

**STUDY OF ELECTRICAL AND CHEMICAL PROPERTIES OF TRANSFORMER  
INSULATING OILS**

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**This report submitted in partial fulfillment of the requirement for degree of Bachelor of  
Electrical Engineering (Industrial Power)**

**Faculty of Electrical Engineering**

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**MAY 2014**

“I hereby declare this report entitle “*Study of Electrical and Chemical Properties of Transformer Insulating Oils*” 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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This project and research work is dedicated to my beloved parents for their devoted caring throughout my life, also my friends for their encouragement and support.

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## ABSTRACT

Transformer is a device in static condition. The transformer transforms electrical energy from one circuit to another and important in the power system for voltage level conversion. Transformer failure might cause by several conditions such as an overload condition and most failure were caused by an insulation problem. This research is carried out to examine the characteristic, particular substance oil and the relationship between these characteristic of transformer oil that can cause failure. This research is to study transformer insulating oil in electrical, physical and chemical properties using Meggar Oil Test Set, Fourier Transform Infrared Spectrometer (FTIR) and Viscotester. The samples only used one type of transformer insulating oils (Hyrax) but in four type conditions which are new transformer insulating oils, breakdown transformer insulating oils, different moisture content and temperature level. Moisture can cause breakdown voltage or dielectric strength value decrease, damage the winding, insulation kraf paper and proven by chemical substance analysis, the moisture break the particle chain, even moisture good in heat transfer and has a low viscosity. Temperature also can affect the viscosity and breakdown voltage value, as the temperature is increase, viscosity value is decrease and breakdown voltage is increase. Moisture and temperature categories as most influence effect to the transformer insulation problems. The result of the chemical substances, breakdown voltage and viscosity analysis shows the moisture and temperature give an impact in insulating oil particle and substances.

## ABSTRAK

Alat ubah adalah alat yang berkeadaan statik , ia mengubah tenaga elektrik dari satu litar kepada yang lain dan penting dalam sistem kuasa untuk menukar tahap voltan. Kegagalan pengubah mungkin disebabkan oleh beberapa keadaan seperti beban berlebihan dan kebanyakan disebabkan oleh masalah penebat. Projek ini adalah untuk mengkaji sifat-sifat elektrik , fizikal dan kimia minyak penebat pengubah menggunakan Meggar Ujian Minyak Set, Fourier Transform Infrared Spektrometer (FTIR ) dan Viscotester . Hanya satu sample jenis minyak pengubah penebat yang digunakan ( Hyrax ) tetapi dalam empat keadaan minyak penebat iaitu minyak penebat yang baru, minyak penebat yang lama, minyak penebat yang mengandungi kelembapan yang berbeza dan tahap suhu . Kelembapan boleh menyebabkan penurunan ketebatan minyak atau kekuatan nilai dielektrik menurun , merosakkan gelung , penebatan kertas Kraf dan dibuktikan oleh analisis bahan kimia, kelembapan memecahkan rantaian zarah , walaupun kelembapan baik dalam pemindahan haba dan mempunyai kelikatan yang rendah. Suhu juga boleh menjejaskan kelikatan, kekuatan dielektrik, peningkatan suhu dan penurunan nilai kelikatan. Kelembapan dan suhu dikategorikan sebagai kesan yang paling mempengaruhi kepada masalah-masalah penebat pengubah. Hasil daripada analisa kandungan bahan-bahan kimia , kekuatan dielektrik dan analisa kelikatan menunjukkan kelembapan dan suhu memberi kesan dalam kandungan penebatan zarah minyak.

## TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	<b>PROJECT TITLE</b>	<b>i</b>
	<b>DECLARATION</b>	<b>ii</b>
	<b>DEDICATION</b>	<b>iv</b>
	<b>ACKNOWLEDGEMENT</b>	<b>v</b>
	<b>ABSTRACT</b>	<b>vi</b>
	<b>ABSTRAK</b>	<b>vii</b>
	<b>TABLE OF CONTENT</b>	<b>viii</b>
	<b>LIST OF FIGURE</b>	<b>xi</b>
	<b>LIST OF TABLE</b>	<b>xiii</b>
	<b>LIST OF ABBREVIATION</b>	<b>xiv</b>
	<b>LIST OF APPENDICES</b>	<b>xv</b>
<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.1 Project Background	1
	1.2 Problem Statement	2
	1.3 Objective	3
	1.4 Project Scope	3
<b>2</b>	<b>LITERATURE REVIEW</b>	<b>5</b>
	2.1 Introduction	5



2.2	High Voltage Generation	5
2.3	Principle of Transformer	6
2.4	Transformer Insulating Oils as Insulating Material	7
2.5	Experimental Setup	9
2.5.1	High Voltage AC Breakdown Voltage Test	9
2.5.2	Viscosity Test	10
2.5.3	Chemical Substances Analysis	12
2.6	Effect of Temperature	13
2.7	Effect of Moisture	13
2.8	Summary	14
<b>3</b>	<b>METHODOLOGY</b>	<b>16</b>
3.1	Introduction	16
3.2	Methodology	17
3.2.1	Experimental Review	19
3.3	Safety Precautions	21
3.4	Testing Procedure Manual	24
3.4.1	Samples Preparation	26
3.4.2	Procedure of Testing	26
3.5	Flowchart of Testing	28
<b>4</b>	<b>RESULTS &amp; DISCUSSION</b>	<b>31</b>
4.1	Introduction	31
4.2	Comparison on Viscosity of New and Breakdown Transformer Insulating Oils	32
4.3	Viscosity Testing on New Transformer Insulating Oils (Moisture Control)	33

4.4	Viscosity Testing on New Transformer Insulating Oils (Temperature Control)	34
4.5	Comparison on Chemical Substances of New and Breakdown Transformer Insulating Oils	35
4.6	Chemical Substances Testing on New Transformer Insulating Oils (Temperature Control)	36
4.7	Chemical Substances Testing on New Transformer Insulating Oils (Moisture Control)	37
4.8	Comparison on Breakdown Voltage of New and Breakdown Transformer Insulating Oils	38
4.9	Breakdown Voltage Testing on New Transformer Insulating Oils (Temperature Control)	39
4.10	Breakdown Voltage Testing on New Transformer Insulating Oils (Moisture Control)	40
4.11	Discussion of Results	41
<b>5</b>	<b>CONCLUSIONS AND RECOMMENDATIONS</b>	<b>52</b>
	5.1 Conclusion	52
	5.2 Recommendations	53
	<b>REFERENCES</b>	<b>54</b>
	<b>APPENDICES</b>	<b>56</b>

## LIST OF FIGURES

<b>FIGURE</b>	<b>TITLE</b>	<b>PAGE</b>
1.1	Percentage and cause of Transformer Failure in USA (1997-2001)	2
2.1	Power Transformer	7
2.2	Megger Oil Test Set (OTS 60PB)	10
2.3	Fourier Transform Infrared Spectrometer	12
2.4	Description of Overall	15
3.1	Flow Chart of Project Methodology	19
3.2	Flow Chart of Testing (Viscotester)	28
3.3	Flow Chart of Testing (FTIR)	29
3.4	Flow Chart of Testing (Megger OTS 60PB)	30
4.1	Comparison of New and Breakdown Transformer Insulating Oils (Substances)	35
4.2	Chemical Substances of New Transformer Insulating Oils with Changing the Temperature	36
4.3	Chemical Substances of New Transformer Insulating Oils with Changing Moisture Content	37
4.4	Average Value Of New and Breakdown Transformer Oils Viscosity	42
4.5	Average Value Of New Transformer Oils Viscosity (Moisture Content)	43
4.6	Average Value Of New Transformer Oils Viscosity (Temperature Content)	43

<b>FIGURE</b>	<b>TITLE</b>	<b>PAGE</b>
4.7	Comparison of New and Breakdown Transformer Insulating Oils (Substances)	44
4.8	Breakdown Transformer Insulating Oils (Substances)	45
4.9	Comparison of New Transformer Insulating Oils substances (Temperature Control)	46
4.10	New Transformer Insulating Oils at 180°C (Substances)	46
4.11	Comparison of New Transformer Insulating Oils substances (Moisture Control)	47
4.12	New Transformer Insulating Oils Add 4 ml Moisture (Substances)	48
4.13	Average Value Of New and Breakdown Transformer Oils Breakdown Voltage	49
4.14	Average Value Of New Transformer Oils Breakdown Voltage (Moisture Control)	50
4.15	Average Value of New Transformer Oils Breakdown Voltage (Temperature Control)	50

## LIST OF TABLES

<b>TABLE</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Physical Characteristic Specification Limits of New Oils	9
2.2	Viscosity Values of Selected Substances Conditions	12
2.3	Measuring Range for Selected Rotor	12
4.1	Viscosity of New and Breakdown Transformer Insulating Oils	32
4.2	Viscosity of New Transformer Insulating Oils with Changing Moisture Content	33
4.3	Viscosity of New Transformer Insulating Oils with Changing the Temperature	34
4.4	Breakdown voltage of New and Breakdown Transformer Insulating Oils	38
4.5	Breakdown Voltage Testing on New Transformer Insulating Oils (Temperature Control)	40
4.6	Breakdown Voltage Testing on New Transformer Insulating Oils (Moisture Control)	41

**LIST OF ABBREVIATIONS**

kV	- kilo Volt
BS	- British Standard
UTeM	- Universiti Teknikal Malaysia Melaka
DC	- Direct Current
AC	- Alternating Current
mA	- mili Ampere
IEEE	- Institute of Electrical and Electronic Engineers
ml	- mili liter
Mm	- mili meter
Hz	- Hertz
FTIR	- Fourier Transform Infrared Spectrometer
ATR	- Attenuated Total Reflectance

**LIST OF APPENDICES**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	Testing Works	57
B	Average Viscosity of New Transformer Insulating Oils (Temperature)	69
C	Average Viscosity of New Transformer Insulating Oils (Moisture)	71
D	Average Breakdown Voltage of New Transformer Insulating Oils (Temperature)	72
E	Average Breakdown Voltage of New Transformer Insulating Oils (Moisture)	74

## CHAPTER 1

### INTRODUCTION

#### 1.1 Project Background

The purpose of this research is to study electrical and chemical properties of power transformer insulating oil. The main point is to understand the basic of transformer function and its liquid dielectric. The transformer is a device in static condition. It transforms electrical energy from one circuit to another circuit and maintains the same frequency which is 50 Hertz (Hz) in Malaysia.

Besides that, the transformer has become important in the power system for voltage level conversion and maintaining the power flow. The transformer may step up or step down the voltage level depends on its needed. In manufacturing field, the transformer needs a lot of constructional parts. Basically, there are three main parts of transformer which is a primary winding, a secondary winding and a magnetic core. Transformer failure might cause by several conditions such as an overload condition. There is a statistic of transformer failures in the United State of America (USA) from 1997 to 2001. The most caused were by an insulation problem [1].

Insulation system is one of many reason plays in the transformer life. These three parts of the transformer are insulating and cooling by solid dielectric and liquid dielectrics. Solid dielectric, usually made of pressboard, wood and unbleached softwood pulp. The widely used know as “Kraft Paper”, made of unbleached softwood pulp and flow into sulfate process. Liquid dielectric is important due to its dual purposes as heat condition and insulation to high voltage system. In this case, liquid dielectrics refer to petroleum-based mineral oils.



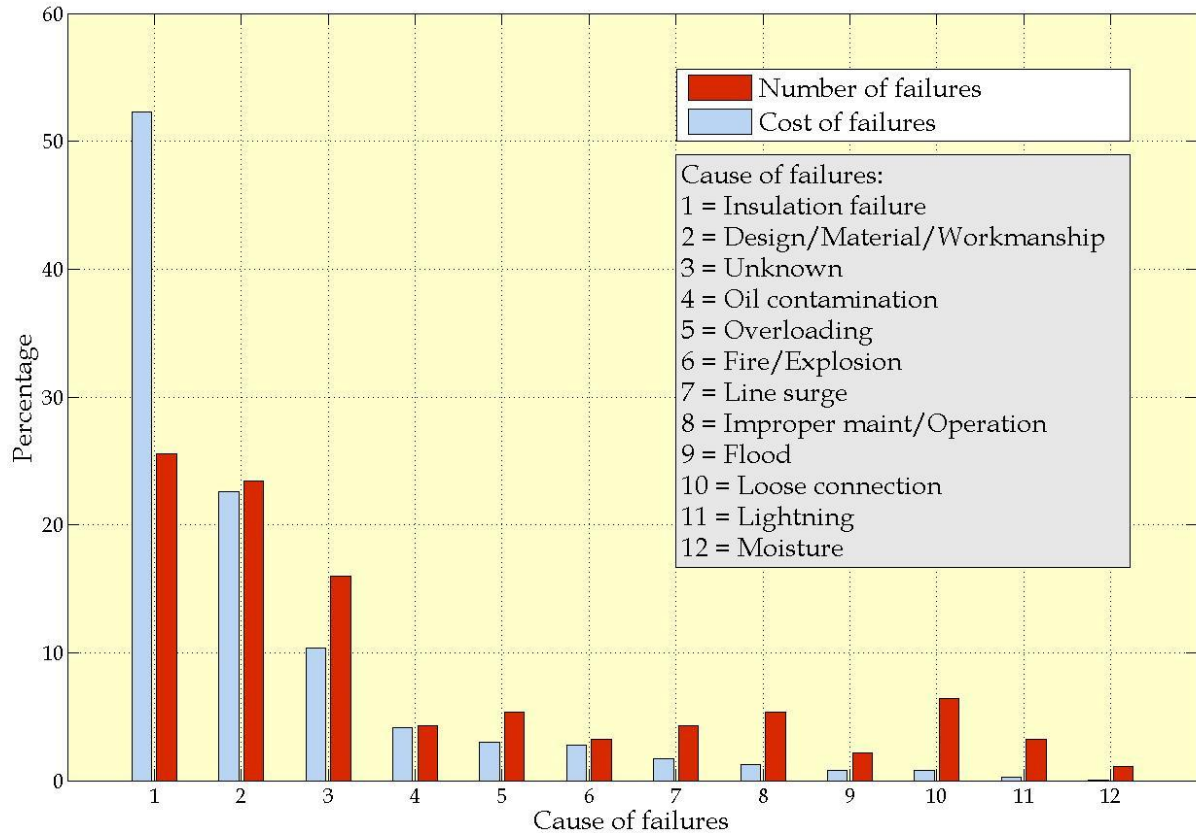


Figure 1.1: Percentage and cause of Transformer Failure in USA (1997-2001) [1]

The figure 1.1 shows the statistics of the percentage and the cause of transformer failure in the United States of America in year 1997 until year 2001. Insulation problem present the highest number of percentages and show the highest cost of transformer failure. While, moisture has the smallest number of percentages and show the less cost of transformer failure.

## 1.2 Problem Statement

Liquid dielectric is insulating materials that had been used widely in high voltage system include the high voltage of capacitors, cables, circuit breaker and transformers. Petroleum-based mineral oils or transformer insulating oils is one of liquid dielectric that has been analyzed in this research due to its function as heat transfer fluid and electrical insulation

for the transformer. The quality of the insulating oil plays the most important role in the circulation of transformer life. Nowadays, the statistic shows that the total percentage of transformer failures increases from year 1997 until year 2001 and mostly caused by an insulation problem.

### **1.3 Objective**

The objectives of this research are to differentiate the characteristics of the new transformer oils and effected transformer oils which are from breakdown transformer. The detail explanations will discuss in this report. Besides that, this research was conducted to analyze the power transformer insulating oil in electrical and chemical properties. This research was use the several type of tester such as Meggar Oil Test Set, FTIR and Viscotester to analysis the insulation oil in electrical and chemical properties. Lastly, this research is to determine and analyze the properties of transformer insulating oil that can cause failure in different moisture content and different temperature degree.

### **1.4 Project Scope**

The main issue in this research is to examine the characteristics of the particular substance oil and the relationship between their characteristics of transformer oil and their causes of failure in three aspects which is in electrical, chemical and physical aspect. At the mean time, this research will limited on certain standard and guideline of each analysis to ensure the reliability of the outcome result from the experiment and has describe in detail on the next chapter.

This research deals with the high voltage generation of the electrical and the chemical properties. The experiments have been done at the high voltage laboratory Faculty of Electrical Engineering (FKE) and the physical laboratory Faculty of Information and Communication Technology (FTMK), Universiti Teknikal Malaysia Melaka (UTeM). Besides that, the transformer type use in this experiment is transformer insulating oils (Hyrax). The

experiment will focus on the four aspects which in new transformer oil, breakdown transformer oil, the different moisture content and the different temperature degree have been tested.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Introduction

Nowadays, high voltage plays an important role in life. High DC voltages, high AC voltages and high impulse voltages are three main types of generators [2]. In generation system, transformer is one of the important and the main parts in high voltage system. The heat and the insulate problem are consuming some problem and can cause transformer failure. In order to cope with this problem, liquid dielectric as insulating material due to its function as heat transfer fluid and electrical insulation and able to adapt the problem. In order to make sure the transformer work in good condition, use the transformer insulating oil or petroleum-base mineral oil that fulfill all the requirement, specification and characteristic of good dielectric.

#### 2.2 High Voltage Generation

Electronic valve rectifiers normally use at high DC voltages, it is able to produce up to 100 kV and as low as 100 mA output currents [2]. Basically, High DC voltage is used to transmit high power for long distances. The half wave, the voltage doubler type and the full wave have been used to convert from AC sources to produce high DC voltages act as a rectifier circuit [2]. DC voltages commonly produce using semiconductor rectifier stack that preferred silicon diodes due to the peak inverse voltage of 1kV to 2kV [2].

High AC voltages performed at the same working frequency for all equipment. Single transformer has an insulation problem due to its construction and only applicable for testing

purpose. This problem is able to overcome with the use of resonant and cascade transformer. The cascade transformers consist of step-up transformer with the limited number of ground potential which is from first transformer and the insulators from second transformer [2]. The leakage reactance of the windings, the shunt capacitance and the magnetizing reactance are the construction of resonant transformer [2].

High impulse voltages can produce an ultra-short high voltage pulse by using pulse compression stages. The strength from switching surges and lightning can be tested by using high impulse voltages.

The consideration in this research is the high voltages testing such as high DC voltage testing, high impulse voltage testing and high AC voltage testing. In order to determine the flashover voltages of the insulating material, high AC voltage testing has been held [2].

### **2.3 Principle of Transformer**

This project started with the study about high voltage generation. There are three types of generation which is the high DC voltages, higher AC voltages and the impulse voltages [3]. In this project, the transformer has been chosen as the high AC voltage. The transformer is a static electrical device that transfers energy by inductive coupling between its winding circuits [3]. The transformer has been used to increase the voltage before transmitting electrical energy over long distances through wires from one circuit to another circuit without changing frequency. The transformer can be categorized in many ways, depending on their purpose, use, construction, and others. In manufacturing field, the transformer needs a lot of constructional parts. Basically, there are three main parts of transformer which is a primary winding, a secondary winding and a magnetic core. Transformer failure might cause by several conditions such as an insulation system. [3]. In Figure 2.1 below shows a power transformer with capability of 100MVA with maximum voltage of 150kV.



Figure 2.1: Power Transformer

#### 2.4 Transformer Insulating Oils as Insulating Material

Insulation system is one of the issues that play a role in the transformer's life. Its function is to insulate and cool the transformer. Like other high-voltage systems, transformers also need an insulating material to prevent heat problems. Insulating material is divided into two, which are solid and liquid dielectrics. Solid dielectrics, usually made of pressboard, wood, and unbleached softwood pulp, but the widely used one known as "Kraft Paper" is made of unbleached softwood pulp and goes through a sulfate process [4].

Liquid dielectric is a dielectric in a liquid state. Liquid dielectrics are used to prevent electric discharge, a good liquid dielectric has high dielectric strength, able to prevent breakdown when in electrical stress, cool the windings, non-flammable nature, chemical stability, and good heat transfer properties [4]. The electric capacitance per unit of volume is determined by the dielectric constant and depends on the operating temperature of the liquid and the frequency or structure of its constituent molecules. Even solid insulators are important to the electrical industry, but liquid insulators are contained in many electrical parts or products. Transformers, circuit breakers, capacitors, and cables are major devices that utilize liquid dielectrics. The liquid dielectric has properties that need to be determined to see if it's a good liquid dielectric or not.

Liquid dielectric is important because of its dual purposes as heat condition and insulation to high voltage system. In this research, liquid dielectrics refer to petroleum-based mineral oils. Several properties need to count on consideration to analyze a good liquid dielectric. The properties are electrical properties, chemical properties and physical properties. The electrical properties are focused on breakdown voltage, dielectric dissipation factor and specific resistance [4]. The chemical properties of good liquid dielectric are focused on its acidity, sludge content and water content. Meanwhile, liquid dielectrics for physical properties are focused on pour point, viscosity, conductivity and flash point.

The distillations of a petroleum crude stock produce a fraction of the hydrocarbons and will produce transformer oil by refining. The collected fraction boiling range and refining degree of process was set up early. The characteristic of resulting oils has fallen within limits and suitable to use in transformers. Many international refining companies made the transformer insulating oils by using particular crude oils. The physical, chemical and electrical properties produced to some degree to assure the properties follow the standard and acceptable for use in specific apparatus. The result that has been measured for each characteristic are compared with specific standard that have been agreed by manufacturer and refiners of oils [5]. In a transformer, the amount of oils contained with several of load that the transformer carrying capability and its physical size. For example, the distribution transformer rated 25kVA and contains around 20 gallons of insulating oils. The physical characteristic of transformer insulating oil standard method of measurement and its limit that have been imposed on them are listed in Table 2.1. This table shows the various characteristics with the limitation and their standard ASTM test method.

The viscosity of oil is very important for heat transfer by natural convection and as principal parameter in design calculations. While the transformer is in operation, the transformer oils are in electrical and mechanical stresses. Interactions of chemical and winding can cause contamination and speeds up a chemical reaction by high operating temperature and make the changes of original chemical properties [5]. Its electrical and chemical properties periodically tested, to know whether it is suitable to use or not. In this research, breakdown voltage or flashover point will be determined as electrical properties. While the contaminant, molecular and substance group will be examined as chemical properties.

Table 2.1: Physical Characteristic Specification Limits of New Oils

Physical Characteristic		
Characteristic	Limits D3487	Standard ASTM Test Method
Kinematic Viscosity,cSt		D445
@100C	< 3.0	
@40C	< 12.0	
@0C	< 76	
Pour Point, C	< -40	D97
Flash Point, C	> 145	D92

## 2.5 Experimental Setup

In this research, firstly need to determine three properties which are electrical, chemical and physical properties. For each property will have one experimental setup using instruments that can fulfill the analysis specifications. Three experimental setups need to be done in order to analyze, breakdown voltages, viscosity and chemical substances of transformer insulating oils. These three analyses need to consider two parameters which are moisture and temperature of the characteristic of new and breakdown transformer insulating oils.

### 2.5.1 High Voltage AC Breakdown Voltage Test

Dielectric strength or breakdown voltage is a minimum voltage that caused a portion in insulator and it becomes conductor [6]. It happened when the insulating oil reached the time of spark between electrodes. Condition of molecular properties and atomic insulating oils may cause the breakdown voltage, but in high voltage breakdown test, material of the electrodes, moisture, temperature and gas content might cause the breakdown voltage reading increase or