STUDY OF ELECTRICAL DISCHARGE EFFECT ON THE NATURAL ESTER INSULATING OILS PROPERTIES

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A report submitted in fulfilment of the requirements for the degree of Bachelor of Electrical Engineering With honours

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"I hereby declare that I have read through this report and in my opinion this project is sufficient in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering with Honours"

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Date :

"I declare that this report entitled " *Study of Electrical Discharges Effects on The Natural Ester Insulating Oils Properties* " is the result of my own research expect as cited in the references. The report has not been accepted for any degree and is not currently submitted in candidature of any other degree".

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Date : 6th June 2018

DEDICATION

To my beloved mother, father and family

For their boundless love, prayer and support

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ABSTRACT

Natural Ester Insulating oil NEI is an environmental friendly source due to its high rate biodegradability which is very environmental friendly. Although, the cooling properties of the natural ester oil are poorer than mineral oil it is still widely used because of its flash point and fire point and lower fire risk. The natural ester insulating (NEI) oil PFAE and Midel eN had been chosen to investigate the effect of electrical discharge. In this research work, the oil sample need to pass the initial condition by following ASTM D974, D6871, D1816 and D1533 standards in terms of acidity, moisture and breakdown (BDV) before proceed to the next stage. Hence, the treatment process will be performed if the moisture content of the oil sample does not achieve the standard. Next, partial discharges inception voltage (PDIV) will be tested on the test cell to determine the PDIV value of oil sample. All the equipment and setup for PDIV is according to IEC 61294 standard. Next, the electrical discharges will apply from 200 until 1000 discharges with a constant voltage based on the PDIV value. Electrical discharge is the emission and transmission of electricity in an electric field applied to the medium such as liquid. Hence, this study will determine the effect of the electrical discharge to the physicochemical properties in terms of moisture content, acidity level and breakdown voltage of the Midel eN and PFAE. The properties of PFAE and Midel eN after electrical discharge test also will be analyzed to compare with initial properties of natural ester insulating (NEI) oil. According to the experiment conducted, the PFAE oil change is not significant in terms moisture content, acidity and breakdown voltage (BDV) compared to Midel eN oil. This result is due to its saturated fatty chain acid with good oxidation stability. The BDV of PFAE oil also not much affected by the high electrical discharges. Hence, it shows that PFAE has better performance in terms of good oxidation stability and also the BDV value that can withstands.

ABSTRAK

Natural Ester Insulating oil NEI adalah minyak daripada sumber mesra alam kerana kadar biodegradasi yang tinggi yang sangat mesra alam. Walaupun, sifat penyejuk minyak ester semulajadi lebih rendah daripada minyak mineral yang masih digunakan secara meluas kerana titik kilat dan titik api dan risiko kebakaran yang lebih rendah. Penebat ester semula jadi (NEI) minyak PFAE dan Midel eN telah dipilih untuk menyiasat kesan pelepasan elektrik. Dalam kajian ini, sampel minyak perlu melepasi keadaan awal dengan mengikuti piawaian ASTM D974, D6871, D1816 dan D1533 dari segi nilai asid, kelembapan dan kerosakan voltan (BDV) sebelum meneruskan ke peringkat seterusnya. Oleh itu, proses rawatan akan dilakukan jika kandungan lembapan sampel minyak tidak mencapai standard. Seterusnya, voltan penunaikan pelepasan separa (PDIV) akan diuji pada sel ujian untuk menentukan nilai PDIV sampel minyak. Semua peralatan dan persediaan untuk PDIV adalah mengikut piawaian IEC 61294. Seterusnya, pelepasan elektrik akan dikenakan dari 200 hingga 1000 pelepasan dengan nilai voltan yang tetap berdasarkan nilai PDIV. Pelepasan elektrik adalah pelepasan dan penghantaran elektrik di medan elektrik yang digunakan untuk medium seperti cecair. Oleh itu, kajian ini akan menentukan kesan pelepasan elektrik kepada sifat-sifat fizikokimia dari segi kandungan lembapan, tahap keasidan dan kerosakan voltan Midel eN dan PFAE. Sifat-sifat PFAE dan Midel eN selepas ujian pelepasan elektrik juga akan dianalisis untuk membandingkan dengan sifat awal penebat ester semula jadi (NEI). Menurut eksperimen yang dijalankan, perubahan minyak PFAE tidak signifikan dalam kandungan kelembapan, keasidan dan voltan kerosakan (BDV) berbanding minyak Midel eN. Keputusan ini disebabkan oleh asid rantai lemak tepu dengan kestabilan pengoksidaan yang baik. BDV minyak PFAE juga tidak banyak dipengaruhi oleh pelepasan elektrik yang tinggi. Oleh itu, ia menunjukkan bahawa PFAE mempunyai prestasi yang lebih baik dari segi kestabilan pengoksidaan yang baik dan juga nilai BDV yang boleh bertahan

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

FIGURE	TITLE	PAGE

LIST OF ABREVIATION

HV	-	High Voltage
AC	-	Alternating Current
MI	-	Mineral Insulation
NEI	-	Natural Ester Insulation
ASTM	-	American Society for Testing and Materials
IEC	-	International Electrotechnical Commission
BDV	-	Breakdown Voltage
FPO	-	Fresh Palm Oil
VDE	-	Verband Deutsher Elektrotechniker
PDIV		Partial Discharge Inception Voltage

CHAPTER 1

INTRODUCTION

1.0 Introduction

This chapter highlights the importance of the study through the description on the background of the research and the related issues that motivate this research work. The objectives of this study are explained which limited to the scopes stated here. Lastly, the structure of the thesis is given, showing the connection between the chapters.

1.1 Research Background

A transformer is one of the vital asset in power network system which that transfer electric energy from one alternating current circuit to one or more other circuits, either increasing or reducing the voltage [1]. For more than hundred years, liquid-immersed transformers have been mainly filled with mineral oil due to its wide availability, good properties, and low cost. However, there have also been major environment concerns over the toxic effects of uncontained mineral oil spills. Thus, it is crucial to use insulating oil with a high biodegradability and more environmental friendly. The recent availability of natural ester fluids based on vegetable oils has provided a new insulating liquid for use with transformers [2].

The reliability of a power transformer is largely determined by its insulation condition [1]. The insulation fluids of the transformer able to lengthen the transformer life span by protecting solid insulation and serve as a coolant by absorbing the temperature heat occurring produced in transformer's winding and core [2,3,4]. Most of the distribution transformers in Malaysia are oil filled that has capability to dissipate heat more efficiently compared to gas and solid materials [5]. Mineral oil has been widely used in Malaysia for a long time due to its reasonable price. Moreover, mineral oil has high dielectric strength, medium viscosity, less susceptible to oxidation, able to running well in low temperature and good heat transfer capacity [6].

However, mineral oil has some disadvantages such as low fire point, consist of toxic substance and poorly biodegradable [7]. The usage of mineral oil also not environmental friendly because it is a toxic waste thus affect the fertile of soil. The environment will get influenced if mineral oil spill occur because 20% of mineral oil can only biodegrade within 28days. Then, it could contaminate the soil and ground water [8]. Furthermore, the mineral oil sources do not last long because it's from fossil like petroleum and gas.

More research work has been conducted to find other available sources that better than mineral oil. Natural ester is a better alternative and has been use since early 1990's [6]. In 2000's, a number of companies in US, UK and Japan such as LION, MIDDLE and FR3 have started to commercialised the vegetable oil. Ester oil is increasing due to its properties that are better than mineral oil i.e non-toxic, biodegradable, lower fire risk, high flash point and fire point [7].

1.2 Motivation

Natural ester insulation (NEI) oil are the derivatives from the naturally available plants and seeds of the plants for example sunflower, palm oil and rapeseed. The natural ester characteristics depend on the fatty acids compositions.

Recently, there is researcher study about the partial discharges characteristics on Palm Fatty Acid Ester (PFAE) oil as High Voltage Insulating Material and as biodegradable oil for power transformer oil application. Besides that, the characteristics of PFAE also compare to other insulation oil which is mineral oil, to show the PDIV value between two oil samples. It also shows the result revealed that the partial discharges number of PFAE is lower than mineral oil. On top that, it makes as a catalyst for this research work by comparing the properties of Midel eN and PFAE. This give an idea to investigate the electrical discharges effect to natural ester insulating (NEI) oil by using palm oil and rapeseed based. Hence, this research work also to study on it physicochemical properties as the insulator for transformer. Therefore, this research work aims to investigate the capability of Midel eN and PFAE oil as the transformer insulation oil after the electrical discharge.

This research work studies the effect of electrical discharge on the natural ester insulating oil in terms of the acidity, water content and BDV in the transformer. Hence, to strengthen use the Midel eN and PFAE insulation oil transformer and to reduce pollution to the environment. Finally, to compare the PDIV, acidity, moisture and BDV between Midel eN and PFAE before and after electrical discharges.

1.3 Problem Statement

Power transformer is one of the expensive and important equipment in power generation and transmission system that no exceptions to faced serious failure for example insulation breakdown. One of the causes of insulation failure is electrical discharge. Electrical discharge is the release and transmission of electricity in an electric field applied to a medium such liquid in transformer. The electrical discharges usually happen many times in transformer oil and it will cause the breakdown. The electrical stress in unavoidable in power equipment and the capability of oil to resist decomposition under electrical stress is one of the important things for the safety of the transformer. However, there is still lack of data and needs to study for further analysis in terms of the effect to the physicochemical properties after electrical discharges to the natural ester insulating (NEI) oil. On top of that, by investigating the effect of electrical discharges on MIDEL eN and PFAE, it can show the best result to choose the best performance of the NEI. It also a lesser extent, to support a green campaign by using rapeseed and palm oil. Does the Midel eN can perform better than PFAE oil ?

Therefore, this research work will focus on the PDIV, breakdown voltage and the effect of electrical discharge on natural ester insulating (NEI) oil which is Midel eN and PFAE in terms of acidity, moisture content and BDV. It is widely known that ester oil has better quality as transformer oil compared to mineral oil. The characteristic of PFAE also are similar with commercially mineral oil. Even though, vegetable oil is more expensive but it can be an alternative to reduce the environmental pollution resulting from the use of transformer and also reducing the dependence on mineral oil use. Moreover, Malaysia is one of the main producers of palm oil in the world.

1.4 Objectives

- To investigate the effect of electrical discharge on the natural ester-based insulating oil.
- To compare the properties of natural ester insulating oil after electrical discharges.

1.5 Scope

The scopes of this work are given as follow:

- The effect to the natural ester-based insulating oil in terms of acidity, moisture and BDV
- Types of natural ester insulation oil (NEI) used are Midel eN 1204 (rapeseed based) and PFAE.
- The ASTM D974 & D1533 Standard with compliance of D6871 standard is followed for acidity and moisture experiment.
- The ASTM D1816 Standard is followed for Breakdown Voltage BDV experiment.
- Partial Discharges Inception Voltage procedure for insulating liquid is followed the IEC 61294 standard.
- Type of electrode used in the experiment to analyse the electrical discharge stability of the Midel eN and PFAE is point to plane with 10mm gap.
- Type of needle used in the experiment to analyse the electrical discharge stability of the Midel eN and PFAE is needle of 50mm length and 1mm diameter from Ogura Jewel Industry Co Ltd.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter gathers all the related information to this research work from the previous researchers such as type of transformer oil, properties of insulating oil, and electrical discharge. The published results on the properties of natural ester oil (NEI) also are attached for comparison. On top of that, there are also the detail of method and type of insulation oil that been used by other researcher in this chapter. The most appropriate method is selected for this study.

2.2 Transformer

Transformers are one the precious equipment in a substation and power plant. There are a few types of transformer which is power transformer and distribution transformer. Transformer also known as important component of high voltage equipment for power generation plants, transmission systems and big industrial plant. In 1884, the early transformer produce is a dry type transformer. In 1891, the petroleum oil was used on an experiment basis in the insulation of three phase transformer. Due to the higher demand of electric energy and the growing power transmission network, air- insulated transformer become large. To reduce the volume, petroleum oil application in power transformer was generalized from 1905 but mineral oil did not provide the necessary fire protection [9]. Almost 60% of the total cost power station covered by power transformer. There is a few type of

distribution transformer, for example hermetically sealed and free breathing with rating 11/0.433kV, 22/0.433Kv and 33/0.433kV [10].

2.3 Insulation System of the Transformer

In general, one of the factors electrical faults occurring in power transformers increase due to its weak insulating performance. Hence, the life span of transformer also depends on its insulating condition. There are three different states of insulation system in transformer; gas, solid and liquid (transformer oil) [11].

2.3.1 Gas Insulation

Air is one of the examples of gas insulation that commonly used as the insulating medium in the most of the electrical apparatus. Other than that, nitrogen (N^2), carbon dioxide (CO^2), freon ($CC1_2F_2$) and sulphur hexafluoride (SF_6) are also used as the insulating medium. Therefore, there are several preferred properties of a gaseous insulation for practical use in high voltage applications. The properties includes high dielectric strength, thermal and chemical stability inactivity towards materials of construction, non-flammability, low temperature of condensation, and good heat transfer. Regarding to the previous research, it state that SF_6 seem to possess most of these requirements [12].

2.3.2 Solid Insulation

Solid insulation is one of the type insulation that needs to consider in the system of transformer. However, there are few factors that affected the degradation solid insulation (cellulose based products) in transformer which is temperature, moisture content, oxygen and acid exists in the insulation system. The degradation of solid insulation produces chemical products such as furanic derivatives, carbon monoxide (CO) and carbon dioxide (CO_2) which dissolved in the transformer oil. These chemical products are produced due to the chains of cellulose molecular are

getting shorter after the degradation process occurs. Degree of polymerization (DP) is an average measurement of the number of glucose units per molecule chain. Besides, the location of cellulosic materials that need to be replaced can be identified with the help of DP analysis. Moreover, cellulose materials are the weakest link in the insulation system. Hence, the life span of the transformer will end when the paper reaches DP of 200 or less where the paper becomes very brittle [13].

2.3.3 Liquid Insulation

Insulation oil is one of the important parts in transformer that need to consider during do the maintenance of transformer. The right way to ensure the insulating oil able to operate well is choosing the oil that fulfils the standard requirement. Liquid insulation also has been used to operate the transformer rating more than 10-25kV and also been used in power distribution equipment as the dielectric liquids. Liquid insulation also widely used because of its capable of long service life with low cost, less maintenance issue, good dielectric and compability with other materials. There are some characteristics that need to consider in selecting liquid dielectric system which are dielectric strength, dielectric constant value, liquid viscosity, thermal characteristics, flammability and physical environmental conditions [14]. However, there are several factors that affect the quality of insulating oil such as oxidation, contamination, and excessively high temperature. Based on these factors, oxidation is the most factors that give influence to cause of oil deterioration. Hence, many transformer manufacturers overcome this problem by sealing the transformer from the atmosphere. Besides, moisture is the main contaminants in the oil where its presence can reduce the dielectric properties of the insulating oil. Apart from that, an excessively high temperature in transformer will cause decomposition of the oil and will increase the rate of oxidation. The best way to overcome this situation is by preventing the transformer from overloading [15].

2.4 Types of Insulating Oil in Transformer

There are two type of insulating oil in transformer which is mineral and natural ester oil.

2.4.1 Mineral insulating Oil

The mineral insulating oil produced from crude oil has been widely used in power transformer, since the development of the power sector was newly used. Besides that, mineral oil compatible and reliable used for over a century. Mineral oil also has been used all over the world due to its ageing behaviour, good dielectric strength, low viscosity, less susceptible to oxidation and able to operate in low temperature. However, mineral oil has low biodegradability [16]. Mineral oil has some characteristics that unfavourable properties which are low fire point, toxicity and poor biodegradable[7]. Hydrocarbon in molecules mainly found in mineral oils. Hydrocarbon composed only of a carbon backbone more or less saturated with hydrogen[16]. There are three different types in crude oils which are paraffinic, naphthenic and mix crudes [5]. However, in varying amounts, molecules sizes and structures, the composition affects the physical properties such as viscosity, viscosity index, density, cloud point, pour point and solving power [16].

2.4.2 Natural Esters Insulating (NEI) Oil

Recently the use of ester oil are increasing in order to support the green technology. Natural ester liquids which known as vegetables oil is seen as an alternative to mineral oil because it is non-toxic and good biodegradable. Natural ester also has lower fire risk, higher flash point and fire point compared with mineral oil [6]. Besides that, natural ester rarely used in industrial applications because of the lack of oxidative stability. The viscosity of mineral oil also is three to four times less than natural ester insulating (NEI) oil [17].

Natural ester oil consists of triglycerids which are naturally synthesized by esterification of the tri-alcohol with three fatty acids that from the plant [18,19].