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FINAL YEAR PROJECT REPORT

INFLUENCE OF MOISTURE CONTENT TO AC BREAKDOWN VOLTAGE OF MINERAL OIL BASED NANOFLUIDS

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2015

" I hereby declare that I have read through this report entitle "*Influence of Moisture Content to AC breakdown voltage of mineral oil based nanofluids*" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

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INFLUENCE OF MOISTURE CONTENT TO AC BREAKDOWN VOLTAGE OF MINERAL OIL BASED NANOFLUIDS

MUHAMAD YAHYA BIN RAZIFF

A thesis submitted in fulfillment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

I declare that this report entitle "*Influence of Moisture Content to AC breakdown voltage of mineral oil based nanofluids*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : MUHAMAD YAHYA BIN RAZIFF

Date : ....

Dedicated to my beloved mother, father and whole family

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ABSTRACT

The power transformer is a very important and costly part of the electrical generation, transmission and distribution system network. Electric transformers depend on the high dielectric strength and cooling properties of insulating oil to maintain normal operation. Statistically, most of the transformer damages occur due to the dielectric insulation problems. The dielectric insulation problems affected by several factors, such as moisture, suspended particles, acidity, and pressure. The electrical strength of dry oil can be decreased due to the presence of water in the transformer oil. Hence, it is important to improve the insulating characteristics of transformer oil. Recently, transformer oil based nanofluids have been developed by dispersing nanoparticles in the oil. It has been shown that some of these nanofluids have much greater dielectric breakdown strength or thermal conductivities than the host transformer oil. Nanoparticles have affected changes in electrical properties when dispersed in insulating oil. Thus, this project aims to prepare nanofluids using mineral oil by dispersing it with Fe_3O_4 conducting nanoparticles. Then, a setup of High Voltage (HV) apparatus for breakdown voltage test according to IEC 156 standard will be prepared. Next, the nanofluids will be tested to determine their AC characteristic which is breakdown voltage under moisture effect. Mineral oil as a base oil is compared with the percentage of water presence in the Fe_3O_4 nanofluid. This project expected to give benefit to electrical generation, transmission and distribution system network by improving the breakdown voltage of transformer oil based nanofluids. This is because nanoparticles dispersed in insulating oil are promising to enhanced the AC breakdown voltage.

ABSTRAK

Pengubah kuasa sangat penting dan mahal dalam bahagian penjanaan elektrik, penghantaran dan sistem pengagihan rangkaian. Pengubah elektrik bergantung kepada ketinggian kekuatan dielektrik dan sifat penyejukkan minyak penebat untuk mengekalkan operasi normal. Secara statistik, kebanyakan kerosakan pengubah berlaku disebabkan oleh masalah penebat dielektrik. Kerosakan penebat dielektrik dipengaruhi oleh beberapa faktor seperti kelembapan, zarah tercemar, keasidan dan tekanan. Kekuatan elektrik minyak kering akan menurun disebabkan kehadiran air dalam minyak pengubah. Oleh itu, ciri-ciri penebat minyak pengubah adalah sangat penting untuk ditingkatkan. Baru-baru ini, cecair nano berasaskan minyak pengubah telah dikembangkan dengan menyebarkan nanopartikel ke dalam minyak. Ia telah terbukti bahawa sebahagian daripada cecair nano ini mempunyai kekuatan dielektrik yang lebih bagus atau keberaliran haba lebih daripada minyak pengubah asli. Nanopartikel telah mempengaruhi perubahan dalam sifat-sifat elektrik ketika tersebar dalam minyak penebat. Oleh itu, projek ini bertujuan untuk menyediakan cecair nano menggunakan minyak mineral dengan menyuraikan Fe_3O_4 nanopartikel konduktor kedalamnya. Kemudian satu persediaan peralatan Voltan Tinggi (HV) untuk ujian ketahanan tembus mengikut piawain IEC 156 akan disediakan. Seterusnya, cecair nano akan diuji untuk menentukan ciri-ciri elektrik di bawah kesan kelembapan mereka iaitu ujian ketahanan tembus. Minyak mineral sebagai minyak asas dibandingkan dengan peratusan kehadiran air di nanofluid Fe_3O_4 itu. Projek ini dijangka memberi manfaat kepada penjanaan elektrik, penghantaran dan sistem pengagihan rangkaian dengan meningkatkan ketahanan voltan cecair nano berasaskan minyak pengubah. Ini kerana nanopartikel tersebar dalam minyak penebat menjanjikan kepada peningkatan AC ketahanan voltan.

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LIST OF ABBREVIATIONS

HV	-	High Voltage
IEC	-	International Eletrotechnical Comission
AC	-	Alternating Current
DC	-	Direct Current
EHV	-	Extra High Voltage
nm	-	nanometer
BDV	-	Breakdown voltage
PVD	-	Physical Vapor Diposition
g	-	gram
kV	-	kilovolt
mm	-	milimeter
l	-	liter
kPa	-	kilopascal
MF	-	Mass fraction
M	-	Mass
PFAE	-	Palm Fatty Acid Easter

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter will discuss about research background, problem statement, project objectives, scopes of project and contribution of project. Background of the project will explain the purpose, motivation and significance of the project. Problem statement is a short brief of the issues that need to be avoided and solve. While the objectives and scope will explain the purpose and goals of the project. Lastly, project contribution is the expected improvements to be achieved after this project is complete.

1.2 Research Background

Power transformer is a very important apparatus and it is the most costly part of the electrical generation, transmission and network of distribution system. Power transformer depends on high dielectric strength and the cooling properties of insulating oil to maintain normal operation [1]. It is so significant to improve the insulating properties of transformer oil because the possible Extra High Voltage (EHV) power transformer failures were due to dielectric insulation problems [2]. Recently, transformer oil based nanofluids have been developed by dispersing nanoparticles in the oil. It has been shown that some of these nanofluids have greater dielectric breakdown strength or thermal conductivities than the host transformer oil [3]. Nanoparticles have affected changes in electrical properties when dispersed in insulating oil. Thus, this project aim is to prepare nanofluids using mineral oil by dispersing it with conducting nanoparticles. Then, a High Voltage (HV) apparatus for breakdown voltage test will be prepared. Next, the nanofluids will be tested to determine their electrical characteristic which is Alternating Current (AC) breakdown voltage. It is expected that by dispersing nanoparticles into mineral oil, it will improve the AC breakdown voltage of the insulating oil.

1.3 Problem Statement

Transformer damage can cause interruption of power system operation and income losses because power transformer is a very important and costly part of the electrical generation, transmission and distribution system network. Statistically, most of the transformer damages occur due to the dielectric insulation problems. The dielectric insulation problems affected by several factors, such as moisture, suspended particles, acidity, and pressure [4]. The electrical strength can be decreased to 20% of the dry oil value due to the presence of 0.01% water in the transformer oil [5]. Hence, it is important to improve the electrical characteristics of the transformer oil. Thus, this project will focus on improving the AC breakdown voltage of mineral oil by dispersing it with conductive nanoparticles and and test it under the influence of moisture.

1.4 Objectives

The objectives of this project are:

i. To prepare nanofluids by dispersing conductive nanoparticles into mineral oil.
ii. To prepare a liquid insulation's Breakdown Voltage Test set.
iii. To determine the conductive nanofluids AC breakdown voltage level under moisture effect.

1.5 Scope of Research

The scope of research are:

i. Prepare nanofluids by dispersing the conductive nanoparticles (Iron Oxide, Fe_3O_4) into mineral oil.
ii. Mineral oil that is used in this project is HYRAX HYPERTRANS transformer oils manufactured by Malaysia company as a base oil.
iii. AC Breakdown Voltage Test (Megger Oil Test Set OTS60PB) according to IEC 156.

1.6 Contribution of Research

This research gives benefit to electrical generation, transmission and distribution system network by improving the breakdown voltage of transformer oil based nanofluids. This is because of nanoparticles dispersed in insulating oil are expected to enhance the breakdown voltage.

1.7 Report Outlines

This thesis is covered with five chapters. Chapter 1 is explained about the research background, problem statements, project objectives and scopes of project. Chapter 2 will describes the theory or general concept that related to the project and review the previous research works. It will more focus on the performances of the insulation oil that has been dispersed with nanoparticles. Then, Chapter 3 will illustrated methodology applied in order to get the required output. The flow of project development will be explained by a flow chart. Chapter 4 interpreted and explained the result by presents the tables and graph. Analysis and discussion on the problem issued were discussed. Lastly, Chapter 5 is about the conclusions and recommendations should be made through out this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter contains of review of some of previous studies that relate to this project. There are some previous studies on the theory and basic principle, electrical properties of transformer oil, application and uses of nanoparticles. Principles of the methods or techniques used in the previous work also provided in this chapter.

2.2 Theory and Basic Principles

This project is based on nanotechnology studies because nanoparticles are the main material that use to determine the breakdown voltage of nanofluids when it's dispersed into insulating oil. Nanotechnology offers a new innovative process and produce extremely small things about 1 nm to 100 nm [6]. Fluids dispersed with nanoparticles are called nanofluids. Nanofluids are a new generation of heat transfer fluids due to enhancement of heat transfer performance. Nanofluids have a good cooling properties compared to conventional heat transfer fluids [7]. From the literature review, there are two theories to explain on how nanoparticles can improve the AC breakdown voltage level which is nanoparticles relation times and electron trapping and de-trapping process.

2.2.1 Nanoparticles Relaxation Times

The fundamental electrodynamic processes are the basic principles that show why a transformer oil based nanofluids indicates the different characteristics of electrical breakdown of pure oil. The charge relaxation time constant of nanoparticles in liquid modified has an influence on the extent to which electrodynamic process. If the nanoparticles charge relaxation time constant shows that a short relative to the timescales of interest for a streamergrowth, indirectly it's present in the oil may change the electrodynamics. Otherwise, if the nanoparticles relaxation time constant is long relative to the timescales of interest for streamer growth, the presence of nanoparticles will less effects on the electrodynamics process[8].

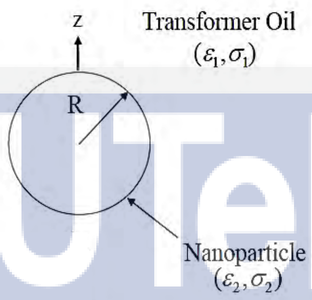


Figure 2.1: Material of nanoparticles in transformer oil [8]

Figure 2.1 shows a material of nanoparticle in transformer oil instead of calculate the relaxation time constant. Where ε1 and σ1 are respectively the permittivity and conductivity of the mineral oil, and ε2 and σ2 are the corresponding quantities for the nanoparticles. Below is the equation of the charge relaxation time constant τ_r of nanoparticles dispersed in transformer oil is [8]:

$$\tau_r = \frac{2\varepsilon 1 + \varepsilon 2}{2\sigma 1 + \sigma 2} \tag{2.1}$$

If the equation of relaxation time constant of the nanoparticles is shorter than a few microseconds, which is the time scale that involved in the development of the streamer in mineral oil, the polarized nanoparticles will capture fast electrons and effectively reduce their mobility. Otherwise, if the nanoparticle relaxation time is much longer than the streamer development time scale, the nanoparticles will have less effect on the high electron mobility [9].

2.2.2 Electron Trapping and De-trapping Process

Based on the previous research, the space charge characteristics of nanofluid semiconductive nanoparticles found that it can produce many electron shallower traps in nanofluid. The shallower traps could capture the mobile electrons and release them rapidly. When moving from high electric field to the lower field, the electrons can transform from fast electrons to the slow electrons by repeats the trapping and de-trapping process in the oil. It is the high shallow traps that contribute to the rapid charge dissipation and result in the improvement of breakdown performance [10].

The trap features of the nanofluid modified by insulating nanoparticles and pure oil, demonstrates that adding insulating nanoparticles in the oil produce shallower traps, which is consistent with the research of oil modified by semi-conductive nanoparticles [10]. In the transformer oil, conductive nanoparticles with extremely low charge relaxation time constant could capture the fast electrons and convert them into the low mobility that negatively charged nanoparticles. Such a change, in the oil it can modify the electrodynamics and the propagation of streamers can be slows. Therefore, the dielectric performance of the oil adding the conductive nanoparticles is enhanced. Adding semi-conductive nanoparticles and insulating nanoparticles can both produce shallower traps in the oil. These shallower traps could capture mobile electrons and release them rapidly. During this process, the speed of the electrons is reduced [11].

2.3 Review of Previous Related Works

Review from the previous related works shows there are some research, investigation, case study and analysis that have been done related with nanofluids, mineral oil, insulation in power transformer and others. All the information gets from books, journals and articles that are useful to support the approach that has been made.

2.3.1 Electrical Properties of Transformer Oil

Transformer oil is also known as insulating oil. It is produced by the fractional distillation process and treatment of crude petroleum. Figure 2.2 shows the transformer oil. The transformer oil performs two important functions. First, to create an insulation resistance level in the combination of the insulating materials that used in the coils and conductor. Then, serves as a coolant to remove heat from the core and the windings of the transformer. Additionally, this oil have two other functions which is to maintain the core and winding as it was sunk in the oil and other functions are preventing direct contact of atmospheric oxygen with cellulose made paper insulation of windings that susceptible to oxidation [12].

Figure 2.2: Insulating oil in an electrical power transformer [13]

The electrical properties of the transformer have two which is an electrical breakdown voltage strength and resistivity. Under a prescribed condition the voltage breakdown occurs between the two electrodes when the oil was subjected to an electrical field, it is known as the breakdown voltage (BDV) of transformer oil. The breakdown voltage was measured by a BDV testing instrument shown in Figure 2.3 [13]. The electrical breakdown strength is used as a basic parameter for insulating system design of the transformer. The breakdown voltage strength of transformer oil should be high. If the transformer has a lower strength it shows that the presence of the impurities agents such as moisture, fibrous materials, carbon particles, precipitable sludge a sediment. The breakdown voltage of the new sample of transformer oil is 30kV. While for a sample after filtration, it must has BDV of 60kV [13].

Figure 2.3: BDV testing instrument [13]

The resistivity is also equivalent to the resistance that occurs between opposite faces of a centimeter cube of the liquid. The insulation resistance of the windings depends on the insulation of the oil. To have a good transformer oil, the resistivity should be high and the low resistivity of transformer oil shows that the presence of moisture and conductive impurities agents [12].

2.3.1.1 Mineral Oil

Petroleum oil has been utilized as transformer oil since 1891 which is discovered by Sebastian de Ferranti. There are two methods for a creation process for petroleum oil which is crude petroleum and refining petroleum. Initially, petroleum oil comes from the extraction source namely crude petroleum. Hydrocarbons are a main content in this oil and also contains a little portion of sulfur and nitrogen. Fundamentally, hydrocarbon molecule can be isolated into three groups which are paraffin, naphthenes and aromatics [14]. The quality of oil is very important to reduce the failure of transformer operation expectancy of at least forty years. Mineral oil is utilized generally among the world for as long as the century. Every different power rating will significantly have different amount of oil contained by the transformer [15].

2.3.2 Moisture Presence in Insulating Oil

The moisture content of oil and paper is important because both of it have effects on the dielectric properties of insulation. There are many factors affect this insulation such as raising the temperature and the ageing of the transformer. Generally, the endurance of dielectric insulation is reduced by half for each doubling in water content [11]. The presence of moisture in a transformer will become worse in quality or condition of the transformer insulation by diminishing both electrical and mechanical strength. Generally, water contained in the transformer oil is found in the dissolved and undissolved structure. The electrical strength can be decreased to 20% of the dry oil value is due to the presence of 0.01% water in the transformer oil [5]. Power transformer depends on high dielectric strength and the cooling properties of insulating oil to maintain the normal operation [1]. A major causes of transformer failures are by the moisture is partial discharge, bubble formation, dielectric breakdown and deterioration of insulating liquid and paper. Insulating oil which is transformer oil has a low affinity for water. Moisture like an oxygen can enter the transformer from the main tank through loss of integrity of the mechanical seal. This will be lead to failure which is oil level drop, exposing the winding and moisture contamination. Comprehending moisture in oil might also can predict the stability state of moisture content in transformer board in equilibrium with oil [12].

2.3.3 Application and Uses of Nanoparticles

Nanoparticles have one dimension that measures 100 nanometers or less. Any conventional materials that were formed from the nanoparticles, it will change the properties of the materials itself. This is due to nanoparticles that have a greater surface area per weight than larger particles which causes nanoparticles to be more reactive to some other molecules.

Nanoparticles are widely used and being evaluated in many fields and industry. Figure 2.4 shows the diagram of solid nanoparticles. The several applications and uses of nanoparticle are in medicine, manufacturing and materials, environment technology, electrical power industrial, energy and electronics and others [16].

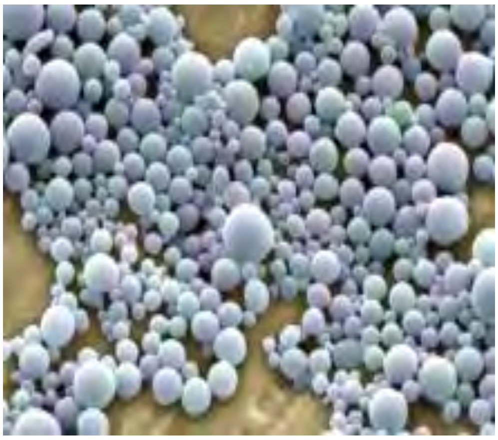


Figure 2.4: Solid nanoparticles [17]

From the previous research on applications of nanoparticle in medicine, the researchers at Rice University have demonstrated that cerium oxide nanoparticles act as an antioxidant to remove oxygen free radicals that are present in a patient's blood stream following a traumatic wound. The nanoparticles absorb the oxygen free radicals and then release the oxygen in a less dangerous state, freeing up the nanoparticle to absorb more free radicals. Then, researchers from Massachusetts Institute of Technology (MIT) have used nanoparticles in their research to deliver vaccines. The nanoparticles act to protect the vaccine, thus it allows a time to trigger a stronger immune response by the vaccine. Besides that, researchers are exploring ways on how to use carbon nanoparticles which is known as nanodiamonds in medical applications. For an example, the nanodiamonds contains of protein molecules attached which is can be used to increase bone growth especially on dental or joint implants. They also have tested in the brain tumor treatment by using the chemotherapy drugs attached to nanodiamonds. Besides that, there is a group of researchers have tested to treat leukemia by using the chemotherapy drugs attached to nanodiamonds [18].

Several review articles about the investigation by dispersing of nanoparticles into mineral oil with the aims of improve the dielectric properties of liquid insulating material has been published. It has been demonstrated that some of these nanofluids have a greater dielectric breakdown strength or thermal conductivities than the host transformer oil [3]. These nanoparticles have been divided into three groups, namely conducting nanoparticles (Fe_3O_4, Fe_2O_3, ZnO, SiC), semiconducting nanoparticles (TiO_2, CuO, Cu_2O) and insulating nanoparticles (Al_2O_3, SiO_2, BN). The results of percentage increase in breakdown strength relative to host oil by dispersing nanofluids into mineral oil are listed in Table 2.1. The results are collected from the literature. The type of host oil that used in the experiment is mineral oil and the synthesis method that used to preparation of nanofluids is two-step method. The mechanisms through which the nanoparticles increase the breakdown strength of the oil are still not fully understood [3].

Table 2.1: Analysis of transformer oil based nanofluids system in literature [3]

Nanoparticle	**Average nanoparticle size (nm)**	**Nanoparticle loading (vol%)**	**Percentage increase in breakdown strength relative to host oil**	**Ref**
Fe_3O_4	10	Not specified	42.8% AC 82.5% Positive impulse	[18]
Fe_3O_4	8.6	0.25	21.4% DC	[19]
Fe_2O_3	7.4	0.016	12.8 AC	[20]
ZnO	34	0.0005	8.3% AC	[21]
SiC	80	0.005	Breakdown strength reduction	[22]
TiO_2	20	0.075	19% AC 24% Postive impulse	[10]
Al_2O_3	80	0.1-1.0	Breakdown strength reduction	[23]
SiO_2	15	0.0074	17% AC	[24]

2.4 Principles of Methods Used in the Previous Work

Before using a nanoparticles, the main step that need to be taken is preparing the nanofluids. The nanaofluids is used to enhance the thermal conductivity of fluids. There are two methods of preparation of nanofluids, which is a single-step and the other is a two-step method.

2.4.1 Single-Step Method

A single-step method is a method which is the process that combining the preparation of nanoparticles with the synthesis of nanofluids, meanwhile the nanoparticles are directly prepared either by using physical vapor deposition (PVD) technique or by liquid chemical method. Before this, nanoparticles are prepared and dispersed in the base oil simultaneously, the drying, storage, transportation, and dispersion processes of nanoparticles are being avoided, therefore the collections is being minimized and it also has improved the stability of the nanoparticle dispersion in the oil [25]. There is some disadvantage has been discovered from this method, it is a low vapor pressure fluids are compatible with the process. This experiment is to prepared nanofluids of TiO2 nanoparticles dispersed in water by a one-step chemical method using a high pressure homogenizer. This method is called modified magnetron sputtering [26].

2.4.2 Two-Step Method

In the two-step methods, solid nanoparticles are prepared by chemical or physical methods, and then dispersed in the mineral oil using magnetic stirring, ultrasonic treatment, high-shear mixing, or ball milling. Figure 2.5 shows the magnetic stirrer used for sample preparation [27]. These methods are more widely used than the one-step methods because of their low cost, and the wide range of nanoparticles with which they are compatible [3].

However, nanoparticle agglomeration may occur during both stages of the two-step methods because of the large surface area and the high surface activity of the nanoparticles.

Figure 2.5: Magnetic stirrer [27]

Surfactants and dispersants can be used to improve the nanoparticle dispersion stability in the oil [3]. It has been reported that iron oxide nanoparticles surface-functioned using an oleic acid surfactant showed the dispersibility and stability of TiO2 nanoparticles in the oil is dramatically improved. It also has a good long-term dispersion stability in transformer oil at room temperature over a period of 24 months [28].

2.4.3 Breakdown Voltage Test

The breakdown voltage is the most important factor in determining the oil performance as an insulation in transformer. The breakdown voltage test has three types namely AC breakdown voltage test, DC breakdown voltage test and Impulse breakdown voltage test. The breakdown voltage value depends on many factors such as presence of moisture pressure, the presence of bubbles, solid particles and acidity [29]. Mostly, the AC breakdown voltage test was selected to find out the level of breakdown voltage of conductive, semiconductive and insulative nanofluids.

The AC breakdown voltage test found that can increase the AC breakdown strength, the dispersing of conductive nanoparticles into mineral oil, increased with increasing water content of the oil [3]. Based on the IEC60156 standard, the OPG-100A insulating oil tester is used to measure the AC breakdown voltage. The electrode configuration contains of two spherical brass electrodes with the gap distance of 2.5 mm. The rate of voltage rise has been rised to 2 kV/s [30]. Figure 2.6 shows the OPG-100A insulating oil tester.

Figure 2.6: OPG-100A insulating oil tester [31]

Figure 2.7 on the obove shows the average AC breakdown voltage with the minimum 0.01% SiO_2 nanofluids and maximum 0.02% SiO_2 nanofluids values of mineral oil. From the above figure, it indicates that the AC breakdown voltage is increased as there are an increasing of nanoparticle concentration. Thus, from all the three fluids, the moisture content has contributed a big impact on the AC breakdown voltage. Meanwhile, the AC breakdown voltage has decreased as there is an increasing of the moisture content. The breakdown voltage enhancement is smaller at lower humidity level, compared to at the high humidity level [30].

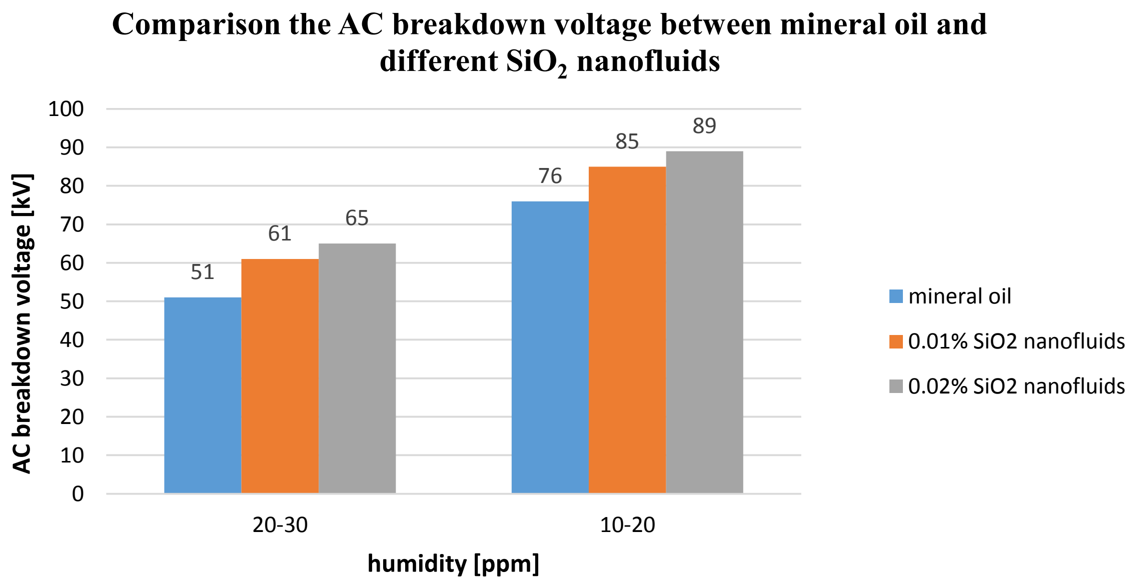


Figure 2.7: Comparison AC breakdown voltage between mineral oil and different percentage SiO_2 nanoflluids [30]

2.5 Summary

Theory and basic principles that related to this project has two which is the relaxation times of nanoparticles and another one is the process of electron trapping and de-trapping. If the relaxation time of nanofluids is shorter than microsecond timescales involved in streamer propagation, the nanoparticles could capture the fast electrons and convert them into a nanoparticles which is low mobility charged. This process increases the potential drop along the streamer channel in the nanofluid and leads the improvement of insulating properties.

Then, the theory of the process of electron trapping and de-trapping, discusses that a fast electron can be converted to slow electrons by the hopping process in the shallower traps. During this process, the speed of the electrons is reduced. It had concluded that the three different types of nanoparticles, which is conductive, semiconductive and insulative nanofluids suspension can improve the dielectric performance of the oil.

The review of previous related work that has been discussed in this proposal are about the mechanism of heat conduction by nanofluids, the application and uses of nanoparticles and electrical properties of transformer oil. From the previous research, nanoparticles are the new technology to generate heat transfer fluids due to can enhance heat transfer performance compared with pure liquids. They have good properties compared to conventional heat transfer fluids. Besides that, the results of dispersing three of different type nanofluids into mineral oil respectively show that mostly the percentage of breakdown strength relative was increased. The breakdown voltage of transformer oil based nanofluids is measured by the BDV testing instrument. The enhancement of the insulating properties of the transformer oil is very important because most of the transformer failures occur due to the dielectric insulation problems.

CHAPTER 3

METHODOLOOGY

3.1 Introduction

This chapter contains the principles of methods or techniques that used in this project. Experimental procedures used in this project have come from the previous work. A procedure such as preparation of nanofluid, preparation of sample and breakdown voltage test set will be discussed briefly.

3.2 Flow Chart of Methodology

This project is aim to prepare nanofluids using mineral oil by dispersing it with nanoparticles. The preparation of nanofluids is based on the two-step method. Then, the process of moisture addition is done by adding drops of water into nanofluid using syringe as oil samples for test. After that, a setup of High Voltage (HV) apparatus for the breakdown voltage test will be prepared. Next, the nanofluids will be tested to determine their AC characteristic which is breakdown voltage. Figure 3.1 shows the flow chart of the methodology of this project.

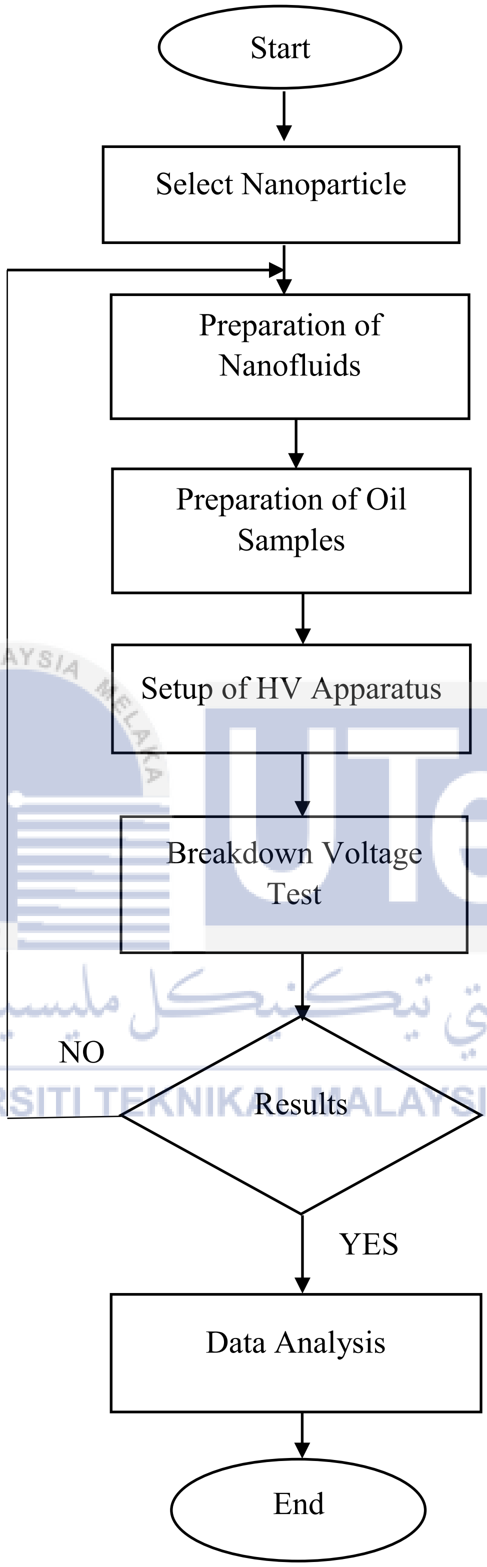


Figure 3.1: Flow chart of the methodology

i. Select Nanoparticle

This project uses conductive nanoparticles namely Iron Oxide, Fe_3O_4 with average particle sizes of 15 to 20 mm. This nanoparticle will be dispersing into mineral oil with the concentration of 0.01g/L.

ii. Preparation of Nanofluids

Two-step method will be uses for the preparation of nanofluids by dispersing Fe_3O_4 conductive nanoparticles into mineral oil. 0.05ml of Oleic acid surfactants mixing with nanoparticle into a mineral oil to improve the nanoparticle dispersion stability in the oil. The preparation of nanofluids used ultrasonic treatment and vacuum oven. 2000 ml of nanofluid with the concentration of 0.01g/L conductive nanoparticle will be prepared.

iii. Preparation of Oil Samples

After the completion of Fe_3O_4 nanofluid preparation, the 2000 ml of nanofluid will be divided into five samples. Every sample will contain 350 ml of the nanofluid. One sample will be used as a base nanofluid and while the other samples will be dropped few drops of water with a different volume as a moisture effect in the base nanofluids. The value of the water that have been added in nanofluid using syringe are 0.05 ml, 0.1 ml, 0.15 ml and 0.2 ml.

iv. Setup of HV Apparatus

A setup of HV apparatus namely Megger Oil Tester OTS60PB for AC breakdown voltage test according to IEC 156 standard. The electrode configuration which contains of two spherical brass electrodes is set to a gap distance of 2.5 mm.

v. Breakdown Voltage Test

After setup the HV apparatus and set the appropriate option with according to the standard, this test will be started. The AC breakdown voltage test is performed to determine the AC breakdown voltage level of mineral oil based nanofluids under moisture effect.

vi. Result

After complete the test, the result of the breakdown voltage level will be shown. The result of the breakdown voltage for each sample is collected in order to define the dielectric performance of the insulation under moisture effect.

vii. Data Analysis

The data will be analysed to determine their AC characteristic under moisture effect. The analysis of the experiment should relate to the objectives of this research. At the end, some conclusion will be made.

3.3 Preparation of Nanofluids

Hyrax Transformer oil was taken as base fluid. 2000 ml of nanofluid with concentration of 0.01g/L nanoparticles will be prepared. The concentration of conductive nanoparticles namely Iron oxide, Fe_3O_4 is selected to prepare by oleic acid and then dispersed in the base oil. The mixture has been put in an Ultrasonic-homogenizer LABSONIC exactly for 2 hours to break agglomeration of nanoparticles. Lastly, nanofluid has been placed in vacuum oven at least 72 hours. Below is the preparation procedure of nanofluids is shown in Figure 3.2.

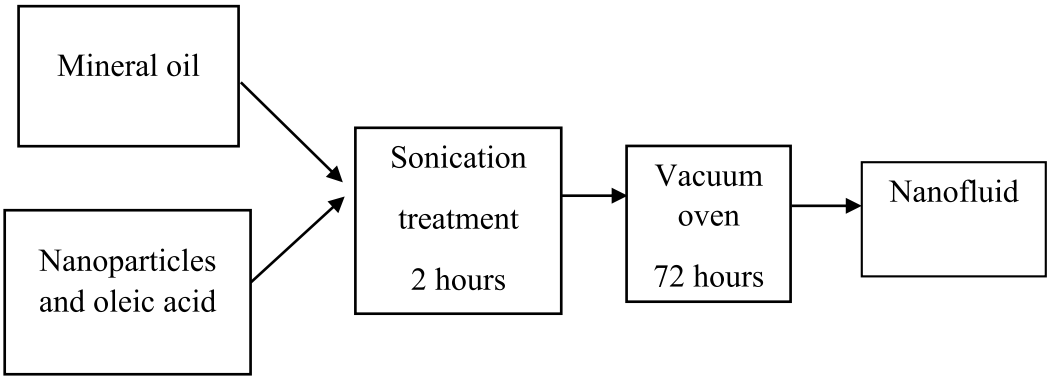


Figure 3.2: Flowchart of a preparation procedure for mineral oil based nanofluids

3.3.1 Weight and Mixing Process

Nanopowder with average particle sizes of 15 to 20 mm, Hyrax mineral oil and surfactant namely oleic acid was used to produce a nanofluids for the breakdown voltage test. Figure 3.3 shows the Iron Oxide, Fe_3O_4 nanopowders. In this process, safety must be taken seriously because nanopowder is hazardous if been inhaled. The safety items that should be wear are masks, waterproof gloves and safety glasses.

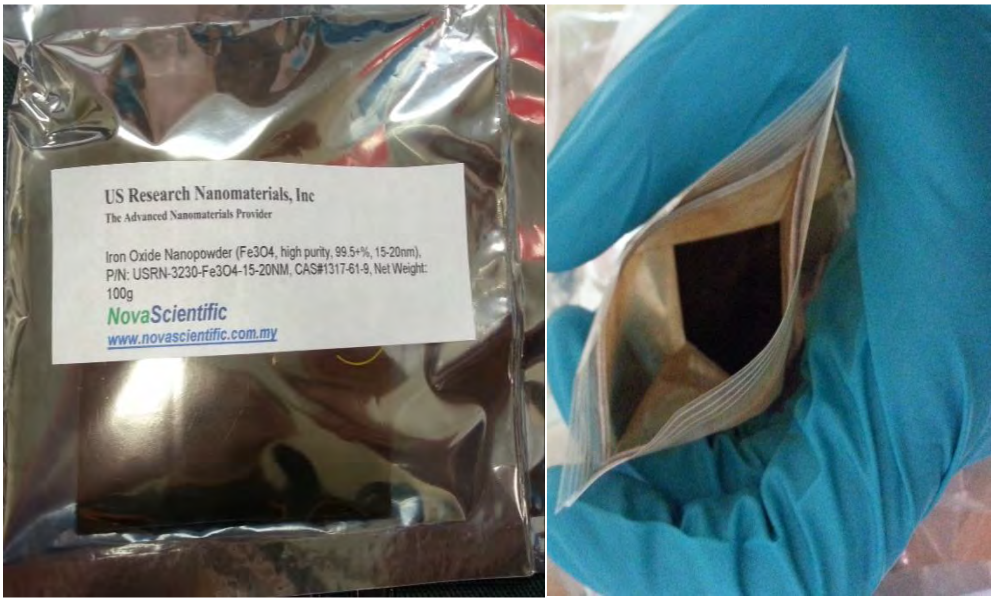


Figure 3.3: Iron Oxide Nanopowder, Fe_3O_4

Digital analytical balance is used to weighing the nanopowder with precisely. 0.01g of Fe_3O_4 conductive nanopowder weighed for mixing with 1 liter of mineral oil and 0.5ml of Oleic Acid. An analytical balance measures the masses to within 0.0001g and have a high precision. Figure 3.4 shows the weighing of nanopowder by using a digital analytical balance and Figure 3.5 shows the mixing of Oleic Acid with mineral oil using syringe.

Figure 3.4: Weighing of nanopowder by using a Digital analytical balance

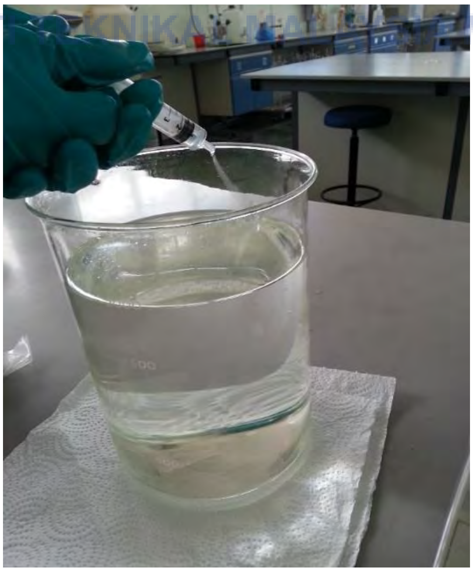


Figure 3.5: Mixing of Oleic acid with mineral oil using syringe

3.3.2 Ultrasonic Treatment Process

The Ultrasonic-Homogenizer LABSONIC was used for this process to break agglomerations of nanoparticles. The mixture was placed in ultrasonication for 2 hours with setting at 50% for the pulsed-mode operation (Cycle) and 50% for the ultrasound power (Amplitude). This equipment have a various probe to use for ultrasonication treatment. The choice of a suitable probe depends on the intended application. Table 3.1 shows the list of the probes made of Titanium.

Table 3.1: List of the probes made of Titanium

Type of probes	Size of diameter (mm)	For sample volume (ml)
853 5124	3	5-200
853 5132	7	20-500
853 5140	14	100-2000
853 5159	22	100-2000
853 5167	40	200-4000

From the above list, it shows that there are three types of probe can be use in this experiment which is 14 mm, 22 mm and 40 mm due to it's suitability for sample volume of 2000 ml. Each of the probe shows that the different results of the motion of vibration in oil and the results of agglomerations of nanoparticles dispersed in mineral oil.

Figure 3.6: 40mm probes made of Titanium

Figure 3.6 shows the 40mm probes made of Titanium was selected to be used in this project due to the energy has spread out over a larger surface area in a beaker through the motion of vibration from the titanium tip immersed in the mixture. Figure 3.7 shows the ultra-sonication treatment process. Nanoparticles will be greatly dispersed in mineral oil and become as nanofluids after completion of this process.

Figure 3.7: The ultra-sonication treatment process.

3.3.3 Vacuum Drying Oven Process

The last process of nanofluid preparations is nanofluid should be placed in vacuum drying oven at least 72 hours or 3 days to eliminate the influence of gas and moisture. The temperature was set a 70°C and 1kPa of vacuum pressure in this process. Figure 3.8 shows the vacuum drying oven process.

Figure 3.8: The vacuum drying oven process.

3.4 Preparation of Oil Samples

After the completion of Fe_3O_4 nanofluid preparation, the 2000 ml of nanofluid will be divided into five samples. Every sample will contain 350 ml of the nanofluid. One sample will be used as a base nanofluid and while the other samples will be dropped few drops of water with a different volume as a moisture effect in the base nanofluids. The value of the water that have been added in nanofluids using syringe are 0.05 ml, 0.1 ml, 0.15 ml and 0.2 ml. Figure 3.9 shows the process of dropping water into the nanofluids.

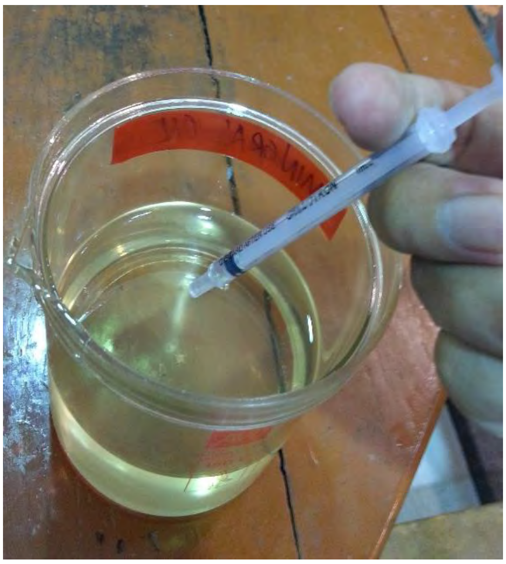


Figure 3.9: The process of dropping water into the nanofluids

Additionally, one sample of pure mineral oil is also prepared as a base oil to compare the breakdown voltage of the base nanofluid. The mass fraction concept is used to measure of the concentration of a solution. That have some calculation to show the percentage of mass fraction concept. The ratio of the mass of water of the oil to the total mass of the oil is given by :

$$MF_{water}\,(\%) = \frac{M\ water}{M\ oil + M\ water} \times 100 \tag{3.1}$$

Calculation for volume of 0.05 ml of water:

Mass of water = 0.05 ml = 0.05 gm

Mass of oil = 350 ml = 350 gm

$$MF_{water}\,(\%) = \frac{0.05}{350 + 0.05} \times 100$$

$$= 0.0143\% \approx 0.015\%$$

Table 3.2 shows the list of the percentage mass fraction of water to the total concentration of nanofluid that used in the experiment. Meanwhile, the calculation of the mass fraction for 0.1 ml, 0.15 ml and 0.2 ml is shown in Appendix A.

Table 3.2: The list of the percentage mass fraction of water to the total concentration of nanofluid

Sample	**Nanofluids (ml)**	**Water (ml)**	**Percentage of water (%)**
1	350	0.00	0.0
2	350	0.05	0.015
3	350	0.10	0.03
4	350	0.15	0.045
5	350	0.20	0.06

3.5 AC Breakdown Voltage Test

The AC breakdown voltage was measured with Megger Oil Tester OTS60PB according to IEC 156 standard. The Megger oil tester is an automatic oil dielectric strength test set with maximum test voltages of 60 kV. Figure 3.10 shows the Megger oil tester. According to IEC 156 the electrode configuration which contains of two spherical brass electrodes is set to a gap distance of 2.5 mm [32]. All the steps in this standard are been followed. Figure 3.11 shows a list of electrode shapes and gap spacing for standard testing specifications.

Figure 3.10: Megger oil tester OTS60PB

Standard test specification selected	EN60156 AS 1767 BS 5874 IEC 156 NFC 27 SABS 555 UNE 21	BS148 CEI 10-1 IP 295 ГОСТ 6581 VDE 0370 STAS 286	ASTM D1816	ASTM D877
Electrode shape		OR		
Electrode spacing	2,5 mm		1 or 2 mm	2,5 mm

Figure 3.11: A list of electrode shapes and gap spacing for standard testing specifications [32]

3.5.1 Preparation of the Electrode

The cleanliness of electrode is very important in the breakdown voltage test. First step, electrodes must be washed and cleaned thoroughly until it looks shiny and dry without any dust by using wipes and dry cloth. If necessary, use a suitable solvent which is acetone or autosol metal polish to make sure the electrode is free from contaminant. After clean the electrode, rinsing with the oil sample that to be used for testing. Then, set the gap distance of 2.5 mm of the electrode according to IEC 156. Figure 3.12 shows the setting of the gap distance between the both electrodes.

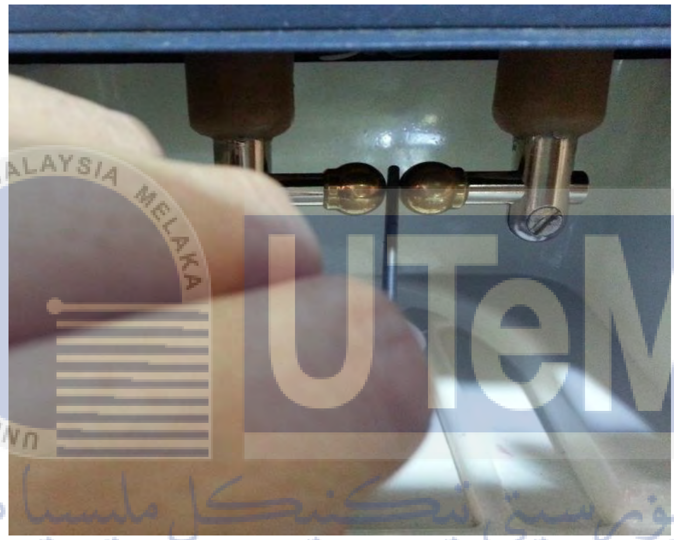


Figure 3.12: The setting of the gap distance between the both electrodes

3.5.2 Preparation and Loading the Test Vessel

Firstly, clean both inside and outside of the test vessel with thoroughly. Open the test chamber cover by pulling it outward. Place the test vessel in the chamber. Then load the sample in the test vessel and close the chamber door. Figure 3.13 shows the placed of the sample in the test vessel.

Figure 3.13: The placed of the sample in the test vessel

3.5.3 Preparing the Oil Test Set

To operate the oil test set, switch ON the supply and the test set. After a few seconds, the main programme menu appears on the display and select the IEC 156 standard as the required test. After selecting the appropriate options at Megger tester, the AC breakdown voltage test will be started. Each test sequence is carried out complete automatically and record the breakdown voltage level. Figure 3.14 shows the selecting the IEC 156 at the options menu display.

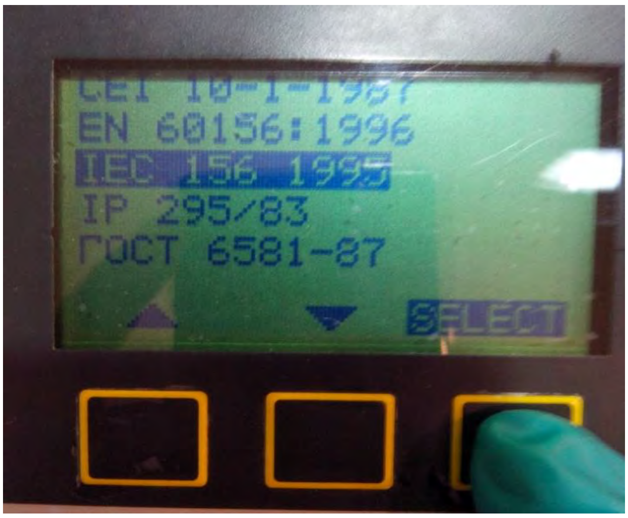


Figure 3.14: The selecting the IEC 156 at the options menu display

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, the recorded results will be analyzed based on the experiment that has been done. To accomplish the objective of this research, the preparation of nanofluids and AC breakdown voltage test need to be done successfully. To determine the conductive nanofluids AC breakdown voltage level under moisture effect, all recorded results are presented in a graph to make easier for a comparison between pure mineral oil and conductive nanofluids.

4.2 Comparison of AC Breakdown Voltage Between Base Oil and Fe_3O_4 Nanofluids

The breakdown voltage result for base oil and Fe_3O_4 nanofluids are recorded in Table 4.1. Mineral oil as a base oil in this experiment will undergo the vacuum oven process for 72 hours to equivalent with the preparation of nanofluid that also undergo the same process to eliminate the influence of gas and moisture. There were six recorded data and the average value for a breakdown voltage in this test for base oil samples and Fe_3O_4 nanofluid samples.

Table 4.1: The breakdown voltage result for base oil and Fe_3O_4 nanofluids

Sample	AC Breakdown voltage (kV)						
	Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**	**Test 6**	**Average**
Base Oil	22	17	24	14	18	19	19
Fe_3O_4 nanofluid	33	35	34	36	34	31	34

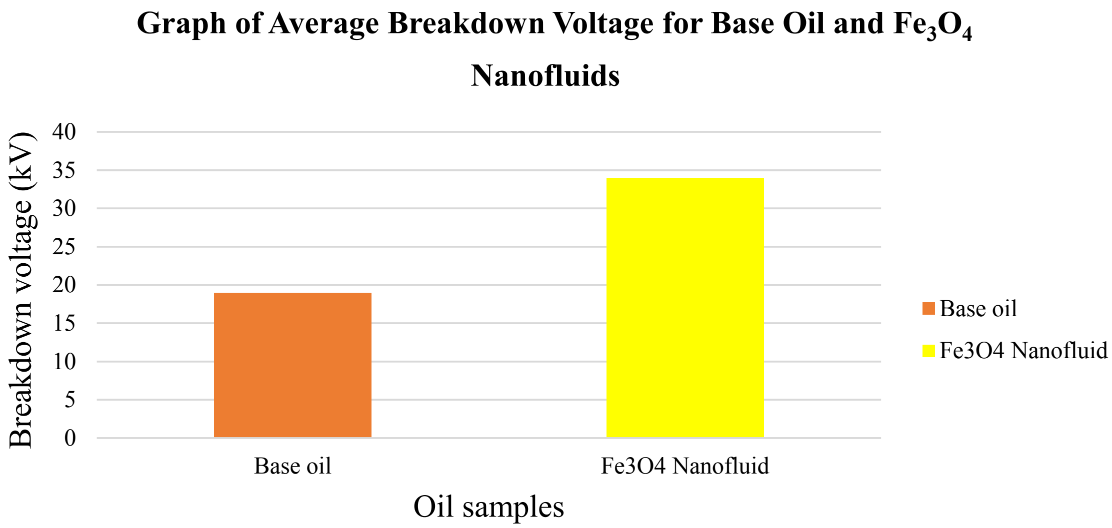


Figure 4.1: Graph of Comparison of Average Breakdown Voltage between Base Oil and Fe_3O_4 Nanofluids

Graph on Figure 4.1 shows the comparison of average AC breakdown voltage test between mineral oil and Fe_3O_4 nanofluids. From Table 4.1 and Figure 4.1, it can be seen that the breakdown voltage of Fe_3O_4 nanofluid is higher than the base oil. The average breakdown voltage of Fe_3O_4 nanofluid had increase compared with the average breakdown voltage of base oil. The nanofluid modified by conductive nanoparticles Fe_3O_4 records the average AC breakdown voltage of 34 kV, while average breakdown voltage for base oil is 19 kV. The increases breakdown voltage is approximately 15 kV. It is observed that the breakdown voltage achieves an increase of 78.9% by the presence of concentration of 0.01g/L nanoparticles. Based on a research work from Sima [33], the average time to breakdown of Fe_3O_4 nanofluids is longer than the corresponding value for base oil. That is because nanofluid takes more time for the streamer to traverse the electrode gap to cause the breakdown. Thus, it has high capability of insulation oil to avoid the breakdown when there is electrical stress compared to the base oil. This means that by dispersing conductive nanoparticles into mineral oil, it will improve the AC breakdown voltage of the insulating oil.

4.3 Results of Fe_3O_4 Nanofluids AC Breakdown Voltage Under Moisture Effect

The results of Fe_3O_4 nanofluids AC breakdown voltage level under moisture effect are recorded in Table 4.2. Four samples of Fe_3O_4 nanofluids influenced by the moisture will be prepared. A little of water will be dropped in every sample with a different volume as a moisture effect in the base nanofluids. Initially, breakdown voltage test for Fe_3O_4 nanofluids samples without moisture effect has been done. Then, proceed with the nanofluids affected by the moisture. There were six recorded data and the average value of a breakdown voltage in this test for each sample.

Table 4.2: Results of Fe_3O_4 nanofluids AC breakdown voltage under moisture effect

Sample	**Volume of water (ml)**	**AC Breakdown voltage (kV)**						
		Test						**Average**
		1	**2**	**3**	**4**	**5**	**6**	
Fe_3O_4 nanofluids	0	33	35	34	36	34	31	34
	0.05	32	28	33	29	33	26	30
	0.10	27	26	22	24	22	22	24
	0.15	16	21	20	13	19	18	18
	0.20	10	12	14	11	14	13	12

Analysis of Fe_3O_4 nanofluid under the moisture effect is to determine the AC breakdown voltage level based on the volume of water content in the tested samples. Each of the sample is dropped a some of the water with a different volume which is 0.05 ml, 0.1 ml, 0.15 ml and 0.2 ml as a moisture effect in the base nanofluids. The results of breakdown voltage for Fe_3O_4 nanofluid under moisture effect are given in Table 4.2 and corresponding graph is shown in Figure 4.2. The graph shows the results of average breakdown voltage for each sample.

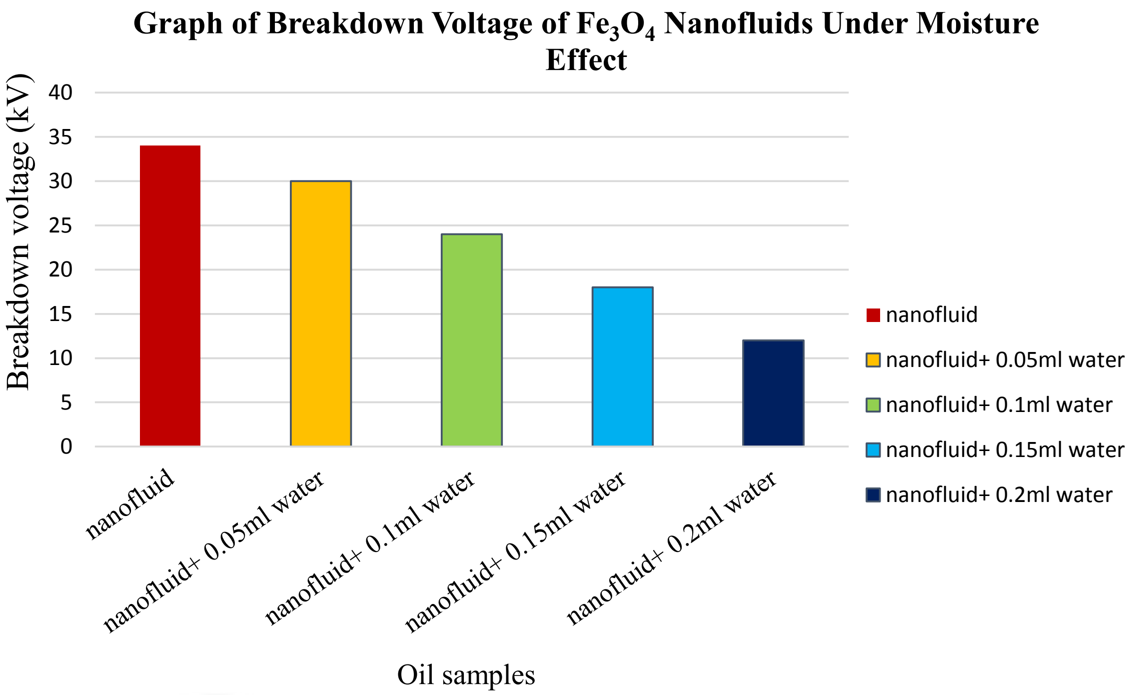


Figure 4.2: Graph of breakdown voltage of Fe_3O_4 nanofluids under moisture effect

From Table 4.2 and Figure 4.2, it can be seen that the average breakdown voltage of Fe_3O_4 nanofluids under the moisture effect is decreased when the volume of water is increased. When 0.05 ml of water was dropped into nanofluids, the breakdown voltage value decreased about 4 kV, which is from 34 kV to 30 kV. While, the sample of 0.1 ml has been dropped in the base nanofluids as a moisture effect show a decreased about 10 kV of the breakdown voltage level. The volume of 0.2ml of water are dropped to the nanofluid records the average AC breakdown voltage of 12 kV while average breakdown voltage for base nanofluid is 34 kV. The decreases breakdown voltage is approximately 22 kV.

This result indicates that the nanofluid modified by conductive nanoparticle Fe_3O_4 cannot withstand the moisture stress. This means that the free water contents had changed the physical and chemical properties in the nanofluids. The presence of some volume of water in nanofluid reduces its electrical strength compared to the dry nanofluid value. Besides that, it can be seen that Fe_3O_4 nanofluid cannot absorb a water and reduce the amount of free water at moisture condition. The more nanofluids exposed to the moisture, thus the AC breakdown voltage level is decreased. Therefore, conductive nanoparticle Fe_3O_4 cannot withstand the moisture stress because the presence of water has affected changes in the electrical properties. If the oil can absorb and reduce the amount of free water, it will help to maintain the performance of insulation in the transformer at moisture condition. Figure 4.3

shows the graph of comparison of average AC breakdown voltage between base oil and the percentage of water presence in the Fe_3O_4 nanofluids. Equation (3.1) is used to obtain the percentage of water presence in the Fe_3O_4 nanofluids.

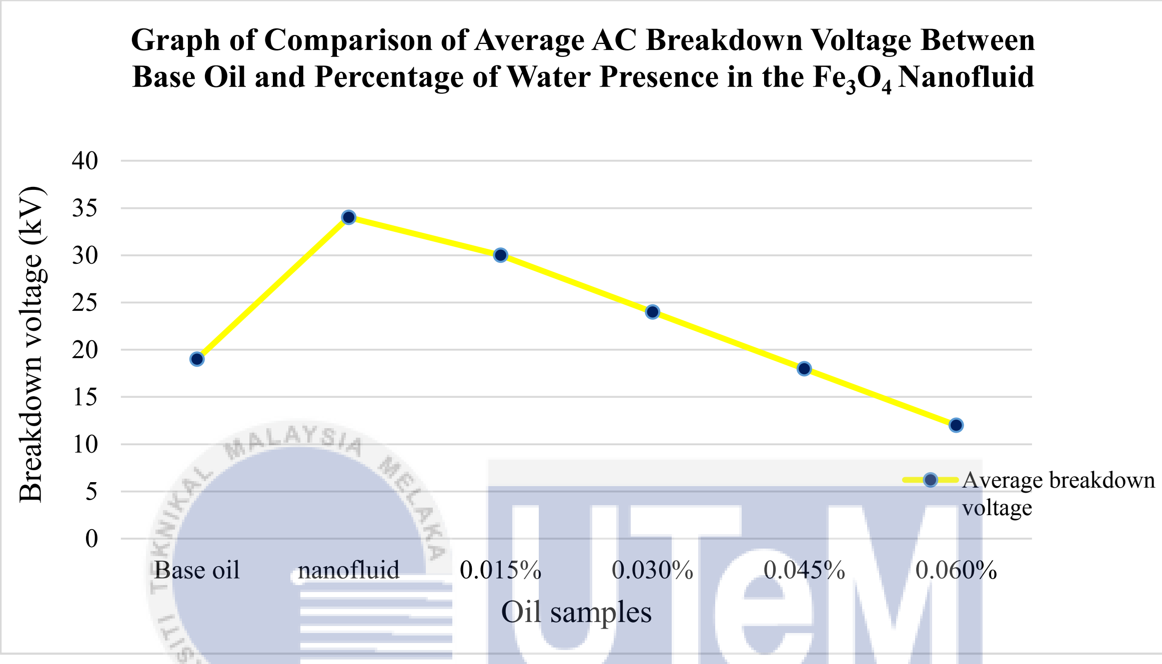


Figure 4.3: The graph of comparison of Average AC breakdown voltage between base oil and the percentage of water presence in the Fe_3O_4 nanofluid

From Figure 4.3, the breakdown voltage level of nanofluid is increased due to Fe_3O_4 conductive nanoparticle has improved the electrical strength by dispersing it into mineral oil. The presence of 0.015% water in nanofluid as a moisture reduces its breakdown voltage level from 34 kV to 30 kV of the base nanofluid value. The breakdown voltage value decreased about 4 kV which is 11.76% of the base nanofluid. Based on the theory proposed by Naidu and Kamaraju [5] which state the presence of even 0.01% water in transformer oil reduces its electrical strength to 20% of the dry oil value. That means the Fe_3O_4 conductive nanoparticle had proved can enhance the electrical strength of insulating oil by dispersing into it. While, the presence of 0.03% water in base nanofluid reduces its breakdown voltage to 29% of the dry nanofluid value. If compare with the theory, the presence of 0.03% water in transformer oil will reduce its electrical strength to 60% of the dry oil but the Fe_3O_4 conductive nanofluids only decreases about 29%. This result indicates that the performance of electrical strength of nanofluid modified by Fe_3O_4 conductive nanoparticle more better than pure transformer oil under the moisture stress. Despite the water contents in the nanofluids, it still has a good performance of dielectric strength compare to the pure transformer oil. The dispersing of the Fe_3O_4 conductive nanoparticles into the transformer oil doesn't show drastic decreased in breakdown voltage level during moisture effect compared to the pure transformer oil.

4.4 The Effect of Different Size of Probes During Ultrasonication Processes

The Ultrasonic-Homogenizer LABSONIC was used in this process to break the agglomerations of nanoparticles. Based on table 3.1, this equipment has a various probe to use for ultrasonication treatment. The choice of a suitable diameter tip size of probe depends on the intended application. Table 4.3 shows the differences motion of vibration produced at the tip by two types of probes in oil.

Table 4.3: The differences motion of vibration produced by two types of probes in oil

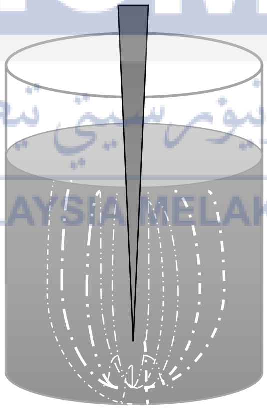
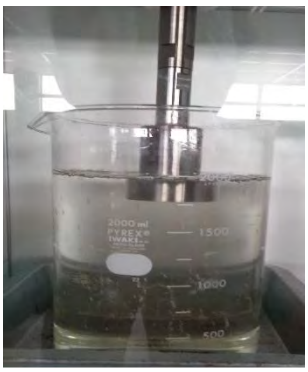
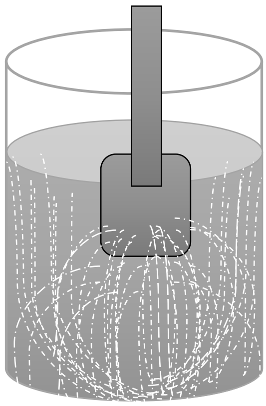
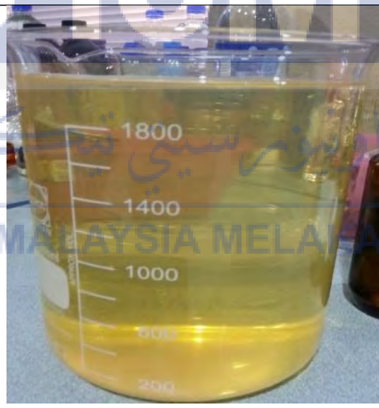
Size of probe	Motion of vibration in oil
14 mm 	
40 mm 	

Table 4.3 above shows the comparison of two sizes of probes can be use in this experiment which is 14 mm and 40 mm due to it's suitability for sample volume of 2000 ml. Each of the probe shows the differences motion of vibration produced at the tip immersed in the oil during the ultrasonication treatment. From Table 4.4, it can be seen that probe with the diameter size 40 mm is more satisfying due to the energy had spread out over a larger surface area in a beaker through the motion of the vibration from the titanium tip immersed in the mixture. Thus, the larger of processing area will allowing for more mixture to be processed. While a tip with a very small diameter is only focused on a very small area. So, this project needs to use the 40mm probe to break all the agglomerations of nanoparticles that have been mixed into the mineral oil. But at the end of this process, the use of both probe shows that have produced differences nanofluids in terms of colour and the fraction of nanopowder agglomeration. The probe vibrates in a longitudinal direction and transmits this motion to the titanium tip immersed in the mixture. The longitudinal vibration in the tip causes the mixture to cavitate and creates the energy that causes the nanopowder disrupted and dispersed into mineral oil. This investigation is to ensure that the preparation of nanofluids is stable and perfect to be tested. Moreover, the quality of nanofluids surface modifications will influence to AC breakdown voltage test level.

4.5 Physical Change During Preparation of Nanofluids

The preparation of nanofluids by dispersing conductive nanoparticles into mineral oil is one of objective of this project. From the Table 4.4, it can be seen that after complete the preparation of nanofluid, the oil became yellowish. Besides that, the nanofluid also producing a rather strong smell. Therefore during the preparation of nanofluid process, the safety glasses and mask shall be wear. Table 4.4 shows the physical change during preparation of nanofluid. Based on the physical change during the preparation of nanofluid, its show that the process had broke the agglomerations of nanoparticles very well. It's also to show that the Fe_3O_4 conductive nanoparticles had been greatly dispersed in mineral oil and become as nanofluids.

Table 4.4: The physical change during preparation of nanofluid.

Process	Physical change
After mixing	
After ultrasonication process	
After vacuum oven process	

4.6 Summary

This chapter is contained of the results and discussion of the entire experiment. The topics have been discussed are the result and analysis of the breakdown voltage level, effects of different probe and the physical change during preparation of nanofluids. Next chapter will explain about the conclusion and recommendation of the project.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

As a conclusion, all of the objectives had been achieved. For the first objectives, the preparation of nanofluids using mineral oil by dispersing it with Fe_3O_4 conducting nanoparticles is successfully conducted. All the procedure and standard of the equipment that used during the experiment is followed. The conductive nanoparticles affected physical changes when dispersed in mineral oil. Then, the preparation of liquid insulation's breakdown voltage test set namely Megger OTS60PB according to IEC 156:1995 is successfully conducted. All required standards were being used to make sure the results were properly determined. The Fe_3O_4 conductive nanofluids AC breakdown voltage level under the moisture effect is been tested and analyzed. The average breakdown voltage of Fe_3O_4 nanofluids had increased as compared with the average breakdown voltage of base oil. Although the Fe_3O_4 conductive nanoparticles have proved can improve the electrical strength of insulating oil, the investigation has indicated that the nanofluid modified by conductive nanoparticle cannot bare the moisture effect. The breakdown voltage value has decreased as the water content increased. The presence of water in nanofluid reduces its electrical. However, the performance of electrical strength of nanofluid modified by Fe_3O_4 conductive nanoparticle better than pure transformer oil under moisture effect. Hence, uses of conductive nanoparticles by dispersing it into mineral oil as insulation oil in the transformers should be implemented. Through the implementation, it will help to improve the insulating properties of transformer oil because the possible HV power transformer failures were due to dielectric insulation problems.

5.2 Recommendations

Based on the investigation, it clearly shows that conductive nanofluids are promising to enhance the breakdown voltage of mineral oil. There are a few recommendations for future plans studies related to this project:

i. Use a good mineral oil and has never exposed to the oxidation process as a base sample.
ii. Use another type of nanoparticle which is semiconductive and insulative nanoparticle.
iii. Use another type of oil as a base sample such as Palm Fatty Acid Ester Oil (PFAE), vegetable oil and others insulating oil.

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APPENDIX A– CALCULATION OF MASS FRACTION OF WATER TO THE TOTAL CONCENTRATION OF NANOFLUID

$$MF_{water}\,(\%) = \frac{M\ water}{M\ oil + M\ water} \times 100 \tag{3.1}$$

i. Calculation for volume of 0.05 ml of water:

M water = 0.05 ml = 0.05 gm

M oil = 350 ml = 350 gm

$$MF_{water}\,(\%) = \frac{0.05}{350 + 0.05} \times 100$$

$$= 0.0143\% \approx 0.015\%$$

ii. Calculation for volume of 0.1 ml of water:

M water = 0.1 ml = 0.1 gm

M oil = 350 ml = 350 gm

$$MF_{water}\,(\%) = \frac{0.1}{350 + 0.1} \times 100$$

$$= 0.0285\% \approx 0.03\%$$

iii. Calculation for volume of 0.15 ml of water:

M water = 0.15 ml = 0.15 gm

M oil = 350 ml = 350 gm

$$MF_{water}\,(\%) = \frac{0.15}{350 + 0.15} \times 100$$

$$= 0.043\% \approx 0.045\%$$

iv. Calculation for volume of 0.2 ml of water:

M water = 0.2 ml = 0.2 gm

M oil = 350 ml = 350 gm

$$MF_{water}\,(\%) = \frac{0.2}{350 + 0.2} \times 100$$

$$= 0.057\% \approx 0.06\%$$