Research Article

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Understanding the Lightning Impulse Discharge Characteristics of Nano Silica Modified Sunflower Oil for High-Voltage Insulation Applications

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ABSTRACT

Vegetable oils with nanotechnology added to them are a possible replacement for mineral oils in power transformer applications today. Because of the size and production cost reductions as well as the oil's high level of biodegradability, this could result in an increase in the dielectric strength of insulating fluid. Since transformers are mainly used for outdoor applications, understanding the capability of insulating fluid to withstand lightning discharge is a vital issue. This study used experimental analysis to compare the lightning discharge performance of pure sunflower oil and sunflower oil modified with SiO_2 (Nano) at various weight-per-volume concentrations of 0.01 %, 0.05 %, and 0.1 %. This experimental work was conducted with 1.2/50 µs of standard lightning impulse voltage with positive polarity. The result illustrated that the nano-modified sunflower oil had greater lightning impulse withstand strength than the pure sunflower oil.

Keywords: Transformer; Nanofluid insulation; Nanoparticle; Lightning discharge; Breakdown strength.

1. INTRODUCTION

Vegetable oils, also known as natural esters, are produced from plant seeds. These oils are considered environment-friendly, non-toxic and non-flammable substitutes for mineral oils because vegetable oils are almost biodegradable and their flash point can exceed 300 ^{0}C. The introduction of vegetable-based oils on high voltage transformers may lead to a compact design of the transformer with a reduction in manufacturing costs. Many researchers are working on developing vegetable oil-based insulation systems for high voltage applications (Chandrasekar and Gian, 2014). Recently nanofluids have been under research for insulation applications (Sankarganesh *et al.* 2016; Du *et al.* 2011; Anandhan Elansezhiyan and Chandrasekar 2016; Liu *et al.* 2011; Prasad and Chandrasekar 2016). Developments in nanotechnology provide an improvement in the dielectric strength of the oil. Nano-based oil not only improves the dielectric strength but also enhances the cooling performance of the transformer.

Knowing the lightning impulse strength of the nanofluid is more crucial for the insulation design of high-voltage power transformers because they are made for outdoor applications (Potao *et al.* 2016; Choi, 2013; Liu and Wnag, 2011). Lightning impulse strength as a basic insulation level is commonly used as the criterion of insulation design for large power transformers. In addition, according to IEC standard 60076-3, lightning impulse tests are usually required as factory routine tests for transformers. Most insulation materials inside a transformer are exposed to a quasi-uniform electric field. Therefore any alternative insulation material should have acceptable electrical strength in a quasi-uniform field. In this work, experiments were carried out on nano-modified sunflower oil to understand its lightning impulse withstand characteristics in comparison with that of pure sunflower oil. The characteristics of nano-modified oil and pure oil under lightning impulse voltage were evaluated by testing with the standard lightning impulse (1.2/50µ s) in accordance with the pertinent IEC standard.

2. EXPERIMENTAL WORK

2.1 Nano Fluid Preparation

Sunflower was used as the base oil, filtered, dehydrated and degassed, to minimize the impurities present in the oil. The base oil was mixed with the SiO_2 nanoparticles at concentrations of 0.01 %, 0.05 %, and 0.1 % by weight while being stirred with a magnetic stirrer for 20 minutes and an ultrasonicator for 5 minutes. Before testing, the moisture content of the pure oil and the nano-modified oil was reduced using thermal treatment.

2.2 Lightning Impulse Test

Fig. 1 shows the block diagram of the experimental setup for analyzing the lightning discharge characteristics of nanofluids. The clear test cell contained a needle-plane electrode setup and 200 ml of nanofluid. Distance between the needle and the plane electrode was maintained at 10 mm. The plane electrode was firmly grounded while the needle electrode was linked to the source of the lightning impulse.

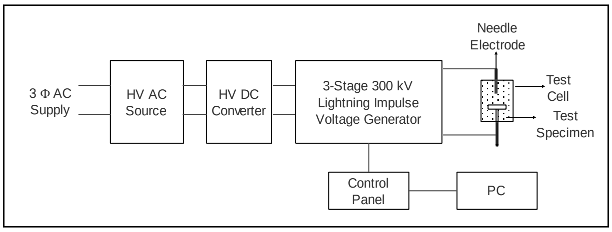

Fig. 1: Block diagram of lightning impulse experimental setup.

Fig. 2: 3-stage, 300 kV Lightning Impulse Generator connected to the test cell.

The Marx circuit-based, 3-stage, 300 kV lightning impulse generator used in this investigation is depicted in Fig. 2. The test specimen was housed in a clear test cell that was attached to it. This Marx circuit charged the capacitor bank parallel to the DC source and discharged in series to deliver 1.2/50 µs standard lightning impulse. Utilizing a conventional high voltage 400 pF measuring capacitor, voltage was measured. All the oil samples were tested at room temperature and the waveforms are measured using a PC, integrated with a digital storage oscilloscope.

3. RESULTS AND DISCUSSION

The positive polarity of 1.2/50 µs LI voltage is used for testing nano-modified sunflower oil samples. The usual positive 1.2/50 µs LI withstand and breakdown waveforms for pure sunflower oil are displayed in Fig. 3. It shows the applied voltage's peak value (Up), as well as the applied LI voltage waveform's front (T_1) and tail (T_2) times. It can be seen that the oil sample can endure peak LI of up to 93 kV before failing when the applied LI peak exceeds 95 kV. Tests were repeated with ten different oil specimens of the same type, in order to compute the minimum, maximum and average breakdown voltage.

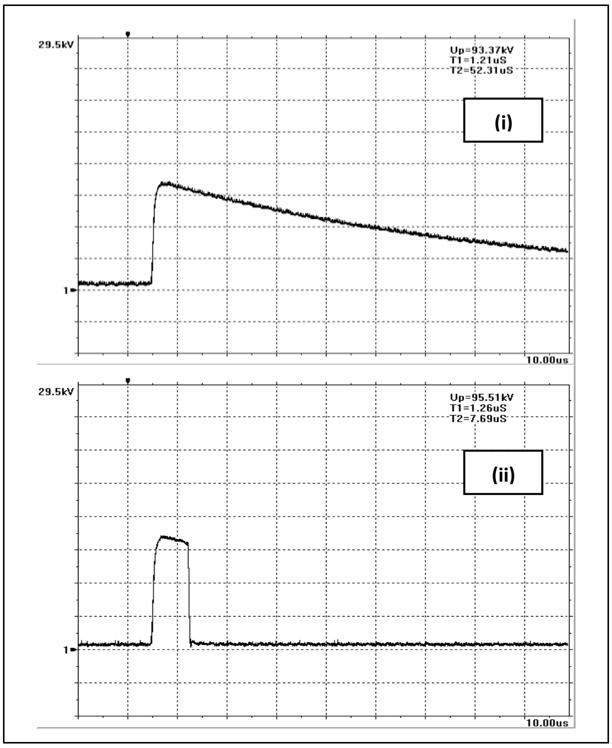

Fig. 3: Positive 1.2/50 µs LI (i) withstand and (ii) breakdown waveforms of pure sunflower oil.

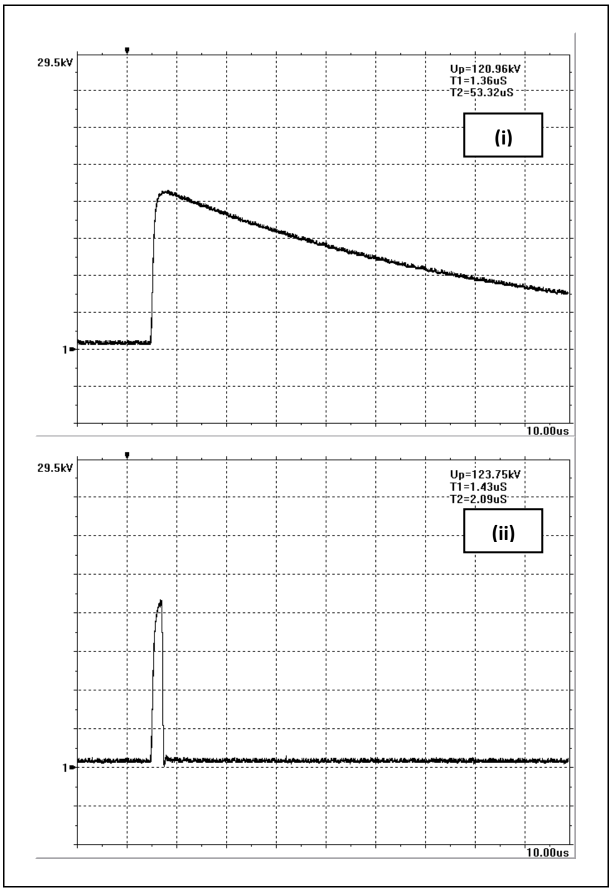

Fig. 4: Positive 1.2/50 µs LI (i) withstand and (ii) breakdown waveforms of 0.1% wt. SiO_2 modified sunflower oil.

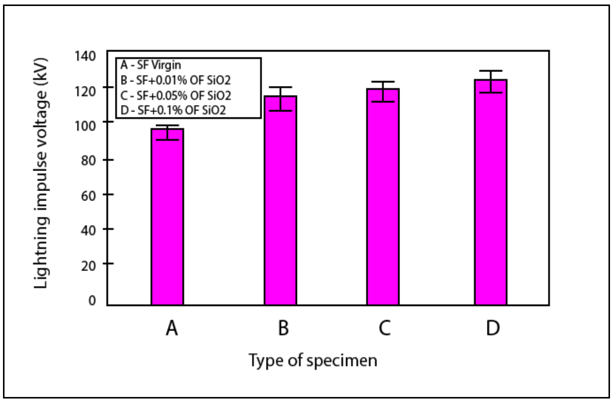

Fig. 5: Positive LI breakdown strengths of Virgin Sunflower oil and Nano-modified Sunflower oil at different % wt. concentrations.

Similarly, Fig. 4 shows the typical positive 1.2/50 µs LI withstand and breakdown waveforms of 0.1% wt. SiO_2 modified sunflower oil. The LI breakdown strength in this sample is higher and is closer to 122 kV. With increasing nanofiller concentration, a discernible rise in breakdown strength was seen. Similar outcomes were also attained using materials with concentrations of 0.01 and 0.05 % by weight.

Fig. 5 shows nano-modified sunflower oils' positive lightning impulse breakdown strengths at different % wt. concentrations, along with that of pure (virgin) sunflower oil. The 0.01 % wt. oil has shown a higher percentage increase in breakdown strength when compared to the base oil. However, the percentage increase in LI breakdown strength was not so significant with 0.1% wt. concentration. The studies mentioned above made it clear that pure sunflower oil does not generally have a higher breakdown strength than nano-modified sunflower oil.

4. CONCLUSION

This paper investigated the effect of SiO_2 nanoparticles on positive lightning discharge characteristics of sunflower oil. Based on the experimental results, it was concluded that SiO_2 nanoparticle plays a vital role in increasing the LI breakdown strength of the sunflower oil. Further extensive studies may better explore its suitability for high voltage transformer insulation applications.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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