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Effect of magnetic nanoparticles on the lightning impulse breakdown voltage of transformer oil

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ABSTRACT

In this study, the lightning impulse breakdown voltage of magnetic nanofluids based on transformer mineral oil for use in power systems was reviewed. Magnetic nanofluids are obtained from dispersion of the magnetic nanoparticles (Fe_3O_4) within transformer oil, as the base fluid. The Fe_3O_4nanoparticles, using a coprecipitation method, were synthesized, coated with a surfactant, and dispersed using an ultrasonic processor, within the uninhibited transformer mineral oil NYTRO LIBRA. The lightning impulse breakdown voltage was obtained using sphere–sphere electrodes in an experimental setup for nano-oil, in volume concentration of 0.1–0.6%. Results indicate improved lightning impulse breakdown voltage under optimal conditions. Increase in the lightning impulse breakdown voltage of the nano-oil is mainly due to the dielectric and magnetic properties of Fe_3O_4 nanoparticles, acting as free electrons snapper, and reduce the rate of free electrons production in the ionization process.

1. Introduction

Since transformers are one of the most expensive and important parts of the power generation and distribution network, their optimum performance is dependent on many factors. Transformer mineral oil is a very essential component of transformers, and is responsible for two major tasks: (1) as a cooling fluid, it transfers to the outside heat generated in the active parts of the transformer and (2) as an insulating material; it prevents the passage of electricity to the outside of the electrical components. Transformer oil has low thermal conductivity, which causes limitations in the performance of transformers, because conditions such as excessive increase in temperature, and overloading causes an excessive local rise in temperature in areas with oil (hotspot), so the efficiency of the transformer oil is limited. In recent decades, the use of nanoparticles dispersion within the fluid to enhance thermal properties has attracted the attention of scientists. This idea about transformer oil would be useful, if nanoparticles have no negative impact on the electrical and dielectric characteristics.

1.1. Breakdown mechanism within insulating medium

One of the most important insulating components of oil is breakdown voltage. According to Fig. 1, the breakdown voltage of oil is the voltage at which it fails to resist the passage of electricity [1].

Electric field dependent molecular ionization is the key mechanism for streamer development in transformer oil [2]. By ionizing oil molecules into slow positive ions and fast electrons, an area of net positive space charge quickly develops because the highly mobile electrons are swept away to the positive electrode from the ionization zone, leaving behind the low mobility positive ions. The net homocharge modifies the electric field distribution in the oil, such that the electric field at the positive electrode decreases while the electric field ahead of the positive charge in the oil increases. The new field distribution causes ionization to occur further away from the positive electrode, which results in further modification of the electric field distribution. The ultimate result of these electrodynamic processes is the development of an ionizing electric field wave, which is a moving dissipative source that raises the temperature to vaporize transformer oil and create a gas phase. This oil vaporization leads to the formation of the low density streamer channel in transformer oil [3]. Streamers are structures having low-density which are formed in parts of the oil with high electric field gradient.

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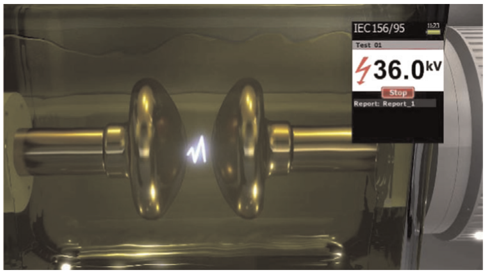

Fig. 1. Breakdown within oil in the distance between sphere–sphere electrodes.

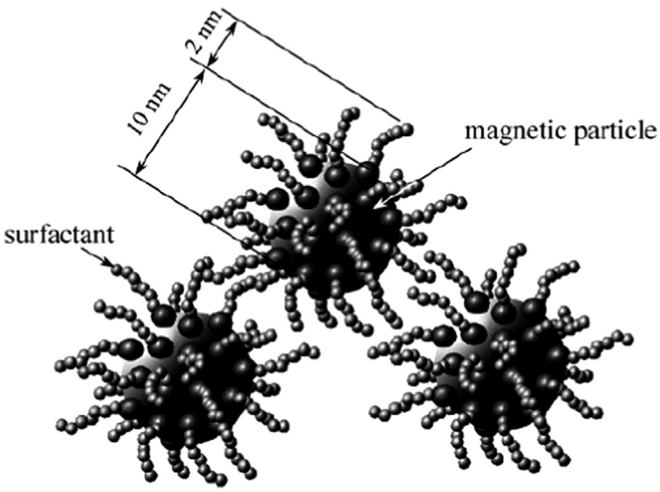

Fig. 2. Schematic view of the coated magnetic nanoparticles in a ferrofluid.

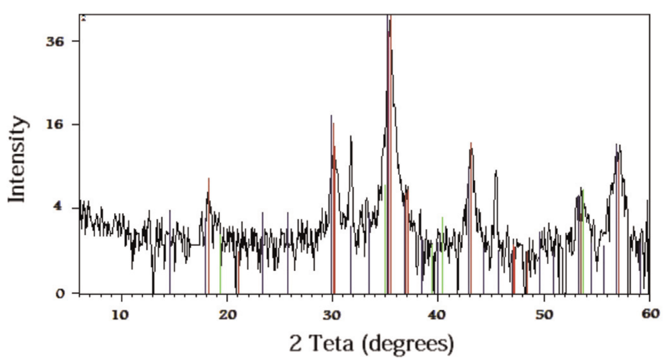

Fig. 3. XRD image of the synthesized (Fe_3O_4) nanoparticles.

1.2. Ferrofluid in transformers

In recent years, many studies have been done on the impact of nanoparticles on the electrical and thermal characteristics of transformer oil. Segal et al. [4] showed that the addition of magnetic nanoparticles to transformer oil did not negatively affect the insulation resistance of the oil and its AC breakdown voltage was approximately equal to the base oil (oil without nanoparticles). Their results also show that the impulse breakdown voltage of magnetic nanofluids based on transformer oil (called ferrofluid) for needle-sphere electrodes, when the needle is in positive polarity, is 50% improved compared to the base oil. Kapcansky et al. [5] showed that the DC dielectric breakdown voltage of magnetic nanofluids produced by transformer oil with nanoparticles of an average diameter of 8.6 nm and volume fraction of 0.01 improved, compared to transformer oil. Kudelcik et al. [6] dispersed magnetic nanoparticles with mean diameter of 10.6 nm in ITO 100 inhibited transformer oil, and showed that the humidity effects were

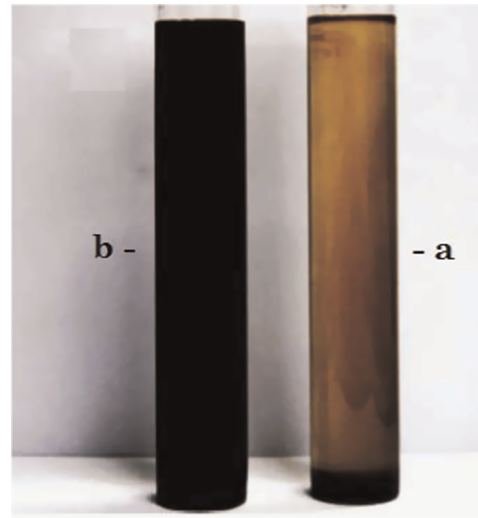

Fig. 4. Nano oil (a) without surface coating by surfactant and (b) with surface coating by surfactant.

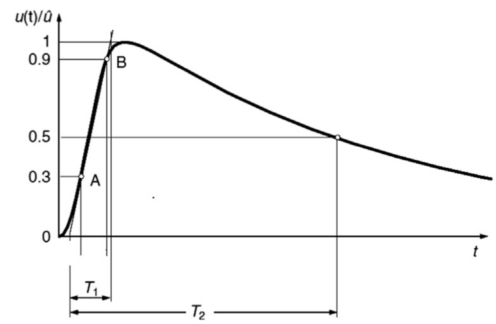

Fig. 5. Standard impulse full wave.

magnified within the base oil without nanoparticles. In other words, nano-oil strengthens more than base oil against breakdown, in the presence of humidity. They also examined the change of breakdown voltage versus varying the gap distance between electrodes and aimed at increasing the distance between electrodes as the breakdown voltage increased. According to their results, it was found that the optimum volume concentration of nanoparticles is approximately equal to 0.2%, which leads to the best results.

Because of the magnetic field within the transformer, many studies have been done on the interaction of magnetic nanoparticles and the field. Ferrofluids are temperature-sensitive and when 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 the transformer, the insulating fluid is weakly magnetized due to the high core temperature and in the outer surface region, the fluid is strongly magnetized (because of the low temperature) and because of this field gradient, magnetically induced convection takes place [7]. By considering the cooling efficiency of ferrofluid, Segal and Raj [8] indicated that for magnetic nano oils with saturation magnetization lower than 3.9 emu/g, the cooling efficiency improves compared to the base oil. by applying a magnetic field to the oil under breakdown test, Lee et al. [9] concluded that 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