TO UNDERSTAND THE IMPROVING EFFECTS OF TITANIA NANO PARTICLE ON THE BREAKDOWN STRENGTH OF TRANSFORMER OIL

A Project Report

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CERTIFICATE

This is to certify that the thesis titled "**Understanding the improving effects of Titania Nano particle on the Breakdown strength of Transformer oil".** Submitted by **M. Arun Kumar (EE12M031)**, to the Indian Institute of Technology Madras, Chennai for the award of the degree of **Master of Technology,** in Electrical Engineering is a bonafide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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M. Arun Kumar

ABSTRACT

Transformer is one of the most important components of electrical power distribution and transmission systems. Their span of life largely depends on the degree of insulation that has been installed and at what quality it has been degraded as a consequence of ageing. Mineral oil is the most widely used liquid insulating medium in transformers all over the world. Much effort has been devoted to explore the effective way to improve its dielectric strength and anti-aging property. Recently, nanoparticles with unique electrical and physical properties have been used to improve the dielectric properties of transformer oil. TiO_2 nanoparticle with good dispersibility and stability in transformer oil was prepared and used to modify insulating property of aged oil. A new class of colloidal dielectric fluids is formulated with the objective of enhancing the dielectric performance of mineral oil for application in power system.

TiO_2 nanoparticles modified by different organic reagents are suspended by means of ultra-sonication. Dielectric strength measurements are carried out for a number of different colloidal systems with varying particle mass fraction. It was found that breakdown voltages under power frequency condition have been improved at the optimum composition. The enhancement of breakdown strength (50 Hz) of transformer oil-based nanofluid is mainly attributed to dielectric property of TiO_2 Nanoparticles, which may act as electron traps in the process of electron transfer in electrically, stressed nanofluids. Furthermore, the high specific surface area of nanoparticles also increases the probability of electron scattering in the nanofluids; this reduces the impact energy of electrons and prevents the oil from ionizing. All these results confirmed that transformer oil modified with TiO_2 nanoparticles hold a promise to improve its insulating properties.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVATIONS

SD Surface Discharge
PM Particle Movement
PD Partial Discharge

HV	High Voltage
FP	Floating Particle
FFT	Fast Fourier Transform
DG	A Dissolved Gas Analysis
HFCT	High Frequency Current Transformer
IEC	International Electro Committee
UHF	Ultra High Frequency
HVDC	High voltage direct current
BDV	Break down voltage
TiO_2	Titanium dioxide
CIV	Corona inception voltage
OIP	Oil impregnated press board

CHAPTER 1

INTRODUCTION

Transmission and distribution transformers form a critical, highly loaded and expensive part of the electricity generation and distribution network. Power transformers rely on the high dielectric strength of insulating oil to achieve normal operation. The potential consequences of transformer failure can be quite damaging.

1.1. BACK GROUND

Nowadays, large numbers of transformers around the world are approaching the end of their design life. Failure statistics of 110-500 kV transformers operated for 25-30 years have shown that 47% of the defects are attributed to the insulation failure induced by deteriorated oil. Aging will lead to a decline in working performance of transformer oil due to deterioration of dielectric strength and cooling property. Furthermore, partial discharge occurs more easily and frequently in aged oil. Products of partial discharge such as moisture, acid and so on in turns accelerate aging process of the oil and form a vicious cycle. Consequently, it is extremely urgent to explore an effective and economical way to improve the dielectric capability of aged transformer oil. Nowadays nanocomposite materials have been gaining more and more attention due to their promising and unique characteristics compared to normal composite materials. Therefore, Nanocomposite materials became of great importance to many industrial fields, including cooling and electrical insulation of electrical power equipment. Nano-composite materials using liquid dielectrics as the base material are referred to as Nanofluids.

Titanium oxide (TiO_2) also known as Titania nanoparticles, were used to enhance the breakdown strength of transformer oil. Regarding the mechanism behind enhancement of breakdown strength for Nanofluids, it is considered that nanoparticles act as electron scavengers leading to converting fast moving electrons into slow negatively charged nanoparticles and hindering streamer propagation. TiO_2nanoparticles were chosen because of their high dielectric constant as well as their good thermal conductivity.

Our recent work has also found that transformer oil modified by TiO_2 nanoparticle had higher dielectric strength rate than that of the pure Oil. In comparison of unaged and aged transformer oil, aged oil is more complicated in study of Partial discharge due to the formation of water, organic polar molecules, and organic acid, which will influence the process of charge injection, migration, and decay in the oil.

1.2. OBJECTIVE

The present aim of the study is “To understanding the improving effects of Titania nano particles on Breakdown strength of Transformer oil” and to understand the effect of TiO_2 nanoparticle on the behavior of normal transformer oil.

The objectives of this study are as follows:

- We will find a new type of nanoparticle modified transformer oil withTiO_2 for better insulating properties than traditional mineral transformer oil.
- Based on the trap characteristics in both TiO_2 Nanofluids and pure oils, we propose a modification mechanism of nanoparticles on the insulating properties of transformer oils.
- Titanium oxide nanoparticles, known as Titania nanoparticles, with unique electrical and physical properties have been used to improve the dielectric properties of transformer oil.
- Both AC and DC breakdown strengths of transformer oils are tested can be enhanced by Proper modification of nanoparticles.

1.3. LITERATURE SURVEY

Diaa-Eldin et al. National Research Centre, Dokki, and Giza 2012, Egypt, Author says that the physical mechanisms behind the enhancement of breakdown strength can be explained considering the electro negativity. In general, electro negativity is a measure of the ability of an element to attract electrons in a chemical bond. Titanium Nano particles have higher electro negativity in nature.

Yuzhen Lv, Yuefan Du, January 2013,In this paper author has come up with a new idea of colloidal of nano particles with transformer oil saying that nanoparticles with unique electrical and physical properties have been used to improve the dielectric properties of transformer oil.

In recent times, for condition monitoring of power apparatus a variety of sensors are used like HFCTs with capacitive or magnetic coupling, acoustic emission sensors and other resonant circuits (Birlasekaran and Leong, 2007).

Partial discharge tests adopting IEC 60270 is a traditional approach, in which many quantities are processed for identification of type of discharges, discharge energy, discharge power, inception voltage, extinction voltage and number of discharges (Gulski, 1995).

Pompili et al. (1998) carried out PD analysis in dielectric liquid and have concluded that charge transfer occurring with the first initiating smallest discharge pulse within the pulse bursts, was estimated to be of the order of 1 pC .

In general, there are three important information regarding PD activity are its level, its type and its location. The information of the PD origin together with the surrounding insulation material is essential to assess e.g. the risk potential of the fault. It is important to know about the PD origin to plan and start maintenance and repair actions. This can significantly reduce the cost and time involved (Tenbohlen et al, 2008).

Pompili et al. (2000) studied PD behavior in transformer oil and have concluded that discharges occur in both positive and negative half cycles of the AC voltage. High intensity discharge always occurs in the positive half of the AC voltage and most of the breakdowns occur in the positive half cycle.

Pompili et al. (2005) studied PD behavior in transformer oil with a point plane gap and have concluded that the first discharge magnitude is always high compared to subsequent discharges.

Carraz et al. (1995) carried out experimental study on particle initiated breakdown studies in transformer oil and have concluded that a fixed particle subjected to a step voltage induces breakdown at a much higher level than the same particle free to move under AC voltage. Also they have concluded that free particle under AC voltage induce breakdown at rather low fields which are of the same order of magnitude as the actual fields in the large oil volumes of high voltage transformers.

Dascalescu et al. (1998) carried out studies on the behavior of conducting particle in DC electric fields and have concluded that the particle levitation depends on the particle size, mass density and the coefficient of restitution.

Tobazeon (1993) observed that when the charged conductive particle come close to opposite electrode, charge transfer occurs causing partial discharge and produces a current peak shorter than 1ns duration.

Measurements have indicated that the UHF signals radiated by partial discharges propagate at the speed of light in oil (Convery and Judd, 2003) and are attenuated by about 6 dB per 10 m of travel (Judd et al., 2005a).

Judd et al. (2005a & 2005b) have provided an extensive review on partial discharge monitoring in transformers using the UHF technique, where the details of the sensors, signal interpretation and the applicability of the technique for online condition monitoring can be found.

The UHF PD detection technique is basically a Non-Destructive Testing (NDT) tool to identify any active defects present in the insulation structure during operation.Sarathi (2008) have carried out partial discharge study due to particle movement in transformer insulation, under DC voltages. They have concluded that the PDs generated under DC voltages radiate UHF signal in the range 0.5-3 GHz.

The fundamental advantages of using UHF technique for identification of PDs in transformers include

1. Immune to radio interference signal generated due to corona in substations
2. Identification and location of PD in power apparatus could be done with good accuracy.

It is well established that insulation in converter transformer is stressed by composite voltage of AC and DC voltages. Hence the author has made an attempt to understand the characteristics of UHF signal generated due to particle movement under the composite voltage formed by AC and DC voltage. The results accrued by the author can provide researchers the world over, a database for proper insulation design for converter transformers. Tenbohlen *et al*. (2006) carried out PD analysis in oil filled transformers and they used UHF sensors through drain valves. They have concluded that onsite PD measurement and laboratory measurement shows less UHF signal attenuation.

Lopez-Roldan *et al*. (2008) studied PD activity in transformers using broadband UHF sensors. The selection of antenna was based on computer simulation and experimental results. Theoretically they have studied the performance of the antenna to evaluate differences in radiation pattern, antenna impedance, gain and effective area. Thus have proposed that sensor based on a conical monopole antenna structure is most suitable for fault identification in transformers.

Liu and Li (2010) studied PD activities in transformer adopting UHF technique and have concluded that sensitivity of the UHF sensor with bandwidth in the range 0.5-1.5 GHz is most suitable to identify incipient discharges in transformers.

Luo and Zhang (2010) carried out study on identification of PD in transformers adopting UHF technique and by using HFCT. They have concluded that UHF sensors could identify incipient discharges effectively compared with HFCTs. They also observed that the HFCT which is directly connected to HV apparatus can detect PDs of higher magnitude.

In recent times, intelligent monitoring systems are very important for enhancing the reliability of power system network. Such systems provide the ability to identify defects as they occur, allowing the scheduling of maintenance, avoidance of equipment failure, optimizing the operation of the equipment and increasing reliability (Rudd *et al*., 2010). Automated diagnostic systems can only be successful if there exists a way of capturing information that indicates health of the apparatus. Analysis of partial discharge (PD) data provides one such indication.

Sarathi *et al*. (2008b) carried out FFT analysis for the UHF signal generated due to particle movement under DC voltages in GIS and have concluded that the frequency content of the signal lays in the range 0.5-1.5 GHz. Also by carrying out continuous wavelet transform on the UHF signal generated, a clear information about the nature of signal confirming the signal generated are from one location or different. Similarity function measured for the UHF signal generated due to partial discharges helps to identify whether the signal is generated at one location or from the different sources.

1.4. ORGANIZATION OF THE REPORT

Chapter 1 presents the background and the objectives of this study. Chapter 2 represents the fundamentals of various factors causing the breakdown in transformer oil and its effects. Chapter 3 discusses the existing research on measurement and understands the effect of TiO_2 nanoparticle on the behavior of normal transformer oil. Chapter 4 discusses the results obtained from the experimental study approach. Chapter 5 presents the specific conclusions based on this study, and discusses the scope of future work.

CHAPTER 2

EXPERIMENTAL STUDY AND ANALYSIS

2.1. GENERAL

In this chapter, the details of the experimental setup established in the laboratory to generate partial/incipient discharges due to different defects and equipment used, experimental techniques adopted for PD measurements are discussed. A brief review about the methods of measurement of PD in transformer is included. Also the basic concepts of the techniques adopted for analyzing the UHF signal generated due to incipient discharges and FFT plots for classification of partial discharge defects are explained.

2.2. PARTIAL DISCHARGE STUDIES AND ITS EFFECTS

Partial discharge (PD) activity is usually an early signature of a failure and may lead to insulation degradation with a short circuit as the final consequence. Partial discharge is a localized dielectric breakdown of a small portion of fluid electrical insulation system under high voltage stress. Because the dielectric constant of the void is considerably less than the surrounding dielectric, the electric field across the void becomes significantly higher than that across an equivalent distance of dielectric. If the voltage stress across the void is increased above the corona inception voltage (CIV) for the gas within the void, partial discharge activity will start within the void. Once begun, PD causes progressive deterioration of insulating materials, ultimately leading to electrical breakdown. The effects of PD within high voltage cables and equipment can be very serious, ultimately leading to complete failure. Repetitive discharge events cause irreversible mechanical and chemical deterioration of the insulating material. Damage is caused by the energy dissipated by high energy electrons , sparks from the discharges.

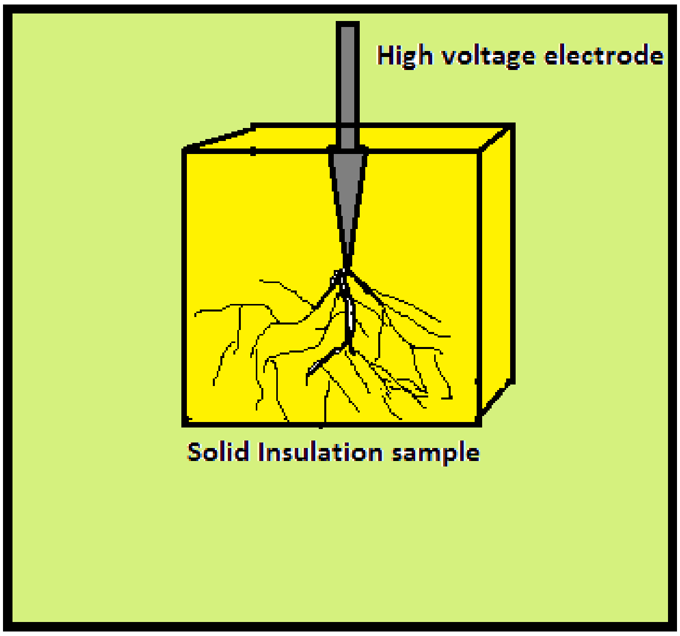


Fig 2.1Partial discharge in solid insulation

2.2.1. CORONA

Corona discharge in insulation is a process by which the current flows from an electrode with a high potential into a neutral fluid, usually air, by ionizing that fluid so as to create a region of plasma around the electrode. Coronas may be positive or negative. This is determined by the polarity of the voltage on the highly-curved electrode. If the curved electrode is positive with respect to the flat electrode, it has a positive corona, if it is negative, it has a negative corona. A positive corona is manifested as uniform plasma across the length of a conductor. A positive corona has much lower density of free electrons compared to a negative corona. The electrons in a positive corona are concentrated close to the surface of the curved conductor, in a region of high potential gradient, whereas in a negative corona many of the electrons are in the outer, lower-field areas. A negative corona is manifested in a non-uniform corona, varying according to the surface features and irregularities of the curved conductor. It appears a little larger than the corresponding positive corona, as electrons are allowed to drift out of the ionizing region, and so the plasma continues some distance beyond it. The total number of electrons and electron density is much greater than in the corresponding positive corona.

2.2.2. SURFACE DISCHARGE

During the process of high voltage operations or testing insulation process huge amount of voltages is allowed to pass through the press board in the required insulation medium in order to test the insulation dielectric strength. The oil and the pressboard structure undergo multistress ageing during high stress operation of transformers causing gradual physical and chemical degradation, which will lead in accelerating of the surface discharge activity. Surface charges present in the insulating material generally can enhance the local electric field, thereby initiating discharges leading to complete damage to the insulation structure. Surface discharge activity was studied through UHF signal analysis. The surface charge measurements are carried out by an electrostatic voltmeter. The surface discharge studies were carried out by adopting IEC (b) electrode configuration.

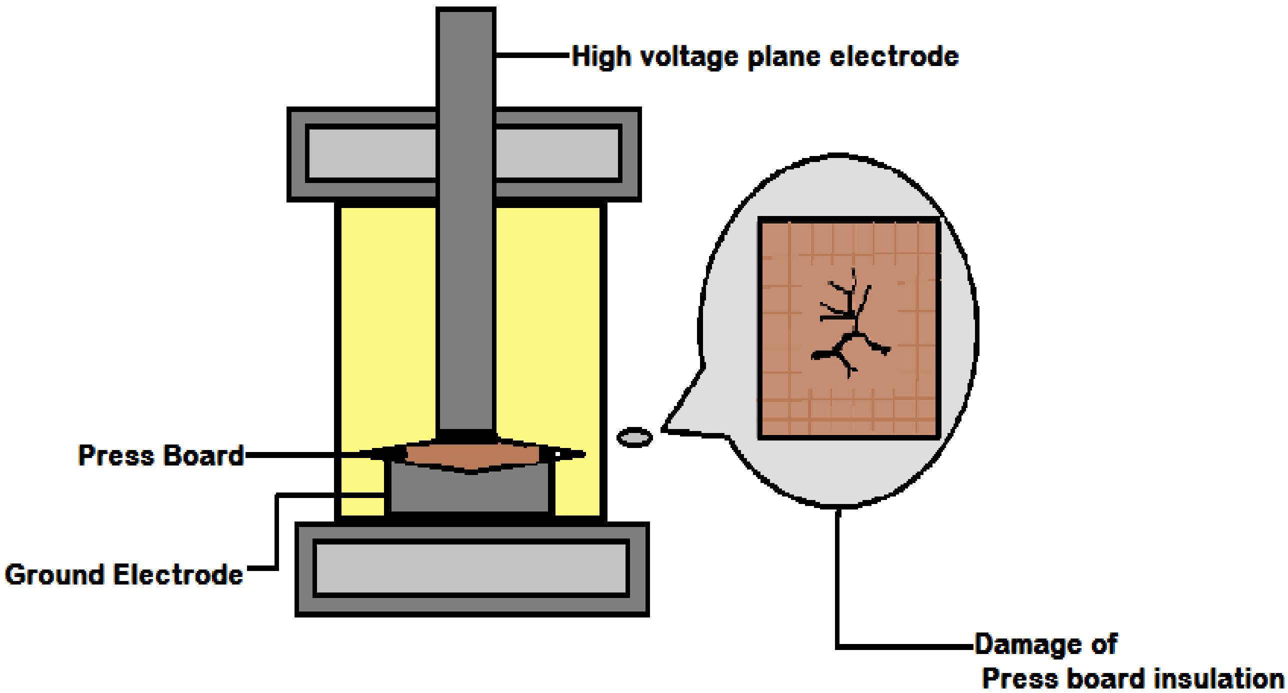
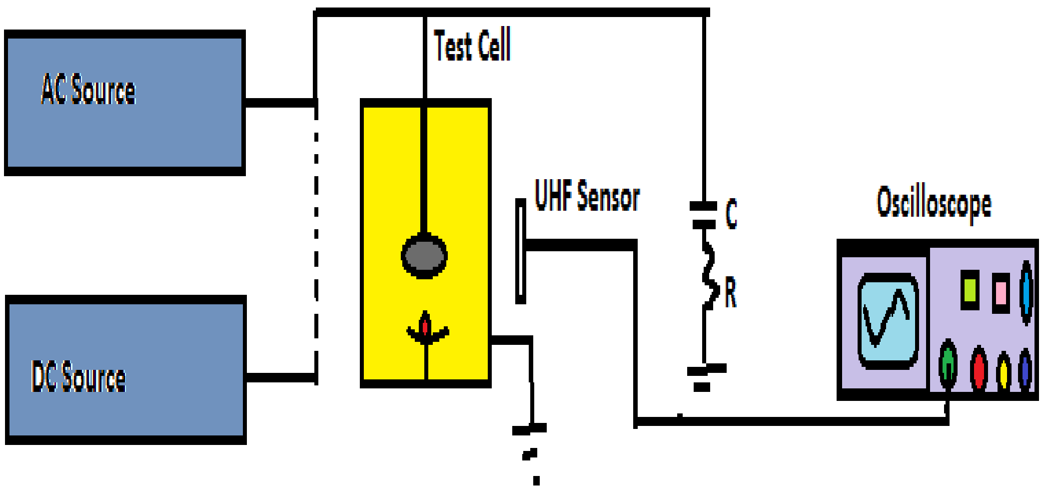


Fig 2.2:The typical photograph of the test cell with press board

The electrode gap set up consists of two electrodes fitted in a cylindrical container filled with transformer oil. The bottom electrode is a plane electrode above which the oil impregnated pressboard (OIP) insulation of 5mm thickness is placed. The upper electrode is a rod electrode with radius of 6 mm placed, which is allowed to touch at the center of the pressboard insulation.

2.2.3. PARTICLE MOVEMENT

Particle discharge is similar to corona discharges occurring in transformer insulation. Partial discharge due to particle movement formation in insulation leads to corona discharges or early uneven discharges when the charged conductive particle comes close to opposite electrode, charge transfer occurs and produces a current peak shorter than 1ns duration. Partial discharge test provides information regarding incipient discharges that occur in the insulation medium, caused due to defects present in the insulation. The UHF technique for partial discharge identification in transformers is gaining acceptance due to its high sensitivity and good signal to noise ratio.



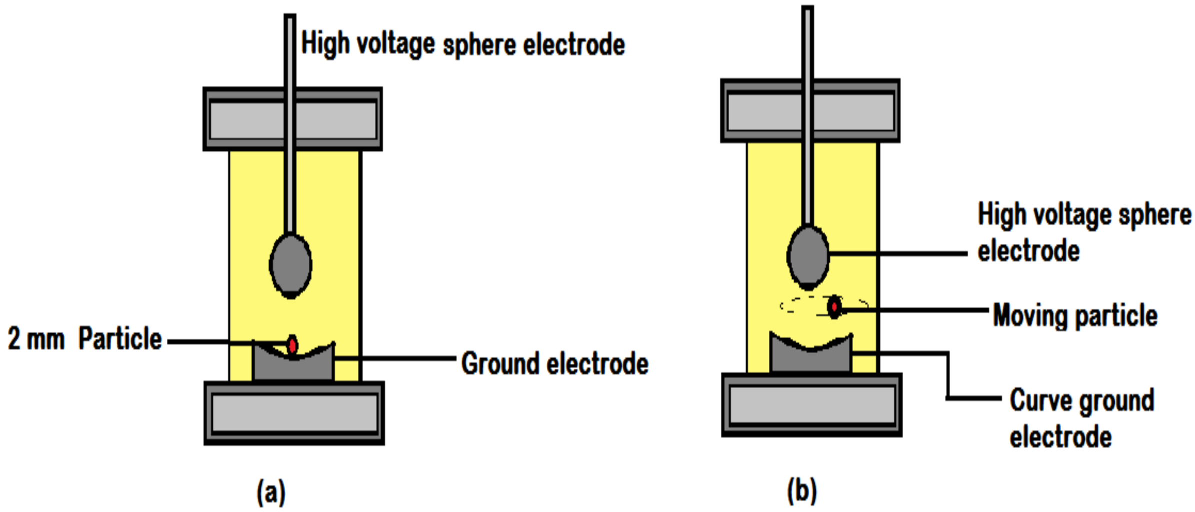


Fig 2.3Test cell for particle movement and corona discharge study

2.3.HIGH VOLTAGE SOURCE

The experimental setup used for the measurement of UHF signal generated due to partial discharges and corona activity in the transformer oil, under the AC and DC voltages. The high AC voltage of power frequency is produced from a transformer rated for 5KVA, 50 Hz, 100 kV units. The AC voltage is measured using the capacitance voltage divider. The DC voltage is generated through a Greinecher voltage doubler circuit and it is measured using the resistance method.

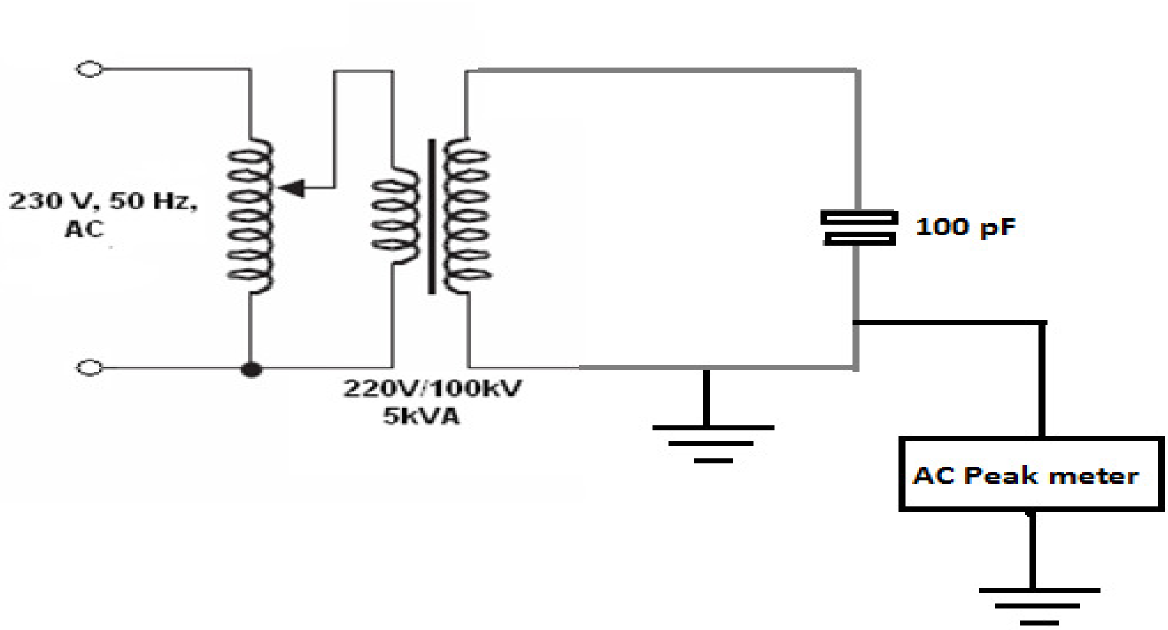


Fig 2.4Basic circuit for the generation of High Voltage AC

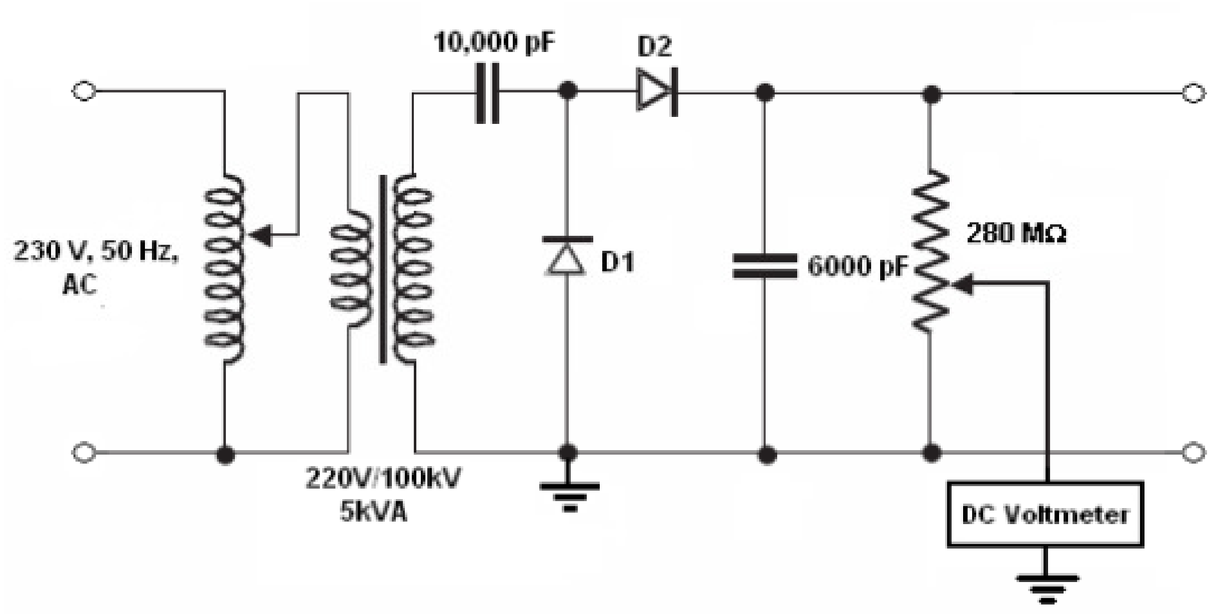


Fig 2.5Basic circuit for the generation of High Voltage (positive) DC

The experimental setup used for the measurement of UHF signal generated by partial discharges formed due to corona, surface discharge particle movement in transformer oil medium, under AC and DC voltages. The basic circuit used for the generation of positive DC voltages. Just by reversing the diodes, it is possible to generate negative DC voltage. The experimental setup, in general, can be sectioned into four parts such as the high voltage source, the transformer oil filled test cell, Phase Resolved Partial Discharge analyzing system and the UHF sensor to be connected to spectrum analyzer/oscilloscope respectively.

2.3.1. TEST CELL DETAILS

In the present work, the magnitude of partial discharges formed due to particle movement, corona discharges, surface discharge and floating discharges were measured through conventional PD measurement process. An attempt has been made to know the sensitivity of UHF technique compared with conventional PD detection method. The test cell used in the present study consists of two electrodes in a cylindrical container filled with transformer oil. The upper electrode was spherical and the lower one was a slightly concave dish to contain the particle. The gap between the two electrodes was maintained at 10mm. A small aluminum ball of diameter 2 mm was placed in the concave lower electrode while the high voltage was connected to the top electrode .The aluminum wire particle of length 4 mm and 1 mm diameter was used for the study.

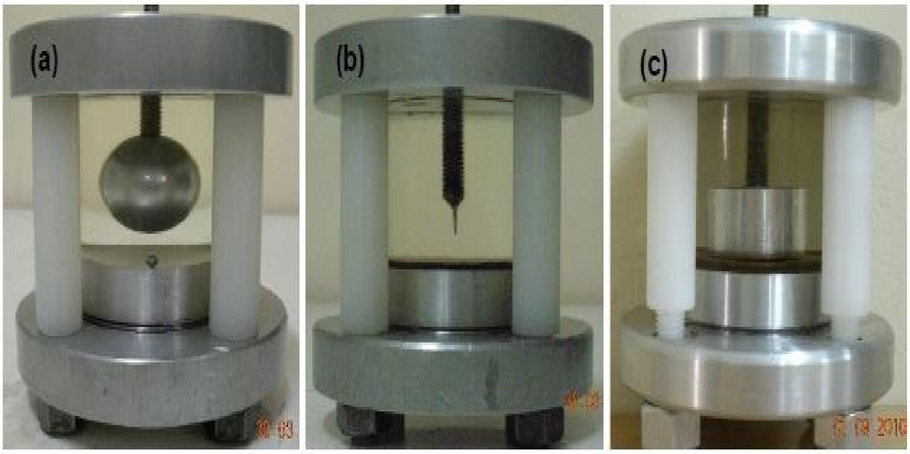


Fig 2.6Photograph of the test electrode configurations to generate PD due to
(a) Particle movement (b) corona (c) surface discharge

Incipient discharges due to corona were initiated with the needle plane configuration, where the top electrode is a needle electrode with its tip radius of curvature of 50 μm and the bottom is a plane electrode over which pressboard of 1 mm thickness is placed .The gap distance between the needle tip to the ground electrode is maintained at 10 mm. The surface discharges were simulated by placing a thin pressboard material of 2 mm thick in the electrode gap.

2.4. UHF SENSOR DETAILS

The UHF sensor used in the present study is a broadband type sensor, which is placed at a distance of 20 cm away from the test cell. UHF signals were acquired using a digital storage oscilloscope (LeCroy, 4 channel, 3 GHz bandwidth) with an input impedance of 50 **Ω**.

2.4.1. PRECAUTIONS THAT HAS TO BE TAKEN DURING THE MEASUREMENT OF UHF SIGNAL

The important precautions considered during measurement of UHF signal are:

1. During UHF measurement it is to be confirmed that there are no interference from external sources.
2. No applied voltage fluctuation is allowed.
3. The length of the cable from UHF sensor to oscilloscope should be same for all the measurement, if any comparison has to be made.
4. Also, position of the sensor should be kept same if any comparison has to be made with the magnitude of UHF signal formed among type of discharges.

5. The contact between the source lead and the test cell should be properly connected, to avoid any contact discharges.

CHAPTER 3

RESULTS AND DISCUSSION

3.1. GENERAL

This chapter presents the results obtained based on the methodical experimental study and the theoretical analysis carried out to understand the partial discharge activity and breakdown strength in transformer oil. Critical assessment of the obtained results has been made and comparisons with the literature in order to accrue important conclusions based on the results obtained are detailed.

3.2. NANOFLUIDS PREPARATION

TiO2 nanoparticle was prepared using a typical procedure in which the reactants were first introduced into a mixed solution of cyclohexane and triethylamine under stirring. After 5 minutes stirring, oleic acid was added into the above solution at room temperature with vigorous agitation. The resulting mixture was subsequently heated to the temperature of 150 ºC. After heating for 24 hours the resulting product was cooled down naturally and washed with distilled water and absolute ethanol for several times to remove the ions possibly remaining in the product, and finally dried in the vacuum at 70 ºC.

3.2.1. MINERAL OIL

Transformer oil or mineral oil is a highly refined mineral oil that is stable at high temperatures and has excellent electrical insulating properties. To improve cooling of large power transformers, the oil-filled tank may have external radiators through which the oil circulates by natural convection. Transformer oils are subject to electrical and mechanical stresses while a transformer is in operation in addition there is contamination caused by chemical interactions with windings and other solid insulation during high operating temperature.

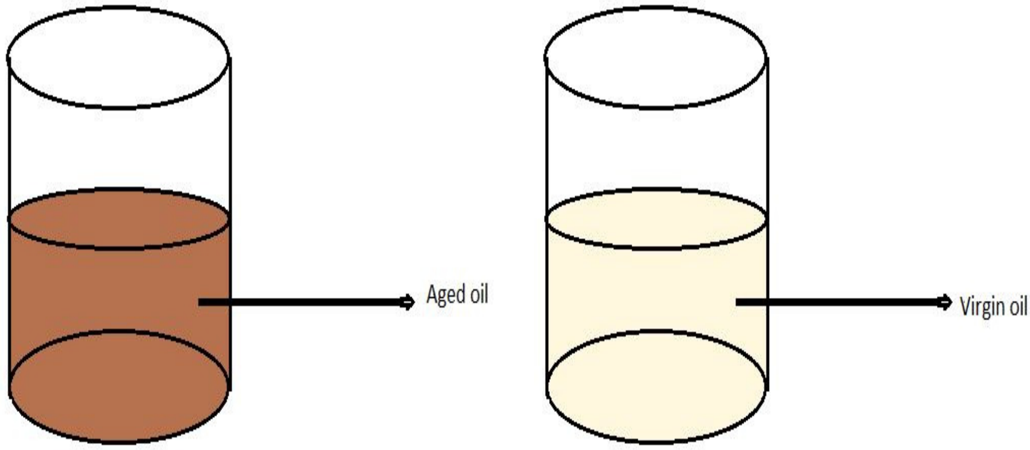


Fig3.1Comparison on virgin oil and aged oil

3.2.2. NANO FLUID OR MODIFIED OIL

TiO_2 nanoparticle with good dispersibility and stability in transformer oil was prepared and used to modify the insulating property of mineral oil to enhance the dielectric performance of mineral oil in power system application. TiO_2 nanoparticles modified by different organic reagents are suspended by means of ultra-sonication. TiO_2 Nanoparticles act as electron traps in the process of electron transfer in electrically, stressed Nanofluids. Furthermore, the high specific surface area of nanoparticles also increases the probability of electron scattering in the Nanofluids this reduces the impact energy of electrons and prevents them from getting ionized and resulting in high efficiency.

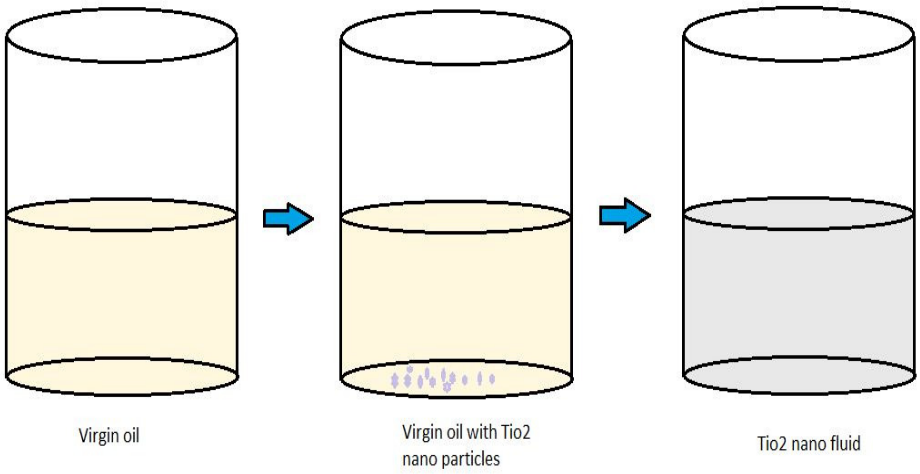


Fig3.2Classification of Virgin oil and modified TiO_2 oil

3.2.3. NANOFLUIDS PREPARATION PROCESS

TiO_2 nanoparticle with good dispersibility and stability in transformer oil was prepared and used to modify insulating property of mineral oil. TiO_2 nanoparticles modified by different organic reagents are suspended by means of ultra-sonication.

The various steps involved in TiO_2 Nanofluids preparation are

- TiO_2 nanoparticle was prepared using tetra-butyl titanate and water vapor as reactants by a solvothermal method.
- To ensure uniform dispersion of nanoparticle in the transformer oil, oleic acid was used to modify the surface of TiO_2 nanoparticle.
- In a typical procedure, reactants were first introduced into a mixed solution of cyclohexane and triethylamine under stirring.
- After 15 minutes stirring, oleic acid was added into the above solution at room temperature with vigorous agitation.
- The resulting mixture was subsequently heated to the temperature of 150 ºC. After heating for 24 hours
- The resulting product was cooled down naturally and washed with distilled water and absolute ethanol for several times to remove the ions possibly remaining in the product, and then finally dried in the vacuum at 70 ºC.
- Now the modified oil was produced by adding a certain amount of TiO_2 nanoparticle into the normal oil.
- Then, TiO_2 nanoparticle with different volume concentration was dispersed into the virgin oil by ultra-sonication treatment for around 3 hours.
- For the comparison between the normal oil and modified normal oil, the normal oil was also treated with the same ultrasonic process.

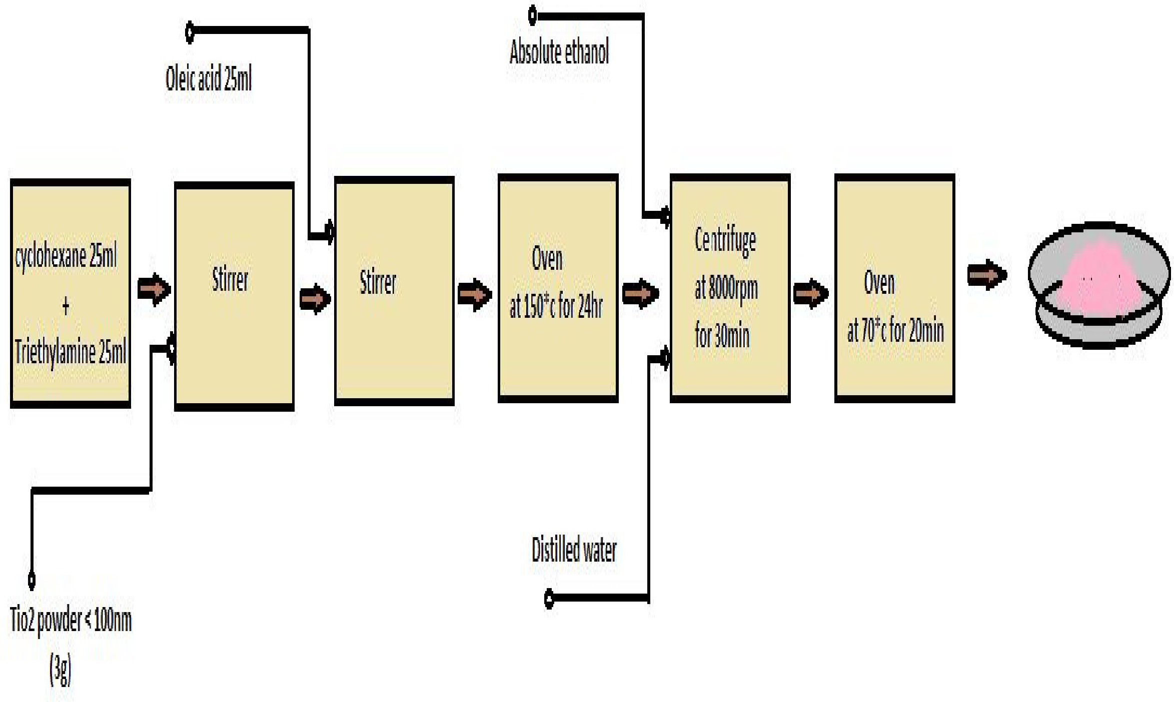


Fig 3.3Flowchart for preparation procedures for oil-based Nano fluid

The concentrations of TiO_2 nanoparticles in transformer oil are in the range from 0.0001g/ml, 0.0002 g/ml to 0.0003 g/ml. The nanoparticles were dispersed in the base fluid through an ultra-sonication method for 3hours.In order to let small micro bubbles created during sonication float toward the surface, the suspensions were left to rest for 8hours before any measurements were carried out.

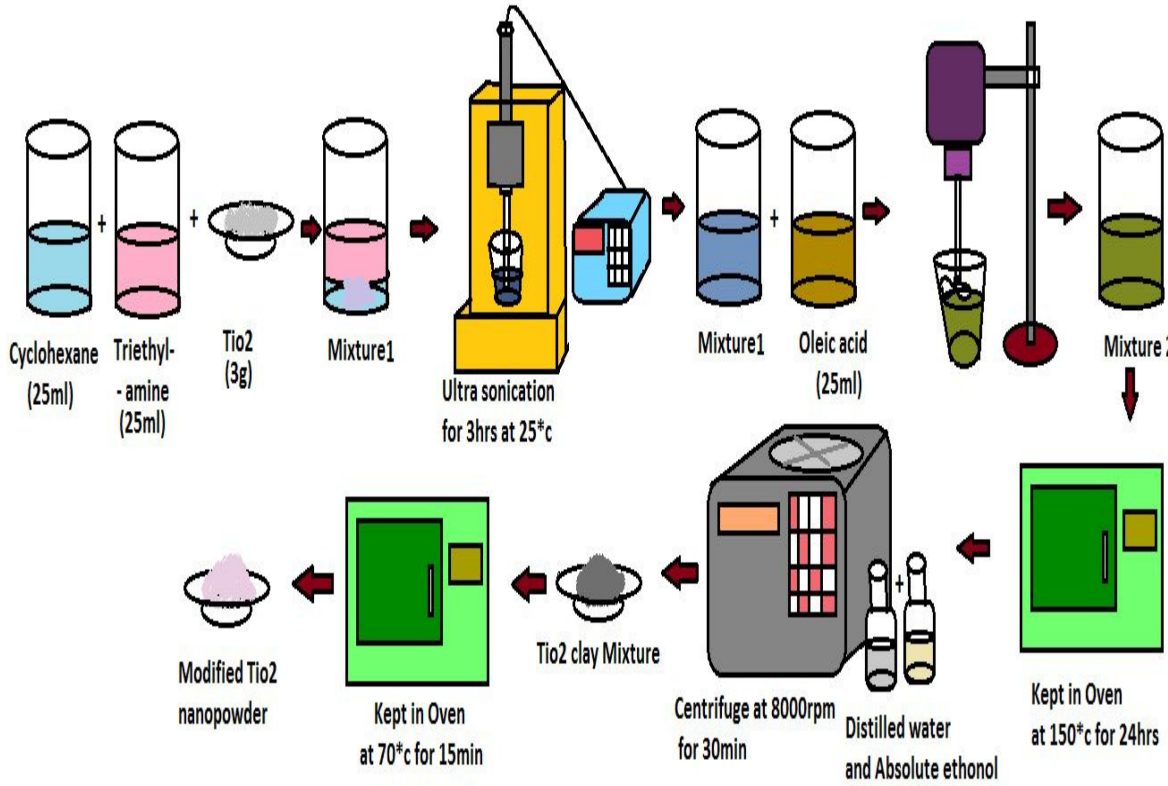


Fig 3.4 Diagrammatic representation of Nano powder preparation

Now this nano fluid which is prepared from the above procedure is subjected to various tests like AC breakdown, DC breakdown, Surface discharge, Corona, Particle moment, inception voltages were measured in accordance with IEC 60156 and IEC 60897 standards.

3.3. TiO_2 NANO FLUID SAMPLE PREPARATION METHOD FOR PD STUDY

TiO_2 nanoparticle with good dispersibility and stability in transformer oil was prepared and used to modify insulating property of mineral oil. The concentrations of TiO_2 nanoparticles in transformer oil are in the range from 0.0001g/ml, 0.0002 g/ml to 0.0003 g/ml. The nanoparticles were dispersed in the base fluid through an ultra-sonication method for 3hours. In order to let small micro bubbles created during sonication float toward the surface, the suspensions were left to rest for 8hours before any measurements were carried out. No additional treatment was applied after the suspension is prepared.

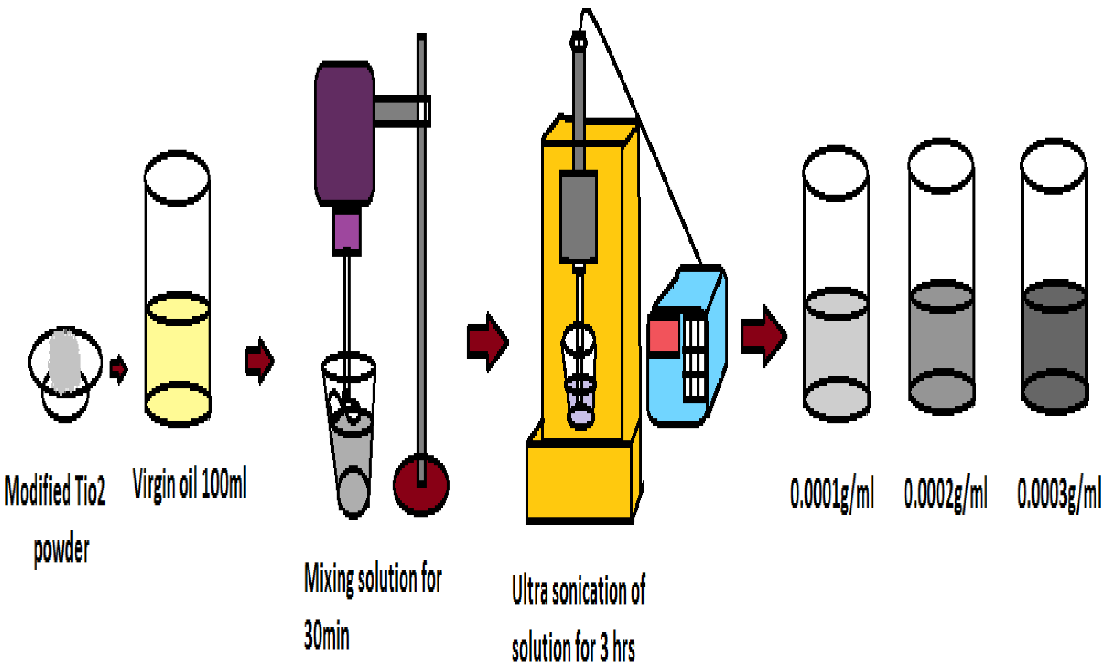


Fig 3.5 Test solutions preparation procedure for different concentration of Modified TiO_2

3.4. AC (50HZ) BREAKDOWN VOLTAGE TEST

The high AC voltage of power frequency is produced from a transformer rating of about 5 kVA, 50 Hz, 100 kV units. The AC voltage is measured using the capacitance voltage divider.[10] Yuzhen Lv, Yuefan (2013) said that TiO_2 nanoparticle with good dispersibility and stability in transformer oil was prepared and used to modify insulating property of aged oil. It was found that space charge decay rate in the modified aged oil can be significantly enhanced to 1.57 times of that in the aged oil. Similarly in our study we saw that both AC and direct current (DC) breakdown strength of transformer oils can be enhanced by proper modification of nanoparticles.

Our recent work has also found that transformer oil modified by TiO_2 nanoparticle possesses higher charge decay rate than that in the pure oil. Here study and conduction of the breakdown voltage tests were carried out and it was found that space charge decay rate in the modified aged oil can be significantly enhanced to 2 times of that when compared to normal oil in all the electrode configurations and therefore the process of enhancement has been clearly seen from the breakdown test results of both sphere plane and needle plane electrode configurations. Table 3.1 and 3.2 gives us the AC breakdown voltage results of sphere plane and needle plane configuration.

In all the above study it has been clearly seen that the breakdown voltage has been enhanced and is higher in rate compared to virgin oil. Test has been carried out for variable distances from 2-10mm and it has been seen that the voltage has been increased with distance increased.

3.4.1. BDV OF AC SPHERE PLANE CONFIGIURATION

Table 3.1Breakdown voltages of AC sphere plane configurations

S.No	Distance (mm)	Virgin Oil (kV)	TiO_2 Modified Oil (0.0003g/100ml) (kV)	Configuration Set up
1	2	15	17.21	Sphere Plane
2	4	19	22.5	Sphere Plane
3	6	23	25.3	Sphere Plane

4	8	25	27	Sphere Plane
5	10	28	31	Sphere Plane

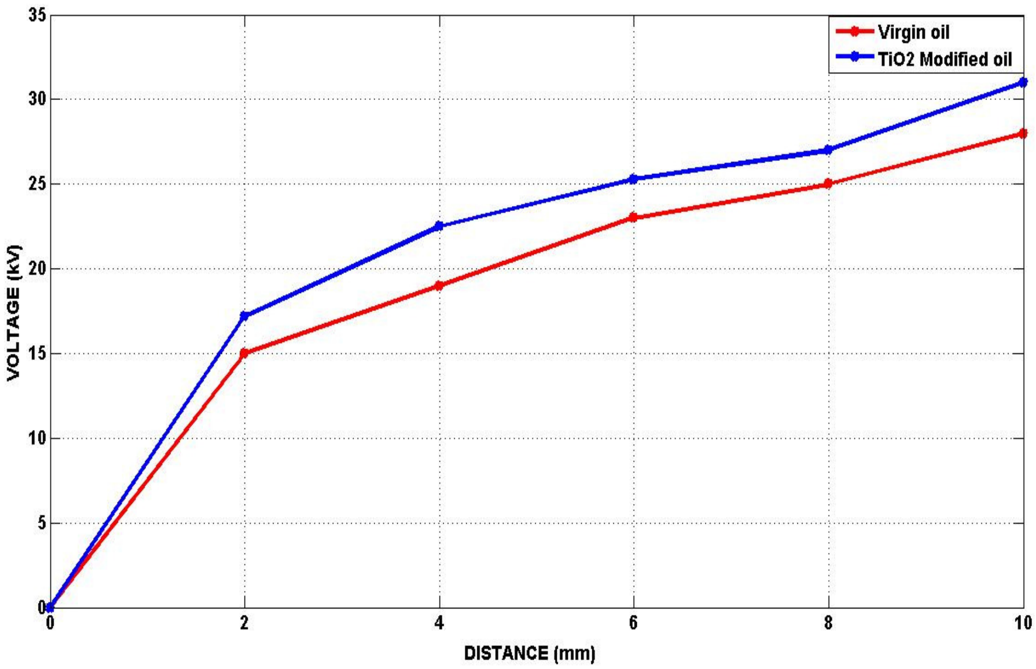


Fig 3.6 Comparison of AC breakdown voltage of both Normal oil and TiO_2 modified oil in Sphere plane configuration

3.4.2. BDV OF ACNEEDLE PLANE CONFIGIURATION

Table 3.2Breakdown voltages of AC Needle plane configurations

S.No	Distance (mm)	Virgin Oil (kV)	TiO_2 Modified Oil (0.0003g/100ml) (kV)	Configuration Set up
1	2	7	10	Needle Plane
2	4	8	11.5	Needle Plane
3	6	10	12.8	Needle Plane
4	8	12	14.92	Needle Plane

5	10	14	16.4	Needle Plane

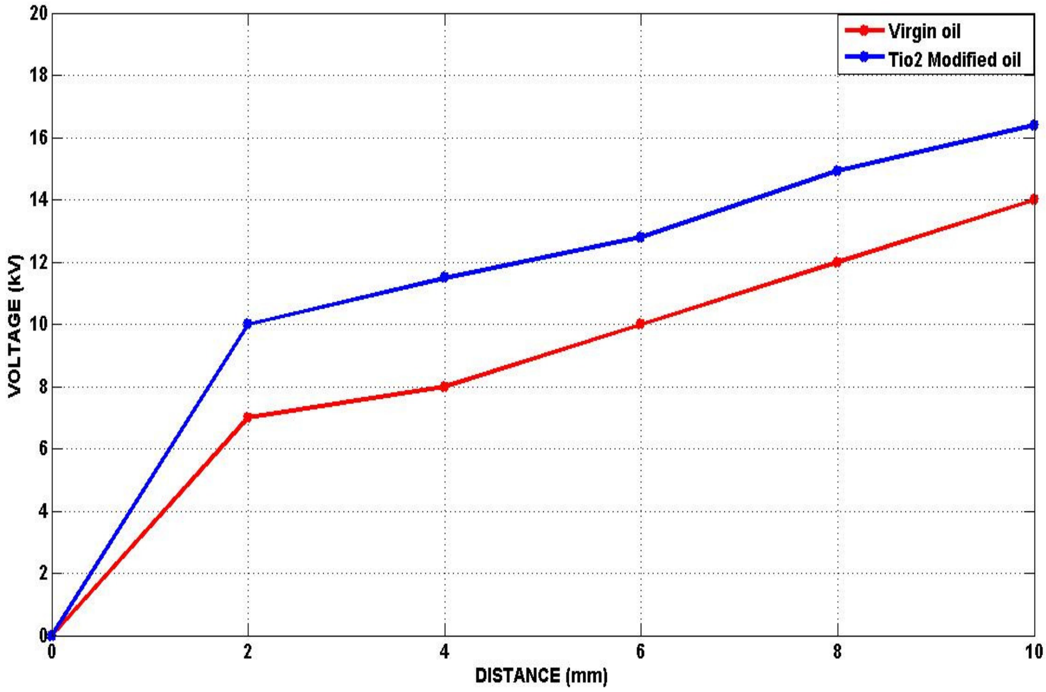


Fig 3.7 Comparison of AC Breakdown voltage of both Normal oil and TiO_2 modified oil in needle plane configuration

3.5. DC BREAKDOWN VOLTAGE TEST

The DC voltage is generated through a Greinecher voltage doubler circuit and measured using the resistance divider method. Just by reversing the diodes, it is possible to generate negative DC voltage. [10] Yuzhen Lv, Yuefan said that TiO_2 nanoparticle with good dispersibility and stability in transformer oil was prepared and used to modify insulating property of aged oil. It was found that space charge decay rate in the modified aged oil can be significantly enhanced to 1.57 times of that in the aged oil. Similarly in our study we saw that both AC and direct current (DC) breakdown strength of transformer oil can be enhanced by proper modification of nanoparticles.

Tests were carried out with both sphere plane and needle plane set up of different distances were varied from 2-10 mm. Our recent work has also found that transformer oil modified by TiO_2 nanoparticle possesses higher charge decay rate than that in the pure oil. It was found that space charge decay rate in the modified aged oil can be significantly enhanced to 2 times of that when compared to normal oil in all the electrode configurations and therefore the process of enhancement has been clearly seen from the breakdown test results of both sphere plane and needle plane electrode configurations.

While from the results acquired table 3.3 and 3.4 gives us the breakdown voltage of DC sphere plane voltages and 3.5 and 3.6 gives us the breakdown voltages of DC needle plane voltages and Fig 3.8 and 3.9, 3.10 and 3.11gives us the comparison plot between the virgin oil and modified oil in positive DC and negative DC respectively which clearly shows the increase in breakdown voltages. Test has been carried out for variable distances from 2-10mm and it has been seen that the voltage has been increased with distance increased.

3.5.1. BDV OF POSITIVE DC SPHERE PLANE CONFIGURATION

Table 3.3Breakdown voltages of Positive DC sphere plane configurations

S.No	Distance (mm)	Virgin Oil (kV)	TiO_2 Modified Oil (0.0003g/100ml) (kV)	Configuration Set up
1	2	17	21	Sphere Plane
2	4	21.59	25.7	Sphere Plane
3	6	24.5	28	Sphere Plane
4	8	27	30.27	Sphere Plane
5	10	29.8	31.62	Sphere Plane

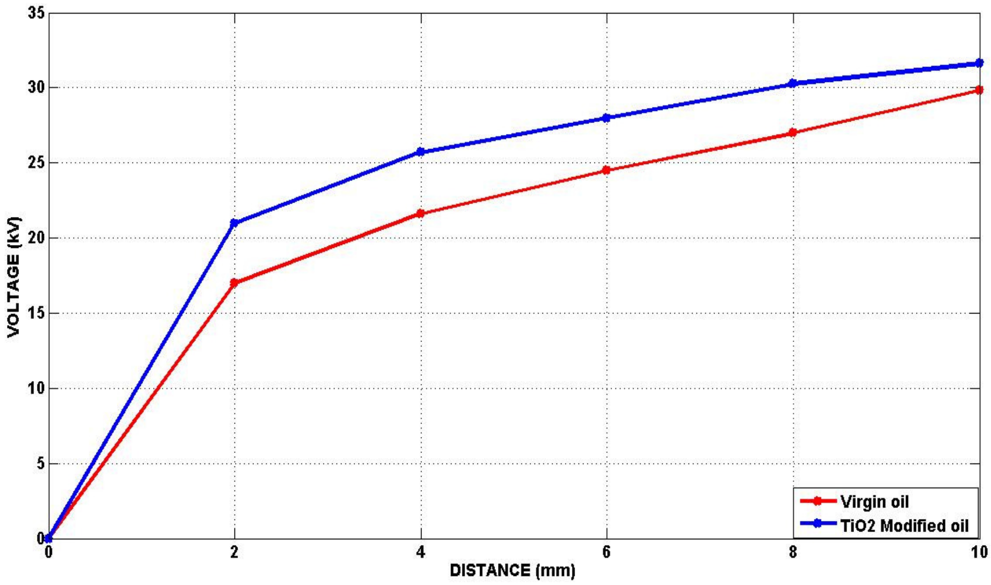


Fig 3.8Comparison of +ve DC breakdown voltage of both Normal oil and TiO_2 modified oil in Sphere plane configuration

3.5.2. BDV OF NEGATIVE DCSPHERE PLANE CONFIGURATION

Table 3.4Breakdown voltages of Negative DC sphere plane configurations

S.No	Distance (mm)	Virgin Oil (kV)	TiO_2 Modified Oil (0.0003g/100ml) (kV)	Configuration Set up
1	2	21	23.81	Sphere Plane
2	4	24	27.2	Sphere Plane
3	6	26	30.09	Sphere Plane
4	8	28	32.72	Sphere Plane
5	10	30	35	Sphere Plane

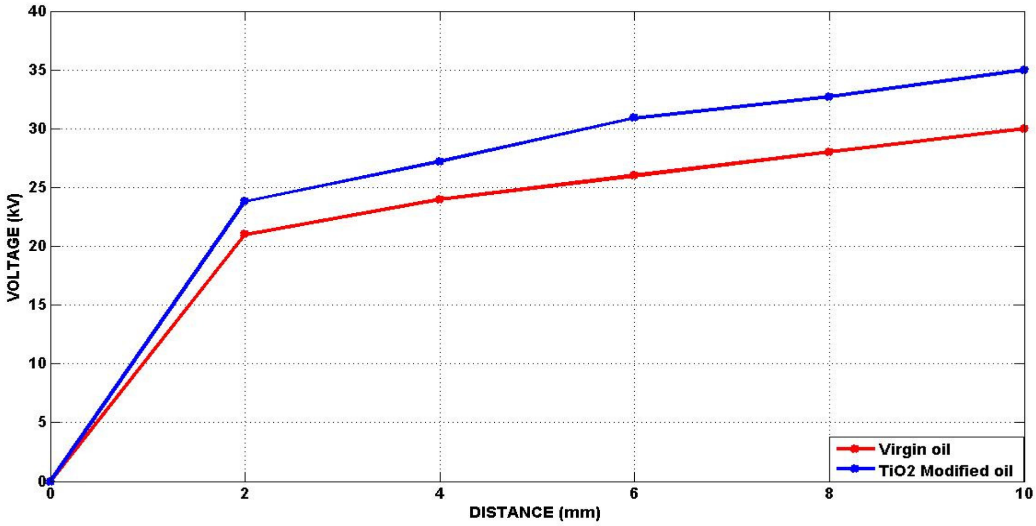


Fig 3.9Comparison of -ve DC breakdown voltages of both Normal oil and TiO_2 modified oil in Sphere plane configuration

3.5.3. BDV OF POSITIVE DCNEEDLE PLANE CONFIGURTION

Table 3.5Breakdown voltages of positive DC needle plane configurations

S.No	Distance (mm)	Virgin Oil (kV)	TiO_2 Modified Oil (0.0003g/100ml) (kV)	Configuration Set up
1	2	9	11	Needle Plane
2	4	12	13	Needle Plane
3	6	14.5	16	Needle Plane
4	8	18	20	Needle Plane
5	10	21	23	Needle Plane

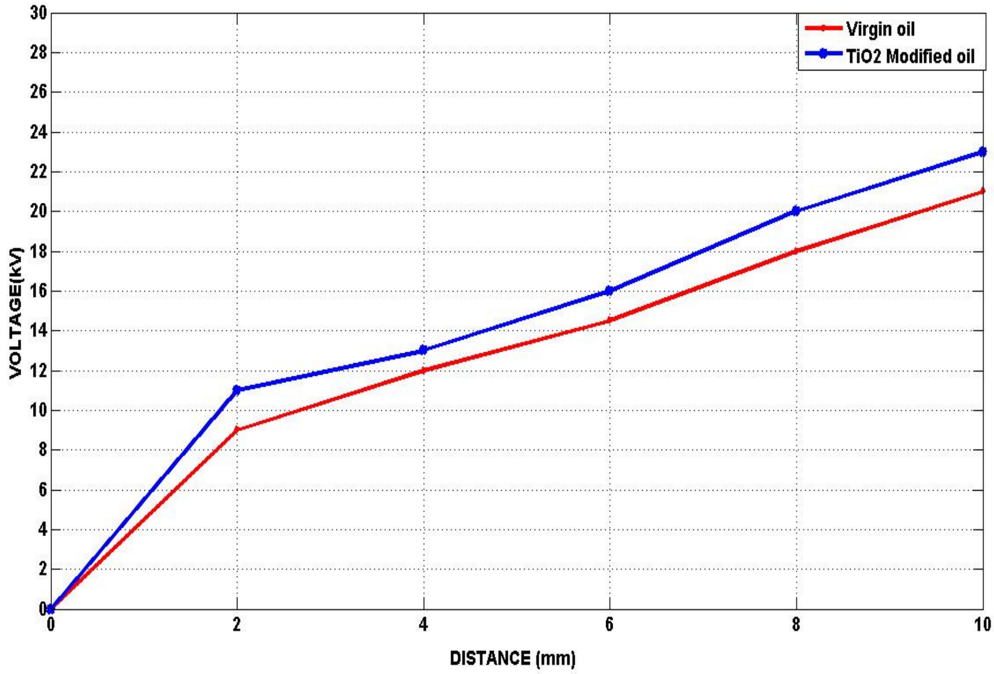


Fig 3.10Comparison of +ve DC breakdown voltage of both Normal oil and TiO_2 modified oil in Needle plane configuration

3.5.4. BDV OF NEGATIVE DCNEEDLE PLANE CONFIGURATION

Table 3.6Breakdown voltages of negative DC needle plane configurations

S.No	Distance (mm)	Virgin Oil (kV)	TiO_2 Modified Oil (0.0003g/100ml) (kV)	Configuration Set up
1	2	10	12.31	Needle Plane
2	4	13.8	15	Needle Plane
3	6	16	17.59	Needle Plane
4	8	19	20.4	Needle Plane
5	10	22.76	24	Needle Plane

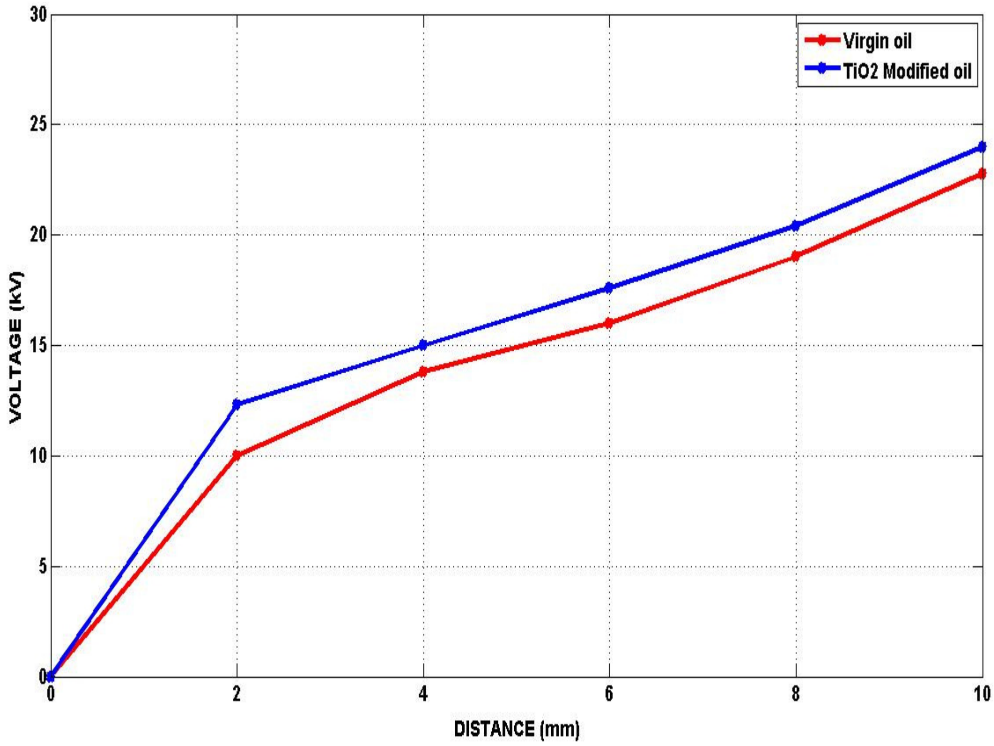


Fig 3.11Comparison of -ve DC breakdown voltage of both Normal oil and TiO_2 modified oil in Needle plane configuration

3.6. ANALYSIS OF PARTIAL DISCHARGE INCEPTION VOLTAGE IN TRANSFORMER OIL

Incipient discharges occur due to different defect conditions in transformer oil, adopting UHF technique are carried out under different voltage conditions. The levitation voltage or the partial discharge inception voltage due to particle movement, corona activity, surface discharge and discharge from floating metallic components is obtained based on the first UHF pulse that is captured by the oscilloscope during the test from the UHF sensor output. It is observed that the bandwidth of the UHF signal formed by the occurrence of PD due to particle movement lies in the range 0.5-1.5 GHz. It is evident that the signal frequency up to few GHz is a consequence of current pulses with nanosecond rise time.

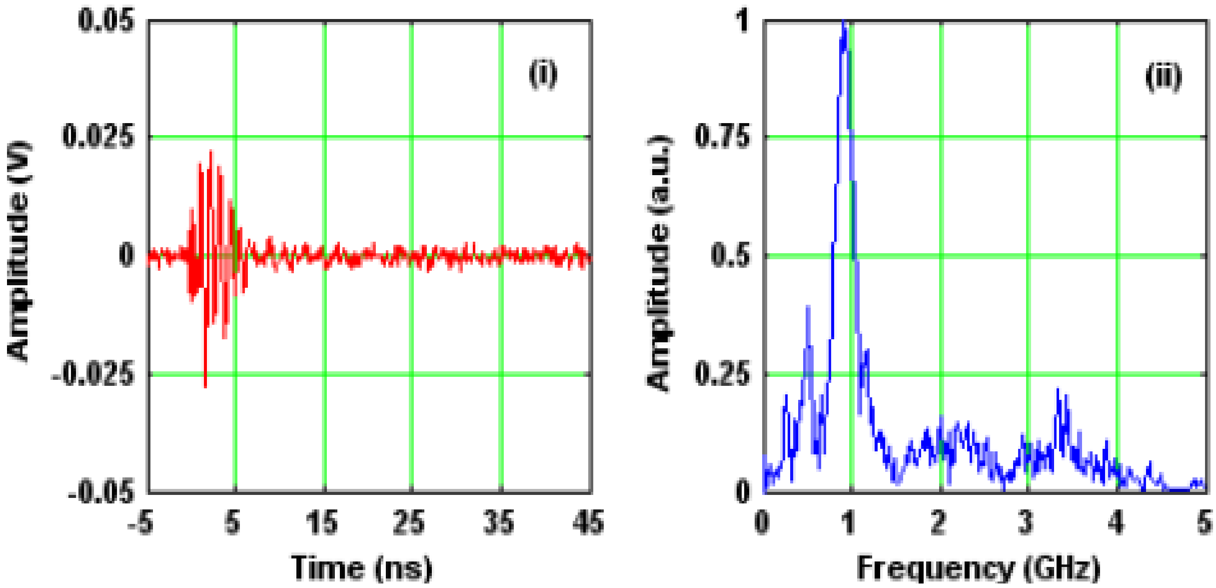


Fig 3.12Typical UHF signal due to incipient discharges in transformer (i) Time domain (ii) corresponding FFT analysis

3.6.1. ANALYSIS OF UHF SIGNAL GENERATED DUE TO CORONA INCEPTION DISCHARGES IN TRANSFORMER OIL

The characteristic variation in frequency content of UHF signal generated due to corona discharge in transformer oil at low field (near to inception) under AC and DC voltages. Needle plane electrode set up of distance 10 mm was used in the analysis of UHF signals generated due to corona discharge. Test is repeated more than once with the oil changed every time of different concentration in order to avoid the errors in the calculations. From the study of captured UHF signals at different distances of the electrode configurations shows variation in UHF magnitude generated due to corona with time.

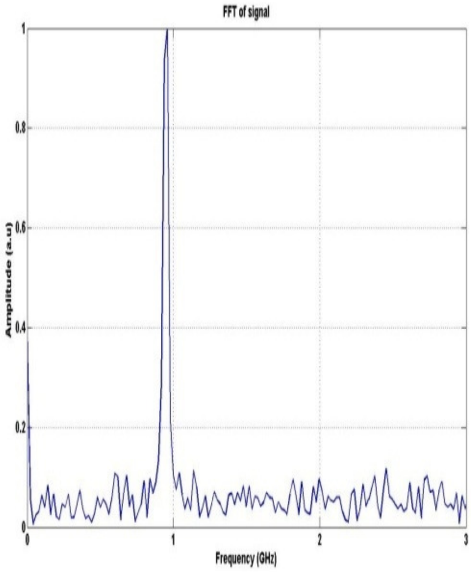
It is observed that the UHF signals generated due to corona are time varying but the average trend of the magnitude of discharges is almost constant it is observed that the bandwidth of the UHF signal formed by the occurrence of PD due to corona lies in the range 0.5-1.5 GHz in case of both normal oil(i, iii, v, ix)and inTiO_2 modified oil (ii, iv, vi, x) in all AC and DC voltages. But in case of modified TiO_2 oil there is small range of discharges seen at the range 1.5-1.8GHzfor the entire distance configuration in both AC and DC fields which may be due to the presence of free electrons and ions in the medium, which would have accelerated the discharge process effectively at a rapid rate.

[1]. Du et al., have concluded that electron shallow trap density and charge decay rate are greatly increased in nano fluids i.e., fast electrons may be converted in to slow moving low electrons by electron trapping and also de-trapping in shallow traps of nano fluids. In the present work, it can be observed that with the increase in the gap distance, the concentration of the nano particles in the high field region also has increased.[17] This process decreases the speed of electrons and avoids the accumulation of space charge in the oil.

[18] Also, the bubble formation in the high field regions plays a significant role in the initiation of the discharges. The nano particles being high permittivity material tend to move towards the high field region under the influence of its homogenous field. [1] Du et al., have concluded that the high concentration of the nano particles in the high field region reduces the probability of bubble formation. Tests were carried out with both sphere plane and needle plane set up of different distances were varied from 2-10 mm.

From the experimental results we see that the breakdown voltages have increased in compared with virgin oil. Table 3.7, 3.8 and 3.9 shows us the experimental levitation voltages of AC and DC voltages and it is seen that modified oil has higher inception voltage in compared with normal oil.[2] Sarathi *et al.* (2008b) carried out FFT analysis for the UHF signal generated due to particle movement under DC voltages in GIS and have concluded that the frequency content of the signal lays in the range 0.5-1.5 GHz.

Also by carrying out continuous wavelet transform on the UHF signal generated, a clear information about the nature of signal confirming the signal generated are from one location or different Similarly UHF signals captured which are shown in the Fig 3.13 for both AC and DC voltages says that discharges are in the range of 1GHz in both virgin and modified oil. Fig 3.13 3.14 and 3.15 gives us the voltage comparison plot of inception voltages of both virgin and modified oil acquired during experimental studies. But in case of modified TiO_2 oil there is small range of discharges seen at the range 1.5-1.8 GHz for the entire distance configuration in both AC and DC fields which may be due to the presence of free electrons and ions in the medium, which would have accelerated the discharge process effectively at a rapid rate.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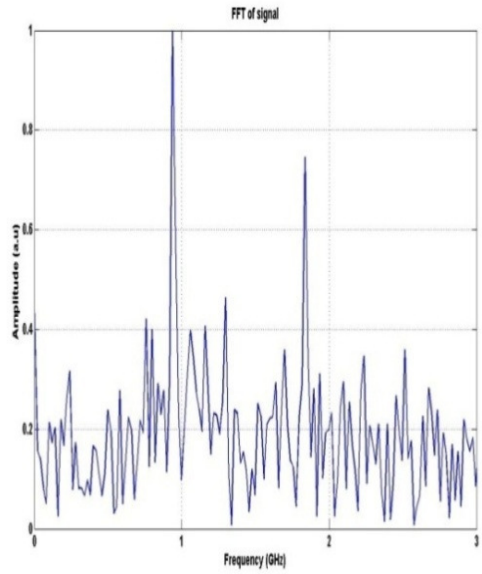
Amplitude (a.u)
Frequency (GHz)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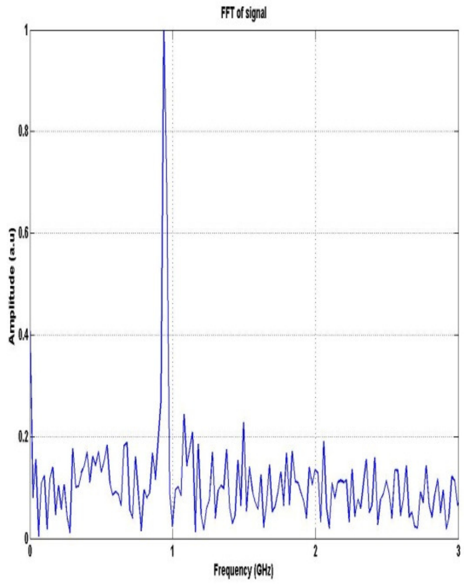
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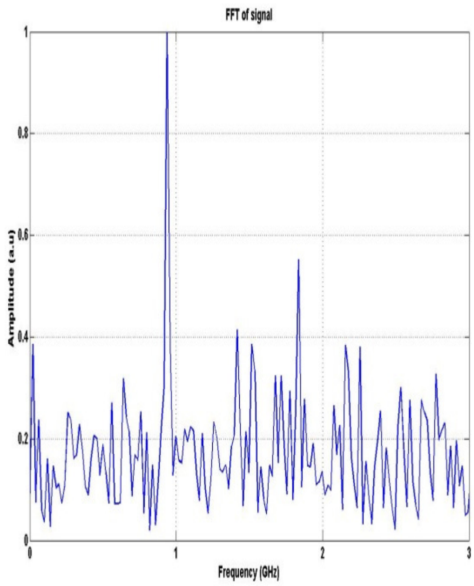
FFT of signal
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Frequency (GHz)

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