INVESTIGATION OF INCREASING FAULT GAS IN EXCITATION TRANSFORMERS

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This study is to carry out investigation on increasing fault gas in oil insulation in three similar excitation transformers in Tanjung Bin Power Plant; Transformer A, Transformer B, and Transformer C. The research covers the transformer oil sample collection, and the experiment of Dissolved Gas Analysis (DGA) in laboratory. Then, the DGA results as raw data are evaluated using two methods which are Duval Triangle and Rogers Ratio in order to interpret and estimate the possible internal fault that may present in all transformers. The research is also included with three mitigation procedures and one verification test on selected transformer respectively. First procedure study is replacing Transformer A with spare. Second method is oil insulation degasification from Transformer B. Third procedure is continued with high frequency of DGA monitoring of Transformer C. The results from all case studies are again interpreted and checked with Duval Triangle and Roger’s Ratio for before and after outcome comparison. In addition to, the investigation is widened with electrical diagnostics tests which are carried out on Transformer A in order to verify the root cause of internal fault. The decision of serviceability of all excitation transformers are successfully made by having a Transformer Health Index (THI) using the condition factors as mentioned above. It is concluded that, all excitation transformers are good to be keep in service with several recommendations.
ABSTRAK

# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE</td>
<td>i</td>
</tr>
<tr>
<td>DECLARATION</td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>vi</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>x</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF SYMBOLS AND ABBREVIATIONS</td>
<td>xii</td>
</tr>
</tbody>
</table>

## CHAPTER 1

**INTRODUCTION**

1.1 Project Background 1
1.2 Excitation System 1
1.3 Excitation Transformer 2
1.4 Transformer Insulation System 4
1.4.1 Liquid Insulation 4
1.4.2 Solid Insulation 5
1.5 Problem Statement 6
1.6 Objectives 7
1.7 Scope of Study 7

## CHAPTER 2

**LITERATURE REVIEW**

2.1 Degradation of Solid Insulation in Transformer 9
2.2 Degradation of Oil Insulation in Transformer 10
2.3 Evaluation of Possible Faults by Dissolved Gas 11
Analysis (DGA)
2.3.1 Duval Triangle: A Noble Approach for DGA Datasets
2.3.2 Roger’s Ratio Method as a Proper DGA Interpretation
2.3.3 Comparison of DGA Interpretation Methods
2.4 Oil Sampling as a Transformer Condition Based Maintenance (CBM)
2.5 Transformer Diagnostic Using Electrical Routine Tests
2.5.1 Dielectric Dissipation Factor Measurement
2.5.2 Excitation Current Measurement
2.5.3 Turn Ratio Measurement
2.5.4 Winding Resistance Measurement
2.5.5 Insulation Resistance Measurement
2.5.6 Magnetic Balance Measurement
2.5 Transformer Health Index (THI) as an Asset Management Tool

CHAPTER 3 METHODOLOGY
3.1 Introduction
3.2 Sampling of Excitation Transformer Oil
3.2.1 Sampling Mandatory Conditions and General Information
3.2.2 Sampling Device and Container
Dissolved Gas Analysis (DGA) in Laboratory
3.3.1 Method A
3.4 Evaluation of Transformer Using Gas Level Criteria
3.5 DGA Interpretation Using Duval Triangle Method
3.6 DGA Interpretation Using Roger’s Ratio Method
3.7 Comparing Duval’s and Roger’s Ratio Results
3.8 Fault Gas Mitigation Procedures
3.8.1 Replacement of Transformer 31
3.8.2 Degasification of Oil Insulation 31
3.8.3 High Frequency of DGA Monitoring 32
3.9 Electrical Diagnostic Tests 33
3.9.1 Dielectric Dissipation Factor 33
3.9.2 Excitation Current Measurement 34
3.9.3 Turn Ratio Measurement 34
3.9.4 Winding Resistance Measurement 35
3.9.5 Insulation Resistance Measurement 36
3.9.6 Magnetic Balance Measurement 36
3.10 Development of Transformer Health Index 38

CHAPTER 4 RESULT, ANALYSIS AND DISCUSSION
4.1 Introduction 42
4.2 Dissolved Gas Analysis (DGA) 43
4.2.1 Fault Prediction Using Duval Triangle 43
4.2.2 Fault Prediction Using Roger’s Ratio 46
4.3 Fault Gas Mitigation 48
4.3.1 Replacement of Transformer 48
4.3.2 Degasification of Oil Insulation 49
4.3.3 High Frequency of DGA Monitoring 51
4.4 Electrical Diagnostic Tests 51
4.4.1 Dielectric Dissipation Factor 52
4.4.2 Excitation Current 53
4.4.3 Turn Ratio 53
4.4.4 Winding Resistance 54
4.4.5 Insulation Resistance 55
4.4.6 Magnetic Balance 56
4.5 Transformer Health Index (THI) 56

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS
5.1 Conclusions 58
5.2 Recommendations 59

REFERENCES 61
LIST OF TABLES

Table 2.1: Regions within Duval Triangle
Table 2.2: Roger’s Ratio Code and Characteristics
Table 3.1: Excitation Transformer Specification
Table 3.2: Types of Mitigation and Verification Methods
Table 3.3: L1 Limits and Gas Generation Rate
Table 3.4: DGAF Calculation
Table 3.5: DGAF Rating Code, Condition and Description
Table 3.6: Transformer Health Index
Table 4.1: Dissolved Key Gas Concentration Limits
Table 4.2: Roger’s Ratio Analysis for Transformer A
Table 4.3: Summary of Fault Predications by Roger’s Ratio
Table 4.4: Dielectric Dissipation Test Result
Table 4.5: Duration of Dielectric Test Limit
Table 4.6: Excitation Current Measurement Result
Table 4.7: Turn Ratio Measurement Result
Table 4.8: HV Winding Resistance Result
Table 4.9: LV Winding Resistance Result
Table 4.10: Insulation Resistance Measurement Result
Table 4.11: Insulation Resistance Factory Test
Table 4.12: Magnetic Balance Result
Table 4.13: THI for Transformer A
Table 4.14: Transformer Condition-Based Ranking
LIST OF FIGURES

Figure 1.1:  Excitation System
Figure 1.2:  Excitation Transformer
Figure 1.3:  Active Part of Excitation Transformer
Figure 2.1:  Fundamental Steps of Gas Generation
Figure 2.2:  Duval Triangle
Figure 3.1:  Flow Chart of Investigation
Figure 3.2:  Procedure of Extracting Oil Sample
Figure 3.3:  Transformer Oil Sample
Figure 3.4:  Gas Chromatograph
Figure 3.5:  Extraction of Gas from Insulation Oil
Figure 3.6:  Degasification Equipments
Figure 3.7:  Electrical Diagnostic Test Connection Diagram
Figure 4.1:  Ethane Gas Concentration
Figure 4.2:  Plotted Duval Triangle
Figure 4.3:  Transformer Replacement Effect on C₂H₆ Level
Figure 4.4:  Degasification Effect on Transformer B C₂H₆ Level
Figure 4.5:  Performance of Transformer Replacement and Degasification
Figure 4.6:  Transformer C C₂H₆ Level at High Frequency of DGA Monitoring
# LIST OF SYMBOLS AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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</thead>
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<tr>
<td>°C</td>
<td>Degree in Celsius</td>
</tr>
<tr>
<td>%</td>
<td>Percent</td>
</tr>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
</tr>
<tr>
<td>AVR</td>
<td>Automatic Voltage Regulator</td>
</tr>
<tr>
<td>BS</td>
<td>British Standard</td>
</tr>
<tr>
<td>C₂H₄</td>
<td>Ethylene</td>
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<tr>
<td>C₂H₆</td>
<td>Ethane</td>
</tr>
<tr>
<td>C₂H₂</td>
<td>Acetylene</td>
</tr>
<tr>
<td>Cap</td>
<td>Capacitance</td>
</tr>
<tr>
<td>CBM</td>
<td>Condition Base Maintenance</td>
</tr>
<tr>
<td>CH₄</td>
<td>Methane</td>
</tr>
<tr>
<td>CH</td>
<td>High voltage winding to earth</td>
</tr>
<tr>
<td>CHL</td>
<td>High voltage winding to low voltage winding</td>
</tr>
<tr>
<td>CL</td>
<td>Low voltage winding to earth</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon Monoxide</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>Corr factor</td>
<td>Correction Factor</td>
</tr>
<tr>
<td>DGA</td>
<td>Dissolved Gas Analysis</td>
</tr>
<tr>
<td>DGAF</td>
<td>Dissolved Gas Analysis Factor</td>
</tr>
<tr>
<td>DP</td>
<td>Degree of polymerization</td>
</tr>
<tr>
<td>HV</td>
<td>High voltage</td>
</tr>
<tr>
<td>H₂</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrotechnical Commission</td>
</tr>
<tr>
<td>IPP</td>
<td>Independent Power Producer</td>
</tr>
<tr>
<td>kV</td>
<td>kilo Volt</td>
</tr>
<tr>
<td>kVA</td>
<td>kilo Volt Ampere</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>LV</td>
<td>Low voltage</td>
</tr>
<tr>
<td>mA</td>
<td>mili Ampere</td>
</tr>
<tr>
<td>MCB</td>
<td>Malakoff Corporation Berhad</td>
</tr>
<tr>
<td>MΩ</td>
<td>Mega Ohm</td>
</tr>
<tr>
<td>mΩ</td>
<td>mili Ohm</td>
</tr>
<tr>
<td>N₂</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>ONAN</td>
<td>Oil Natural Air Natural</td>
</tr>
<tr>
<td>O₂</td>
<td>Oxygen</td>
</tr>
<tr>
<td>PD</td>
<td>Partial Discharge</td>
</tr>
<tr>
<td>pF</td>
<td>piko Farad</td>
</tr>
<tr>
<td>PF</td>
<td>Power Factor</td>
</tr>
<tr>
<td>P.I</td>
<td>Polarization Index</td>
</tr>
<tr>
<td>ppm</td>
<td>Particles per molecule</td>
</tr>
<tr>
<td>PTFE</td>
<td>Polytetrafluoroethylene</td>
</tr>
<tr>
<td>TBPP</td>
<td>Tanjung Bin Power Plant</td>
</tr>
<tr>
<td>TDGC</td>
<td>Total Dissolved Gas Content</td>
</tr>
<tr>
<td>THI</td>
<td>Transformer Health Index</td>
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<tr>
<td>TNB</td>
<td>Tenaga Nasional Berhad</td>
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</tbody>
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CHAPTER 1

INTRODUCTION

1.1 Project Background

It is a rule for the transformer to provide satisfactory and uninterrupted service as it is well known that transformers are the main link providing power for any type of plant. Transformer failure cannot be tolerated in any installation. A failure of a transformer can be due to many reasons, such as overloading, unbalanced load conditions, improper maintenance on oil level, deterioration of oil characteristics and presence of moisture that affecting the life of transformer insulation system. Therefore, it is a huge responsibility for transformer custodians to have a rigorous system of operation and maintenance that will ensure long life, trouble free service and low maintenance cost.

The maintenance consists of a few strategies, for example regular inspection, testing, investigation, diagnostic, condition assessment and reconditioning. The main objective of the said maintenance strategies are to maintain and to verify transformer insulation systems whether they are in good condition or deteriorating. This project will discuss in detail the periodic inspection by oil sampling, condition assessment by oil insulation and basic electrical diagnostic test.
1.2 Excitation System

An excitation system in a power plant provides field current for a generator including all power, regulating, control and protective elements. Generator works on the principle of Faraday’s electromagnetic induction. The essential part of this principle is the magnetic field. The magnetic field is produced when a Direct Current (DC) power source from an excitation transformer is supplied to rotating rotor in generator. Then the rotor or the field coils in a generator produce the magnetic flux that is essential to the production of the electric power.

![Figure 1.1: Excitation System](image)

1.3 Excitation Transformer

Excitation transformer has no major differences in transformer construction features compare with other power transformers, distribution transformers, indoor and outdoor transformers, etc. The design criteria and specifications of type of transformers that will be subjected in this research are:

- Core type construction where the winding surround the core
- The input and output of transformer is three phase
- Two windings which are primary and secondary
• Uses oil as a cooling medium
• Installation method is outdoor application

Figure 1.2 shows the installation of an excitation transformer in a power plant. The enclosure tank is conventional tank which is flat and tank to cover junction is at the top. The tank contains of the live parts such as core and winding assembly, electrical connections, and insulating oil. This transformer also is equipped with conservator tank mounted on the highest point of the tank to permit free expansion and contraction of oil due to variation of the transformer oil volume with temperature.

![Figure 1.2: Excitation Transformer](image)

The main components of a transformer are two or three sets of windings wrapped around the core and the assembly is housed in a tank. Before closing the tank by manufacturer, it is filled it with mineral oil. The winding is insulated from the non conducting components- core and tank, through the oil. The two conductors- winding coil and tank, are separated by two dielectrics-Kraft paper and mineral oil. Figure. 1.3 below displays the basic internal construction of an excitation transformer. It is a three phase core form construction. The core is made from laminated of low reluctance magnetic steel containing silicone. The core is held in place with a clamping structure. Core configuration is three phase three limb. The primary and secondary winding are made from high grade copper and insulated with paper coating to avoid inter-turn
winding contact. Cylinder shaped windings concentrically arranged around a cylinder shaped core limb. This excitation transformer also uses oil insulation to function as its coolant, dielectric, drying and information carrier. However, this oil insulation will have its degradation or failure which can lead to the failure of transformer either immediately or over a period of time.

Figure 1.3: Active Part of Excitation Transformer

1.4 Transformer Insulation System

The transformer design, operation and maintenance depend on the transformer insulation system. As a result, proper designs of insulation system, insulation materials and the use of condition monitoring techniques to determine insulation condition are necessary. The above transformer insulating system consists of two primarily components which are liquid insulation and solid insulation.
1.4.1 Liquid Insulation

The main function of liquid insulation such as above oils is to protect the solid insulation because heat, water and oxygen in transformer insulation system can break down the function of solid insulation. Clean and dry oil will displace the oxygen and cools the solid and conductor. Second function of oil is to provide heat transfer as transformer cooling system. Oil has to flow into those areas inside the transformer where heat buildup and carry that heat to the outer shell where heat can be dissipated. Third function of oil insulation is to provide dielectric strength for insulation system of transformer. A combination of solid and liquid can provide increase in dielectric strength [2]. Lastly, the role of liquid or oil insulation is to provide means to monitor transformer condition and operation.

The liquid insulation is created from several types of oil such as:

- Natural or mineral oil
- Synthetic oil
- Vegetable oil

In the excitation transformers, mineral oil is used because it is composed of complex mixture of basic saturated hydrocarbon liquids. Mineral oil is classified into three which are paraffinic, naphthenic and aromatics. Naphthenic is the preferred oil which is mainly used for transformers in Malaysia as it is suitable with the country climate.

1.4.2 Solid Insulation

Solid material such as paper is mostly used as oil immersed transformer winding insulator. Press board cylinders are used to support and separate the winding from the core. Press board cylinders also support and separate the high voltage winding from the low voltage winding. Besides that, press board spacer support and separate each turn in the winding. The functions of these insulations which are paper and press board are to provide mechanical strength, dielectric strength and physical dielectric isolation. A
common solid or paper insulation used in transformer is Kraft paper. It is very important to monitor the life of paper insulation because it determines the life of transformer. Therefore early and prompt action if any signs of degradation are detected.
1.5 Problem Statement

Tanjung Bin Power Plant (TBPP) which is owned by Malakoff Corporation Berhad (MCB) is one of the largest Independent Power Producer (IPP) in Malaysia. TBPP produces 2100MW energy which is 10% from total national energy margin. This energy is supplied through Tenaga Nasional Berhad (TNB) into national grid and distributed to consumers all over the country. In this power plant, power transformers numbering around 27 unit transformer for TBPP assets. The excitation transformers are among the most expensive and the most important power transformers in TBPP electrical system.

Faults in transformer can cause extensive damage and can result in large revenue losses to power utilities like TBPP. One of the main factors of transformer failure is degradation of insulation system. The insulation system can deteriorate due to many operational stresses such as electrical, thermal, mechanical, environmental and chemical. Excitation transformers are continuously exposed to wide variety of abnormal conditions and faults. One example of uncharacteristic condition detected was increasing of fault gas which was Ethane, C\textsubscript{2}H\textsubscript{6} gas in oil insulation in all transformers. The limit is set by IEEE Standard C57.104 Guideline Dissolve Gas Analysis (DGA) Gas Limit at 65ppm.

The response to the fault condition as above is very crucial. Immediate actions were required to put these transformers in investigation mainly to determine their compliance with operational considerations set by TBPP. The investigations were the main method to verify the performance of components inside transformer that possible to be one of major root cause increasing of fault gas. The technique of investigation also must be practical and cost effective in diagnosing the signs of distress which exhibited by transformers.
1.6 Objectives

The aim of this project is to investigate the increasing trend of fault gas in excitation transformers oil insulation by Dissolved Gas Analysis (DGA). The other objectives of this research are:

- Evaluate and interpret DGA using Duval Triangle and Roger’s Ratio methods in order to find possible fault prediction
- Investigate the effect of replacing new transformer, effect of degasification method and close monitor sampling relate to fault gas trend
- Carry out electrical diagnostic tests to find out condition of electrical and mechanical property of transformer
- To produce a Transformer Health Index (THI) as an asset management tool for excitation transformer

1.7 Scopes of Study

Scopes of the project are mainly focused on the investigation of increasing fault gas in three unit of excitation transformer from Tanjung Bin Power Plant (TBPP). Further exploration of knowledge in high voltage, and power quality engineering will be extensively used in this project. Specifically, these are the scopes that will be followed with in order to complete this project:

- Application of oil sampling technique and Dissolved Gas Analysis (DGA) to investigate the increasing fault gas
- Application of Duval and Roger’s Ratio Method to interpret DGA results
- Replace one unit of transformer with similar specification
- Application of degasification method on selected transformer
- Trending of fault gas level by close monitor sampling on one transformer
- Application of electrical routine test as diagnostics test on one unit
- Using readily available parameters and weighting factors are adjusted based on current practice of TBPP to set up Transformer Health Index (THI) for an
excitation transformers
CHAPTER 2

LITERATURE REVIEW

This chapter will discuss briefly about the theory and research from other researchers related to the project.

2.1 Degradation of Solid Insulation in Transformer

Transformer solid or paper insulation system using cellulose impregnated with mineral oils has provided a high degree of reliability [5]. However, early faults in this insulation system can occur under certain operating conditions and the paper insulation system can break down. An example of such fault is electric load losses in the transformer which can cause thermal stress in the active part. This leads to aging and decomposition of both liquid and solid insulation material, oil and cellulosics. In the case of oil immersed transformers, when sufficient energy dissipated by faults is applied to solid insulation such as cellulosic paper or press board, the polymerized glucose molecules which form cellulose will break up into smaller chains. Depending on the level of fault energy, various bonds are broken forming different kinds of molecules. Combustible and non-combustible gases are generated in the process of recombining of formed molecules and
are dissolved into oil. In general, the hydrocarbon gases such as Hydrogen (H₂), Oxygen (O₂), Nitrogen (N₂), Methane (CH₄), Carbon Monoxide (CO), Carbon Dioxide (CO₂), Ethylene (C₂H₄), Ethane (C₂H₆), and Acetylene (C₂H₂) are formed in oil when faults are occurred in transformer.

Since the average number of glucose molecules in each cellulose cluster is determined by the degree of polymerization (DP), therefore the value of DP also can be an indicator for the mechanical stability of Kraft paper insulation. Recent publication shows that, the ageing process depends on the transformer's operation temperature and is accelerated by the presence of moisture and acids in the insulation system [6]. During the decomposition reaction of cellulose chains furanic compounds and water is generated. Aging of solid insulation is always in combination with degradation of transformer oil. Oxidation is the predominant mechanism leading to formation of carboxylic acids in oil.

2.2 Degradation of Liquid Insulation in Transformer

Early detection of liquid or oil insulation system degradation of can be detected in the transformers and later can be verified to have an abnormality when some kind of hydrocarbon gases are generated at above limit rate due to aging. At initial stages of operation, it is normal for a transformer to have a large amount of CO and H₂ trace. Transformer is not determined to have a problem but still have to be put under continuous monitoring. Combustible gases such as, C₂H₂ and C₂H₄ are the characteristic gases which would be generated by arc discharge and thermal decomposition with high temperature [7]. If the trace of them is in large quantity or increasing rate, the transformers are subjected to a follow-up analysis so that diagnosis of the type and degree of internal abnormality can be compared with other gases. It can be conclude that analysis of the insulating oil components is an effective means of evaluating aging degradation. Below Figure 2.1 is explaining the fundamental process of fault gas formation in transformer oil.
Mineral transformer oils are mixtures of many different hydrocarbon molecules. During the thermal and electrical faults, a complex decomposition of these molecules will take place. First, carbon–hydrogen and carbon–carbon bonds are broken. Then, active hydrogen atoms and hydrocarbon fragments are formed. These free radicals can combine with each other to form gases, molecular H₂, CH₄, C₂H₆, etc., or they can recombine to form new, condensable molecules [3]. Finally, further decomposition and rearrangement processes lead to the formation of products such as C₂H₂ and C₂H₄.

2.3 Evaluation of Possible Fault by Dissolved Gas Analysis (DGA)

Dissolved Gas Analysis is a powerful tool to diagnose transformer condition. Remaining life of the oil-immersed transformer is decided due to deterioration of the insulation paper. The DGA method which is based on routine oil sampling is commonly used to estimate the insulation paper deterioration status condition. It is proven by other researchers that DGA by gas chromatography can predict catastrophic failures in transformers such as arcing, corona, overheated oil, and cellulose degradation [8]. These problems result in gas production as they start to develop and gas production increases with increasing severity of the problem. Some internal fault can be depicted with the amount of generated gases or the ratio of some generated gases. These gases have some characteristic gas composition patterns and gas levels according to fault energy and the characteristics are used in DGA for transformer diagnosis.
There are many approaches developed for analyzing these gases and interpreting their significance include Key Gas, Dornenburg Ratio, Rogers Ratio, IEC Ratio, and Duval Triangle. There are recent studies to compare the efficiency of these DGA methods. Some studies show that the Duval Triangle method is the most consistent method followed by the Roger Ratio [9]. It is also mandatory to some methods to take into account the limit value of fault gases before doing diagnosis. As a result, there will be better success and consistency result in predicting the normal condition and methods rather than have no limit value of faults gases always fail to predict the normal condition.

**2.3.1 Duval Triangle: A Noble Approach for DGA Datasets**

This method was developed by Dr. Michel Duval, by using the database belonging to thousands of transformers and spanning many years. This method also has proven to be accurate and dependable over many years and is now gaining in popularity. The Duval Triangle in Figure 2.2 provides a graphical method of identifying a fault. It uses a three-axis coordinate system, where concentrations of CH₄, C₂H₄ and C₂H₂ are used as coordinates. By plotting the relative percentages of CH₄, C₂H₄ and C₂H₂ the coordinate system, a graphical output of the likely cause of gassing is generated. The cause of the fault is then determined based on the concentration percentages of combustible gases evolved. Most likely fault falls within one of the fault regions of the triangle [10]. The Triangle coordinates corresponding to DGA results in ppm can be calculated as follows:

\[
\%\text{C}_2\text{H}_2 = \left[\frac{\text{C}_2\text{H}_2}{(\text{C}_2\text{H}_2 + \text{C}_2\text{H}_4 + \text{CH}_4)}\right] \times 100
\]  (2.1)

\[
\%\text{C}_2\text{H}_4 = \left[\frac{\text{C}_2\text{H}_4}{(\text{C}_2\text{H}_2 + \text{C}_2\text{H}_4 + \text{CH}_4)}\right] \times 100
\]  (2.2)

\[
\%\text{CH}_4 = \left[\frac{\text{CH}_4}{(\text{C}_2\text{H}_2 + \text{C}_2\text{H}_4 + \text{CH}_4)}\right] \times 100
\]  (2.3)

Where, CH₄ = Methane, C₂H₄ = Ethylene, C₂H₆ = Ethane, and C₂H₂ = Acetylene
However, it is recommended to use Duval method after the confirming the existence of a problem in the transformer by the presence of hydrocarbon gases and their rate of evolution. One advantage of using the Duval Triangle is that it always provides a diagnosis. There will always be a point within the triangle for known concentrations of CH₄, C₂H₄ and C₂H₂. The drawback with the Duval Triangle method is, sometimes wrong diagnosis may occur when data is in proximity to a boundary [11].

Nowadays, there are many implementations of Duval Triangle method were done by researchers and utilities and they are interested in visualising the DGA results using software programs. These programs such as Java language, C#, MATLAB, and Microsoft Excel are used because of their growing importance in modern application development. These programs are developed based on theories and practices of insulation assessment techniques of oil-filled power transformers. The particles per molecule (ppm) values of recorded gasses from the transformer are used as the input variables. In this project, Duval Triangle will be plotted using Microsoft Excel program. As a result, the accuracy and prediction result between each method has increased the fault-analysis classification of these DGA methods by up to 20% [12].
The various regions within the triangle are given in Table 2.1

**Figure 2.2: Duval Triangle [10]**

<table>
<thead>
<tr>
<th>Region</th>
<th>Fault</th>
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<tbody>
<tr>
<td>D1</td>
<td>Discharges of low energy</td>
</tr>
<tr>
<td>D2</td>
<td>Discharges of high energy</td>
</tr>
<tr>
<td>T1</td>
<td>Thermal fault, $t &lt; 300$ °C</td>
</tr>
<tr>
<td>T2</td>
<td>Thermal fault, $300$ °C $&lt; t &lt; 700$ °C</td>
</tr>
</tbody>
</table>
2.3.2 Roger’s Ratio Method as a Proper DGA Interpretation

Roger’s Ratio Method provides a scheme to determine faults based upon the relative gas concentrations of hydrogen (H$_2$), methane (CH$_4$), Ethylene (C$_2$H$_4$), Ethane (C$_2$H$_6$), and Acetylene (C$_2$H$_2$). It will identify a pair of gasses and developed a coding system to help define potential fault condition. Gas ratios calculated from gas concentrations are used in the diagnosis of the fault. The ratios used are; C$_2$H$_2$/CH$_4$, CH$_4$/H$_2$, C$_2$H$_4$/C$_2$H$_6$ and C$_2$H$_6$/CH$_4$. Table 2.2 shows how the fault classification is done base on gas ratio. The Roger’s method does not depend on specific gas concentrations to exist in the transformer for the diagnosis to be valid.

The validity of this method is based on correlation of the results of a much larger number of failure investigations with the gas analysis for each case [13]. However, some ratio values are inconsistent with the diagnostic codes assigned to various faults in this method. Also, since the method does not consider dissolved gases below normal concentration values, a precise implementation of the method may still misinterpret data. Unlike with other diagnostic techniques this method also gives typical gas ratios when the unit is in normal operation. The major drawback with this method is certain values of ratios can fall outside the ranges given in Table 2.2, and therefore, the fault could be indeterminate.
Table 2.2: Roger’s Ratio Code and Characteristics [12]

<table>
<thead>
<tr>
<th>Code of Range of Ratio</th>
<th>Ratios of Characteristic Gases</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₂H₆/ C₂H₄</td>
<td>CH₄/ H₂</td>
</tr>
<tr>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

**Characteristics Faults**

- 0 0 0 0: Unit normal
- 0 5 0 0: Partial discharge of low energy density arcing
- 1 5 0 0: Partial discharge of high energy discharge arcing
- 0 5 1 0: Coincidental partial discharges and conductor overheating
- 0 5 0 1: Partial discharge of increasing energy density
- 1 to 2 0 0 0: Low energy discharges; flashover without power follow through
- 1 to 2 0 1 0: Low energy discharges; arc with power follow through
- 1 to 2 0 2 0: High energy discharges; arc with power follow through
- 0 0 1 0: Insulated conductor overheating
- 0 0 1 1: Complex thermal hotspot and conductor overheating
- 1 0 0 1: Coincidental thermal hotspot and low energy discharge
- 1 1 0 0: Thermal fault of low temperature range < 150°C
- 0 1 0 0: Thermal fault of temperature range 100-200°C
- 0 0-2 0 1: Thermal fault of low temperature range 150 - 300°C; overheating of copper due to eddy current
- 0 1 1 0: Thermal fault of low temperature range 300 - 700°C; bad contact/joints; core and tank circulating current
2.3.3 Comparison of DGA Interpretation Methods

Using multiple DGA methods to analyze transformer faults might obtain different fault interpretations. Therefore, optimizing the combination of various diagnostic techniques is an important issue. Besides that, many uncertainties can exist in gas data because of gas generating processes in oil, gas sampling processes and in chromatographic analysis in a laboratory. Moreover, varied patterns and amounts of gases are generated due to different intensities of energy dissipated by different faults, which are affected by many factors, including oil type, oil temperature, sampling method, insulation characteristics and environmental effects. Even under normal conditions, misjudgement may result from unscheduled operations such as oil-tank welding and the electric charge carried by the oil-flow.

As a result, comparing the fault interpretation by DGA methods is very useful to determine which techniques are giving accuracy and consistency. Some of the DGA diagnosis techniques are using simple calculation and effective for diagnosing severe faults. For example, Duval Triangle and Roger’s Ratio methods are rely on expert analyses, which could be insensitive to slowly developing and insignificant faults. Many studies were done to evaluate the accuracy of each method in predicting the fault and the consistency of each method. In addition to, it is important to compare because it was found that those methods that take into account the limit value of fault gases before doing diagnosis have better success in predicting the normal condition and methods that have no limit value of faults gases always fail to predict the normal condition [17].
2.4 Oil Sampling as a Transformer Condition Based Maintenance (CBM)

As the entire energized and high temperature transformer components such as windings are immersed in the transformer oil, the transformer oil is a key source to detect incipient faults, fast developing faults, insulation trending and generally reflects the health condition of the transformer [13]. Oil sampling contributes very important rules in Condition Based Maintenance (CBM) of transformer oil insulating healthiness. The sample is used to determine the condition of oil insulation, to determine the operating condition of the transformer, to check the condition of oil in storage whether it is new or used and also to ensure the oil retains its characteristics during its operating life. Once the sample is retrieved, it will be stored no longer than a few days before sending it to laboratory for analysis. A typical oil sample test result will immediately apparent if major problems are imminent and urgent action needs to be taken.

In order to determine the condition of the oil insulation the standard of for sampling insulating liquids must be followed as the quality of test result are very much influenced by the quality of oil sample. The standard used in this study is ASTM D 923: Standards Practice for Sampling Electrical Insulating Liquids which is discussed with more detail in Chapter 3. This standard focuses on getting representative samples without loss of dissolved gases or exposure to air. It is also important that the quantity and composition of dissolved gases remain unchanged during transport to the laboratory. It is also instructed to avoid prolonged exposure to light by immediately placing drawn samples into light-proof containers and retaining them there until the start of testing [14]. In order to maintain the integrity of the sample, the time between sampling and testing is kept as short as possible.
2.5 Transformer Diagnostic Using Electrical Routine Tests

The purpose of this test is the extent investigation on transformer after the DGA result requires further electrical test to be carried. This test should follow the standards that are practised internationally as below:


2.5.1 Dielectric Dissipation Factor Measurement

Field dielectric tests may be warranted on the basis of detection of combustible gas. Measurement of the dissipation power factor is to evaluate the overall condition of the insulation system and to measure the fundamental AC electrical characteristics of insulation. This electrical test is able to indicate the aging of transformer winding, water content in oil and paper insulation and contamination by particles.

2.5.2 Excitation Current Measurement

Excitation current measurement provides means of detection of extensive core problems, like shorted lamination or winding problems, partial or high resistance short circuit between winding turns, poor joints or contacts, etc. Excitation current tests also may be used to locate certain types of faults in a transformer, such as a defect in the magnetic core structure or an insulation failure which has resulted in a conducting path between winding turns.
2.5.3 Turn Ratio Measurement

The main objective of this test is to determine the turn ratio of transformer. It is also capable to measure the number of turns of the primarily winding with respect to the number of turns in secondary winding. The benefit of having this test is to verify the transformer meets the design specification, errors in turn count can be identified and any short circuit turns can be known.

2.5.4 Winding Resistance Measurement

The main objective of this test is to establish the copper losses in the winding varying with load. Another purpose of this measurement is to verify the continuity, connection and the ohm value of transformer winding. Another importance of this measurement is as a diagnostic tool for assessing possible damage. As a diagnostic tool, winding resistance result can show any damage to the transformer, to determine if it is safe to re-energize, to determine if corrective action is required and to establish priority of corrective action.

2.5.5 Insulation Resistance Measurement

Measurement of the transformer insulation resistance is performed between high voltage winding and low voltage/earth winding respect to earth. This test is used as a quality control measure at the time of transformer is produced. It is also applied to ensure the specifications of transformer are met. In power plant, insulation resistance is applied as preventive maintenance and a troubleshooting tool.
2.5.6 Magnetic Balance Measurement

This test determines the failure of core ground, winding faults whether they are short circuit or open circuit, and to detect any defect in magnetic core structure. Measurements are performed by applying a 240VAC voltage at one phase and measuring the output voltage at the other two phases. The sum of output voltage at the other two phases must be equal or approximately same on the injected phase.

2.6 Transformer Health Index (THI) as an Asset Management Tool

Transformer Health Index (THI) is useful for economic and technical justifications for engineering decisions and capital replacement plans on transformers. As a result, maximum balance among capital investments, asset maintenance costs, and operating performance can be achieved [22]. The Health Index (HI) represents a practical tool that combines the results of operating observations, field inspections, and site and laboratory testing into an objective and quantitative index, providing the overall health of the asset.

Several studies have been done to analyze the different power transformer condition assessment and life-management techniques. These techniques include measuring or monitoring of dissolved gas, oil or conductor temperature, moisture or water content, oil quality (dielectric strength, acidity, colour, and interfacial tension, and partial discharge), frequency response analysis, recovery voltage method, and thermal imaging [22]. Such tests are conducted on a routine or condition basis to evaluate the condition of power transformers. However, no method is available to quantify the condition of the asset through combining all available data. This research uses a practical asset THI calculation method that combines the impact of all available data and also utilizes criteria based on the TBPP common practices.
CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains in detail the materials, data gathering, data interpretation, and procedures that involved in project investigation. The main materials in this research are three units of similar excitation transformers and their insulation oil sample. The detail of transformer is shown in Table 3.1 below. The data gatherings involved were oil insulation sampling, and Dissolved Gas Analysis (DGA) by laboratory experimental. Then, the collected DGA data were interpreted using Duval Triangle and Roger’s Ratio methods to predict possible type of fault. After that, driven by fault prediction given by above two methods, there were some procedures were performed on each transformer respectively which were transformer replacement, degasification, and high frequency of DGA monitoring. These procedures were part of investigation methods to mitigate the increasing C₂H₆ gas and the summary of type of procedures which were carried out on which transformer is shown in Table 3.2 below. Field electrical diagnostic tests were done as a verification of electrical and mechanical properties of transformer are still in good condition or vice versa.
Table 3.1: Excitation Transformer Specification

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Toshiba, Japan</td>
</tr>
<tr>
<td>Type/Function</td>
<td>Excitation Transformer</td>
</tr>
<tr>
<td>Date Manufactured</td>
<td>2005</td>
</tr>
<tr>
<td>Capacity</td>
<td>9900 kVA</td>
</tr>
<tr>
<td>Primary</td>
<td>26000 V</td>
</tr>
<tr>
<td>Secondary</td>
<td>1140 V</td>
</tr>
<tr>
<td>Weight</td>
<td>2700 kg</td>
</tr>
<tr>
<td>Trans Class</td>
<td>ONAN</td>
</tr>
<tr>
<td>Impedance</td>
<td>15.7%</td>
</tr>
<tr>
<td>Liquid Type</td>
<td>Oil</td>
</tr>
<tr>
<td>Oil Capacity</td>
<td>8800 liter</td>
</tr>
</tbody>
</table>

Table 3.2: Types of Mitigation and Verification Methods

<table>
<thead>
<tr>
<th>Transformer</th>
<th>Replacement</th>
<th>Degasification</th>
<th>High Frequency DGA Monitoring</th>
<th>Electrical Diagnostic Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td>√</td>
</tr>
</tbody>
</table>

The activities as mentioned above are the common methodology included in Condition Base Maintenance (CBM) for transformer. This methodology is necessary for power utilities like TBPP to reduce the maintenance cost and to reduce the risk of premature failure. It can also offer an improved approach to change the maintenance strategy and the strategy can avoid the disadvantage of the regular overhaul in excess or shortage condition. In addition to, this methodology can be a tool for fault investigation.
REFERENCES


Japan: Toshiba Corporation.

