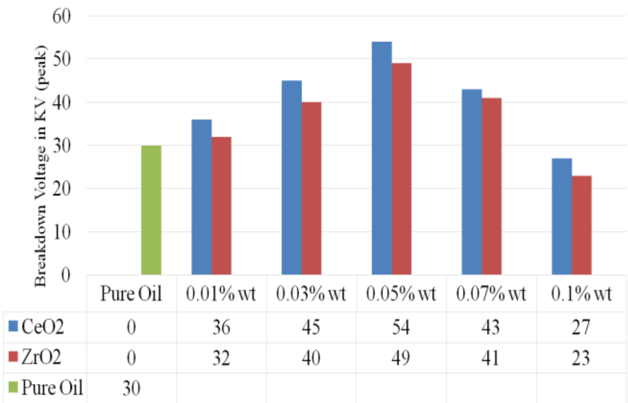

Figure 5. Break Down voltages of transformer oil filled with nano-particles

V. CONCLUSION

Oil based nanofluids are considered to be better choice to replace conventional transformer oil because nanofluids exhibit improvement in both electrical and thermal properties. In this work, new colloidal solutions comprising of $CeO_2$and ZrO_2nanofillers in Transformer oil were prepared and their dielectric and thermal properties were studied. The main contribution of this work is the achievement of enhanced breakdown strength of mineral oil due to the addition of nanoparticles. A possible explanation for this enhancement: the adsorption of moisture and acid on the surface of nanoparticles. The enhancement in the breakdown Voltage values were found to be higher in CeO_2nanofluids when compared to ZrO2 nanofluids. This may be due to the higher relative permittivity of CeO_2nanofillers.

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