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INVESTIGATION OF DIELECTRIC PROPERTIES OF COMPOSITE NANOFLUID WITH SURFACTANT

R. GAYATHRI*, P. DEIVA SUNDARI
Department of Electrical and Electronics Engineering, KCG College of Technology, Chennai 600 097, India

Mineral oil in transformer is replaced by the ester oil due to its biodegradability and good thermal & dielectric properties. Ester oil plays a vital role in enhancing the design of high voltage apparatus, as it has better electric and thermal properties. In this paper, the impact of dielectric properties on the mixture of 20% ester oil and 80% mineral oil, due to the effect of TiO_2 nanoparticles was studied. The optimum volume concentration of TiO_2 nanoparticles was found based on the Corona Inception Voltage (CIV) and Break Down Voltage (BDV) and also the optimum concentration of nanoparticles having CTAB surfactant and having oleic acid surfactant was analyzed. The solubility of TiO_2 in composite fluid depends upon the percentage weight of nanoparticles and surfactant. It is concluded that Titania (TiO2) nanoparticles dispersed composite oil having CTAB surfactant has greater CIV and BDV when compared to the oleic acid surfactant. It is also found that Negative Direct Current (NDC) voltages have higher breakdown voltage than Positive Direct Current (PDC) voltages and AC voltages. The statistical analysis depending upon the CIV and BDV of the composite oil, nanofluid and nanofluid with surfactants were made.

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Keywords: Mixed oil nanofluid, Corona discharge, Nanoparticles, Surfactant, UHF sensor

1. Introduction

In the power system grid, transformer plays an important and vital role. It is also the most expensive component in the power system network. Normally, mineral oil is considered for insulation and also as the coolant for the transformer [1]. But nowadays, due to its non-toxicity and biodegradability, ester oil is used for insulation and as a coolant in the transformer [2]. Ester oil also has high dielectric strength, better thermal conductivity, good fire point and pour point which makes it the most preferred. However, ester oil is expensive.

Nowadays, researchers and manufacturers concentrate on the combination of ester and mineral oil as it is cost effective and also has the benefits of the dielectric properties of ester oil [3]. The cost of pure ester oil is very high so the combination of ester and mineral oil is more cost effective. When ester oil is added to the mineral oil, the gasification tendency decreases due to its local stress [2]. So in this work, combination of 20% ester oil with 80% mineral oil is taken as best proportion because it has good break down strength, dielectric properties and cost effective [3-4]. This combination of mineral and ester oil has greater electrical stability as well as good thermal conductivity under the condition of aging [5].

Researchers also have found that addition of small quantity of nano particles to the nano fluid increases the dielectric properties and thermal properties of the fluid. So in this work, nano particles are added along with the proper surfactant in the preparation of the nano fluids containing mineral and ester oil. The thermal and electrical stress of these nano fluids exhibit higher stability [6]. Breakdown strength also increases by adding the nano particles to the combination of ester oil and mineral oil. Statistical analysis showing the effect of breakdown strength uniformation of electric stress in the nanofluid is explained in [8]. The effect of surfactant in the nanofluid in terms of its high dielectric strength, breakdown voltage and also the aging criteria is explained in [9]. Moreover, when nano particles are added to the surfactants, it improves the surface

* Corresponding author: gaya3sbrcdm@gmail.com

characteristics and also makes proper dispersion. Kumar et. Al [10] also stated that the TiO_2 nanoparticle of semi conductive nature present in the combination of mineral oil and ester enhances their electrical and physico chemical properties.

The main reason for the failure of liquid oil insulation inside the transformer is due to the corona partial discharge. The inception of the corona can also cause erosion of transformer material. The surface carbonization also leads to electrode gap bridging resulting in the catastrophic failure of the structure. So it is necessary to find the formation of corona in transformers. This incipient discharge occurs in the liquid insulation mainly due to the weak bond or links and the sharp protrusions from the edges and windings. This incipient discharges are in the order of Ultra High Frequency (UHF). In order to capture this incipient corona discharger, the UHF techniques are adopted. This provides a method to observe the corona incipient discharges [11, 12]. In this work, the corona inception voltage under different voltages was studied based on signals of UHF.

In the current study, the researchers have also carried out the experiment to study the impact of nano particles as well as surfactant in the characteristics of the Corona Inception Voltage (CIV) and Break Down Voltage (BDV) of composite oil based nanofluid. These results suggest the usage of high dielectric composite oil in the transformer. Also, its physical strength makes the replacement of mineral oil with this composite oil. The database available for the performance and characteristics of nano particles present in the mineral and ester oil is not exhaustive.

In the present work, experiments were done with the combination of composite oil of 80% mineral oil and 20% natural (rapeseed) ester oil. The objectives are sectionalized as following: (i) To understand the level of corona inception voltage of composite oil and the impact of Tio_2 nanoparticles along with the surfactant in the optimized composite oil (ii) To understand the level of breakdown voltage of composite oil and the impact of Tio_2 along with the surfactant in the optimized composite oil.

2. Experimental studies

2.1. Procedure for the preparation of composite oil

In this work, APAR Power oil, TO335 make mineral oil and MIDEL 1204 make rapeseed oil were considered. The procedure for the preparation of composite oil is shown in Figure 1 as a block diagram. MIDEL 1204 rapeseed oil and TO335 make mineral oil are mixed in the ratio of 20:80 using magnetic stirrer for 2 hours. The composite oil was kept as it is for a month in order to check the composite oil stability. By keeping this for a month, there is no change in colour and separation of the oil. For understanding, Mineral oil is referred to as [MO], Ester oil as [EO], Mixed composite oil as [XO], XO along with nanoparticle as [NO], NO with Cetyl Trimethyl Ammonium Bromide (CTAB) surfactant as [CNO] and NO with oleic acid surfactant as [ONO].

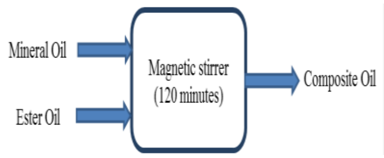


Fig. 1. Preparation of XO.

2.2. Procedure for the preparation of nanofluid

A known volume of TiO_2 which was kept for 3 hours in the hot air oven at the temperature of 150°C is then added to the composite oil. Due to this heating, the moisture present in the TiO_2 was removed. Then the composite oil is added with the CTAB or Oleic Acid surfactant. This mixture of XO, TiO_2, CTAB or Oleic Acid surfactant is thoroughly mixed by using magnetic stirrer for 60 minutes. After this, the sample was left to the sonication process for 3 hours at about the temperature of 40°C using 500 W 20 kHz Sonics Vibra-cell sonicator. After the XO was sonicated, it was kept for three days in order to avoid the micro bubbles formed during the process of sonication. The procedure for the preparation of NO having nanoparticles and surfactant is shown in Figure 2 as a block diagram.

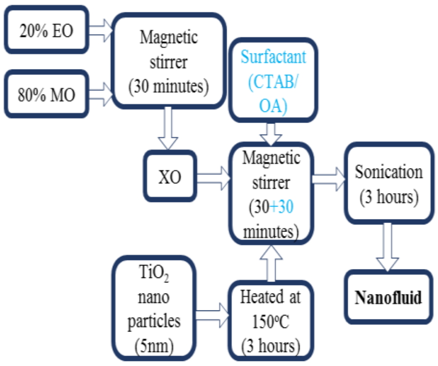


Fig. 2. Procedure for the preparation of NO.

2.3. Experimental set up for CIV and BDV test.

Fig. 3 shows the experimental setup for the generation of different voltages for CIV and BDV analysis for the considered XO. The experimental setup is mainly divided in to three areas. One is test cell having the oil sample to test the corona/breakdown levels, second is the high voltage source and finally the ultrahigh frequency (UHF) sensor which possesses a high bandwidth Digital Storage Oscilloscope (DSO) and a spectrum analyzer.

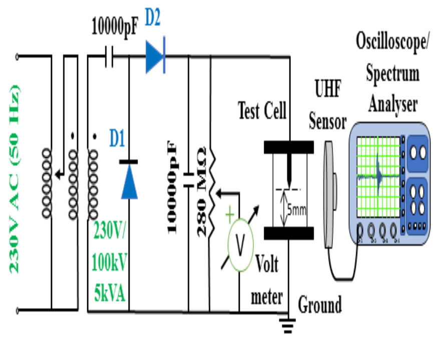
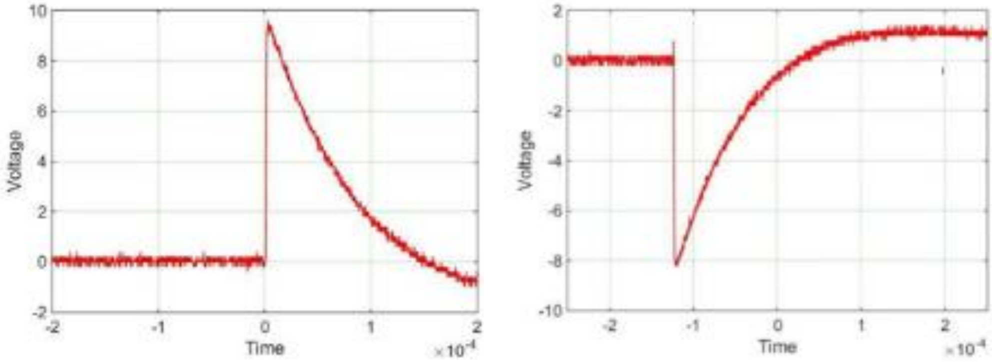


Fig. 3. Experimental setup.

2.3.1 AC and DC voltage sources

In order to generate the AC voltages, the transformer of 100 kV, 5 kVA, 50 Hz was used. With the help of voltage doubler circuit, the DC voltages of both the negative polarity and positive polarity were generated. Figure 3 shows the experimental set up for the generation of DC voltage of positive polarity (PDC).

In order to generate the DC voltage of negative polarity (NDC), the diodes shown in the experiment set up should be reversed. For AC voltage, the supply from the transformer secondary was given to the test cell directly without using any diodes. While measuring the AC voltages, the capacitor divider has been used and for the DC voltages, resistance divider has been used [13]. Voltage at the rate of 300V/s is applied to the test cell. The standard lightning impulse voltage of positive as well as negative polarity are shown in Fig. 4.

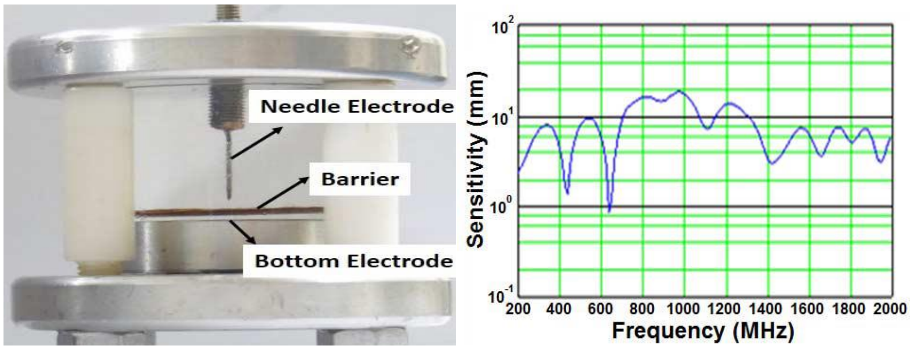


a) *b)*

Fig. 4 Lightning impulse - a) Positive polarity; b) Negative polarity.

2.3.2 Test cells

The configuration of needle plane used in the test cell is shown in Fig. 5a. It is used to generate the corona and breakdown inside the test cell. The diameter of the bottom plane electrode was 5 cm and the radius of curvature of needle electrode of high voltage was 50 μm. The gap between the needle-plane electrodes which is located inside the cylindrical container was 5mm always. The oil to be tested was filled inside the cylindrical container.



a) *b)*

Fig. 5 a) Test cell. b) Frequency response using UHF sensor.

2.6. UHF sensor

The emitted UHF signal due to the Corona Inception Voltage (CIV), was predicted by the UHF sensor (Broad Band). Normally, this UHF sensor is placed away at a distance of 20cm from the test cell containing oil samples. Figure 5b represents the response of system frequency having UHF calibration system. The DSO or spectrum analyzer was connected to the output of UHF sensor.

The DSO model used in this experiment is Lecroy Wavepro 07, bandwidth is 3.5GHz, digital real time oscilloscope of 4 channel operated at 40 GSa/S with 50 Ω input impedance. The range of the signal frequency is 0-3 GHz and its resolution is of 3 MHz bandwidth. This was measured by an Agilent spectrum analyser at zero span modes.

3. Results and discussions

3.1. Optimization of ratio of ester oil and mineral oil and the selection of nanoparticles

Fig. 6a shows the Corona Inception Voltage of different proportions of mineral oil (MO) and ester oil (EO). Moreover the values are higher in the voltage of Negative DC Voltages (NDC) than in the Positive DC Voltages (PDC) and AC voltages. It is seen that there is an increase in Corona Inception Voltage from 0:10 to 10:0 proportions. But in the ratio 2:8 of ester oil and mineral oil which be referred as (XO), the value of Corona Inception Voltage (CIV) is the highest [3].

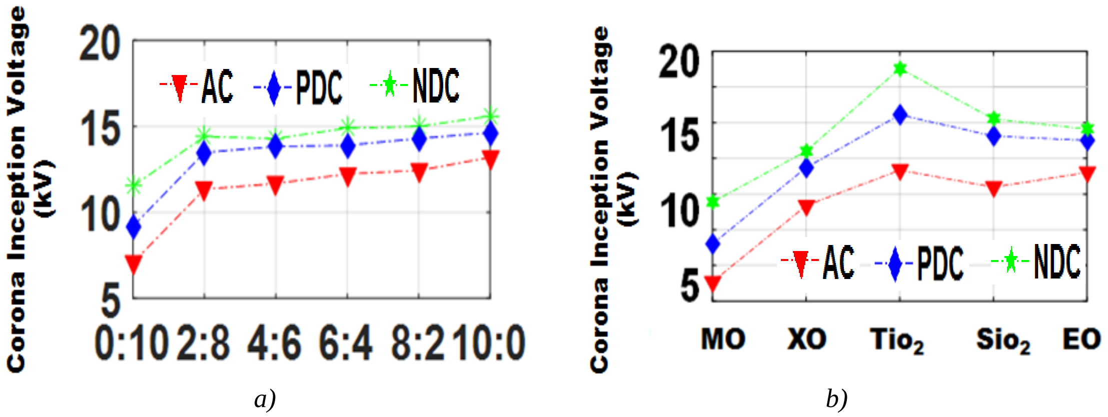


Fig. 6. Corona Inception Voltage under different voltages for different proportions of a) MO and EO; b) MO, XO, XO+Tio$_2$, XO+Sio$_2$, EO.

Fig. 6b represents the CIV of mineral oil (MO), Composite oil (XO), Nano oil of Tio$_2$, Nano oil of Sio$_2$ and Ester oil (EO). It is seen that the Nano oil of Tio$_2$ has higher value of CIV [14]. So for this study, nano oil (NO) with the mixture of composite oil and titania nanoparticles is chosen.

3.2. Statistical analysis

Figs. 7a, 7b, 7c show the probability distribution plot for CIV which was observed with the configuration of needle plane for MO, XO and EO. It is seen that the mineral oil has high scattering data than the composite oil.

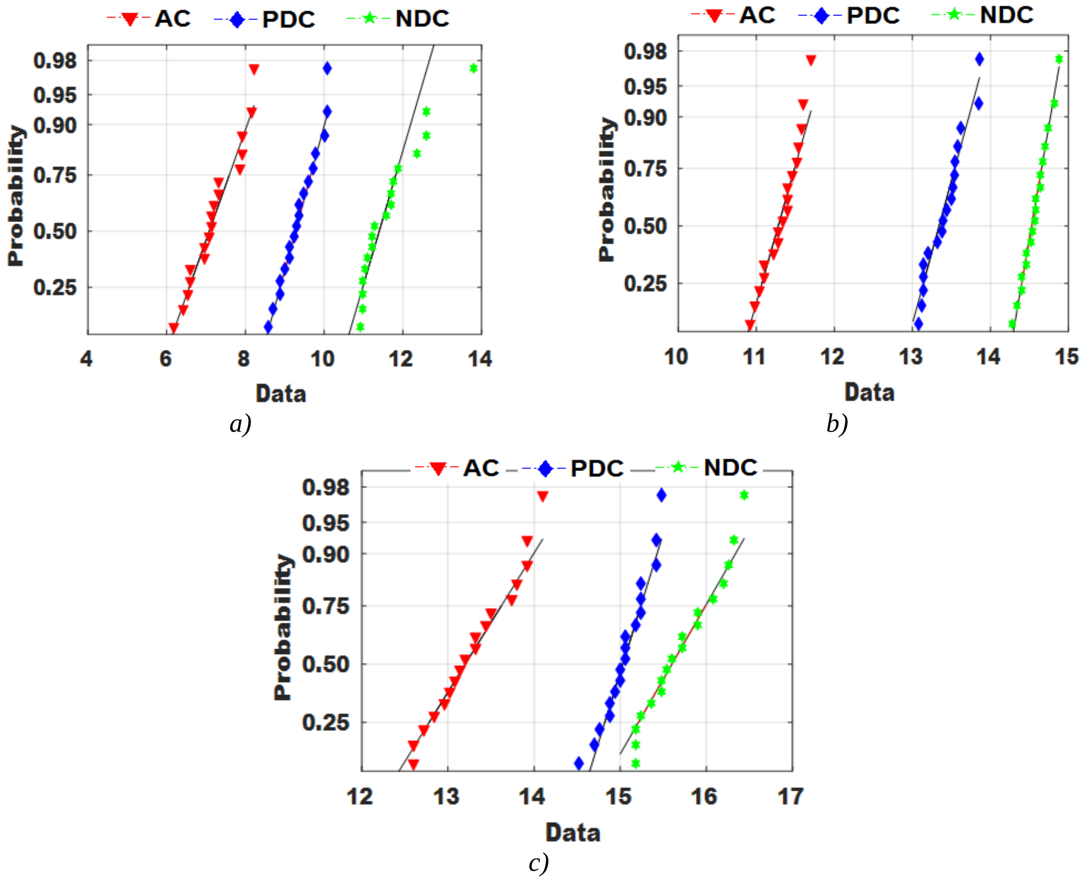


Fig. 7 Probability distribution plot for CIV of a) MO; b) XO; c) EO.

Figs. 8a, 8b, 8c represent the probability plot for CIV which was measured with needle plane electrode configuration for titania nanoparticles dispersed composite oil, titania nanoparticles with CTAB surfactant and titania nanoparticles with oleic acid surfactant for all optimized values. Minimum and maximum CIV values, Mean CIV values and Standard Deviation of nano oil, nano oil with CTAB and nano oil with oleic acid are listed in Tables 1 and 2. It was observed that below V10% and above V90% normal distribution under different voltages seem to be highly scattered [15].

Figs. 8d, 8e, 8f show the distribution probability plot for breakdown which was observed using configuration of needle plane for nano oil, nano oil with CTAB and nano oil with oleic acid for all optimized values. Minimum and maximum breakdown values, Mean breakdown values and Standard Deviation values of nanoparticles dispersed composite oil, titania nanoparticles with CTAB surfactant and titania nanoparticles with oleic acid surfactant are listed in tables 3 and 4. It was observed that there is a high scattering of data on breakdown. This is due to the contaminants formed in composite oil and the formation of carbon content also. It is also observed that there is a colour change in the composite oil after a few breakdowns in different voltages. In all the types of the oil, the Break Down Voltage (BDV) under the Negative DC Voltage (NDC) possess greater value than that at the Positive DC Voltage (PDC) and AC voltages.

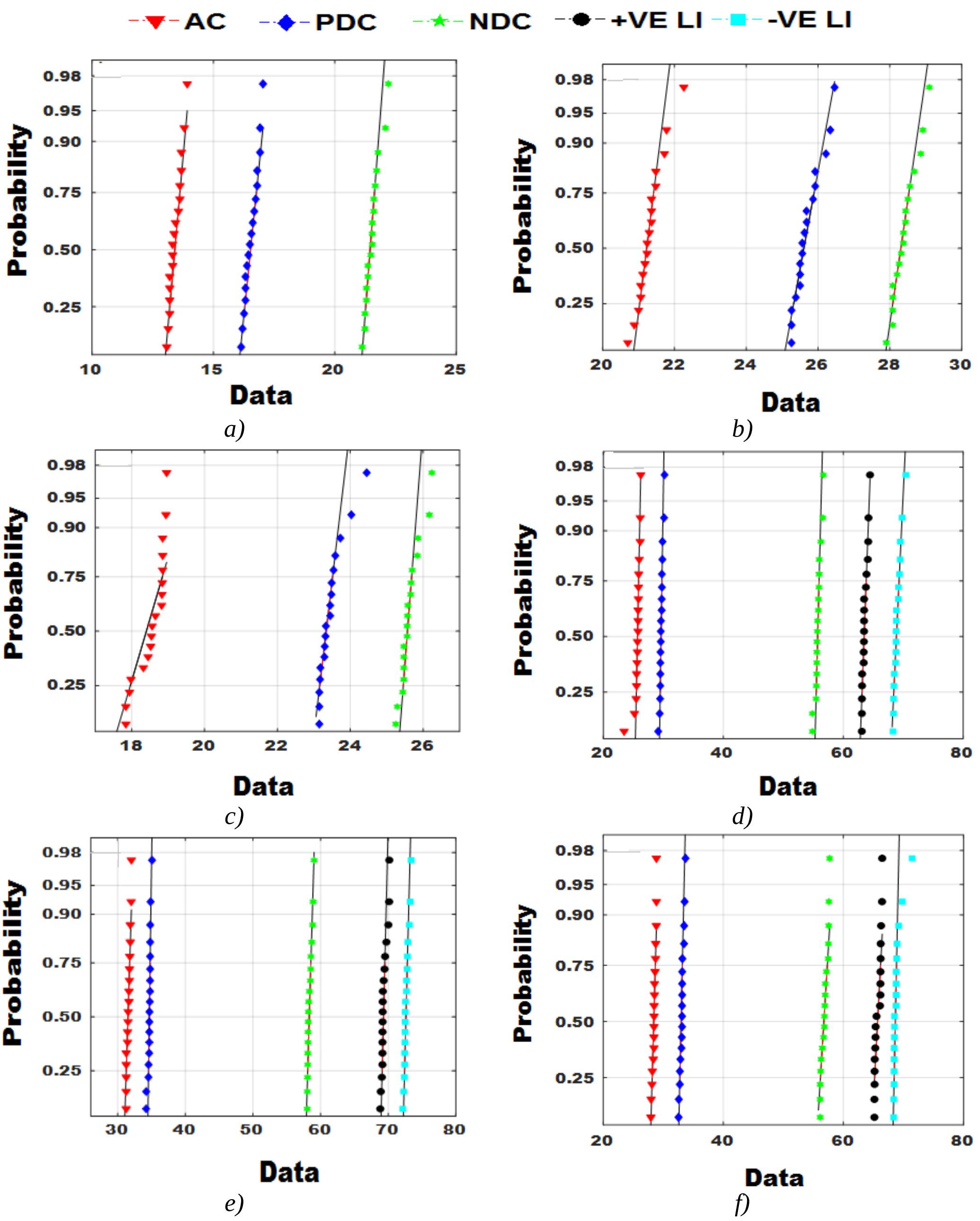


Fig. 8 Statistical analysis of CIV of a) NO; b) CNO; c) ONO; d) NO; e) CNO; f) ONO.

Table 1. Values of CIV at 5%, 25%, 50% and 90% normal distribution for NO, CNO and ONO under different voltages (AC, PDC and NDC).

Different voltages	**Different oils**	**Normal distribution**			
		V5%	**V25%**	**V50%**	**V90%**
AC	NO	15.78	16.02	16.20	16.38
	CNO	20.68	21.06	21.24	21.78
	ONO	17.47	17.94	18.54	18.94
PDC	NO	20.70	20.46	20.70	20.76
	CNO	25.08	25.38	25.26	26.34
	ONO	23.14	23.17	23.33	24.03
NDC	NO	21.12	21.30	21.54	22.08
	CNO	27.84	28.08	28.38	28.92
	ONO	24.57	25.47	25.56	26.17

Table 2. Values of BDV at 5%, 25%, 50% and 90% normal distribution for NO, CNO and ONO under different voltages (AC, PDC and NDC).

Different voltages	**Different oils**	**Normal Distribution**			
		V5%	**V25%**	**V50%**	**V90%**
AC	NO	23.19	25.53	25.78	26.15
	CNO	30.94	31.25	31.54	31.98
	ONO	27.92	28.18	28.46	28.86
PDC	NO	29.09	29.49	29.57	30.13
	CNO	34.20	34.56	34.69	34.85
	ONO	32.48	32.77	33.13	33.56
NDC	NO	52.28	55.51	55.68	56.58
	CNO	57.70	58.10	58.20	58.90
	ONO	55.91	56.20	56.84	57.58

Table 3. Mean, Standard Deviation, Minimum and Maximum values of CIV for NO, CNO and ONO under different voltages (AC, PDC and NDC).

Different Voltages	**Differen t Oils**	**Mean CIV (kV)**	**SD CIV (kV)**	**Min CIV (kV)**	**Max CIV (kV)**
AC	NO	25.38	1.00	22.79	26.23
	CNO	31.51	0.33	30.86	32.01
	ONO	28.37	0.44	26.98	28.86
PDC	NO	29.60	0.30	29.06	30.20
	CNO	34.61	0.29	33.85	35.07
	ONO	33.03	0.39	32.15	33.71
NDC	NO	55.37	1.26	51.61	56.68
	CNO	58.29	0.41	57.35	59.04
	ONO	56.77	0.60	55.84	57.70

Table 4. Mean, Standard Deviation, Minimum and Maximum values of BDV for NO, CNO and ONO under different voltages (AC, PDC and NDC).

Different Voltages	Different Oils	Mean CIV (kV)	SD CIV (kV)	Min CIV (kV)	Max CIV (kV)
AC	NO	16.02	0.62	13.50	16.38
	CNO	21.25	0.39	20.70	22.26
	ONO	18.43	0.48	17.47	18.96
PDC	NO	20.66	0.37	19.80	21.12
	CNO	25.61	0.42	24.72	26.46
	ONO	23.42	0.34	23.06	24.45
NDC	NO	21.48	0.32	21.00	22.20
	CNO	28.34	0.37	27.66	29.10
	ONO	25.52	0.41	24.56	26.24

3.3. Analysis of different oils

Fig. 9 indicates the corona inception voltage values of all types of oils. The CIV value of composite oil having titania nanoparticles at 2.5mg/L is high as shown in Figure 9b. This is considered as an optimized composite oil. Moreover, CIV value of composite oil having 2.5mg/L TiO_2 nanoparticles along with 0.05 mg/L CTAB surfactant is higher as shown in Figure 9c and so it can be taken as the optimized value. The CIV value of composite oil having 2.5mg/L TiO_2 nanoparticles along with 0.5 µL/L oleic acid surfactant is higher too as shown in Figure 9d and so it can be considered as the optimized value. By comparing Figures 9c and 9d, it is understood clearly that the optimized CIV for composite nano oil mixed with CTAB surfactant has a greater value than the other optimized CIV for the composite nano oil mixed with oleic acid surfactant. This is due to the coat covering of the nanoparticle by the surfactant and as it decreases the van der Waals force, it becomes stable.

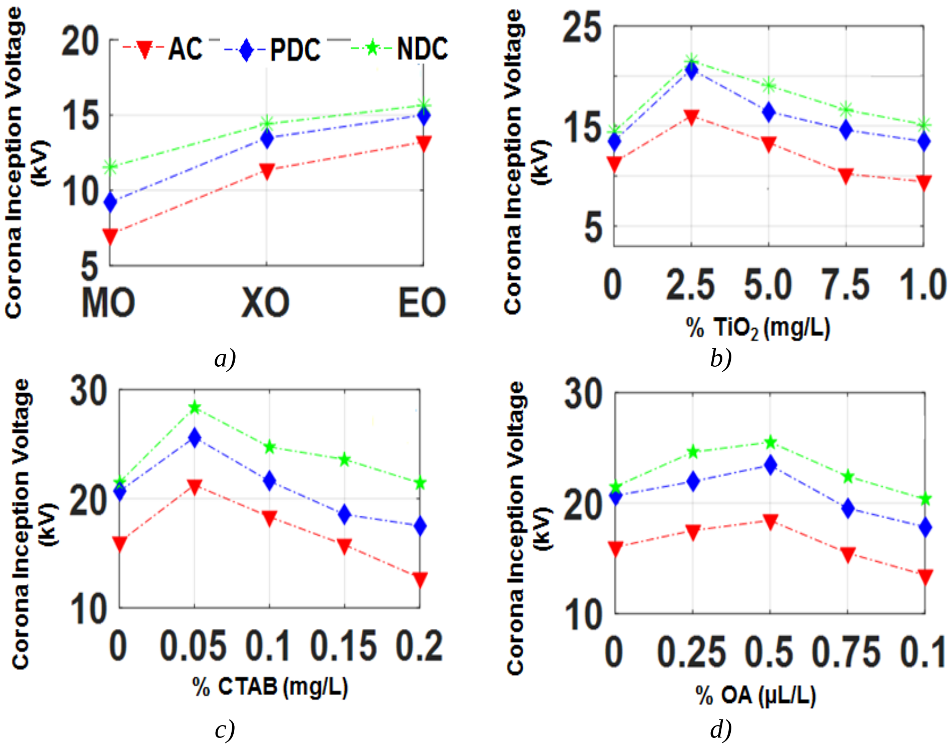


Fig. 9 Corona Inception Voltage (CIV) a) MO, XO and EO; b) NO; c) CNO; d) ONO

Fig. 10 indicates the breakdown voltage values of all types of oils. The BDV value of composite oil having titania nanoparticles at 2.5mg/L is high as shown in Figure 10b. This is considered as an optimized composite oil. Moreover, BDV value of composite oil having 2.5mg/L TiO_2 nanoparticles along with 0.05 mg/L CTAB surfactant is higher as shown in Figure 10c and so it can be considered as the optimized value. The BDV value of composite oil having 2.5mg/L TiO_2 nanoparticles along with 0.5 µL/L oleic acid surfactant is higher too as shown in Figure 10d and so it can be considered as the optimized value. By comparing figures 10c and 10d, it is understood clearly that the optimized BDV for the composite nano oil mixed with CTAB surfactant has a greater value than the other optimized BDV for the composite nano oil mixed with oleic acid surfactant. This is due to the coat covering of the nanoparticle by the surfactant and as it decreases the van der Waals force, it becomes stable.

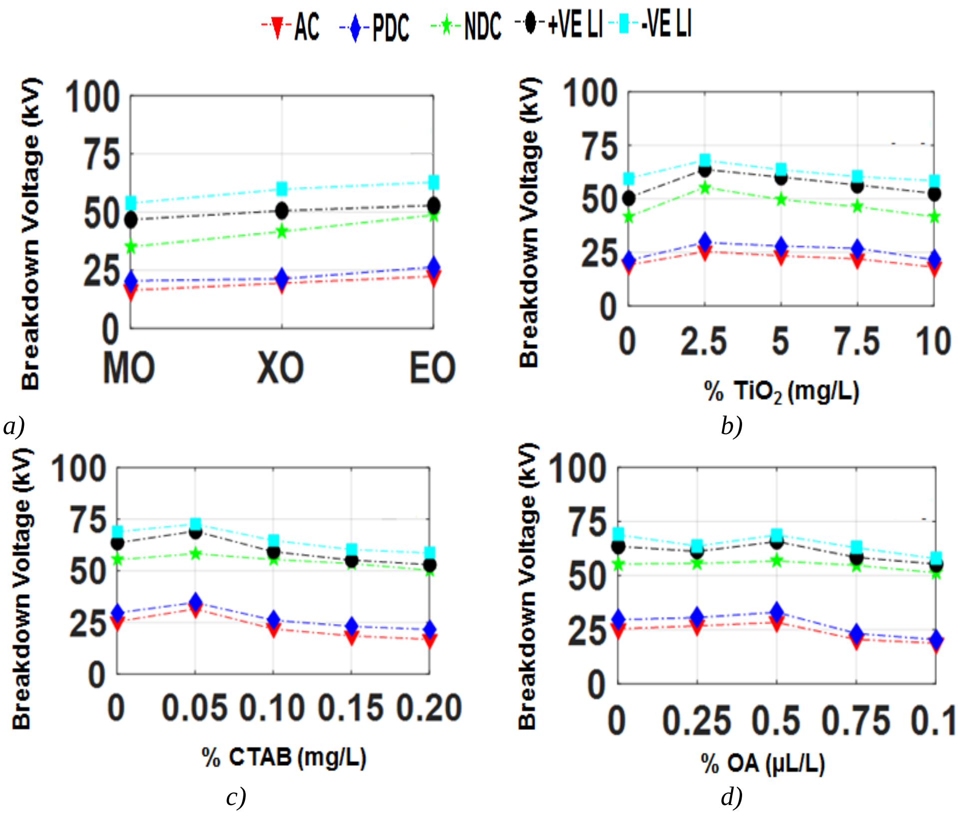


Fig. 10 Break down voltage (BDV) for a) MO MO, XO and EO; b) NO; c) CNO; ONO.

4. Conclusions

Under different voltage levels, the composite oil with the TiO_2 nanoparticle along with surfactant achieved higher value of Corona Inception Voltage (CIV) and Break Down voltage (BDV) than the virgin oil. Moreover, the CIV and BDV values are higher in Negative DC Voltage (NDC) than in Positive DC Voltage (PDC) and AC voltages. Also the probability distribution plot was studied and the possibilities of different percentage of voltage probabilities were identified under different voltage levels. Finally the optimized ratio of TiO_2 nanoparticle mixed in composite oil along with weighted percentage of CTAB surfactant is considered and recommended for replacing mineral oil.

Nomenclature

CIV	-	Corona Inception Voltage
BDV	-	Breakdown Voltage
PDC	-	Positive DC Voltage
NDC	-	Negative DC Voltage
+LI	-	Positive Lightning Impulse.
-LI	-	Negative Lightning Impulse
PD	-	Partial Discharge
UHF	-	Ultra High Frequency
CTAB	-	Cetyltrimethylammonium bromide
OA	-	Oleic Acid
MO	-	Mineral Oil
EO	-	Ester Oil
XO	-	Mixed Oil
NO	-	Nano Oil
CNO	-	CTAB with Nano Oil
ONO	-	Oleic acid with Nano Oil
DSO	-	Digital Storage Oscilloscope

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