

UNDERSTANDING THE CHARACTERISTICS OF NANO MINERAL OIL UNDER LIGHTNING IMPULSE VOLTAGE

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Abstract: This paper illustrates an experimental investigation about the breakdown in transformer oil under the action of lightning impulse voltage, to increase the life span of a transformer liquid insulation material (oil). Generally, the life span of a normal transformer oil is 5 years, after which it has to be replaced, which is costly. In order to obtain our goal, we have added Nano particles to the existing mineral oil. Titania (Titanium Dioxide- TiO_2) is the Nano particle that we have used here. This will increase the life span of the mineral oil by withstanding wide range of breakdown voltages. The dispersion of nanoparticles in the transformer oil is influenced by the volume of nanoparticles and the amount of surfactant added to it. This was characterized through some tests like viscosity measurement and particle size analysis. Based on normal distribution parameters the breakdown voltage of needle plane electrode configuration was calculated. An impulse voltage generator is used and it is built based on the solid-state switch impulse voltage and the standard wave for that was used is 1.2/50 μs (rise time/ 50% of fall time). Breakdown tests were done in a test cell (IEC 60270) within which the transformer oil is filled.

Keywords: Transformer oil, Titania nanoparticles, Partial discharge, Lightning Impulse Voltage, Breakdown Voltage.

1. Introduction

In the HVDC power system network transformers are the most important and expensive component. The life and reliability of transformer relies basically on its operating condition and insulation design. The breakdown by lightning impulse voltage could actually make any system degrade, which occurs with transformer insulation materials too [1]. The converter transformer insulation is a combination of the transformer oil and oil impregnated pressboard (OIP) material. The OIP materials are placed in between the current-carrying conductor and the

ground, as barrier to increase the electric strength of the medium. Power transformers undergo prolonged drying processes, using electrical self-heating. Mineral oil is generally used as the liquid insulation medium in all transformer. Nanoparticles has been added to the existing mineral oil to increase its breakdown voltage, so that the oil can be changed less frequently and the cost for this process can be reduced. Various Nano particles can be used to enhance the properties of the oil, one such Nano particle is silica Nano fluid [2]. The nanoparticles that's used in this project is Titania (Titanium Dioxide- TiO_2) and for uniform dispersion and nanofluid stability, a surfactant named C TAB (Cetyl Trimethyl Ammonium Bromide) is used [3]. Lightning impulse voltage testing is done to prove our work. AC and DC analyses are done already in favor of the Nano particle that's used [4]. Needle plane electrode configuration with transformer oil in it is used for doing the breakdown voltage testing. The needle gap is varied in different length to increase the corona discharge so that the oil can be tested thoroughly. Breakdown Voltage does not be a constant value and it varies every time. So a number of readings are taken on each needle-plane gap distance and the readings are plotted in a probability distribution graph. From that graph the 50% probability is taken as the breakdown voltage. Breakdown Voltage testing is done in both polarities (positive and negative) lightning impulse voltage.

A DSO (Digital Storage Oscilloscope) is used to see the waveform of lightning impulse and the breakdown voltage. Using these waveforms the time of failure can be calculated. The waveforms are also saved for futuristic purposes.

From these understandings, the following tests were done to understand the characteristics of Nano mineral oil (I) Breakdown tests on both mineral oil and Nano mineral oil under various needle-plane electrode gap. (ii) To understand the characteristics of the oil. (iii) Ratio at which the variation occurs in Nano mineral oil when comparing with mineral oil

2. Experimental Studies

A. Nano Oil Preparation:

The Nano particles used is “Titania” (Titanium Dioxide- TiO_2). At first the Titania has to be heated for 2hrs at 140°C to remove the humidity or moisture content in it because moisture is the biggest enemy for any oil. The quantity of Nano particles used is 10mg for 200ml of mineral oil. After that Surfactant need to be added, before adding the Nano particles to the mineral oil. The surfactant used in our preparation is ammonium surfactant named CTAB ($[(\text{C}_{16}\text{H}_{33})\text{N}(\text{CH}_3)_3]\text{Br}$); (Cetyl Trimethyl Ammonium Bromide) added in the ratio of 0.1mg for 200ml of mineral oil. The CTAB is added to the mineral oil and kept for magnetic stirring for 30min. After it's done, the Nano particles are added to the surfactant mixed mineral and again, the oil is subjected to magnetic stirring for another 30min. After this, the Nano fluid is kept for Ultra sonification. Ultra sonification is the process in which, sound is used to breakdown particles in larger rate and makes them to mix together. The Process is done for 2:30hrs with the frequency of 50 kHz, 40%amplitude, 8pulses on and 2 pulses off. The environment at which the oil kept for ultra-sonification must be cooler. Hence, ice blocks are added outside the beaker. It is to be carefully noted that no water droplets fall into the oil. Figure 1 shows a block diagram representation of Nano oil preparation.

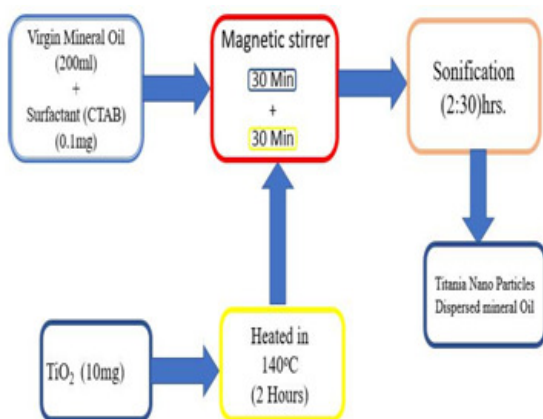


Figure 1. Block Diagram of Nano oil Preparation

B. Experimental Set-up:

The lightning impulse voltage is generated by using a standard lightning impulse voltage generator circuit which is shown in Figure 2. The two spheres represent the sphere gap, whose distance can be varied for varying

pulse voltage. Air acts as the barrier in-between both the sphere. Depending upon the distance in-between the amount of voltage is required to ionize the air and the voltage to pass through. A pulse (5kV) is applied at the sphere gap which lasts for $50\mu\text{s}$, boosts the voltage and provides the desired lightning impulse.

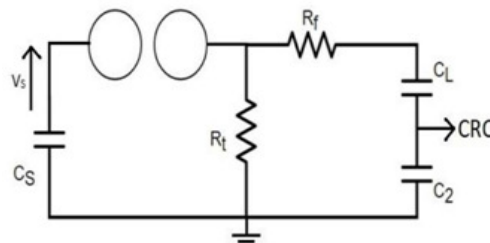
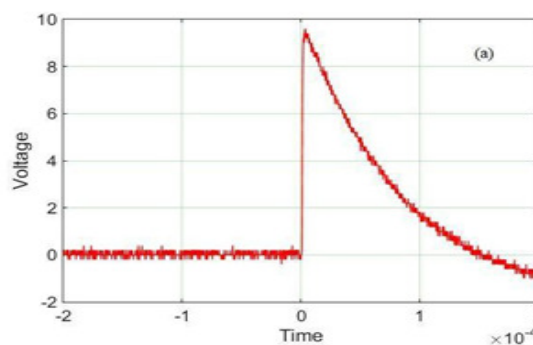


Figure 2. Lightning Impulse generator circuit

Standard lightning impulse voltage is generated by selecting correct values for Front Resistance (R_f) and Tail Resistance (R_t) in Figure 2. Standard lightning impulse is one which has the ratio of rise time to the 50% of fall time as $(1.2/50)\mu\text{s}$. C_s acts as the storage capacitor, V_s is the supply voltage and C_L is the load capacitor. The standard lightning impulse voltage waveforms are shown in Figure 3.

C. High Voltage Supply:

A high voltage transformer rated 50Hz, 5kVA, 100kV generates 50 Hz AC voltage supply. By connecting a Voltage doubler circuit both polarities of DC voltage supply can be generated. The output of the Voltage doubler circuit is V_s which is connected to the storage capacitor (C_s) as shown in Figure 2. Voltage doubler circuit is a rectifier containing two diodes. By changing the polarities of the diodes, DC voltage polarity can be changed. The supply voltage (V_s) can be measured by connecting a resistor in parallel to storage capacitor. A probe is connected from that resistor to a DC voltmeter where the voltage can be viewed digitally.



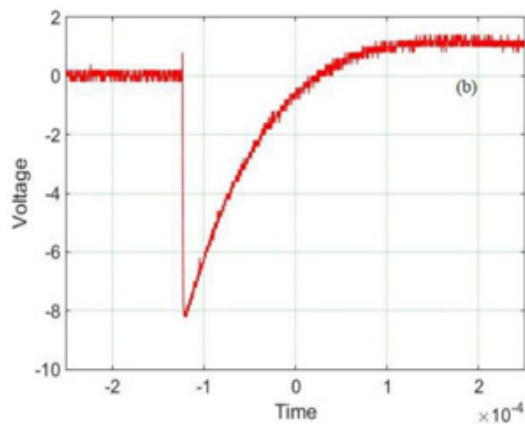


Figure 3. Standard Lightning Impulse Voltage waveform
(a) Positive Polarity (b) Negative Polarity

D. Test Cell:

Figure 4 shows the photograph of the test cell used. The test cell used is based on the standards IEC (International Electrotechnical Commission) 60270. The test cell is a needle-plane configuration. The needle has a radius of curvature of about $50\mu\text{m}$. The diameter of the bottom ground plane electrode is 5cm. The needle must be maintained sharp, only then the particle discharge is possible. The distance between the needle and the plane is varied between 2-5mm for better understanding of the characteristics. The test cell is connected in parallel to the Load Capacitor.

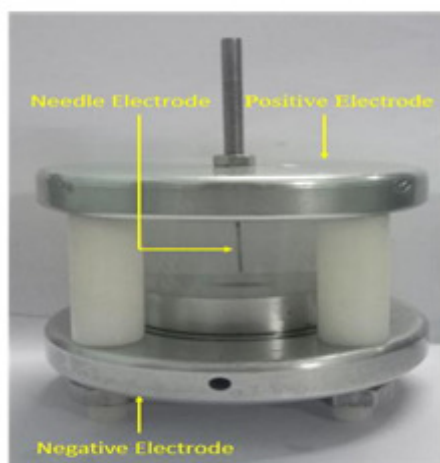


Figure 4. Photograph of test cell

3. Results and Discussion

A. Probability Distribution:

With the breakdown values noted under various tests, a probability distribution graph is plotted to get the value that has maximum chances of occurrence. Probability distribution graph is necessary because a breakdown happening at a value is less likely to happen again at the same value. Hence, a set of 25 readings were taken for each needle-plane gap and plotted in a probability distribution graph using MATLAB.

Figure 5 shows the probability distribution of each needle-plane electrode gap in mineral oil as well as Nano mineral oil under positive Lightning impulse polarity and Figure 6 shows the probability distribution of each needle gap in mineral oil as well as Nano mineral oil under negative Lightning impulse polarity. From these figures it's noted that negative polarity of lightning impulse is nearly 1.5 times greater than that of the positive polarity of lightning impulse.

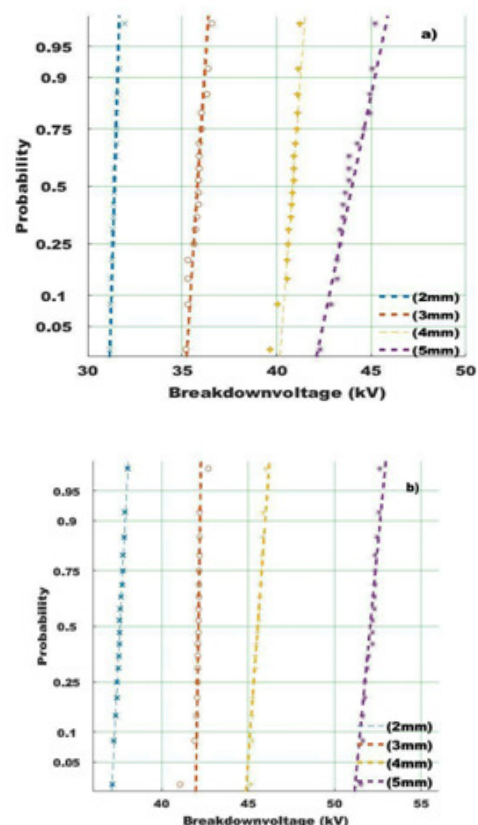


Figure 5. Probability distribution for positive polarity
a) Mineral Oil b) Nano Mineral Oil

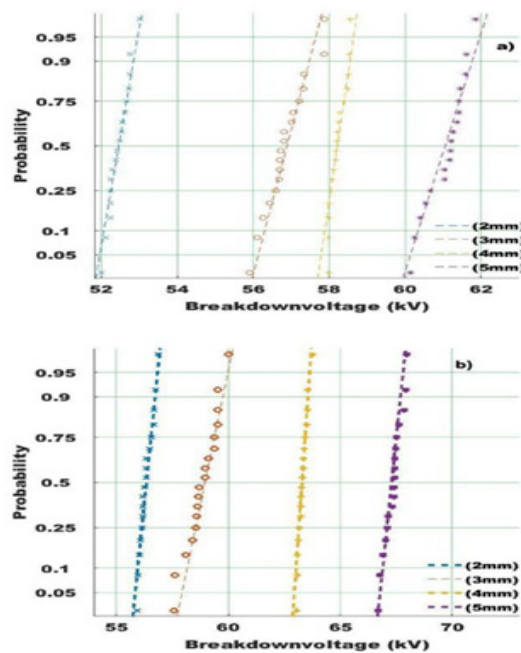


Figure 6. Probability distribution for negative polarity
a) Mineral Oil b) Nano Mineral Oil

B. Lightning Impulse Characteristics:

With From the figure 5 and 6, the value which has 50% probability is chosen for all needle-plane gaps, both mineral oil and Nano oil and for both the polarities are taken. With the help of these values a graph is plotted to understand the characteristics of the lightning impulse under mineral oil and Nano mineral oil under different needle-plane gaps. Figure 7 shows the lightning impulse characteristics graph. From this graph we can understand that Nano oil has higher breakdown voltage than mineral oil.

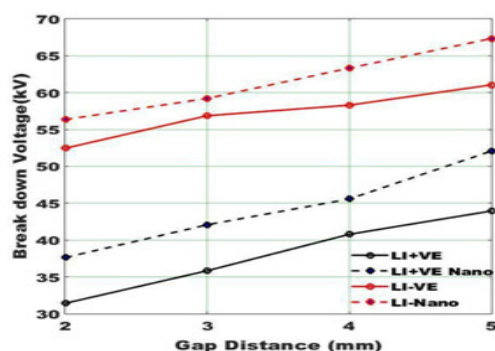


Figure 7. Lightning impulse characteristics

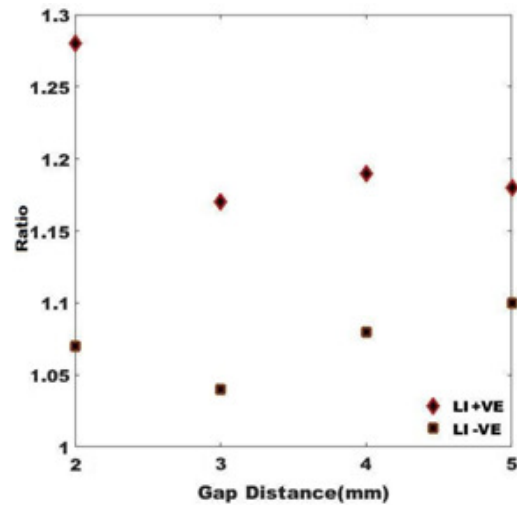


Figure 8. Ratio between Nano oil and mineral oil

C. Nano mineral oil Characteristics:

With the help of the values in figure 7, the ratio at which the changes occur for Nano oil when compared with mineral oil is noted for lightning impulse under both the polarities. Figure 8 shows the graph that describes the rate at which the breakdown value of Nano oil is greater than that of the mineral oil for various needle-plane gap distances. From this graph, it can be said that Nano oil differs at a greater margin for lightning impulse under negative polarity than the lightning impulse under positive polarity.

D. Conclusion:

Based on the experimental studies, the important conclusions that can be summarized are as follows,

- Nano particle dispersed mineral oil has higher breakdown strength than the mineral oil under lightning impulse voltage.
- Breakdown strength increases because of the alumina content present in the Nano particle. Alumina absorbs the carbon produced under each breakdown and settles down, thereby making the carbon content not affecting the breakdown strength of the insulation material.
- The breakdown value of lightning in negative polarity is 1.5 times greater than that of the breakdown value in positive polarity.
- The ratio of increase of breakdown voltage in Nano oil with respect to mineral oil is greater in positive polarity when compared with negative polarity.

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