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Dielectric breakdown strength of magnetic nanofluid based on insulation oil after impulse test

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ABSTRACT

In this study, the dielectric breakdown strength of magnetic nanofluids based on transformer mineral oil for use in power systems is reviewed. Nano oil samples are obtained from dispersion of the magnetic nanofluid within uninhibited transformer mineral oil NYTRO LIBRA as the base fluid. AC dielectric breakdown voltage measurement was carried out according to IEC 60156 standard and the lightning impulse breakdown voltage was obtained by using the sphere–sphere electrodes in an experimental setup for nano oil in volume concentration of 0.1–0.6%. Results indicate improved AC and lightning impulse breakdown voltage of nano oil compared to the base oil. AC test was performed again after applying impulse current and result showed that nano oil unlike the base oil retains its dielectric properties. Increase the dielectric strength of the nano oil is mainly due to dielectric and magnetic properties of Fe_3O_4 nanoparticles that act as free electrons snapper, and reduce the rate of free electrons in the ionization process.

1. Introduction

Since Transformers are considered as one of the most expensive and the most important parts of the network of power generation and distribution which their optimum performance is dependent on many factors. Transformer mineral oil is one of the most vital parts of the transformers, which is responsible for two major tasks: as a cooling fluid, it transfers to the outside heat generated in the active parts of the transformer and as insulating material, prevents passing electricity to outside of the electrical components. Transformer oil has low thermal conductivity [1], which causes limitations in performance of transformers, because conditions such as excessive increase in temperature, and overloading causes an excessive local rise in temperature in areas of oil (hotspot), so the efficiency of the transformer oil is limited. In recent decades, the use of dispersion of the nanoparticles within the fluid to improve thermal properties has attracted the attention of scientists. This idea about transformer oil would be useful if nanoparticles have no negative impacts on the electrical and dielectric characteristics. In this study, the dielectric breakdown strength of magnetic nanofluids based on transformer mineral oil for use in power systems is reviewed.

1.1. Breakdown mechanism within insulating medium

One of the most important insulating components of oil is breakdown voltage. Breakdown voltage of oil is voltage which oil has not been able to resist the passage of electricity, and the electricity will pass through it [2]. Molecular ionization of insulating medium which depends on electric field is the key mechanism for breakdown in transformer oil [3]. Through the ionization, oil molecules turn into fast electrons and slow positive ions, fast electrons are swept away to the positive electrode from the ionization zone because an area of net positive space charge quickly develops. Electric field distribution in the oil is modified during ionization such that the electric field at the ahead of the positive charge in the oil increases whereas at the positive electrode decreases. These electrodynamics processes cause a developing ionizing electric field wave that vaporize transformer oil and create a gas phase due to temperature raise. The result of oil vaporization is the formation of the low density streamer channel in oil [4]. Streamers are structures having low-density which are formed in parts of the oil in which electric field gradient is high.

1.2. Ferrofluid in transformers

In recent years, many studies on the impact of nanoparticles on the electrical and thermal characteristics of the transformer oil have been done. Segal and colleagues [5] showed that the addition

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of magnetic nanoparticles to transformer oil has not had bad influence on insulation resistance of the oil and its AC breakdown voltage approximately is equal to the base oil (oil without nanoparticles). Their results also showed that the impulse breakdown voltage of magnetic nanofluids based on transformer oil (called ferrofluid) for needle-sphere electrodes, when the needle is positive polarity, 50% improved compared to the base oil. Kopcansky [6] showed that the DC dielectric breakdown voltage of magnetic nanofluids produced based on transformer oil with an average diameter of nanoparticles 8.6 nm and volume fraction of 0.01 is improved compared to transformer oil. Kudelcik [7] dispersed magnetic nanoparticles with mean diameter of 10.6 nm in ITO 100 inhibited transformer oil, and showed that the humidity effects will be magnified within base oil without nanoparticles. In other words nano oil strengthens more than based oil against the breakdown in the presence of humidity. They also examined the change of breakdown voltage versus varying the gap distance between electrodes and aimed that increasing the distance between electrodes ascends the breakdown voltage. According to their results it was found that the optimum volume concentration of nanoparticles is approximately equal to 0.2% which leads to best results.

Because the magnetic field within the transformer, many studies have been done on the interaction of magnetic nanoparticles and field. Ferrofluids are temperature – sensitive and when is used in a power transformer, thermal convection occurs by two ways: (1) due to the temperature gradient between the active part (core) and the outer surface of the transformer and (2) because of the temperature sensitive nature of the ferrofluid, magnetically induced convection take places. In the central region of transformer due to the high temperature of core, insulating oil is weakly magnetized and in the outer surface region fluid is strongly magnetized (because of the low temperature) and because of this field gradient, magnetically induced convection takes place [8]. Segal [9] by considering the cooling efficiency of ferrofluid indicated that for magnetic nano oils with saturation magnetization lower than 3.9 emu/gr, the cooling efficiency improves comparing to the base oil. Lee et al. [9] by applying a magnetic field to the oil under breakdown test concluded for the state of applying magnetic field of oil breakdown voltage is 30% more than a state in which there is no field. They also demonstrated that magnetic field reduces agglomeration of nanoparticles and causes better dispersion of the nanoparticles within the oil. One of the main reasons for the breakdown is the aggregation or clumping of nanoparticles. Surfactants are organic materials which cover the surface of the nanoparticles and lead to better dispersion within oil and prevent accumulation of nanoparticles [10]. Magnetic nanofluids based on transformer oil have better stability in the presence of a magnetic field, and because of the use of surfactants, they have less sedimentation than a state in which there is no field [11].

2. Materials and methods

2.1. Preparation of nano oil

In order to prepare transformer oil-based nanofluids, the uninhibited transformer oil NYTRO LIBRA and the magnetic nanofluid developed by Ferro Tech Co., EFH-1, are mixed to produce our transformer oil-based nanofluid. EFH-1 originally contains 5% Fe_3O_4 nanoparticles, 15% surfactant and 80% light hydrocarbon oil [12].

Nanofluid was dispersed within the base oil at volume concentrations of 0.1–0.6%, using ultrasonic device BANDELIN SONOPULS HD 2200 (200 w, 20 kHz) (20 min sonication with power of 80% for each sample). Sonication lead to produce bubbles in the samples which is destructive for the breakdown voltage tests, so after sample preparation in a volume of 500 cc, they are placed in the sealed containers, and at least 10 h, samples were relaxed to be evacuated bubbles in it, and they are ready to test.

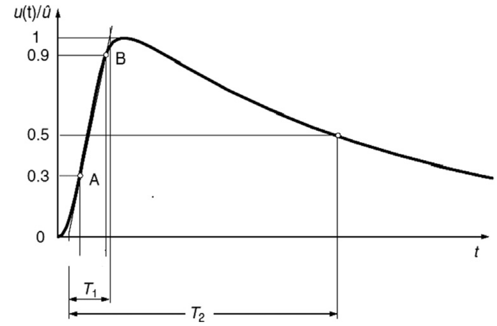

Fig. 1. Standard impulse full wave.

2.2. Measuring the dielectric breakdown strength

In this study, for each sample, first the AC breakdown voltage measurement according to IEC 60156 was carried out using portable Breakdown Analyzer BA 100 (produced by "HIGH VOLTAGE technology") and then impulse breakdown voltage was measured using an experimental set up. After this procedure, the AC breakdown voltage was measured again (same as before) to study the dielectric strength of ferrofluids against the lightning impulse breakdown voltage. In this way for impulse breakdown voltage measurement, standard impulse waveform 1.2 by 50 µs was used. As shown in Fig. 1, in the standard impulse wave, voltage from zero to the peak value has increased in the duration by 1.2 µs, and to 50% of the maximum amplitude in the duration by 50 µs, has decreased [13].

To generate impulse voltage, an impulse wave generator (PRODUCT of the HIGH VOLT COMPANY) was used and oil test under impulse conditions using an experimental setup shown in Fig. 2 was performed.

The impulse generator consisted of capacitors that they are charged in parallel mode by loading resistance, and by sphere gaps are disposed in series mode (theory of Marx generator). This generator was set to generate impulse full wave up to the peak voltage amplitude of 400 KV. Capacitors on the sphere–sphere electrodes will be discharged. The electrodes with the gap distance of 2.5 mm are placed in the test vessel and immersed in oil (Fig. 3).

The starting voltage was set at about 80% of the expected voltage to breakdown and stepped up in 5–10% increments. Five impulses were applied at each level with at least five minute of relaxation time between shots. In 2 min rest period, with stirring,

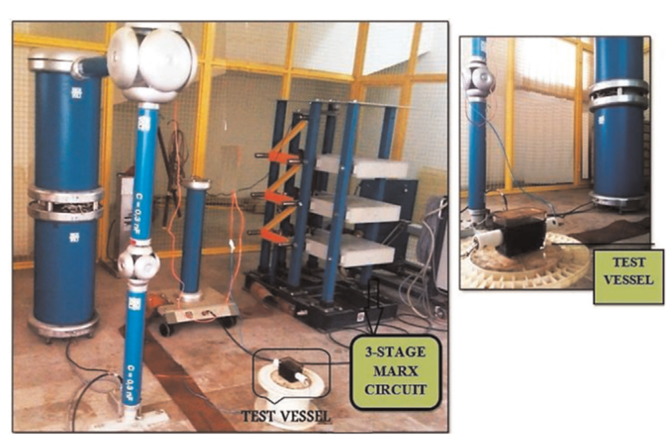

Fig. 2. Experimental setup.