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COMPARATIVE STUDY OF MOISTURE IMPACT AND BREAKDOWN VOLTAGE OF VARIOUS TRANSFORMER INSULATING OIL TYPES

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

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"I declare that this report entitles "Comparative Study of Moisture Impact and Breakdown Voltage of Transformer Insulating Oil (PFAE)" 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"

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Dedicated to my beloved father and mother,

Che Roslan Bin Che Hasan & Wan Nozila Binti Wan Harun

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"Loving can hurt
Loving can hurt sometimes
But it's the only thing that I know
When it gets hard
You know it can get hard sometimes
It is the only thing that makes us feel alive…"

ABSTRACT

Power transformer life span depends heavily on its insulation systems which consist of paper and insulating oil. Recently, the insulating oil used in transformer application are mineral oil, natural ester oil and silicon oil. One of critical factors that impact the long term operation of transformer is moisture. Presence of moisture in insulation oils can alter the physicochemical property of oil and drastically affects the breakdown voltage. Although the importance of this issue, it is not being stressed by previous researchers. This study will present the effect of moisture on breakdown voltage (BDV) in various type of insulation oils. The effects of moisture content are investigated by varying the amount of distilled water added into the oil samples from 0.2ml to 1ml with an increment of 0.2ml. Breakdown voltage (BDV) test is conducted five times and the mean breakdown voltage is determined for each oil sample. In this study discussed that the insulation oil that content high moisture has lower breakdown voltage (BDV) compared with pure insulation oil. Thus, lower value of breakdown voltage (BDV) are expected by addition of 0.2ml to 1ml of distilled water into the insulation oils.

ABSTRAK

Jangka hayat pengubah bergantung sepenuhnya kepada penebat. Seperti yang dinyatakan dalam kajian sebelum ini minyak penebat yang telah digunakan dalam aplikasi pengubah ialah minyak mineral dan minyak ester semulajadi. Kesan kelembapan pada operasi jangka panjang penebat pengubah adalah salah satu faktor yang paling kritikal. Kehadiran kelembapan dalam minyak penebat boleh mengubah fizikokimia minyak dan secara drastic memberi kesan voltan pecahan. Walaupun betapa pentingnya isu ini, kewujudannya tidak ditekankan oleh penyelidik sebelum ini. Kajian ini akan menunjukkan kesan kelembapan pada pecahan voltan dalam pelbagai jenis minyak penebat. Kesan kandungan kelembapan dikaji dengan mengubah jumlah air suling yang ditambah ke dalam sampel minyak dari 0.2ml hingga 1ml dengan kenaikan sebanyak 0.2ml. Ujian voltan pecahan dijalankan lima kali dan min voltan pecahan ditentukan bagi setiap sampel minyak. Dalam kajian sebelum ini membincangkan bahawa minyak penebat kelembapan yang tinggi kandungan mempunyai pecahan yang lebih rendah voltan pecahan berbanding dengan minyak penebat tulen. Oleh itu, nilai yang lebih rendah daripada voltan pecahan dijangka dengan penambahan 0.2ml hingga 1ml air suling ke dalam minyak penebat.

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LIST OF ABBREVIATIONS

BdV	-	Breakdown Voltage
PFAE	-	Palm Fatty Acid Ester
ASTM	-	American Society for Testing and Materials
IEC	-	International Electrotechnical Commission

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Power transformer is among an important equipment in electrical power transmission and distribution system. It can be defined as a static machine used for transforming power from one circuit to another without changing frequency. Static machine means there is no rotating or moving part. Consequently, often breakdown voltage will compromise not only to daily activities of end consumer and businesses but will also incur undesirable costs to electrical energy providers due to maintenance and repair. It is very important to monitor all components of power transformer on a regularly in order to minimize the occurrence of breakdowns [1].

Life expectancy of power transformer is mainly determined by aging condition of its cellulose insulation. Normal life expectancy of the transformer will be about 25 to 30 years [2]. Transformer have normal life expectancy when it loaded below the same plate rating. The most harmful agents for cellulose insulation is called moisture [3]. Moisture is the quantity of water contained in the oil [4]. It can accelerate the cellulose aging rate and reduce dielectric and mechanical strength of cellulose insulation [3].

Moisture in transformer insulation is deleterious because it accelerates the ageing of cellulosic insulation materials and decreases the dielectric strength of both liquid and solid insulation [5]. Therefore, determine moisture content in the insulation system is important to ensure long term reliable operation of a transformer. Usually, moisture is indirectly measured in transformer solid insulation using so-called equilibrium chart method by assuming that there is an equilibrium condition in moisture distribution between oil and paper insulation [6].

Historically, the amount of moisture in the solid insulation have been utilized in equilibrium method by measuring the water content of the oil. However, previous studies have shown to be inaccurate because of changes in load and ambient temperature of the transformer experience that makes it almost impossible to achieve a balance and also because of the effects of aging on the moisture balance [6].

The dielectric strength of the oil is related to the moisture content of the oil [7]. The breakdown voltage of transformer insulation oils reduces as the moisture content increases [8]. Bubbling effect in the transformer can also be affected by the high water content coupled with dissolved gas has a higher pressure than the ambient pressure [8]. Therefore, monitoring of moisture in oil is routine maintenance procedures. The presence of moisture in insulating oil is one of the main causes of electrical damage because it increases the ionic conductivity of the oil was decreases the breakdown voltage.

1.2 Problem statement

There are several types of transformers available in the market now which include dry-type and oil-immersed transformer. Most of the transformer in Malaysia use oil-immersed type as a distribution transformer for convert high voltage to lower value of 240V (single phase electrical power) or 415V (three phase electrical power) [1]. The properties of the chemical and physical of natural ester are different to mineral oil. Natural esters are more hygroscopic and oxidation susceptible than mineral oil. Therefore, influence of moisture and ageing on dielectric response behavior of natural ester paper insulation may not be similar to that of mineral oil paper insulation. There are many types of natural ester that can be uses to insulation oil so there is no in-depth study was conducted to address this issue. Due to this problem the researches have no proper standard of review to be used as natural ester moment. To fill this gap, this study conducted a series of dielectric strength measurement on insulating oil aged in three different liquids (mineral oil, ester and synthetic) under varying moisture level.

1.3 Objectives

The objectives of this study are formulated as follows:

1. To investigate the impact of moisture and breakdown voltage of transformer insulating (PFAE) oil.
2. To analysis the correlation between moisture level and breakdown voltage of PFAE oil.
3. To study the impact of ageing of insulating paper and moisture content of PFAE, Midel eN and Nytro Libra oil.

1.4 Scope of works

The scopes of this study are:

1. Type of insulation oils that uses is natural ester PFAE oil.
2. Type of insulating paper uses for ageing process is Kraft paper and pressboard.
3. The breakdown voltage test complies with ASTM D1816 standard using Megger OTS60PB.
4. The standard specification for mineral insulating oil abide by ASTM D3487 standard while natural ester and synthetic oil complies with ASTM D6871 standard.
5. The standard test for water content in insulating oil using Coulometric Karl Fisher Titration method complies with ASTM D1533 standard by using Metrom Coulometric Karl Fisher.

1.5 Motivational

Even though the assessment out there was a lot for the study of mineral oil but still less research in natural ester oil. Before this there are not many studies on natural ester oil and mineral oil would give an advantage in the study of this time and believes that this research could be beneficial to all. However, there are also disadvantages because despite difficulties in obtaining resources and standards for natural ester oil. Therefore, technical and standard features have earned the right to get the right result in determining the level of moisture and breakdown voltage. Impact of moisture on breakdown voltage can be interpreted with correlation between moisture level and breakdown voltage of several type of transformer insulation oil (mineral oil, natural ester oil, synthetic oil).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the details about the theory and standard that need to be followed in developing the project will be explained. Then, there will be a review a result and discussion of the previous studies in the same area of this project. All the findings obtained in the previous study that are related to the project could help in enhancing the knowledge and understanding.

2.2 Transformer Failures

Faults happened in various section and segments of the transformer because of mechanical, electrical and thermal stress brought on by various conditions [9]. The failure of a transformer can be a devastating and costly experience. There are common failures that occurred from transformer and their causes which are transformer operate under sustained over-voltage condition, exposure to lightning surges and switching surges, partial discharge, static electrification [9]. Electrical disturbance is the most noteworthy hazard for a wide range of transformer failures. Lightning may have a higher recurrence of failure that insulation issues yet the normal claim for insulation issue is much higher than lightning issue [9].

2.2.1 Electrical Factor

Fault causes by electrical typically results in damage to a transformer's insulation system. Transformer operate under sustained over-voltage conditions will give a result in overstressing the insulation and overheating of the core [9]. Besides that, exposure to lightning surges and switching surges also another factor. Both lightning and switching surges impulses are large magnitude traveling waves, which travel at speed of light, and can cause serious damage to the electrical and mechanical integrity of a transformer [9].

2.2.2 Mechanical Factor

Mechanical factor typically results in the deformation of a transformer's winding, resulting in the abrasion or rupturing of its cellulose insulation [9]. In this case, the conductor will buckle inward toward the core between the axial spacers and will transmit the buckling to the core insulating cylinder at the axial spacer location [9]. A severe case of buckling will result in damage to the paper insulation. Next, conductor telescoping involves layer windings made up of thin flat conductors which are supported end-to-end and conductor will telescope over one another when exposed to excessive axial forces [9]. This cause the entire layer to become mechanically unstable as well as damaging the paper insulation.

2.2.3 Thermal Factor

The most common thermal factors are summarized as follows:

i. Overloading of the transformer beyond its design capability for extended periods of time [9]
ii. Failure of a transformer's cooling system. This can include blocking or fouling of the radiators or coolers, failure of the oil pump, and the failure of a directed flow oil distribution system
iii. Operating a transformer in an overexcited condition (over-voltage or under-frequency) [9].

Table 2.1: The number of failures [9]

Cause of Failures	
Electrical Disturbances	29.43 %
Lightning	17.32 %
Insulation Issues	9.80 %
Electrical Connection, Loose or High Resistance	7.38 %
Maintenance Issues	5.91 %
Moisture	4.03 %
Overload	2.01 %
Sabotage	2.01 %
Other	1.24 %

2.3 Winding Failure

Another important part in the transformer is windings. Two windings are commonly uses in distribution side transformer which are primary side and secondary side. The concept voltage/current is transfer from primary side to secondary side winding through electromagnetic. These windings withstand dielectric, thermal and mechanical stress during this process [10]. Due to this stress fault will occur and causes the windings breaking or burn out [9]. Dielectric faults are caused turn-to-turn insulation breakdown in the winding. It means the insulation between the coil of the winding. Usually, insulation breakdown occurs in fact of high voltage and current which are above the rated values. Its makes flashover of the coil winding and cause short circuit. There are two reasons for the high rating which are lighting impulse attack with no lightning arrested and fault voltages [10].

2.4. Liquid Insulation

Liquid insulation such as mineral oil or natural ester oil or synthetic oil non-inflammable dielectric, is utilized as a part of liquid submerged transformer. The liquid utilized as a part of arrangement with solid insulation, impregnates this insulation, accordingly enhancing the dielectric property of the solid insulation [11]. The liquid insulation likewise serves another imperative capacity, that of thermally cooling the solid insulation.

2.4.1 Mineral Oil

In 1887, the year after Stanley designed and built the first transformer in the U.S., Elihu Thompson patented the idea of using mineral oil as a transformer cooling and insulating medium [12]. Despite the fact that materials have enhanced significantly, the fundamental idea of an oil-immersed cellulosic protecting framework has changed almost no in well over a century. Mineral oils are intricate blends of several distinctive natural mixes, comprising fundamentally of carbon and hydrogen in particles with various structure [13]. They are made by refining a fraction of the hydrocarbons collected during the distillation of petroleum crude stock [13]. There are three classifications of unprocessed oils, in particular paraffinic, naphthenic, and mixed crudes.

A. Paraffinic crudes contain a small amount of naphthenic hydrocarbons and can be subdivided into normal paraffins (straight chain wax-type molecules) and isoparaffins (branched paraffin). Isoparaffins are preferred over normal paraffins because of their pour points
B. Naphthenic crudes have higher naphthenic compound content than do paraffinic crudes
C. Mixed crudes are intermediate between paraffinic and naphthenic crudes.

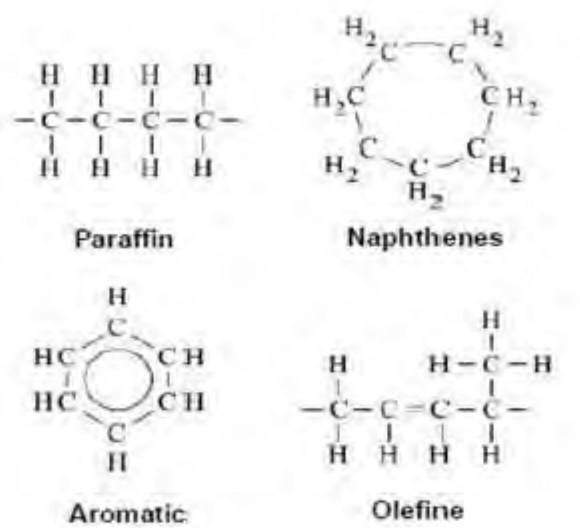

Figure 2.1: Hydrocarbon compounds in mineral oil [14]

The early transformer oils were paraffin-based but in about 1925, it was replaced with naphthenic oils because of the high pour point of paraffinic oils [15]. At room temperature water cannot dissolve in mineral oil than around 50ppm before it is saturated [16]. In general, cellulose absorbs water as it is cooling and desorbs it as it is warming up. Risk situation happen when temperature increase suddenly that the several percent by mass of water adsorbed to the cellulose is suddenly released into the oil, of which the local volume around the cellulose quickly becomes saturated [16]. Precipitation occurs when the oil cannot dissolve water anymore.

2.4.2 Natural Ester Oil

In 1892, experiments with liquids other than mineral oils included ester extracted from seeds [17]. None made operational improvements over mineral oil and were not commercially successful. Vegetable oils are promptly accessible natural products, and along these lines ought to be considered as perfect crude materials for completely biodegradable insulating liquids [13]. The fatty acid composition of some vegetable oil is shown in Table 2.2 [18]. They comprise basically of triglycerides, which are naturally synthesized by esterification of the tri-alcohol glycerol with three fatty acids.