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UNDERSTANDING THE LIGHTNING DISCHARGE WITHSTAND AND BREAKDOWN CHARACTERISTICS OF NANO SiO_2 MODIFIED MINERAL OIL FOR TRANSFORMER APPLICATIONS

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ABSTRACT

The successful operation of electrical power system network depends on the performance of insulation provided in the high voltage power transformers. Recent output of many research works confirm that the nano modified insulation system provides enhanced dielectric and thermal characteristics when compared with conventional system. Now a days nano modified mineral oils are considered as an alternative to conventional mineral oils as a dielectric insulation fluid in power transformers, leading to the improved dielectric strength of apparatus with further reduction in the size and manufacturing cost. Since distribution transformers are mainly used in outdoor applications, understanding its lightning discharge withstand and breakdown characteristics of nano modified insulating fluid is a vital issue. In this paper laboratory experimental works are performed to understand the lightning discharge performance of mineral oil along with SiO_2 nano filler at different %wt concentration such as 0.01%, 0.05% and 0.1%. Standard lightning impulse voltage of 1.2/50 µs time period with both positive and negative polarity is used in the experiments. Results illustrate that the nano modified mineral oil significantly improves the lightning impulse withstand and breakdown strength of insulation system.

Indexing terms/Keywords

Transformer, insulation, nanofluid, mineral oil, lightning discharge

1.INTRODUCTION

Successful operation of electrical transmission and distribution network depends on the reliability of power transformers. Any failure of these expensive apparatus will lead to heavy loss to consumers. With the increasing demand for electrical energy, it is crucial to maintain the reliability of the power supply. Nowadays, avoiding the unpredicted breakdown of power transformers is an important goal before the electrical utilities. Most of the power transformer failures are reported due to insulation breakdown. Majority of the distribution transformers are used with liquid insulation and mineral oil is being used as a liquid dielectric for a longer period of time. Even though mineral oils have excellent insulating properties with good long-term performance and are obtained at reasonably low price, they are usually non-biodegradable and affects our environment.

Considering the drawbacks of conventional mineral oil, many researchers are working towards improving the dielectric properties of liquid insulation used in the transformers [1-6] . Some researchers are working in the vegetable oils obtained from seeds and flowers. Chandrasekar et al., [1] analyzed the applicability of natural esters as an insulating fluid for high voltage transformers. In this work, they have analyzed the breakdown strength and PD characteristics of natural esters as an alternate insulation for mineral oil. Banumathi et al., [3,5] studied the PD properties of olive oil and castor oil as an insulating medium for distribution transformers. Senthilkumar et al., [7] studied the dielectric strength characteristics of thermally aged palm oil and corn oil as an alternate insulating medium for transformer applications.

In recent times, developments in nanotechnology has provided the horizons for the development of nanofluids for power transformer applications. Addition of nano-size filler materials in the base oil known to be the nanofluid attracts attention as an insulating medium for transformers. Many research works are being carried out in nanofluid insulation with both mineral oil and vegetable oils with different filler materials at different concentrations [7-17]. Sankarganesh et al., [8] analyzed the corona type partial discharge signal characteristics of nano-SiO_2 modified mineral oil at different filler percentage concentrations. Appropriate selection of base oil and filler material makes nanofluid more suitable for transformer applications. Dong et al., [9], investigated Aluminum-nitride-(AlN)-transformer oil-based nanofluid at different ambient temperatures. They have shown that in comparison to the pure transformer oil, the electrical conductivity of nanofluid containing 0.5% AlN nanoparticles has increased by 1057 times at 60°C. T.S.Ramu et al., [11], studied the AC, DC and Lightning impulse breakdown characteristics of Fe_3O_4 and SiO_2 nanofiller added transformer mineral oil and they have concluded that the dielectric breakdown strength of investigated nanofluids greatly improved under all forms of voltages and of either polarity. In addition, mineral oil top and hot spot temperatures are considerably lowered in nanofluid filled transformers.

However, there are certain key issues to be investigated before applying nanofluid insulation for real time application in transformers. Since high-voltage power transformers are designed for outdoor applications, understanding the lightning impulse strength of the nanofluid becomes more important for the insulation design [18-23]. Lightning impulse strength as basic insulation level is commonly used as the criterion of insulation design for large power transformers. In addition, according to IEC standard 60076-3 the lightning impulse tests are usually required as factory routine tests for transformers. The majority of insulation materials inside a transformer are exposed to quasi-uniform electric field. Therefore any alternative insulation material should have acceptable electrical strength in a quasi-uniform field.

Considering this, in this paper experimental works are carried out on nano modified mineral oil for understanding its lightning impulse withstand characteristics and comparison is made with pure mineral oil. The characteristics of nano modified oil under positive and negative lightning impulse voltage are evaluated by testing with the standard lightning impulse (1.2/50 µs) in accordance with the IEC standard.

2. EXPERIMENTAL WORKS

2.1. Preparation of Nano Fluid in the Laboratory

Mineral oil, which is commercially available and mostly used as an insulating medium in distribution transformers, is used as a base fluid for the preparation of nanofluid. Silicone di oxide nano particles of size <80 nm with a high purity of above 99% supplied by Hefei Jiankun Chemical Industry was used for preparing nanofluid. The nanofluids were prepared at different filler nanofiller concentrations such as 0.01, 0.05 and 0.1% by weight of the nano-size SiO_2 fillers. In order to improve the stability of the nanoparticles in the prepared nanofluid, two different mixing process was carried out which is shown in Figure 1.

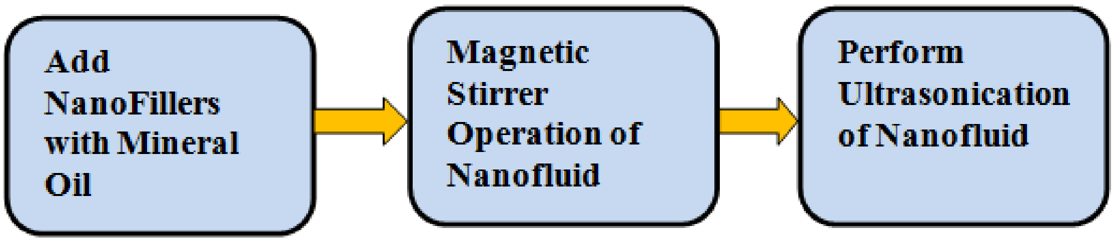


Fig.1 . Steps involved in the preparation of nano-mineral oil

Initially required amount of nanofiller material is added with the base mineral oil and the magnetic stirrer operation is performed for 45 minutes. This process improves the dispersion of aggregations in the base oil. Then ultrasonication is performed for 20 minutes, which results in a well dispersed nanofluid. From the above methodology, sedimentation and agglomeration of nanoparticles in the mineral oil is avoided. Figure 2 shows the photograph of the well dispersed nanofluid prepared in the laboratory at different %wt concentrations. According to the %wt concentration of SiO2 nanofiller material added in the base mineral oil, the samples were given identity as A, B, C and D as shown in the Table 1. The nano modified oil and pure oil was given thermal treatment in order to reduce the moisture content in the oil before testing.

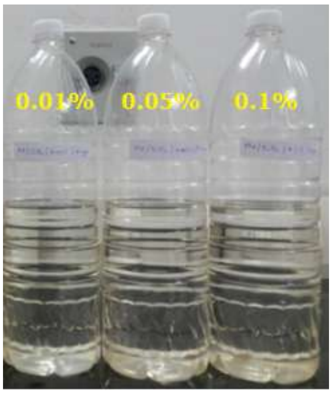


Fig. 2. Photograph of well dispersed nanofluid at different %wt concentrations

Table 1. Sample identity of nano-mineral oil

Sample Identity	Detail
A	Mineral Oil
B	Mineral Oil + 0.01% SiO_2
C	Mineral Oil + 0.05% SiO_2
D	Mineral Oil + 0.1% SiO_2

2.2. Lightning Discharge Test Setup

Fig.3. Photograph of test cell used for lightning impulse test

A needle-plane electrode system was located in the transparent test cell filled with nanofluid of 200ml volume as shown in figure 3. Distance between needle and plane electrode was maintained at 5 mm and 10mm. Needle electrode was connected to the lightning impulse source and plane electrode was solidly grounded.

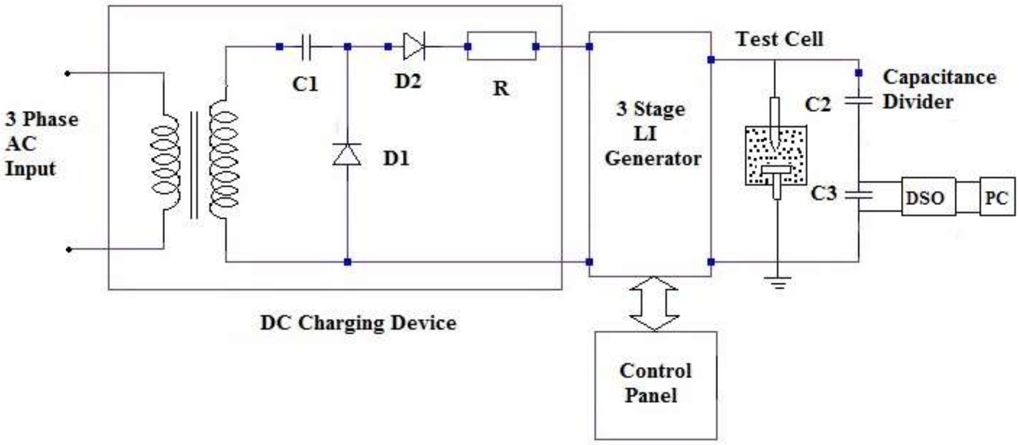


Fig. 4. Schematic diagram of lightning impulse experimental setup

Figure 4 shows the schematic diagram of experimental setup used to understand the lightning discharge characteristics of nano fluids. It consists of a DC charging device connected with a 3 stage lightning impulse generator. A motorized control panel is used for changing the polarity of the lightning impulse generator and to change the gap distance between the spark gaps.

Fig. 5. Photograph of 3 Stage, 300 kV Lightning Impulse Generator connected to the test cell.

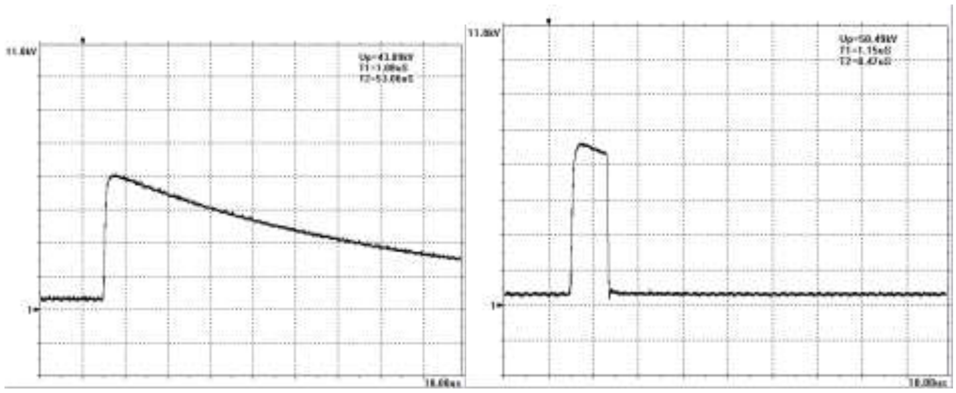
Figure 5 shows the photograph of three stage 300 kV lightning impulse generator used in the present study which works on the basis of Marx circuit, and it is connected to the transparent test cell containing the test specimen. This Marx circuit charges the capacitor bank in parallel from d.c source and discharged in series to deliver 1.2/50µs of the standard lightning impulse. Voltage measurement is carried out using the standard high voltage 400 pF measuring capacitor. All the oil samples are tested under the room temperature. The waveforms are measured using PC integrated with digital storage oscilloscope.

3. RESULTS AND DISCUSSION

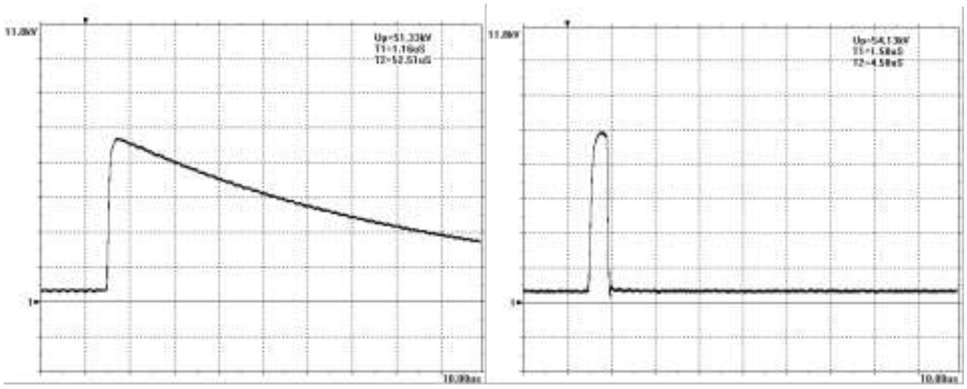
Lightning discharge withstand and breakdown tests were carried out in the prepared nanofluids at both positive and negative polarity of waveform. Needle plane electrode system was used in the present study and the gap distance between the electrodes is maintained at 5 mm and 10 mm. Tests were repeated for 15 times at similar type of fresh samples in order to get 95% confidence level of the test results. Rising voltage method of test procedure as per IEC 60897 was followed in the laboratory experiments in order to evaluate the lightning impulse breakdown voltage of the nanofluid sample. In this method, the applied lightning impulse peak voltage is slowly increased in steps from an initial voltage level at a constant rate until the breakdown of the test oil specimen takes place. As per IEC standard, one impulse shot per step voltage of 10 kV is applied to the test specimen and the time interval between the successive impulse shots is maintained constant as 2 minute. Test procedure is repeated for 15 times after a regular rest period, until a considerable number of breakdown voltage measurements are carried out.

3.1. Positive Lightning Impulse Test Waveforms

Initially the test specimens were subjected to positive polarity lightning impulse stress. Figure 6 shows the resultant lightning impulse waveforms after the application of LI voltage to the test specimen at 5 mm gap distance between the electrodes. Test waveforms are shown for type A (pure mineral oil) and type D (nano modified mineral oil 0.1%wt). The positive polarity of 1.2/50 µs LI voltage is used for testing nano modified sun flower oil samples. Figure 6(a) and 6(b) shows the typical positive 1.2/50 µs LI withstand and breakdown waveform of pure mineral oil and type D specimen respectively. It also shows the peak value of applied voltage (Up), front time (T1) and tail time (T2) of the applied LI voltage waveform.



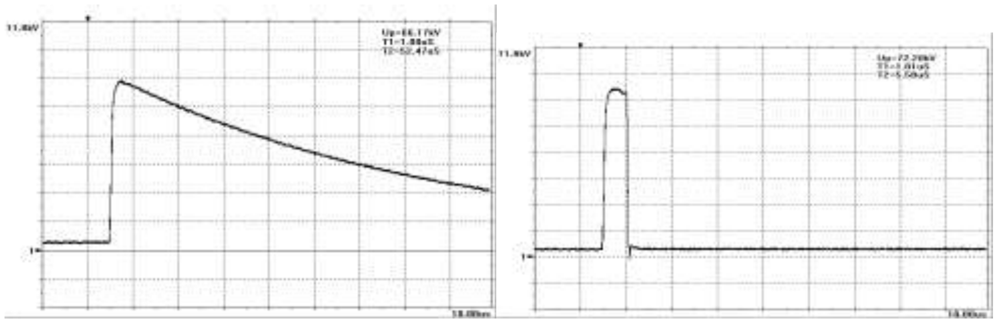
(a)



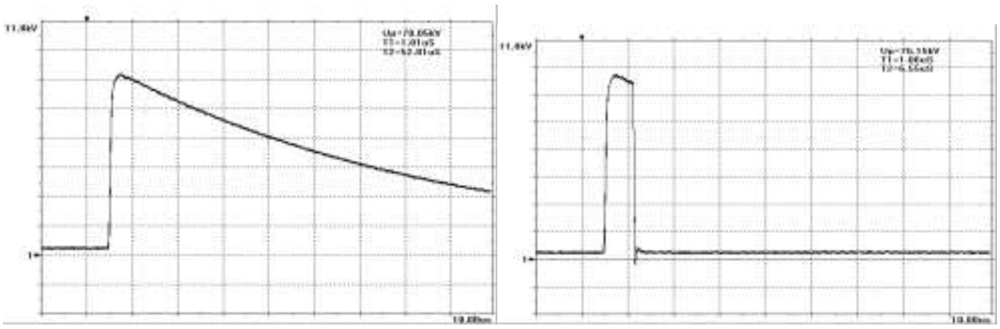
(b)

Fig. 6. Positive lightning impulse withstand and breakdown waveforms obtained at 5 mm gap distance (a) sample A (b) sample D

It is clearly understood from the above waveforms that virgin mineral oil shows 44 kV peak lightning impulse withstand strength whereas it breaks down when the peak value reaches above 50 kV. Whereas in the case of nano modified 0.1% wt mineral oil, it shows 51 kV peak lightning impulse withstand strength and when the voltage reaches above 54 kV it breaks down. It clearly shows that addition of nano filler in the base oil improves the lightning impulse withstand property.



(a)



(b)

Fig. 7. Positive lightning impulse withstand and breakdown waveforms obtained at 10 mm gap distance (a) sample A (b) sample D

Figure 7 shows the positive lightning impulse withstand and breakdown waveforms at 10 mm gap distance. When the gap distance between the electrodes increases, then it is expected that th breakdown strength of the sample also will increase significantly. It is observed that at 10 mm electrode gap distance, lightning impulse withstand voltage of mineral oil goes upto 66 kV and it breaks down at 72 kV. Similarly, in the case of type D specimen with 0.1%wt SiO_2 nano filler, withstand strength improves upto 70 kV and it breaks down at 76 kV. Results obtained at 10 mm gap distance are in similar line with 5 mm gap distance. Similar characteristics are also obtained with other specimens such as Type B and Type C.

3.2. Comparison of Positive LI Breakdown Voltage w.r.t Electrode Distance

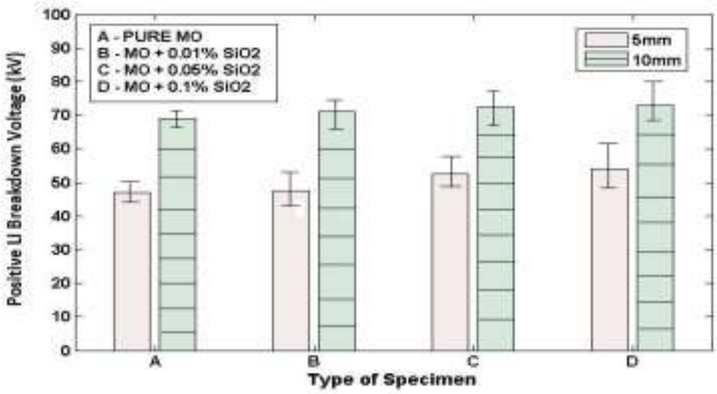
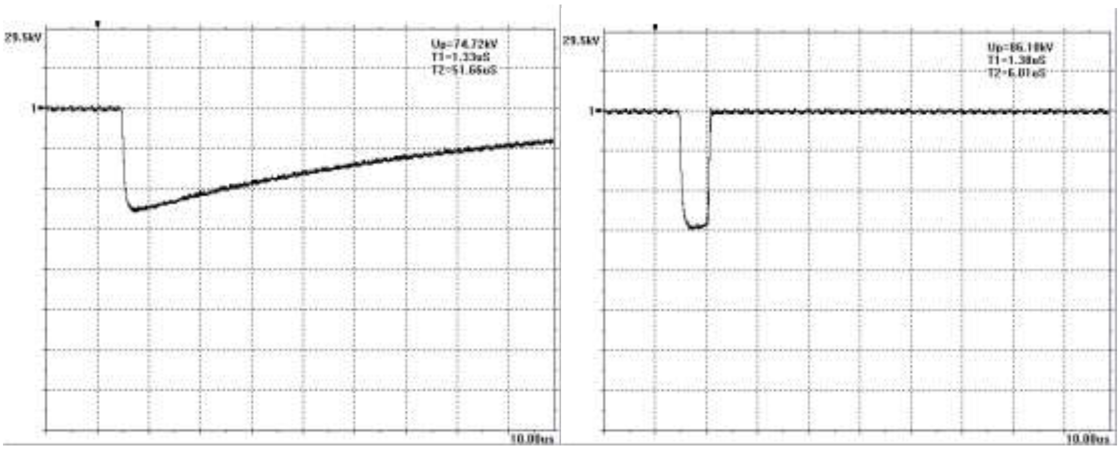


Fig. 8. Comparison of positive LI breakdown voltage of nanofluid specimens A,B,C and D at different electrode gap distance

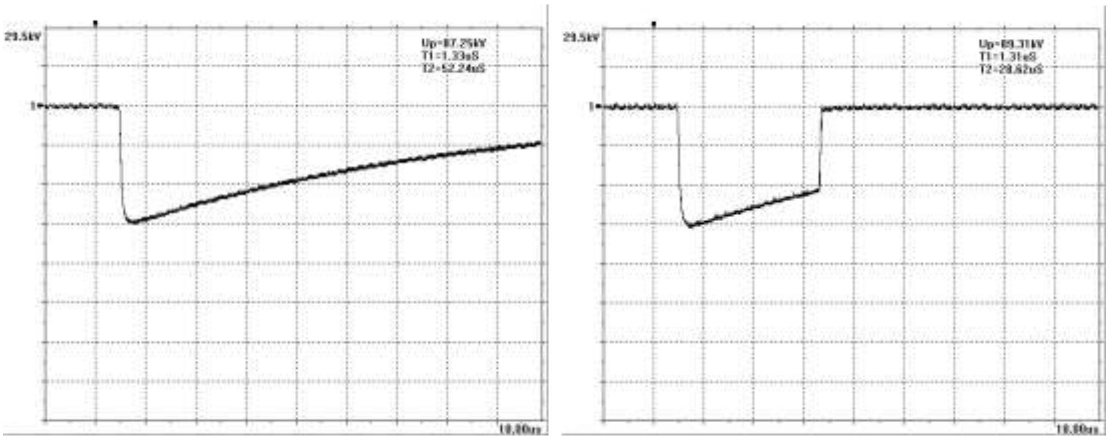
Figure 8 shows the average, minimum and maximum values of breakdown voltage obtained for all the tested oil specimens at different gap distances. It is clearly observed that in general increase in electrode gap distance increases the breakdown strength. Also at each electrode gap distance, it is noted that nano modified mineral oil shows significant enhancement in its breakdown strength when compared with pure mineral oil without any fillers. Considerable improvement in lightning impulse breakdown strength is noticed with 0.05 % and 0.1 % wt nano filler.

3.3. Negative Lightning Impulse Test Waveforms

In this case, the test specimens were subjected to negative polarity lightning impulse stress of 1.2/50 μs time period. Figure 9(a) and 9(b) shows the typical negative 1.2/50 μs LI withstand and breakdown waveform of pure mineral oil and type D specimen respectively at 5 mm electrode gap distance. It also shows the peak value of applied voltage (Up), front time (T1) and tail time (T2) of the applied LI voltage waveform.



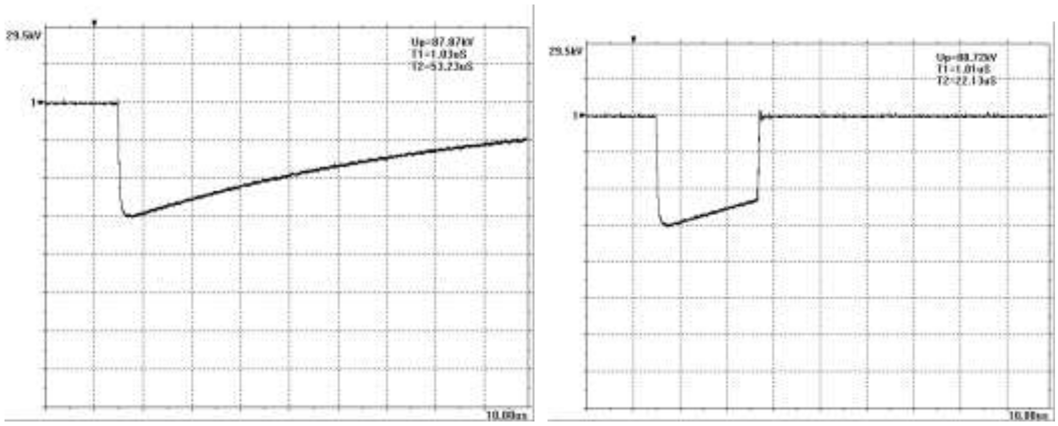
(a)



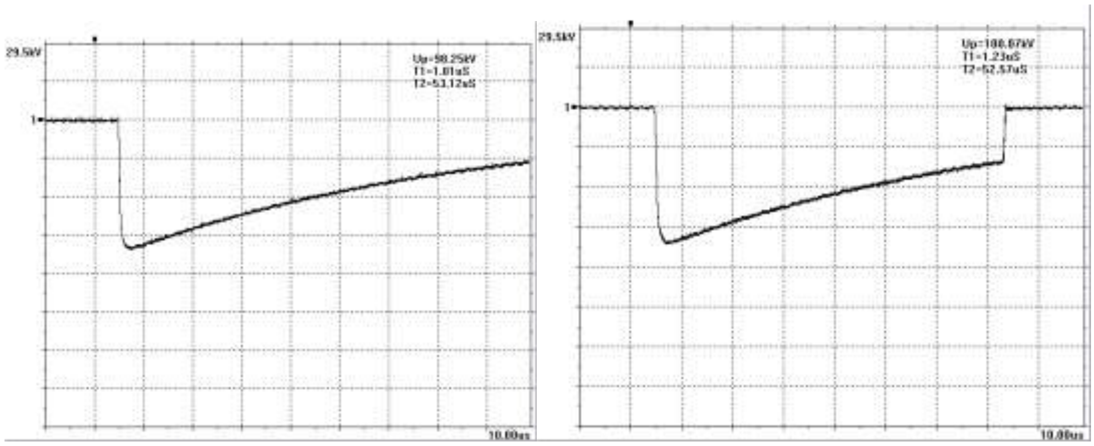
(b)

Fig. 9. Negative lightning impulse withstand and breakdown waveforms obtained at 5 mm gap distance (a) sample A (b) sample D

It is clearly understood from the above waveforms that virgin mineral oil shows 74 kV peak lightning impulse withstand strength whereas it breaks down when the peak value reaches above 86 kV. Whereas in the case of nano modified 0.1% wt mineral oil, it shows 87 kV peak lightning impulse withstand strength and when the voltage reaches above 89 kV it breaks down. It clearly shows that addition of nano filler in the base oil improves the lightning impulse withstand property. When compared with positive polarity results, it is observed that withstand and breakdown capacity of nanofluid insulation is considerably higher in the negative polarity case.



(a)



(b)

Fig. 10. Negative lightning impulse withstand and breakdown waveforms obtained at 10 mm gap distance (a) sample A (b) sample D

Figure 10 shows the negative lightning impulse withstand and breakdown waveforms at 10 mm gap distance. As expected, breakdown strength of the sample significantly increased in this case when compared with 5 mm gap distance. When compared with positive LI case, it is noticed that breakdown strength has significantly increased irrespective of the oil specimen. It is observed that at 10 mm electrode gap distance, lightning impulse withstand voltage of mineral oil goes upto 87 kV and it breaks down at 88 kV. Similarly, in the case of type D specimen with 0.1%wt SiO_2 nano filler, withstand strength improves upto 98 kV and it breaks down at 100 kV. Results obtained at 10 mm gap distance are in similar line with 5 mm gap distance. Similar characteristics are also obtained with other specimens such as Type B and Type C.

3.4. Comparison of Negative LI Breakdown Voltage w.r.t Electrode Distance

Figure 11 shows the average, minimum and maximum values of negative LI breakdown voltage obtained for all the tested oil specimens at different gap distances. It is clearly observed that in general increase in electrode gap distance increases the breakdown strength. Also at each electrode gap distance, it is noted that nano modified mineral oil shows significant enhancement in its breakdown strength when compared with pure mineral oil without any fillers. Considerable improvement in lightning impulse breakdown strength is noticed with 0.05 % and 0.1 % wt nano filler.

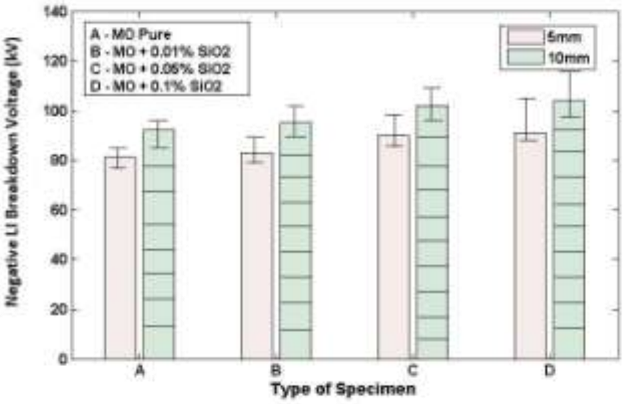


Fig. 11. Comparison of negative LI breakdown voltage of nanofluid specimens A,B,C and D at different electrode gap distance

From the above reported results, it is summarized that negative lightning impulse withstand capacity of nanofluid insulation is considerably higher than positive lighting impulse case. Addition of nano filler above 0.05% wt concentration certainly improves both positive and negative lightning impulse withstand and breakdown capacity of insulation. Hence, nano technology will help the electrical utilities to enhance the lightning discharge characteristics of transformers by using nanofluid insulation.

4. CONCLUSION

In this paper the lightning impulse withstand and breakdown strength of nano modified mineral oil was investigated at both positive and negative polarity of waveform. Laboratory experiments were carried out at 1.2/50 µs lightning impulse waveform and nanofluid insulation was prepared at different %wt concentration of nanofiller. The results show that addition of nanofiller in the base mineral oil certainly improves the lightning impulse withstand and breakdown strength of base oil. In particular, when the %wt concentration of nano SiO_2 filler goes above 0.05% then significant improvement in lightning impulse characteristics are noticed. These preliminary results will be very much useful for electrical utilities while designing the basic insulation level of transformers filled with nanofluid insulation.

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