Effect of Semiconductive Nanoparticles on Insulation Performances of Transformer Oil

S.D. Uma Rani, Geetha Chithira and R. Sreeram

***Abstract* — *Transmission and distribution transformers form a critical, highly loaded, and expensive part of the electricity generation and distribution network. Transformer oil or insulating oil is usually a highly refined mineral oil that is stable at high temperatures and has excellent electrical insulating properties as well as cooling. The electrical parameters such as dielectric strength, permittivity, and resistivity are the factors which influences the insulation properties of the transformer oil. Most of the transformer failure is due to the insulation failure of the transformer oil. So it is necessary to improve the insulation properties of transformer oil. By suspending nanoparticles into transformer oil, we find that the insulating properties of transformer oil can be improved. TiO_2 semiconductive nanoparticles with a large relaxation time constant is added into transformer oil, to form semiconductive nanofluids (SNFs), with the aim of enhancing insulating characteristics. AC breakdown test is used to find out the dielectric strength of insulators. Break down voltage is measured by observing at what voltage, sparking starts between two electrodes immerged in the oil, separated by specific gap. Low value of BDV indicates presence of moisture content and conducting substances in the oil. AC Breakdown tests were conducted on each sample after giving certain settling time. The test kit consists of a shell fitted with electrodes. The distance between these electrodes can be adjusted using feeler gauge. The shell is properly cleaned and the distance between electrodes is adjusted to 2 mm. After removing the precipitate, the nano transformer oil is filled in the shell. The shell is properly placed in the test kit and the test voltage is applied. The voltage is increased at a rate of 3 kV/sec. The breakdown voltage was noted. It is seen that the presence of nanoparticles significantly elevated the breakdown voltage. Furthermore, the increase shows a non-linear relationship with the agitation and settling time.*

Index Terms* – *Nanoparticle, Transformer Oil, Semiconductive Nanofluids

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I. INTRODUCTION

THERE is no accepted international definition of a nanoparticle. Generally any particle having one or more dimensions of the order of 100nm or less is termed as a nanoparticle. As the particle become nano sized, the basic properties changes. Nano particles have a surface charge that attracts the thin layer of ions of opposite charge to their surface. Hence formation of double layered ions occurs and they move rapidly because of the faster motion of nanoparticles. Trapping of fast electrons onto slow conducting nanoparticles is the cause of the decrease in positive streamer velocity and higher electrical breakdown strength. Conductive nano particles act as electron scavengers in electrically stressed transformer oil based nanofluid converting fast electrons to slow negatively charged particles. When nano ions move due to their high mobility, polarization occurs. It must be noted here that the high mobility is due to Brownian motion.

Nanoparticles have been used in previous studies [1, 2] to enhance the performance properties of transformer oil. The dielectric strength has been investigated as a yardstick of measurement of property enhancement [2, 3]. Here it is studied if insulation performance of transformer oil can be enhanced by the addition of TiO_2 nanoparticles. The choice of nanoparticles is due to the relative abundance of the material in the region.

II. SAMPLE PREPARATION

Fig 1: Ultrasonic Agitator used for Preparing Nanofluids

Nano transformer oil is prepared by ultrasonic agitation method. For this an ultrasonic agitator is employed. The working medium in ultrasonic agitator is water. The water level of the ultrasonic agitator and the oil level in the beaker should be same. Here TiO_2 nanoparticles are used for the agitation of oil. Nano particle were added in transformer oil for different concentration for different agitation time. After switching on the ultrasonic agitator, by using the timer the time is adjusted to required value .As the agitation completes,

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the TiO_2 nano particle dispersed in the oil. These oil samples were kept in proper air tight condition during agitation as well as during settling. The changes observed after the agitation of transformer oil are:

1. Cloudy appearance
2. Colour change
3. Decrease in viscosity

III. AC Breakdown Test

AC breakdown test is used to find out the dielectric strength of insulators. Break down voltage is measured by observing at what voltage, sparking starts between two electrodes immerged in the oil, separated by specific gap. Low value of BDV indicates presence of moisture content and conducting substances in the oil. Here AC Breakdown test were conducted on each sample after giving certain settling time. The test kit consists of a shell fitted with electrodes. The distance between these electrodes can be adjusted using feeler gauge. The shell is properly cleaned and the distance between electrodes is adjusted to 2 mm. After removing the precipitate, the nano transformer oil is filled in the shell. The shell is properly placed in the test kit and the test voltage is applied. The voltage is increased at a rate of 3kV/sec. The breakdown voltage was noted.

Fig 2: Semiconductive Nanofluid sample used for AC breakdown test

IV. Results and Discussions

Table 1: Data for sample with nanoparticle concentration of 0.075g/100ml

Agitation time (hours)	Settling time (hours)	Breakdown Voltage (kV)	Remark
2	14	25	+ 2 kV
2	120	33	+ 11 kV
4	18	33	+ 11 kV
4	120	39	+ 17 kV
6	120	30	+ 8 kV
6	240	44	+ 22 kV
6	288	54	+ 32 kV

One of the primary interests of this study is to estimate if the agitation time directly influences the breakdown voltage. Increasing the agitation time is found to result in an increase of breakdown voltage for a sample with nanoparticle concentration of 0.075g/100ml. This can be understood as increased agitation leading to finer mixing and improved Brownian dynamics of the nanofluid. However, in case of practical applications, the settling time of the semiconductive nanofluid becomes more important than the agitation time. This is because the settling time of any mixture is directly indicative of its stability. A nanofluid with considerably enhanced properties but low stability will be of no practical significance. Inorder to assess the stability aspect of the nanofluid sample, settling time is varied. It is interesting to note that the settling time has a stroger influence in determining the breakdown voltage. Increased settling time is found to result in increased breakdown voltage. However this relationship shows a non linear tendency. For an agitation time of 4 hours and settling time of 120 hours, the breakdown voltage is 39 kV. However, for the same settling time but agitation time of 6 hours, the breakdown voltage reduces to 30 kV, well below the 33 kV observed for an agitation time of 2 hours. Within a given agitation time, however, increasing the settling time is found to result in increase the breakdown voltage.

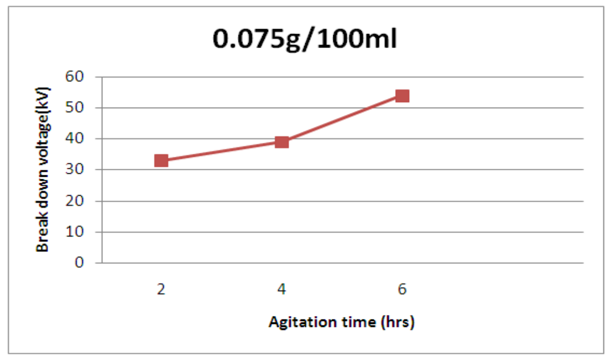

Fig 3: Break down voltage enhancement versus agitation time for a sample with nanoparticle concentration of 0.075g/100ml

In order to understand the effect of concentration, on the electrical properties of semiconductive nanofluids, another set of samples are prepared with a concentration of 0.15g/100ml. It is seen that the increase in concentration results in an increase of breakdown voltage. The effect of a concentration increase is found to be less profound than the effect of settling time. Irrespective of the concentration, it is seen that increased settling time results in increased breakdown voltage.Sets of samples were also prepared for concentrations 0.05g/100ml, 0.1g/100ml and studies. All the results are given below

Table 2: Data for sample with nanoparticle concentration of 0.15g/100ml

Agitation time (hours)	Settling time (hours)	Breakdown Voltage (kV)	Remark
2	120	35	+ 13 kV
2	168	42	+ 20 kV
2	240	58	+ 36 kV
2	312	Above 60	
4	240	54	+32 kV
4	360	58	+36 kV
4	528	Above 60	
6	240	54	+32 kV
6	480	Above 60	

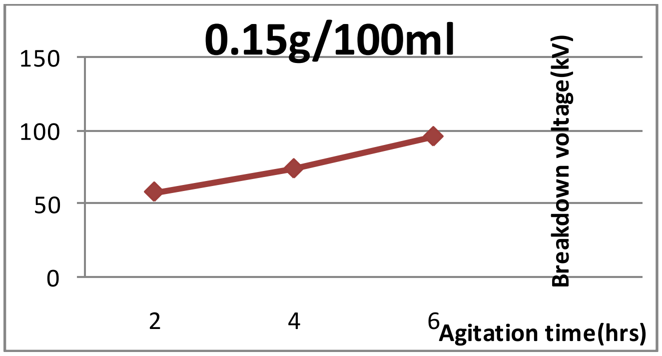

Fig 4: Break down voltage enhancement versus agitation time for a sample with nanoparticle concentration of 0.15g/100ml

Table 3: Data for sample with nanoparticle concentration of 0.05g/100ml

Agitation time (hours)	Settling time (hours)	Breakdown Voltage (kV)	Remark
2	120	40	+18 kV
2	360	43	+ 21 kV
2	528	43	+ 21 kV
4	192	42	+20 kV
4	384	46	+24 kV
6	192	45	+23 kV
6	456	49	+27 kV

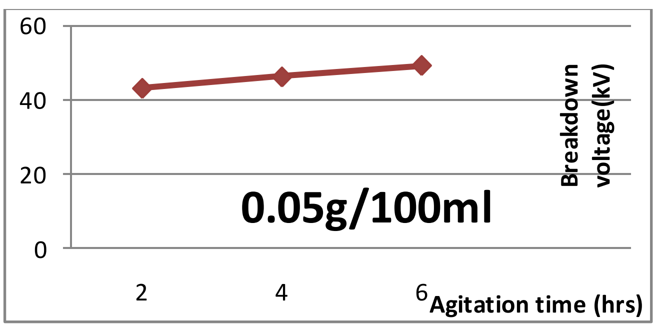

Fig 5: Break down voltage enhancement versus agitation time for a sample with nanoparticle concentration of 0.05g/100ml

Table 4: Data for sample with nanoparticle concentration of 0.1g/100ml

Agitation time (hours)	Settling time (hours)	Breakdown Voltage (kV)	Remark
2	360	35	+ 13 kV
2	528	39	+ 17 kV
4	120	40	+18 kV
4	264	Above 60	
4	384	Above 60	
6	120	42	+20 kV
6	312	Above 60	
6	528	Above 60	

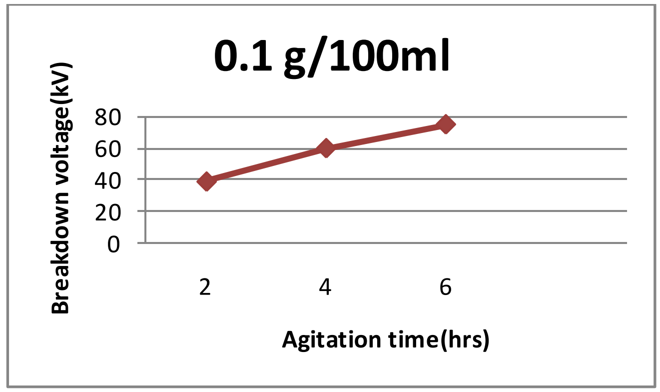

Fig 6: Break down voltage enhancement versus agitation time for a sample with nanoparticle concentration of 0.1g/100ml

The reason for improved performance is that transformer oil-based nanofluids with conductive nanoparticle suspensions have been experimentally shown to have substantially higher positive voltage breakdown levels with slower positive streamer velocities than that of pure transformer oil. Conductive nanoparticles act as electron scavengers in electrically stressed transformer oil. Nanofluids converting fast electrons to slow negatively charged particles. Due to the low mobility of these nanoparticles the development of a net space charge zone at the streamer tip is hindered suppressing the propagating electric field wave. Trapping of fast electrons onto slow conducting nanoparticles is the cause of the decrease in positive streamer velocity and higher electrical breakdown strength.

Particles with diameters of <20 nm have a high mobility in solution due to the applied field and Brownian motion. In addition, these particles have very low light scattering properties, as the intensity of light scattered from particles increases as the 6th power or the diameter. Both of these effects lead to a narrow range of sample concentrations that will yield a satisfactory quality result.Thus there exist an optimum range of concentration which yields maximum insulation.

V. Conclusion

The performance evaluation of semiconductor nanofluids shows some surprising results. From the point of view of breakdown voltage, the settling time is found to be a stronger contributing factor than the nanoparticle concentration. This hints that the mechanisms that contribute to enhancement of breakdown voltage are complex. The increase in breakdown voltage with respect to agitation time is found to be non-linear. The study suggests that there is an optimum concentration of nanoparticles which results in enhanced properties as the breakdown voltage increases with increase in concentration.

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