THE EXPERIMENTAL STUDY OF PARTIAL DISCHARGE OF MALAYSIAN BASED PALM OIL

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ABSTRACT

Insulation is one of the most important parts in a high voltage apparatus, while insulator is a material that resists the flow of the electric current. Most of the transformer used liquid insulating material where its function is to provide electrical insulation and also act as a coolant to prevent overheating of the transformer. Since years ago, petroleum-based mineral oil has been used as a coolant and insulation purpose because of its high electric field strength, low dielectric losses and good long-term performance. There are some reasons that push the search of environmental friendly insulating oils. Conventional transformer insulating materials are usually non-biodegradable. It can contaminate soil and water when serious spill take place. This may disturb the plantation and other lives. In future, this petroleum will be come to an end because it is a non-renewable source. Therefore, this project has been carried out to seek alternatives of vegetables oil that is more environmental friendly. Refined, bleached and deodorized palm oil (RBDPO) has been recognized to be the potential replacement for petroleum-based mineral oil. The main objective of this project is to execute experimental study effect of ageing time and electrical characteristic of Refined, Bleached and Deodorized Palm Oil (RBDPO) by using partial discharge method. Another objective of this project is to make a comparison on electrical properties between new insulating oil, RBDPO with petroleum-based mineral oil. The result indicates the prospect of RBDPO to be further processed to get better dielectric properties and meet all requirements to be used as liquid insulating material. This is because RBDPO has a potential to be a good liquid insulator because of its high breakdown voltage, low dissipation factor and low capacitance when different ageing time were applied.

ABSTRAK

Isolasi adalah salah satu bahagian terpenting dalam peralatan voltan tinggi dan insulator pula adalah bahan bahan yang menolak aliran arus elektrik. Sebahagian besar transformer menggunakan bahan isolasi cair di mana fungsinya adalah untuk memberikan isolasi elektrik dan juga bertindak sebagai pendingin untuk mengelakkan daripada transformer terlalu panas. Sejak dahulu lagi, minyak mineral telah digunakan sebagai bahan penyejuk dan penebatan kerana memiliki sifat dielektrik yang sangat baik, iaitu kekuatan medan elektrik tinggi, kehilangan dielektrik rendah dan prestasi jangka panjang yang bagus. Tetapi masalah yang paling serius adalah membahayakan kesihatan dan mencemarkan alam sekitar. Selain itu, minyak ini juga tidak boleh diperbaharui, maka minyak ini akan habis pada masa depan. Oleh itu, projek ini telah dijalankan untuk mencari alternatif dari minyak sayuran yang lebih mesra alam. Minyak sawit RBDPO telah dikenalpasti mempunyai potensi untuk menjadi pengganti kepada minyak bumi. Objektif utama projek ini adalah untuk mengkaji kesan penuaan dan ciri-ciri electric menggunakan RBDPO menggunakan teknik pengacasan separa.Objektif sampingan pula ialah membuat pembandingan ciri-ciri elektrik dengan minyak berasas kan petroleum. Beberapa eksperimen telah dilakukan untuk mengetahui pengaruh masa terhadap voltan tembus, faktor disipasi dan permitivitas relatif minyak. Dari keputusan yang diperoleh, RBDPO menunjukkan potensi untuk menjadi isolator cair yang baik kerana voltan tembus tinggi, faktor disipasi rendah dan kapasiti rendah apabila masa yang berbeza dikenakan.

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BDV		Breakdown voltages
BS		British Standard
FTIR		Fourier Transform Infrared Spectrometry
RBDPO		Refined Bleached Deodorize Palm Oil
kV	-	kilovolt
kA	-	Kilo Amperes
pCs	-	PicoCoulomb
m	-	Meter
mm	-	Millimeter

CHAPTER 1

INTRODUCTION

1.0 Background

Insulators are devices that are used on electricity supply networks to support, separate or contain conductors at high voltage. Insulation is one of the most important parts in a high voltage apparatus. The insulator intended to support or separate electrical conductors without passing current through themselves. There are three basics types of electrical insulating, which is solid, liquid and gas. These materials are widely employed in electrical network components such as circuit breakers, transformers, cables and capacitors [1].

Liquid insulation is used for filling transformers, circuit breakers and as impregnants in high voltage cables and capacitors. Insulation plays important parts in electrical system to insulate the potential charge materials with the earthed object (including human). Failure in insulation could cause electrical breakdown or short circuit in which may introduced the risk of faulty/damage to the equipment as well as causing potential danger to the human. In general, insulation can be formed of solid (e.g. glass, porcelain, or composite polymer materials and etc.), gases (i.e. nitrogen and sulphur hexafluoride) and liquid such as mineral oils (e.g. naphthenic oil and paraffinic oil) [2].

There are several requirements for transformer insulating oil, which includes:

- To act as a coolant with the main task of absorbing the heat from the core and winding, then transmitting it to the outer surface of the transformer. At higher temperatures the viscosity of the oil decreases, thus facilitating the circulation of the oil. It is important to keep the pour point low so the oil is capable at any observable flow.

- To insulate different parts at different electrical potential. Oil makes a good contribution to transformer insulation by penetrating into and filling the spaces between wound insulation layers.

- In order to minimize the evaporation losses, the oil volatility should remain low. Oil temperature in service should be maintained below its flash point

The three most important properties of liquid are dielectric strength, dielectric constant and the electrical conductivity. Other important properties include the viscosity, thermal stability, specific gravity and flash point. The important factors that affect the dielectric strength of oil are the presence of fine water and the fibrous impurities. Therefore, when oils are used for providing electrical insulation, the oil should be free from moisture, products of oxidation and other contaminants [3].

Recently, several liquid insulating material has been introduced which are generally organics type and obtained from nature that are biodegradable and friendly to environmental. For instance, the new liquid insulating material includes vegetables oil such as Soya-bean oil, Sunflower oil, Coconut oil, Olive oil and Palm Oil.

Malaysia is one of the countries that have indigenous resource of palm oil. The sample of palm oil produced includes Crude Palm Kernel (CPKO), Crude Palm Oil (CPO), Crude Palm (CP8), Crude Palm (CP10), and Refined Bleached and Deodorized Palm Oil (RBDPO). This type of oils is safe and environmentally friendly renewable resources. These oils are widely used and have extensive of resources, hence there is then the assurance of sustainability [4, 5].

1.1 Problem Statement

Petroleum-based mineral oils have been used as liquid insulating materials in power transformer and other high voltage apparatus because of its excellent dielectric properties. Now, the existence of mineral oil in the world has been reduced as the time goes by and probably it will not occupy our needs for the next generation [6].

Due to environmental consideration, recently researches have been put in attempt to search the alternatives of liquid insulating materials. There are some reasons that push the search of environmental friendly insulating oils. Conventional transformer insulating materials are usually non-biodegradable. It can contaminate soil and water when serious spill take place [6, 7].

This may disturb the plantation and other lives. It is important to find alternative oil sources that have similar dielectric characteristics with the existing one and probably can increase the performance of related equipment. Therefore, this oil needs to be replaced with a new type of oil that is friendlier towards the environment.

1.2 Objective

The main objective of this project is to execute experimental study effect of ageing time and electrical characteristic of Refined, Bleached and Deodorized Palm Oil (RBDPO) by using partial discharge method. Another objective of this project is to make a comparison on electrical properties between new insulating oil, RBDPO with petroleum-based mineral oil

1.3 Scope of the Project

The scopes of the project are as the following:

i. Literature Review

Find and understand regarding literature review that covers all study of insulating oil, recent development research, past researcher work and method, characteristics of the liquid insulation, partial discharge method and etc.

ii. Material Sample

Sample used in the experiment is the palm oil and industrial Hyrax transformer oil.

iii. Electrical Properties

The partial discharge (PD) characteristic, which includes PD magnitude and PD numbers.

iv. Data Collected

The data is collected by using partial discharge meter

v. Experimental Area

Partial discharge test is conducted at UTHM High Voltage lab and Polymer and Manufacturing lab to analyze the result based on electrical characteristics and compare result with the international standard such as British Standard.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Nowadays making the suitable choice of insulating material and maintaining for high voltage power system equipment is very important for successful operation throughout their lifespan [8]. For applying this it requires knowledge of the material of insulation and how they would be expected to react in various operating environment for example high load operation in power system, especially over long periods .

For high voltage insulators have been developed rapidly by manufacturer like ABB and Siemens since early this century. All of electrical equipment that available in the market rating from small scale of 240V to big scale of 132kV is using insulation in one form or any other to maintain the flow of electrical current in the desired path or circuits [20]. The power system is growing both in size and complexities with the increasing demand of electrical energy. An insulator can be simply described a material that resists the flow of electric current and prevent the flow of current from undesired path. Insulation is also known as dielectric because it's mainly used to control the flow of the current between two conductors [9].

Dielectric can be divided into three major groups such as shown in Figures 2.1 below:

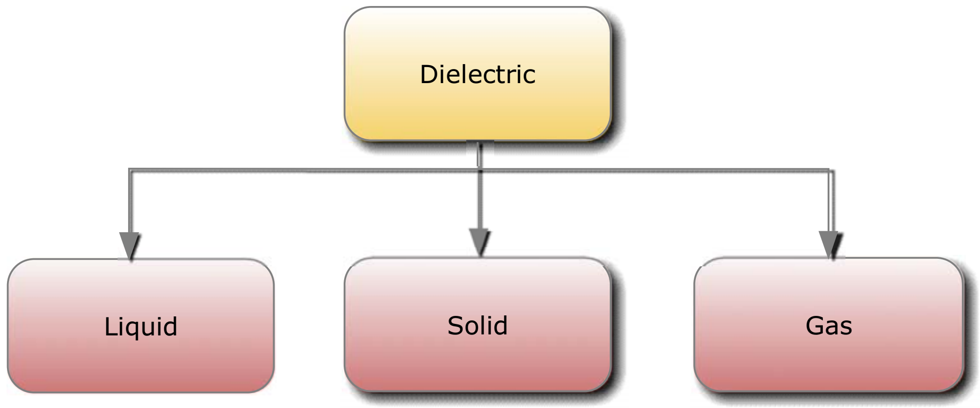


Figure 2.1: Classification of dielectric

Dielectric materials can transmit electrical energy through displacement current but cannot transmit through conduction. Besides that, its primary function depends on its ability to conduct useful electrical current under the conditions of use [10]. Solid dielectric materials are used in all kinds of electrical apparatus and devices to insulate one current carrying part from another when they operate at different voltages. A good dielectric should have low dielectric loss, high mechanical strength, and can be resistant to thermal and chemical deterioration [9]. Solid dielectrics have higher breakdown strength compared to liquid and gases.

The most common dielectrics used are gases. Various phenomena occur in gaseous dielectrics when voltage is applied. When the applied voltage is low, the current flowing will be small throughout the insulation and electrodes that retains the electrical properties. Meanwhile, the current flow will increase sharply when the voltage applied are large. This will conduct an electrical breakdown that produce spark. A short circuit occurs during the spark between electrodes [11].

The gases have wide application in power system to provide insulation to various equipment and substations. The example of gases used are air, oxygen, hydrogen, nitrogen, carbon dioxide and electronegative gases like sulphur hexafluoride and arcton [12]. The various properties required for providing insulation are:

- High dielectric strength
- Thermal and chemical stability
- Non-inflammability
- High thermal conductivity

Liquid dielectric is very useful as insulating material compared to solids or gases because of their inherent properties. This is because both liquids and solids are denser than gases [9]. Liquids also have same properties like gases which fill the complete volume to be insulated and simultaneously will dissipate heat by convection. Liquids are expected to give a very high dielectric strength. This liquid dielectric mainly as impregnates in high voltage cables and capacitors, and for filling up of transformers and also circuit breaker application.

2.2 Liquid as Insulator

Mineral oils has been the main source as liquid insulating material for decades which are produced from middle range of petroleum-derived distillates. In recent years concern have been take due to polynuclear aromatic hyrocarbons in mineral oils [13]. A substitute to mineral oils other polyster oils have been developed to be used in Europe and other countries as transformer oil. In 1885, the first distribution transformer was built in USA by using air as the dielectric coolant and dry type design. Professor Elihu Thompson who's work for General Motor in Lynn had successfully patented transformer in 1882 which the transformer are smaller and more efficient [14]. In 1892 then General Motor produced his idea after 10 years. After that, the industry then focused on determining the ideal properties of mineral oil for dielectric application and developing process for producing more consistent quality fluid. Figure 2.2 shows the timeline for liquid insulator from 1182 to 1976.

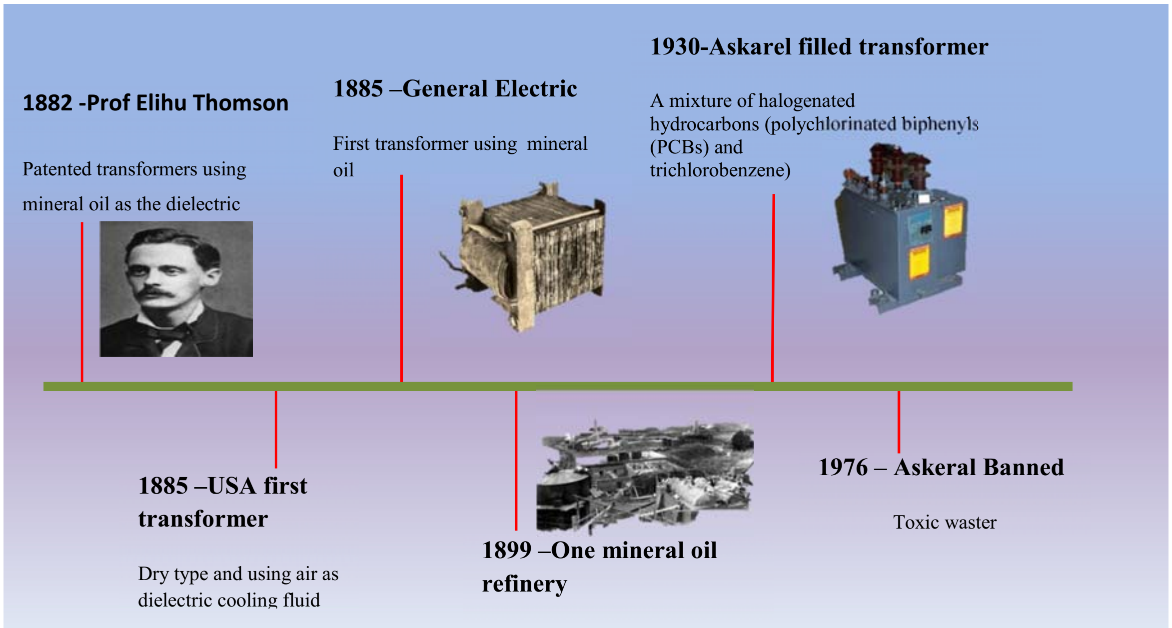


Figure 2.2: Timeline of liquid insulator

As times goes by when personal safety and security become more important for electrical power system equipment especially using mineral oil in power transformer, the usage of alternative insulation fluids is increasing in market [15]. Today people are start to change the view in electrical design equipment analysis by more focusing overall environmental and total life cycle costs beside performance on the equipment. The suggested minimum health and environmental related requirement for applying a material as a dielectric fluid include be essential non-toxic and not be listed as a hazardous material by Environmental Protection Agency (EPA) or Occupational Safety and Health Administration (OSHA). With these trends and concern in mind, the development of potential of non-petroleum, non-hazardous alternative materials with environmental characteristic better than even the highly refined mineral oils. This is because due to its poor biodegradability characteristic to the environment, there is still environmental effect in case of leakage during operation or any accident on the transformer [14, 15].

For improved health and environment safety an additional minimum requirement goals are included:

- Provide a magnitude increase in rate and degree
- Consumed essentially non-toxic material
- Derived from renewable resources of biodegradation

Liquid insulation can be divided into several main groups such as shown in Figure 2.3 below:

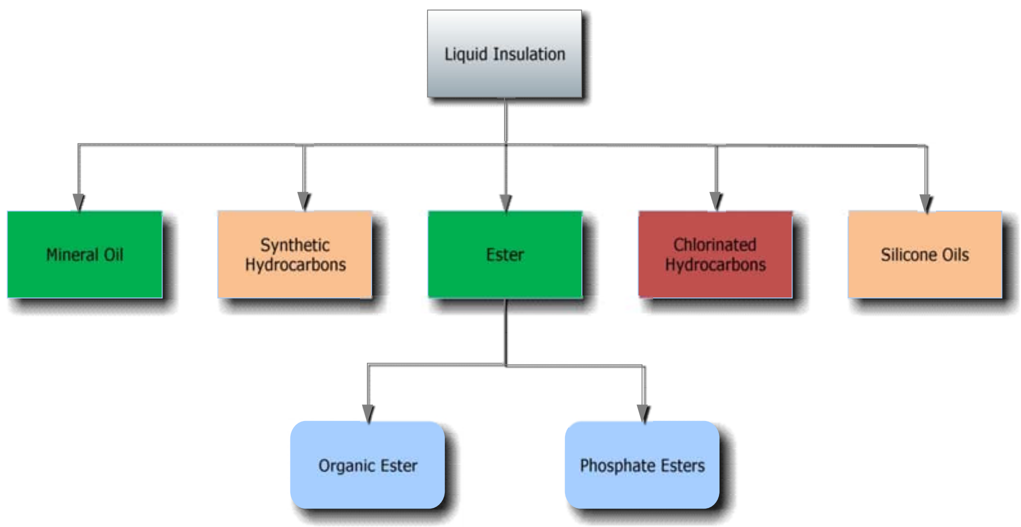


Figure 2.3: Classification of liquid insulation

2.2.1 Mineral Oil

Mineral oil is the most commonly used in dielectric in power apparatus and made of fossil oil. The first mineral oil is used in 1892 by General Electric for transformer that been designed by Prof Elihu Thomson. In early 1899, the usage of the mineral oil as liquid dielectric has been broad because of the development in mineral oil. The usage of mineral oil is more popular than ester that time because the inferior oxygen stability and high pour point, permittivity, and viscosity values. Until today, mineral oils are used for liquid filled transformer as the insulating liquid [13, 14]. When in service, the mineral oil liquid in a transformer undergo a constant heat produce by the operation of the transformer temperatures about 95 °C and consequently it degradation because of ageing process [16].Figure 2.4 shows degradation of insulation .The mineral oil becomes darker due to the formation of acids and resins or sludge in the liquids. Exposing transformer parts to acids for a long time can cause corrosive to the solid insulating material and metal parts in the transformer. Beside that sludge that deposit inside the transformer core reduces the circulation of the oil and thus its heat transfer capability decreased gradually with time. This will effect on performance of transformer [17]. This is based on the specification for testing transformer oils as given in IS 1866 (1983) IEC 296 (1969) and IEC 474 (1974).

Figure 2.4: Degradation of oil insulation from left to right

Mineral oil consists of 14% hydrogen, 84% carbon in various structure and 1-3% sulphur oxygen-nitrogen call heteatoms [13].

There are two types of mineral oil, the first one us crude mineral oil and the second is refining mineral oil, such as shown in Figure 2.5 below.

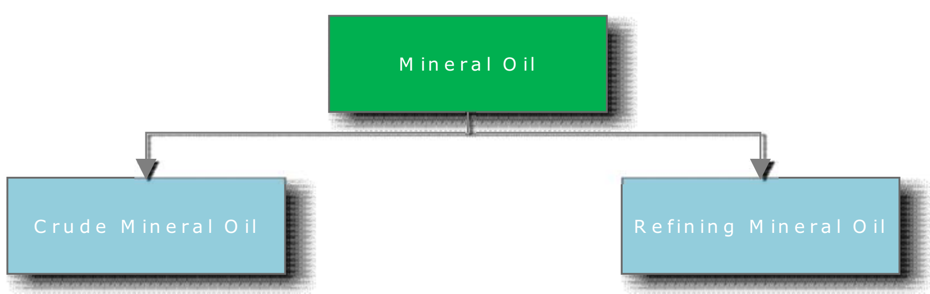
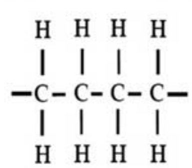
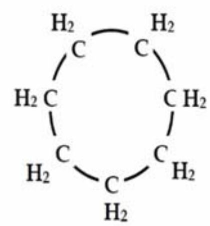
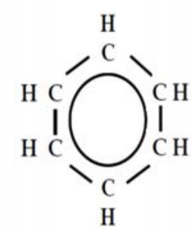


Figure 2.5: Classification of mineral oil

The aim for refining mineral oil is to remove or reduce waxes, sulphur, nitrogen and oxygen-compound and the aromatic hydrocarbon [13, 19]. The mineral oil after refining process has good insulation properties. The basic refining process comprises of a vacuum distillation unit where several step are followed such as such as selective solvent extraction, sulphuric acid extraction, earth filtration, hydrogenation, re-distillation, filtration, and dehydration [16].Table 2.1 below show the main type of mineral oil.

Table 2.1: Main type of mineral oil [6]

Paraffin	Naphthenic	Aromatic
		
Methane (CH4) is a gas, normal butane (C4H10), and isobutene	It has ring structures with six carbon atoms or fourteen Carbon atoms	It has ring structures with six carbon atoms or fourteen Carbon atoms

Generally, liquid insulation is divided into three types of characteristic, which are Electrical, Chemical and Physical properties. The electrical characteristic of liquid insulation is studied in detail. Several of the electrical properties, such as dissipation factor, resistivity and permittivity are tested [9]. The physical and electrical properties of the transformer oil are given in table 2.2

Table 2.2: Dielectric properties of mineral oil [7]

Property	Mineral Oil
Relative Permittivity, 50 Hz	2.2-2.3
Breakdown Strength at 2 0℃	18Kv/mm
Tan δ, 50 Hz	2.5 x 10^{-4}
Resistivity	10^{13}-10^{14}
Maximum permissible water content (ppm)	50
Acid value	NIL
Specific gravity at 20℃	0.89

2.2.2 Ester oil

Easter are broad class of organic compound and available either as natural agricultural products or chemically synthesized from organic precursor in other word natural ester or synthetic ester [14, 20]. Natural ester appears as saturated and single, double and triple unsaturated fatty acids. The difference between saturated and unsaturated acid is saturated acid is more chemically stable than unsaturated acid but disadvantage in high viscosity. Esters with high percentage of single unsaturated acid have proven more useful for insulating liquids. Although past application implement natural ester in capacitor show potential, but its susceptibility to oxidation became the primary obstacle in using as liquid insulation. However modern transformer design practice along with suitable additives and minor design modification, compensate for this characteristic [13, 14, 22].From Figure 2.6 below shows the structure and bonding for vegetable oil (triglyceride).

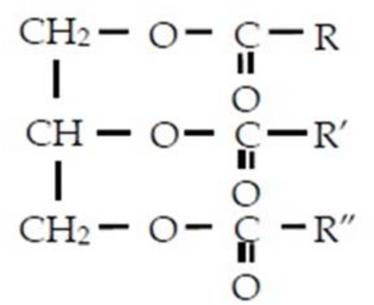


Figure 2.6 : Structure of vegetable oil (triglyceride) [20,21]

Synthetic acid most commonly synthetic polyol ester (POE), have suitable dielectric properties and are significantly more biodegradable if compare to mineral oil or high molecular weight hydrocarbons (HMWH) [14].It’s made of an acid and alcohol. The characteristic of the liquid insulation can be modified due to differ with their base materials and viscosity of synthetic ester is twice higher than viscosity of mineral oil. Synthetic ester liquid MIDEL 7131 are used in transformer are carbon acid ester origin from M&I company [13, 14].From Figure 2.7 shows the structure and bonding for synthetic polyol ester.

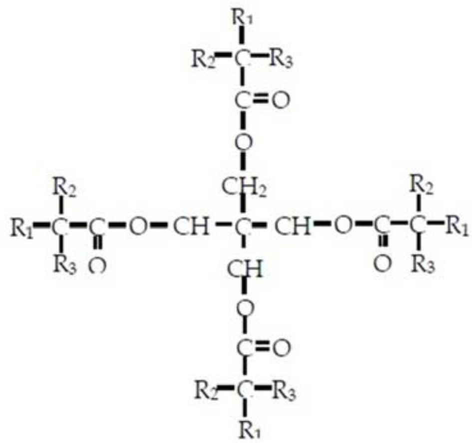


Figure 2.7 Synthetic polyol ester structures [21]

Examples of current, commercially-known, natural ester dielectrics are shown in Table 2.3 below.

Table 2.3: Commercially known vegetable oil transformer [13]

Name	Type	Manufacturer
BIOTEMP®	Comprised mostly of mono-unsaturated high oleic acid triglyceride vegetable oils. Examples of high oleic oils are sunflower, safflower, and rapeseed (canola).	ABB Inc.
BIOTRANS	A mixture of partially hydrogenated soybean oil high in oleic acid content, methyl esters produced from soybeans, palm or coconut oils used to thin the dielectric liquid.	Cargill
Envirotemp® FR3	Edible-seed oil based dielectric liquid. It is a natural ester (triglyceride - fatty acid ester). Suitable vegetable oils, which may be used independently or combined, include: soya, sunflower, and rapeseed (canola).	Cooper Power Systems
Coconut Oil	Coconut oil	University of Moratuwa,

Table 2.4 shows the advantages and disadvantages between natural ester and the synthetic ester oil.

Table 2.4: Advantages and disadvantages between natural and synthetic ester [22]

	Natural ester	Synthetic ester
Advantages	Higher fire point Readily biodegradable Moisture tolerant	Higher fire point Readily biodegradable Moisture tolerant Oxidation stable Low pour point
Disadvantages	Higher viscosity Sensitive of oxidation High pour point	Expensive

Table 2.5 shows the comparison characteristics between the mineral oil and ester based oil.

Table 2.5: Comparison characteristics between mineral oil and ester [22]

Characteristics	Mineral oil	Ester oil
Raw material	Produced from petroleum sources which are non-renewable source.	Produced from the plant, which are renewable source such as corn and sunflower oil.
Environmental safety	Contain non-biodegradable compound.	Highly biodegradable
Fire risk	Catch more easily fire, leading to higher probability of transformer fired	Higher fire point, reduced the impact of transformer fires
Performances	Does not slow down the standard insulation aging rate	Proven to slow down the aging rate of insulation system

2.3 Oil Application inside Transformer

A transformer is a static device that transfer electrical energy from one circuit to another by electromagnetic without change in frequency. The transformer can be either step up or step down transformer. There are varies of transformer in the market that been manufactured in varies of size, shape, function and type [19]. Rating of the transformer is depending on the demand and functionality of supply to the consumer. Liquid insulation in the transformer plays one of the major important roles in transformer life and performance. Most of the accident that related to transformer is mainly cause by failure of the insulation due to degradation. The main purposes of application for transformer oil are shown as Figure 2.8 below.

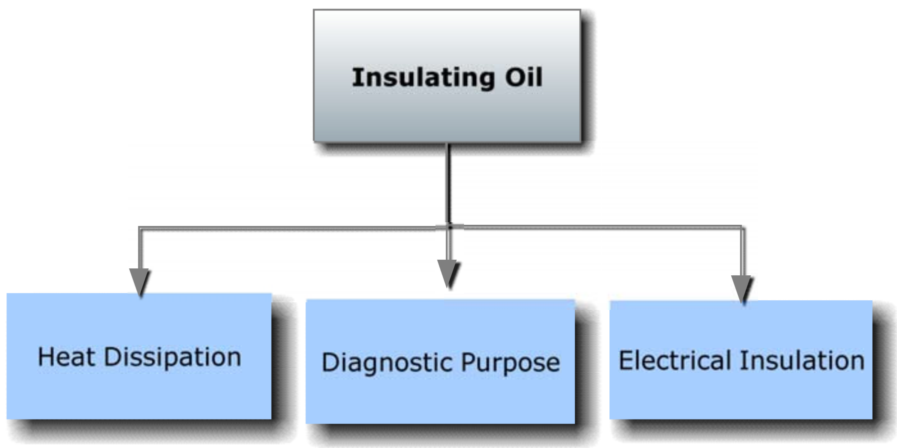


Figure 2.8: Classification of insulating oil

2.3.1 Electrical Insulation

Liquid insulation in the transformer function to provide dielectric medium that acts as insulation surrounding various energized conductor. Besides that, the liquid insulation acts as a protective coating to the metal surface against chemical reacting such as oxidation.

2.3.2 Heat Dissipation

A secondary function of the insulating liquid is to serve as dissipater heat. The oil in the transformer aids by removing the heat from the areas and distribute equally the thermal energy over a generally large mass of oil and tank of the devices. It is transferred by means of conduction, convection and radiation to the surrounding environment.

2.3.3 Diagnostic Purpose

The insulating liquid also can be used to determine the condition (both chemical and electrical) of operational of the liquid filled transformer. When fault happen in the transformer, the cause energy from the fault is dissipated through the liquid by chemical degradation. An analysis for these degradation products can provide information about the type of fault that is present.

2.4 Palm Oil

Palm oil is a form of edible vegetable oil obtained from the fruit of the oil palm tree. Palm oil is a natural food that has been consumed for more than 5,000 years. Palm oil is produced from the fruit of the oil palm, or Elaeis Guinnesis tree, which originated in West Guinea. While the tree was introduced into other parts of Africa, South East Asia and Latin America during the 15th century, it was first introduced 1870 as an ornamental plant.

Large commercial planting and cultivation of the plant in Malaysia did not begin until the mid- 1990's. The world's largest producer and exporter of palm oil today is Malaysia, producing about 47% of the world's supply of palm oil. The palm fruit is the source of both palm oil (extracted from palm fruit) and palm kernel oil (extracted from the fruit seeds). Figure 2.9 below shows the structure of palm oil [6].

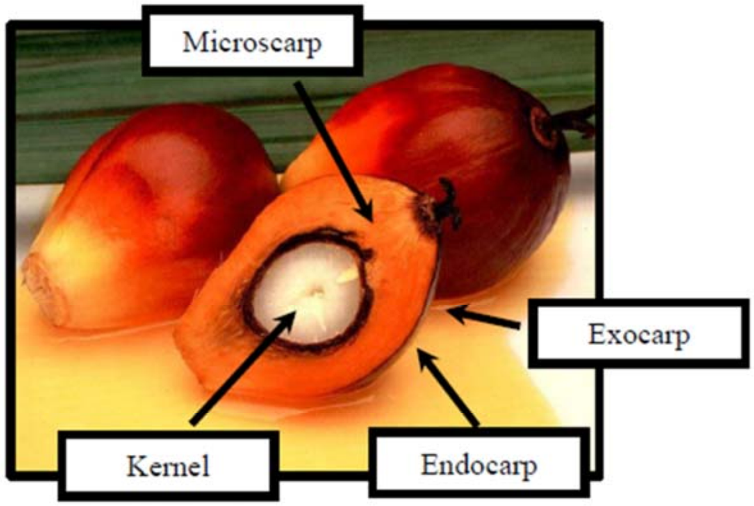


Figure 2.9: Structure of palm oil [5]

As shown in Figure 2.10 below, palm oil products are made using milling and refining processes. The first process is by using fractionation, with crystallization and separation processes to obtain solid (stearin), and liquid (olein) fractions. By melting and degumming, impurities can be removed and then the oil filtered and bleached. Next, physical refining removes smells and coloration, to produce refined bleached deodorized palm oil, or RBDPO, and free sheer fatty acids.

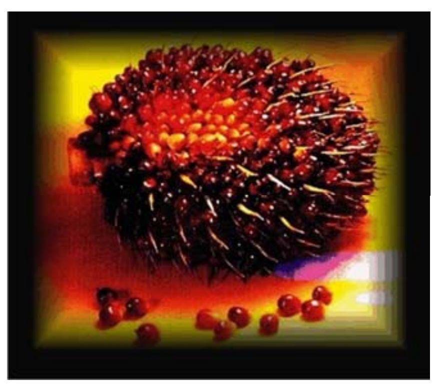


Figure 2.10: Palm oil fruit bunch [5]

RBDPO is the basic oil product that can be sold on the world's commodity markets; although many companies fractionate it out further into palm olein. Splitting of oils and fats by hydrolysis, or under basic conditions saponification, yields fatty acids, with glycerine (glycerol). The split-off fatty acids are a mixture of fatty acids ranging from C4 to C18 depending on the type of oil/fat.

Refined is defined as a process of purification of a substance to obtain edible oils from crude oils through processing steps such as degumming, neutralisation, bleaching and deodorization. Bleached is defined as Removal of colour and oxidizing bodies, residual gums, soap and trace metals by mixing oil with special adsorbents (silica and/or bleaching earth). The adsorbents containing the mentioned impurities are then removed by filtration**.** While deodorized is a process of removing the fatty acids, odour, flavour and destabilizing impurities by subjecting the oil to high vacuum and temperature, under conditions so that the impurities are vaporized and removed while the oil remains liquid [6, 7].

Table 2.6 shows the dielectric properties of the Refined Bleached Deodorized Palm Oil (RBDPO) from an experiment done by other researchers.

Table 2.6: Dielectric properties of the refined bleached deodorized palm oil [7]

	RBDPO
Viscosity at 40 "C	**37**
Flash Point ('C)	**330**
Breakdown voltage (kV) at 40 OC	**52**
Dielectric dissipation factor at 9ooc	**0.0035**

2.5 Partial Discharge

In early 1940's, partial discharge measurement and location has been interest to the most of organization especially who had a stake in the field include independent laboratories, universities, the military, electrical utilities, manufacturer of electrical product and other [23].

Partial discharge is an electrical discharge that only partially bridges the dielectric or insulating medium between two conductors. Electrical discharge are defined as movement of electrical charges through the insulating either liquid, solid or air which is initiated by electron avalanches [24]. Partial Discharges is also includes internal discharge because of the existence of voids for example in solid or liquid insulations, surfaces discharges at the boundary of insulating material, treeing corona as in gaseous dielectric [25]. According to the International Electrotechnical Commission (IEC) International Standard 60270, Section 3.1 published in 2000, the definition of partial discharge is:

“Localized electrical discharge that only partially bridges the insulation between conductors and which can or cannot occur adjacent to a conductor.”

Partial discharge is the main reason of ageing and eventually failure of electrical insulation. Partial discharge is an early detection before breakdown of liquid, solid or air insulation.

2.5.1 Forms of Partial Discharge

The model normally used for partial discharge is shown as figure below. The configuration was suggested by A.Gemant and W.V Philippoff and analyzed further as discussed by Whithead and and others [27]. It does consider a cavity within the bulk of insulation (liquid or solid). The concept of apparent charge shall be first being discussed before explaining the techniques used to measure partial discharge. Figure 2.11 show the insulation between the electrodes and the remaining bulk insulation are represented as capacitance C_v represents the void, C_b the dielectric above and below it and while C_a represents the rest of the dielectric.

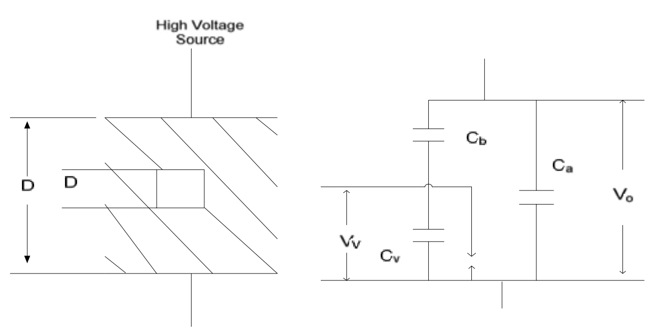


Figure 2.11 : Schematic of void representation and equivalent circuit in dielectric [9]

Partial discharge in the void will occur when an alternating voltage V_a in excess of that corresponding to the breakdown threshold . The processes of the partial discharge are illustrated as the figure below. The voltage that appearing across the void if there is no discharge is V_v and is given by the expression :

$$V_v = \frac{V_a}{1 + \frac{(\frac{d}{d_1 - 1})}{\varepsilon_r}} \qquad 2.1$$

Where d represent the thickness of the insulating sample and the gas void,d1 represent the void and ε_r is the relative permittivity of the dielectric. From the figure 2.12 ,partial discharge in the void will start at a voltage V_i on the positive half-cylce and approximately $-V_i$ on the negative half-cycle. $\pm V_e$ is the voltage at which the discharge stop. A sharp current current pulse are accompanied during the discharge in the void as shown in the figure below.This event will occur several time on the increasing part of the positive half-cycle. At point m the voltage across the void reverses its polarity since at this instant V_v is decreasing and discharge will continue with almost regular negative current pulses [24, 29].Figure 2.12 below shows the waveform voltage and current traces of a partial discharge in a void.

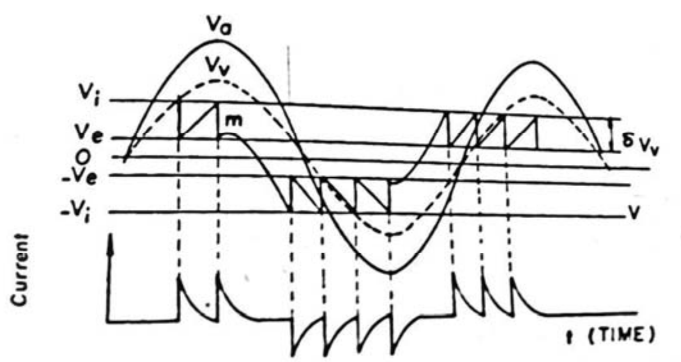


Figure 2.12: Voltage and current traces of a partial discharge in a void [29]

Partial discharges will be seen before the bulk failure or breakdown as the breakdown field in the cavity will be substantially less than that of the surrounding condensed matter. When the discharge occur damage to the void will resulting of dissolved of gaseous by products. These gases will increase the pressure in the void and may eventually extinguish discharges until the void increase in size or the gases diffuses away [26]. During partial discharge take place,electrons and positive ions have sufficient energy are formed and resulting to break the chemical bonds of the insulating material at void surfaces. Besides that, the heat produced in the discharge will carbonize the surface of the void and cause erosion of the material. Figure 2.13 shows the sequences of void breakdown under alternating voltages.

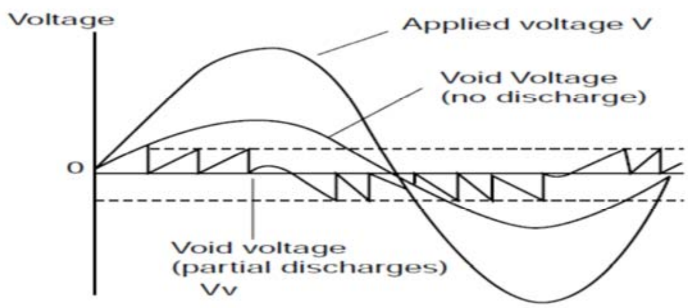
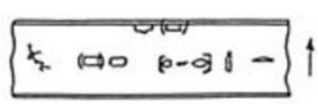
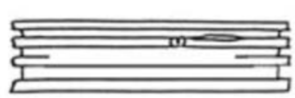


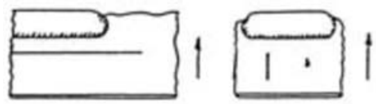
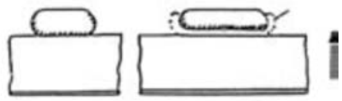
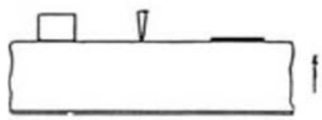
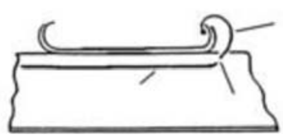
Figure 2.13: Sequences of void breakdown under alternating voltages [29]

2.5.2 Sources of Partial Discharge

Mostly partial discharges occur under alternating voltages conditions due to trapped gas or ambient temperature. Insulation that has lower permittivity and breakdown most likely will tend to be initial location of local partial discharges.From Table 2.7 below shows the sources of partial discharge.

Table 2.7: Example of some sources of partial discharge [25]

Sources of partial discharge	**Description**
	Types of internal discharges in solid materials
	Internal discharges in laminated materials and barriered structures

	Internal discharges due to metal surface/particles embedded in insulation structures
	Discharge in conductor /surface and dielectric /surface wedges
	Surface discharges due to sharp electrodes at dielectric
	Discharges created by changes in the potential differences for example transformer winding shield and bushing outer foil

2.5.3 Measurements Methods of Partial Discharge

In detecting partial discharge in liquid insulation is very important to determine an early detection of failure. Partial discharge test is nondestructive test which are usually carried out on the equipment insulation to ensure that its electrical characteristic comply with the specification without destroying it [29]. The electrical partial discharge detection methods are classified as straight or balanced methods. Figure 2.15 shows two methods of partial discharge measurement.

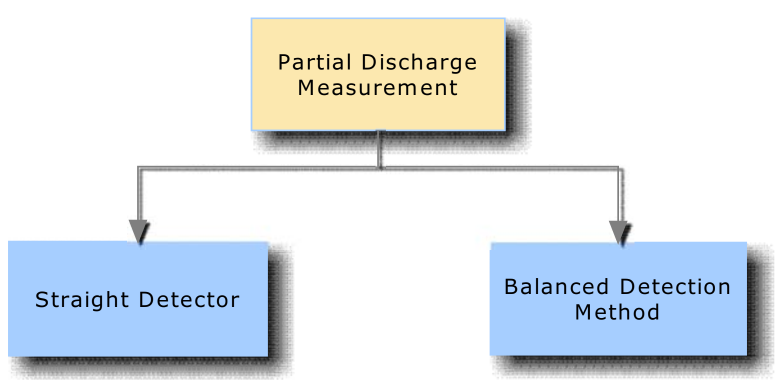


Figure 2.14: Methods of measurement

2.5.3.1 Straight Detector

In straight detection method partial discharge measuring instruments measure the charge released within the discharging sites of the test specimens. Detection of charge displacement is the most popular chosen measurement method. The basic circuit that use for the measurement consist of a series impedance connected between the sample or test object and ground. Figure 2.15 shows the basic circuit of straight detection measurement while Figure 2.16 shows the detail regarding straight detection circuit.

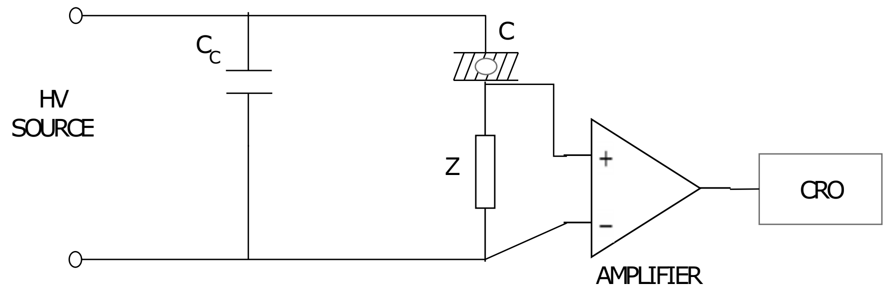


Figure 2.15: Basic circuit of detection measurement [29]

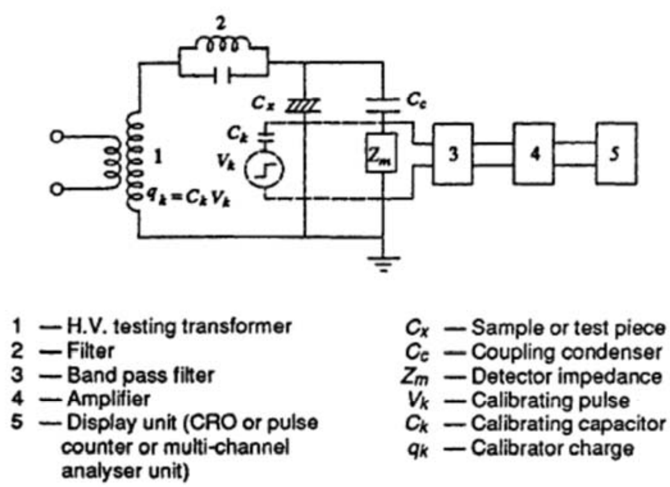


Figure 2.16: Straight discharge detection circuit [29]

The transformer that been used are free from internal discharge by using resonant filter that prevent any pulses that occur from capacitance of the windings and bushings of the transformer. C_x is the test object , C_c is the coupling capacitor and Z_m is a detection impedance. The signal that across the impedance Z_m flow through a band pass filter and amplifier and displayed on a cathode ray oscilloscope or counted by a pulse counter multi-channel analyzer unit [24].Commercial partial discharge measuring instrument are usually calibrated in terms of apparent charge. Figure 2.17 shows the sine wave and elliptic sweep display in CRO.

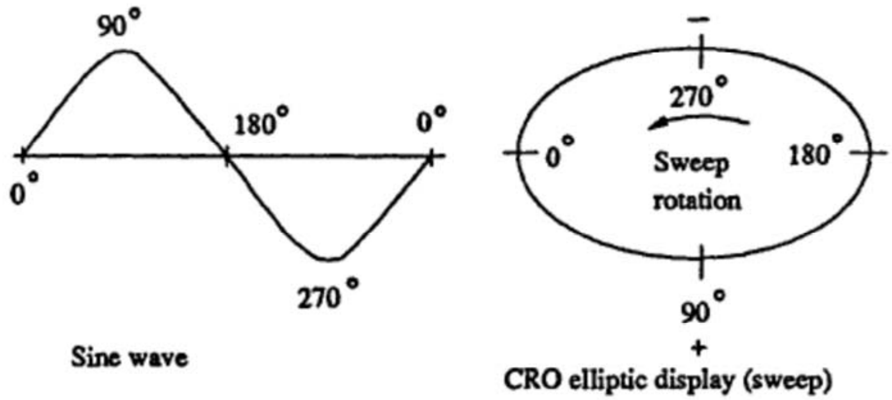


Figure 2.17: Elliptic sweep display [24]

When a breakdown event occur in the void, charge transfer amounts to actual charge Q_v[24]

$$Q_v = \left(C_v + \frac{C_a C_b}{C_a + C_b} \right) \delta V_v \qquad 2.2$$

Where δV_v is the voltage drop in the void at breakdown. The capacitance C_a is usually greater than C_b and Q_v can be assumed approximately as [24]

$$Q_v = (C_v + C_b)\delta V_v \qquad 2.3$$

After the event of void breakdown, the system restores the voltage across the capacitor C_b to its original state which require a charge to be supplied to C_b. Apparent charge equation Q_a is given by [24]

$$Q_a = \left(C_v + \frac{C_b}{C_v + C_b} \right) Q_v \qquad 2.4$$

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