ANALYSIS OF BREAKDOWN VOLTAGE MEASUREMENT UNCERTAINTIES FOR DIFFERENT STANDARDS

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DECLARATION

I declare that this thesis entitled "ANALYSIS OF BREAKDOWN VOLTAGE MEASUREMENT UNCERTAINTIES FOR DIFFERENT STANDARDS" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this report entitled "Analysis of Breakdown Voltage Measurement Uncertainties for Different Standards" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

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DEDICATIONS

Specially dedicated to my beloved parents and families who always give me strength, encouraged, and guided throughout my journey.

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In the name of Allah, the most Merciful and Beneficent

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ABSTRACT

Transformer oil plays an important role in reducing the temperature of the transformer where it reacts as a cooling agent and insulator to the transformer. For a long time, the oil will degrade thus the transformer will have a potential for faults and costly repairs. Dielectric strength is one of the characteristics of the transformer that is used to measure the maximum voltage that the material can withstand without having a failure. Breakdown voltage test of a transformer is known as dielectric strength test. This test will indicate the quality of the oil transformer. Uncertainty of measurement is the doubt that exist about the results of any measurement. The aim of this project is to measure the breakdown voltage of different transformer oil by using different standards. Next, to measure the uncertainty of the breakdown voltage readings. Lastly, to evaluate the breakdown voltage reading from three different standards based on uncertainty measures. The project focuses on two types of transformer oil which are mineral oil and vegetable oil. Three standards are applied in this project which are IEC 60156, ASTM D877 and ASTM D1816. The initial phase of the project study the standards that are related in this project, the methods on how to calculate the measurement uncertainty and the theoretical about the breakdown voltage. The uncertainties factors in breakdown voltage include voltage rise, resolution, repeatability of data and calibration of the instruments. The more factor of measurement uncertainty included in the data, the higher the accuracy of breakdown voltage. This will give effects in the calculation of measurement uncertainty. These standards are slightly dissimilar in terms of test voltage rise, measurement gaps, and electrode shape. These differences are the source of uncertainties in breakdown strength measurement. This project use Megger OTS60PB as a main apparatus in order to measure the breakdown voltage. Prior to the breakdown voltage measurement, moisture content of the transformer oil must meet the requirement of the standard which are 200ppm for vegetable oil and 35ppm for mineral oil. The results of the breakdown voltage analysed using measurement uncertainty for each standards and transformer oil. The result of measurement uncertainty in the range of 95% as in theoretical readings. The result show the data is within the range of measurement uncertainties in every samples. All of the objectives were achieve based on the calculation in this report.

ABSTRAK

Minyak pengubah memainkan peranan penting untuk mengurangkan suhu pengubah dimana ia akan memberi reaksi sebagai agen penyejuk dan penebat didalam pengubah. Untuk masa yang lama keadaan minyak akan berkurang seterusnya pengubah akan mempunyai potensi untuk rosak dan akan memberikan kos untuk pembaikan mahal. Kekuatan dielektrik merupakan salah satu ciri pengubah yang digunakan untuk mengukur tahap maksimum bahan tanpa mengalami kegagalan. Ujian pecah tebat pengubah juga dikenali sebagai ujian kekuatan dielektrik. Ujian ini akan menunjukkan kualiti pengubah minyak. Ketidakpastian pengukuran adalah keraguan yang wujud untuk membuat keputusan didalam apa-apa pengukuran. Tujuan projek ini adalah untuk mengukur pecah tebat minyak pengubah yang berlainan dengan menggunakan piawaian yang berbeza. Seterusnya untuk mengukur ketidakpastian bacaan pecah tebat. Akhir sekali, untuk menilai bacaan pecah tebat minyak dari tiga piawaian yang berbeza dengan menggunakan cara ketidakpastian pengukuran. Projek ini memberi tumpuan kepada dua jenis minyak pengubah iaitu minyak mineral dan minyak sayuran. Tiga piawaian digunakan didalam projek ini iaitu IEC 60156, ASTM D877 dan ASTM D1816. Fasa awal projek akan mengkaji piawaian yang berkaitan dengan projek ini adalah kaedah bagaimana menghitung ketidakpastian pengukuran dan teori tentang pecah tebat. Semakin banyak faktor ketidakpastiaan pengukuran yang dimasukkan didalam data, semakin tinggi nilai pecah tebat. Disebabkan hal ini boleh memeberikan kesan didalam pengiraan ketidakpastiaan pengukuran. Standard yang digunakan memberi sedikit perbezaan dari segi peningkatan voltan, perbezaan pengukuran dan bentuk elektrod. Projek ini menggunakan Megger OTS60PB sebagai alat utama untuk mengukur pecah tebat. Untuk mengukur pecah tebat, kelembapan minyak pengubah mesti memenuhi keperluan piawaian yang ditetapkan iaitu 200ppm untuk minyak masak dan 35ppm ntuk minyak mineral. Keputusan pecah tebat dianalisis menggunakan ketidakpastian pengukuran untuk setiap piawaian dan minyak.Keputusan ketidakpastian pengkuran akan berada di dalam jangka 95% sepertimana yang dinyatakan didalam bacaan teori. Setiap sampel voltan menunjukkan hasil data berada didalam lingkungan yang ditetapkan dengan menggunakan ketidakpastian pengukuran. Semua objektif berdasarkan ketidakpastian data berjaya dihasilkan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

BdV	-	Breakdown Voltage
kV	-	kilovolt
ppm	-	Part Per Million
mm	-	millimetre
IEC	-	International Electrotechnical Comission
ASTM	-	American Standard Society for Testing and Materials
MU	-	Measurement Uncertainty
k_p	-	Coverage Factor
U_c	-	Meeasurement Uncertainty
c_i	-	Sensititivity Coefficient
s	-	Standard Deviation
°C	-	Degree Celcius
JCGM	-	Joint Committee for Guides in Metrology
ISO	-	International Organisation for Standardisation
σ	-	Standard Deviation
V_{eff}	-	Effectiveness Degrees of Freedom
DOF	-	Degree of Freedom

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Project Background

Power transformer is one of the valuable assets in delivering power throughout the nation. There are two types of transformer in this industry which are dry-type transformer and oil-type transformer. Dry-type transformers are particularly useful for indoor locations and areas that are highly prone to fire-related risks. Oil transformers on the other hand mostly used for outdoor which can handle higher rating than the dry type because oil is a very good coolant [1].

Quality of the transformer oil plays a vital role in the performances of transformer in electrical appliances. There are two types of insulating oil that commonly used which are mineral oil and vegetable oils. The advantages of mineral oils are good resistance in oxidation, good viscosity index, easily to use and less cost while vegetable oils are good in biodegradable, high flash point and it is more environmentally fluids. The quality of the transformer can be analysed using several analysis. One of the analysis to analyse the quality of the transformer oil is by using measurement uncertainty.

1.2 Project Motivation

The motivation to contribute and conduct into this project is to measure the measurement uncertainty in breakdown voltage by using different standards. Measurement uncertainty is needed to evaluate the precision and accuracy of the data based on several factors. The project compares the readings between different standards and by using different transformer oil. In this project, it will measure each sample and evaluate on which sample is preferable in terms of standards and transformer oils.

1.3 Problem Statement

There is more than one standard for analysing breakdown voltage of insulating liquid, for example, ASTM D1816, ASTM D877 and IEC 60156. These standards are slightly dissimilar in terms of test voltage rise, measurement gaps, and electrode shape. These differences are the source of uncertainties in breakdown strength measurement. Measurement uncertainty represents the quality of measurement by characterizing the dispersion of the breakdown voltage values that could reasonably be attributed to those different terms of different standards. The role of measurement uncertainty is important in conforming these tolerances in the industrial production which has become more demanding. In addition, measurement uncertainties play a main role in order to meet the accreditation requirement outlined in the ISO 17025. This project therefore aims to evaluate the uncertainties of breakdown voltage readings from the three different standards due to the different setup parameters.

1.4 Objectives

The objectives of this project are as follows:

1. To measure the breakdown voltage of different transformer oil by using different standards
2. To measure the uncertainty of the breakdown voltage readings
3. To evaluate the breakdown voltage readings from three different standards based on uncertainty measures

1.5 Project Scopes

The scopes of this project necessitated as followed:

1) Two types of transformer oil are used in this project to measure the breakdown strength which are mineral oil (Gemini X) and vegetable oil (MIDEL 1204).
2) Three standards of breakdown strength test are applied which are *International Electrotechnical Commission* (IEC) 60156, *American Society for Testing and Materials* (ASTM) D877 and *American Society for Testing and Materials* ASTM D1816
3) The equipment that is used to analyse the breakdown voltage for each standard is Megger OTS60PB.

1.6 Project Structure

This report consists of five chapters. Chapter 1, it explains the importance of this study as well as the objectives and the scopes. Chapter 2 highlights, the background theory of breakdown mechanism in liquids and the equations related to measuring the uncertainties. Next, Chapter 3 explains the methodology of this study mostly on the experimental procedure. The results and discussion in this research written in Chapter 4. Finally, Chapter 5 concludes the finding from the literature review as well as the experimental results and discussion.

CHAPTER 2

LITERATURE REVIEW

2.1 Definition of transformer

Transformer is one of the most important elements in power system. The function of the transformer is to step up voltage from generation to transmission and step-down voltage from the transmission to the consumers. The main component of the transformer is core, winding and insulation material. The main component of the insulation system is either gas or liquid (oil) depending on the type of transformer. Transformer oil not only protect the transformer from failure but also acts as a cooler and heat transfer.

2.2 Transformer Oil

Oil transformer is widely used in power plant, industrial plant and traditional electric utility companies [14]. The transformer is filled with the liquid insulating oil which is also called as transformer oil. Transformer functions as insulator, heat transfer and agent of information as well as isolate the transformer [1].

There are many types of transformer oil in the industry such as mineral oils, vegetable oil, cable oil, capacitor oil, askarels oil and silicone oil [1]. However, due to the limitation sources of the mineral oil, sustainable production of transformer oil is being hotly debated. Also, mineral oil can cause serious environmental disaster since primarily produced from non-biodegradable products [5,16]. Through research, vegetable oil found to be a suitable alternative of mineral oil that used for transformer oil [5].

2.2.1 Mineral Oil

Mineral oil is commonly used in power transformers. Mineral oils are attracted from crude oil which is formed from buried and decayed vegetable matter [2]. The function of transformer oil is as thermal fluid or coolant of electrical component which mineral oil is widely used in industry. Crude petroleum is extracted from the earth and it is a complex mixture of molecules that made up of carbon and hydrogen and a small portion of sulphur and nitrogen [2]. There are three main groups of hydrocarbon molecules which are paraffinic, naphthenic and aromatics [2,3]. Figure 2.1 shows the structure of the molecule. In that figure, paraffinic have a single-bonded atom whilst naphthenic have a single double bond but in ring-like structures. The aromatics contain more ring-like structure of carbon atom, but it is in carbon-carbon double bond. These structures can determine the physical properties in the insulating oils such as low viscosity, low pour point, high flash point, high specific heat, high electrical strength, high thermal conductivity and low density [3]. It is mentioned in [17], that the advantages of mineral oil are good resistance to oxidation, good viscosity index, relatively low fire point. Nevertheless, mineral oil is low moisture tolerance and possible to sulphur corrosion. Mineral oil is used in large power transformers, railway transformers, power capacitors and paper insulated high cables while the other transformer oil is used as insulant and coolant [3]. Table 2.1 shows the detail properties of the insulating oil in the transformer.

Table 2.1: The Properties of the Insulating Oil

Category	Type of Liquid	Applications	Properties of Insulating Oil
Mineral Oil	Naphtenic, Paraffinic	Liquid in Power Equipment (Transformers, Circuit Breakers and Others)	• Good resistance to oxidation • Good Viscosity Index • Relatively low fire point • Possible sulphur corrosion
	Paraffinic (High molecular weight of hydrocarbons)	Transformer, Load tap changer	• High flash point
Vegetable oils	Castor, soybean, cotton, palm and others	Capacitors, Transformers	• Low dielectric losses at frequency higher than 1kHz • Readily biodegradable • Low oxidation stability

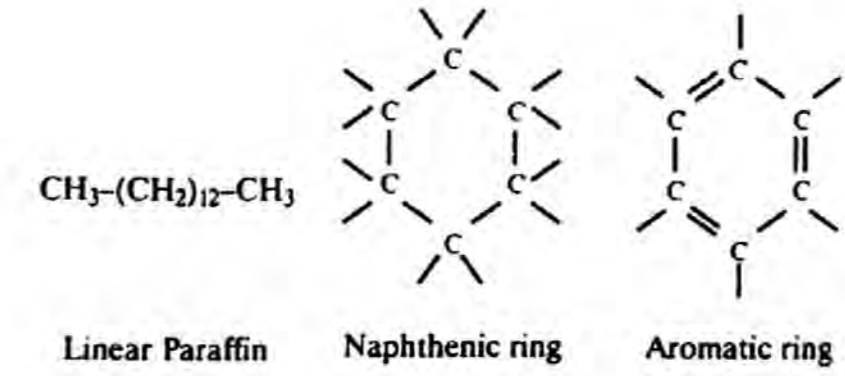

Figure 2.1: Structure of molecules mineral oil [2]

2.2.2 Vegetable Oil

Vegetable oil is also known as one of the new liquid insulating oil of the transformer to replace the mineral oil. The vegetable oils belong to a group of organic compounds. Ester is the elimination of water which are generated by the reaction of acid with alcohol. The collective term for monocarboxylic acids, which consist of a carboxyl group (-COOH) and of a variable long, but nearly exclusively unbranched hydrocarbon chain is name as "fatty acid". Ester oil is known as triglycerides which are the combination of three chemical linkage of three fatty acids to one glycerol molecule. Hydrolysis is the elimination of ester and presence of strong water to form glycerol and fatty acids. Figure 2.2 shows the structure of the vegetable oils in the process of inverse reaction and esterification which is called as the hydrolysis [4]. Figure 2.2 shows that the presence of three fatty acids have a low viscosity but higher in oxidation. The presence of oxidation in transformer oil will decrease the amount of electrical strength [5]. Many researches and industries have performing investigations on vegetable oils for providing them as insulating oils in transformers and pollution free environment. The vegetable oils have the properties like high biodegradable (>95%), low toxicity, high flash point (>300C), fire points(>300C), provide lower flammability and it is considered more environmentally friendly fluids [5].

Table 2.2 shows the difference between mineral oil and vegetable oil in terms of viscosity, flash point, specific heat, thermal conductivity, density, environmental properties and oxidation. This table show mineral oil has higher oxidation stability meanwhile vegetable oil has higher biodegradable in the transformer oil. Based on

Table 2.2, some researches [30] found that vegetable oils are the other alternative method to replace the mineral oil due to it viscosity, flash point, specific heat, thermal conductivity and environmental properties. The oxidation is one of the weakness properties in vegetable oil, but it can control by controlling the exposure of moisture and oxidation to maintain it optimum performance.

Table 2.2: Difference between mineral oil and vegetable oil

Criteria	Mineral Oil	Vegetable Oil
Viscosity	Low viscosity	Twice higher than mineral oil
Flash Point	High flash point	Higher flash point
Specific Heat	High specific heat	Lower flammability
Thermal Conductivity	High thermal conductivity	Higher thermal conductivity
Environmental Properties	Not degradable due it contains compound that can hazards to the environment	High biodegradable
Oxidation	Oxidation stability	Low oxidation

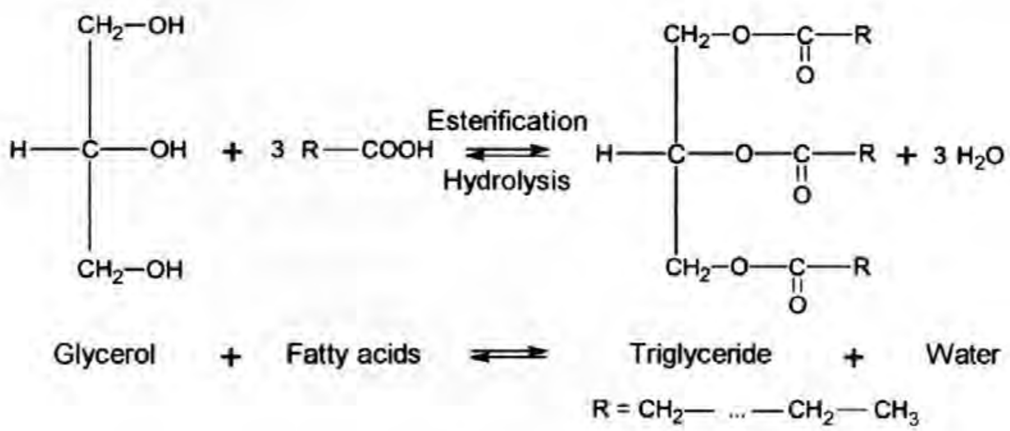

Figure 2.2: Structure of molecules of vegetable oil in esterification and hydrolysis [4]

2.3 Chemical properties of the transformer oil

2.3.1 Water Content

One of the factors that will reduce the good properties of transformer oil as an insulator is moisture or known as water content. It is extremely hazardous to transformer insulation in the presence of oxygen. Generally, the live of the insulation is divided by one and half each time the moisture is doubled in the transformer [8]. This moisture will affect the paper insulation of the core and winding of the transformer where paper is hygroscopic behavior. Hygroscopic behavior is defined as the ability of the substance to absorb water.

The presence amount of water in transformer will affect the paper insulation and reduce its life. It also can become worse in quality or condition of the transformer insulation by diminishing both mechanical and electrical strength. According to the Y. Zhou [5], the presence of 0.02% water in transformer oil will decrease the amount of electrical strength up to 20% of the dry value. To test the water content in the transformer oil, the Karl Fischer method is introduced [3]. The water content in the transformer oil is measured in parts per million or ppm. The accepted value of moisture content is varied for different type of transformer oil; 35 ppm for mineral oil and 200 ppm for natural ester as outlined in ASTM D387 and ASTM D6871.

A major causes of transformer failures are by the moisture is bubble formation, dielectric breakdown, deterioration of insulating liquid and paper and partial discharge. A presence of the moisture will lead the failure of transformer which is oil level drop, exposing the winding and moisture contamination [12]. The maximum amount of moisture in mineral is 35ppm while the vegetable oil is 200ppm [11,15].

2.3.2 Acidity of Transformer Oil

Acidity is a harmful property where the water content in the oil will becomes more soluble hence worsen. The insulating quality of paper insulation acid in transformer oil will quicken the oxidation process in the oil. With the presence of moisture, the insulating material it will be rust due to effect of the acidity. Acidity is a measure of the acid constituents of contaminant. The acidity will quicken the oxidation process in the oil. If there is acid at the material and it have a moisture on it, the material will be rust due to effect of the acidity. Neutralization number express the acidity of oil in mg of KOH required to neutralize the acid present in gram of oil. In addition, measure of acidic constituent of contaminants defines the acidity of the transformer oil [8].

2.4 Physical Properties of transformer oil

2.4.1 Flash point

The flash point and fire point refer to the flammability characteristic of the liquid that being tested. Under specific test the lowest temperature at which water vapor formed above a pool of the liquid can be ignited in air and at pressure of 1 atmosphere; this is the flash point [8]. The flash point is used to access the hazardous nature of a material and the risk of materials ability to support combustion [8].

2.4.2 Pour Point

Pour point of transformer is characterized as an important property where it happens mainly at the places where the atmosphere is frigid. Obstruction of cooling and convection flow of the transformer oil stops when the oil temperature drops below pour point. Wax content in the transformer oil influence the pour point of the transformer oil and the more wax content, the higher the pour point. In mineral oil, paraffin-based oil is one of the higher pour point content [8].

2.4.3 Viscosity

By a definition, viscosity is the resistance of flow in the transformer oil. This term can be defined as the obstruction of convection circulation oil inside the transformer. To not affect the cooling of the transformer, low viscosity is needed so it will be less resistance to the conventional flow of oil. The lower the viscosity of the oil, the lesser resistance in transformer oil flow, and the better insulation oil will have [12]. If the viscosity is low, the temperature of the oil should be low. Every oil becomes more viscous if the temperature reduced [8].

2.5 Electrical Properties of Transformer

2.5.1 Breakdown strength

In a high voltage equipment, the most important material used are conductors and insulators. The conductors will carry the current while the insulators used to prevent the flow of currents in desired paths. Breakdown voltage test for the transformer oil also known as dielectric strength test [13]. The maximum dielectric strength which the material can withstand without having a failure is well known as the dielectric strength of the insulating material. Breakdown occurs when the applied voltage is large, the current flowing through the insulation increases very sharply, thus an electrical breakdown occurs.

Breakdown in liquids is one of the breakdown in the transformer. Liquid are commonly used in the high voltage equipment to serve the deal purpose of insulation and heat conduction. The structure path of the liquid is self-healing where it is one of the advantages in the liquid [1]. Temporary failures due to over voltages are reinsulated quickly by liquid flow to the attacked area. Whereas, the products of the discharges may deposit on solid insulation supports and may lead to surface breakdown over these solid supports. The maximum of purified liquid has the maximum dielectric strength where it can support up to 1 MV/cm. The breakdown mechanism in the pure liquids is the same mechanism as in the gas breakdown but for the commercial liquids the mechanism different by the presence of solid impurities and dissolves gasses. In the