UNIVERSITI TEKNIKAL MALAYSIA MELAKA

FACULTY OF ELECTRICAL ENGINEERING

IMPROVEMENT OF DISSOLVED GAS ANALYSIS USING ARTIFICIAL INTELLIGENCE APPROACH

This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka(UTeM) for the Bachelor of in Electrical Engineering (Power Industry) with Honours.

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DECLARATION OF AUTHORSHIP

"I hereby declare that I have read through this report entitled "Improvement Of Dissolved Gas Analysis Using Artificial Intelligence Approach" and found that it has complete partial fulfilment for awarding the Bachelor of Electrical Engineering"

Signature : …………………………………….

Supervisor's Name : …………………………………….

Date : …………………………………….

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ABSTRACT

This project is to design a robust and reliable intelligent diagnostic method to detect and predict incipient faults in transformer. Transformer is one of the most important components in the power system network. Major fault in these transformers can cause extensive damage which is not only disturbing other features electricity supply, instead causing huge losses. In the transformer, insulation material and faulty equipment will result in the release of gas, hence can be attributed to some kind of electrical fault such as corona, pyrolysis and arcing. The resulting gas generation rate can indicate the severity of the offence and the information obtained can be very beneficial in any preventive maintenance program. By using any of the preventive maintenance programs, the identity of gas is very useful to determine that faults. The key gas considerations for evaluation are hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), carbon monoxide (CO) and carbon dioxide (CO_2). Thus, interpretation of dissolved gas analysis (DGA) is used as the preventive maintenace program to detect the incipient faults. To study in DGA related to incipient fault inside power transformer, several interpretation methods for DGA will be discussed. The interpretation methods are Key Gas Method (KGM), Doernenburg Ratio Method (DRM), Rogers Ratio Method (RRM), IEC Ratio Method (IRM) and Duval Triangle Method (DTM). In order to automate this program, the technique of artificial inteligence by using MATLAB software is developed in this study. Artificial intelligence method is selected because of its ability in storing knowledge and their functions to make decision.

ABSTRAK

Projek ini adalah untuk merekabentuk kaedah diagnostik yang pintar dan boleh dipercayai untuk mengesan dan meramal kesalahan awal pada pengubah. Pengubah adalah salah satu komponen yang paling penting dalam rangkaian sistem kuasa. Kesalahan utama pada pengubah boleh menyebabkan kerosakan besar yang bukan sahaja menganggu sumber bekalan elektrik, bahkan boleh menyebabkan kerugian yang sangat besar. Dalam pengubah, bahan penebat dan peralatan yang rosak akan menyebabkan pembebasan gas. Oleh itu ia boleh berkait dengan beberapa jenis kerosakan elektrik seperti 'corona', 'pyrolysis' dan 'arcing'. Kadar pembebasan gas boleh menunjukkan kesalahan pengubah dan melalui maklumat yang diperolehi menjadi sangat berguna untuk program penyelenggaraan pencegahan. Dengan menggunakan mana-mana program pencegahan, identiti gas adalah sangat berguna untuk menentukan kesalahan yang mungkin berlaku pada pengubah. Pertimbangan gas utama bagi penilaian adalah hydrogen (H_2), metana (CH_4), etana (C_2H_6), etilena (C_2H_4), asetilena (C_2H_2), karbon monoksida (CO) and karbon dioksida (CO_2). Oleh itu, tafsiran analisa gas terlarut (DGA) digunakan sebagai program penyelenggaraan pencegahan untuk mengesan kesalahan awal. Untuk mengkaji DGA yang berkaitan dengan kesalahan awal dalam pengubah, terdapat beberapa kaedah pentafsiran untuk DGA akan dibincangkan. Kaedah pentafsiran tersebut adalah Kaedah Gas Utama (KGM), Kaedah Doernenburg Ratio (DRM), Kaedah Rogers Ratio (RRM), Kaedah IEC Ratio (IRM) dan Kaedah Segitiga Duval (DTM). Dalam usaha untuk mengautomasikan program ini, teknik 'artificial intelligence' dengan menggunakan perisian MATLAB dipilih disebabkan keupayaannya dalam menyimpan maklumat dan keupayaan membuat keputusan.

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LIST OF ABBREVIATIONS

DGA	-	Dissolved Gas Analysis
AI	-	Artificial Intelligence
KGM	-	Key Gas Method
DRM	-	Doernenburg Ratio Method
RRM	-	Rogers Ratio Method
IRM	-	IEC Ratio Method
DTM	-	Duval Triangle Method

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Power transformer is one of the most essential equipment in electrical utilization and distribution system. The function of power transformer is transferring, step up and step down voltage, and isolating an electrical power. Besides that, power transformer are very essential and one of the highest cost equipment used in the power distribution and transmission of electricity. Despite of incredible advances in electrical system design recently, the poor connection in the chamber of insulation system still remain. Normally after the transformers operate for few years, it will be slowly degraded and stress during abnormal condition such as short-circuit current and overloading current that failure may occurred. This failures of power transformer will be very dangerous that can cause to firing, explosion and others.

The fault can be detected at defective insulation when the transformer fail to operate effectively [1-2]. Unexpected failure can makes significant disturbances to operating system, bringing to power delivery problems and unstable output. It may lead to high cost repairing the damage, long time to maintain and possible personal safety risk. Transformer failure can cost up to million ringgit of Malaysia. Therefore, it is important to monitor the life of every transformer to know the execution and situation of transformer. The condition of every transformer can be maintained operate efficiently if it is possible to have an early fault detection.

Furthermore, environmental factors such as fire, pollution and consequential damages are also can affect the performance of the transformer. Therefore early detection of problems can reduce the repairing cost up to 75% and saving 2% of the price of new transformer. The total estimated cost can be save is about $40,000 up to $80,000 if the early detection can be make [3]. The faults can be indentified early by using artificial intelligence technique. Thus, observation on the condition of oil must be assemble before it become serious failures and outages. The investigation of transformer oils will gives more data about the condition of oil and it allows the identification of other potential faults such arcing, partial discharge and thermal faults.

Therefore, it is absolutely vital to monitor the life of power transformer and it should be provided an appropiate techniques to keep its accessibility and dependability in operation. In order to maintain the health of power transformer, maintenance activities are vital. Dissolved Gas Analysis method measure the concentration of gases that released due to thermal, mechanical stress, electrical stress and chemical stress. This method used to detect fault which is very important to know the condition of power transformers.

1.2 Project Motivation

Artificial intelligence has been utilized in electrical field for many years. Artificial Intelligence also can be used in detecting incipient fault diagnosis and condition assessment of power equipment. Therefore, interpretation method for DGA using artificial intelligence techniques can help to produce accurate and precise data.

Fuzzy logic method had been used for many years in electrical fields such as interpretation of data, decision making, image and diagnostic of fault. Basically the theory of fuzzy logic is about in solving problems and using linguistic interpretation method. There are several benefits using fuzzy logic which is exhibits the idea of how human can think wisely and helping in decision making or consideration using linguistic interpretation. Moreover, the directions, control standards and systems, techniques in view of the acknowledgment, experience and suggestion of a human master were encoded in huge way to avoid scientific demonstrating issues.

1.3 Problem Statement

Power transformer is one of the most important apparatus in an power distribution and utilization in electricity. In this modern era, there are more than one thousand power transformers that have been used in Malaysia and it have been conducted by Tenaga Nasional Berhad (TNB). This condition need to be control and maintain because power transformers are very highly cost. The failure in these power transformers will be very serious that may lead to the damage of the power supply to industries. Therefore, in order to know early fault detection in this power transformer maintain techniques are presented.

Over the years, there are a few Dissolved Gas Analysis (DGA) techniques applied and proposed for fault detection in transformer abnormal behavior. Basically, these existing techniques such as Key Gas Method (KGM), Rogers Ratio Method (RRM), Duval Triangle Method (DTM), Doernenburg Ratio Method (DRM) and IEC Ratio Method that have been developed based on empirical experience and knowledge assembled by specialists throughout the world [4].

For example, Key Gas Method (KGM) considers one of the highest main concentration of gases that exist during fault. Based on facts from IEC data bank of inspected transformers states that only 42% of the diagnosis using KGM is precise, while the rest is misinterpretation [5]. Meanwhile Duval Triangle Method (DVM) provides better result compare to others according to some papers [6]. Nevertheless, some individuals are not expert on how to analyze the data by using the triangle coordinates. Therefore, inconsiderate implementation prompts to wrong findings. Furthermore DVM does not incorporate ordinary zone so that it cannot be utilized to recognize incipient faults. [7].

In order to overcome this problem, artificial intelligence method will be develop to overcome this problem. The purpose of designing new method using Artificial Intelligence technique is to perform precise and accurate result for fault detection in transformer abnormal behavior. This method also can be used to detect incipient fault which is before it already happen. Besides that, this technique also can use for SF6 gas analysis [8]. Furthermore, this method is easy to use and suitable for all because the method is simple.

1.4 Objectives

There are several objective that highlighted in this project which is

- To analyze the performance of existing method for DGA.
- To develop a model using artificial intelligence approach for DGA by using MATLAB.
- To analyze the performance of artificial intelligence method for DGA and compare the accuracy between existing method and artificial intelligence approach.

1.5 Scope of Work

This project is conducted to develop an artificial intelligence approach for DGA in order to increase the accuracy and consistency of the result obtain. Hence, in order to get successful result of this project the appropriate technique and procedure used during analysis of the project plays a significant role in order to get successful result of this project. Therefore, the scope of this project from the beginning is using 50 historical data provided from TNB or obtain from previous journal. From the data collected, understand and analyse the result using the existing method that have been used for DGA over the years. Develop an artificial intelligence approach by using the MATLAB and compare the accuracy and consistency of the results between existing method and artificial intelligence approach.

1.6 Final Year Project Outline

This report contain five chapters Chapter 1 will explain about the background of this project, project motivation, scope of work, objectives of this project and problem statement. Chapter two discusses the literature review that had been done by previous research related to basic interpretation method for Dissolved Gas Analysis (DGA). Chapter 3 describes the methodology of the project starting from obtain 50 historical data from previous journal or get from TNB until the procedure to design artificial intelligence method for DGA using MATLAB. Chapter four explains about the comparison of the result between artificial intelligence method and existing method for DGA. Chapter five is the conclusions that have been made and some recommendation on how to improve this technique in future.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Dissolved Gas Analysis (DGA) method has been generally utilized for nearly thirty years to analyze the operating condition of the power transformer. This techniques is rely on the type and amount of concentrated gases in transformer oil due to oxidation or decomposition of cellulose and insulation oil. Despite of incredible advances in electrical system design recently, the poor connection in the chamber of insulation system still remain. Unexpected failure can makes significant disturbances to operating system, bringing to power delivery problems and unstable output. It may lead to high cost repairing the damage, long time to maintain and possible personal safety risk. Transformer failure can cost up to million ringgit of Malaysia. Therefore, it is important to monitor the life of every transformer to know an execution and the situation of transformer. The condition of every transformer can be maintained operate efficiently if it is possible to have an early fault detection.

Dissolved Gas Analysis (DGA) method measures the concentration of gases such hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), carbon monoxide (CO) and carbon dioxide (CO_2). This gases are deliver due to the thermal degradation and electrical anxieties that dielectric insulation of operating transformers experience, paper and oil decomposition occurs evolving gases that dissolve in insulation oil and reduces it dielectric strength [9]. There are several faults that always occurs which is thermal fault, partial discharge and arcing. Every faults produce different types and concentration of gases which can be used for fault quantification and identification. Despite of the way that DGA has been utilized for quite a few years and is a typical diagnostic technique for transformers, there are no universal technique accepted for interpreting DGA results.

There are several DGA methods widely being utilized to examine the gas concentration in transformer insulating oil such as Key Gas Method (KGM), Rogers Ratio Method (RRM), Duval Triangle Method (DTM), Doernenburg Ratio Method (DRM) and IEC Ratio Method. This technique can detect fault in transformer such as overheating, arcing, partial discharge (PD) and thermal stress which could lead to transformer failure and outage. However, the result of each method are not consistent and inaccurate. Sometimes different method produce different result. Therefore, DGA using artificial intelligence techniques can help to produce accurate and precise data. Artificial Intelligence technique can be divided into two method which is fuzzy logic theory and neural network.

Fuzzy logic method had been used for many years in electrical fields such as interpretation of data, decision making, image and diagnostic of fault. Basically the theory of fuzzy logic is about in solving problems and using linguistic interpretation method. There are several benefits using fuzzy logic which is exhibits the idea of how human can think wisely and helping in decision making or consideration using linguistic interpretation. Moreover, the directions, control standards and systems, techniques in view of the acknowledgment, experience and suggestion of a human master were encoded in huge way to avoid scientific demonstrating issues.

2.2 Key Gas Method (KGM)

The basic operation for Key Gas Method (KGM) is based on the amount of fault gases discharged from the insulating oil when a fault happens due to the rising of temperature in the power transformer. Based on the facts stated by IEEE guide, Key gasses are characterized as gases that produced in oil-filled transformer that can be utilized for qualitative determination of fault types. The rising of the temperature in the power transformer will produce higher energy that will break the bonding of chemical structure of insulating oil which is the fault gases is released [6].

Based on the facts stated by IEEE guide, the gases that produced in oil-filled transformer that can be utilized for qualitative determination of fault types. KGM uses the higher individual gas instead of using proportions of gases for detecting fault. There are several type of faults occur due to electrical and thermal stresses such as arcing, partial discharge, overheating in oil and overheating in cellulose. There are several type of gases produce during degradation of insulation. The gases are hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), carbon monoxide (CO) and carbon dioxide (CO_2) [10] [11].

The standard of IEEE Std C57.104-1991 in figure 1 shows that the key gases and their relation between four fault types. Thermal decomposition of oil created over 60% of ethylene (C_2H_4) while thermal decomposition of cellulose deliver 90% of carbon dioxide (CO_2). Meanwhile, electrical fault due to partial discharge in oil produce 80% of hydrogen gas (H_2). Arcing produce 30% of acetylene (C_2H_2) and small amount of hydrogen gas (H_2) [4].

Table 2.1 : Types of fault for Key Gas Method [10]

Fault Types	**Gas Released**
Overheated oil	Methane, Ethylene, Ethane and Hydrogen
Overheated cellulose	Carbon monoxide and Carbon dioxide
Partial discharge	Methane, Hydrogen, Ethylene and Ethane
Arcing	Acetylene, Hydrogen and Carbon dioxide

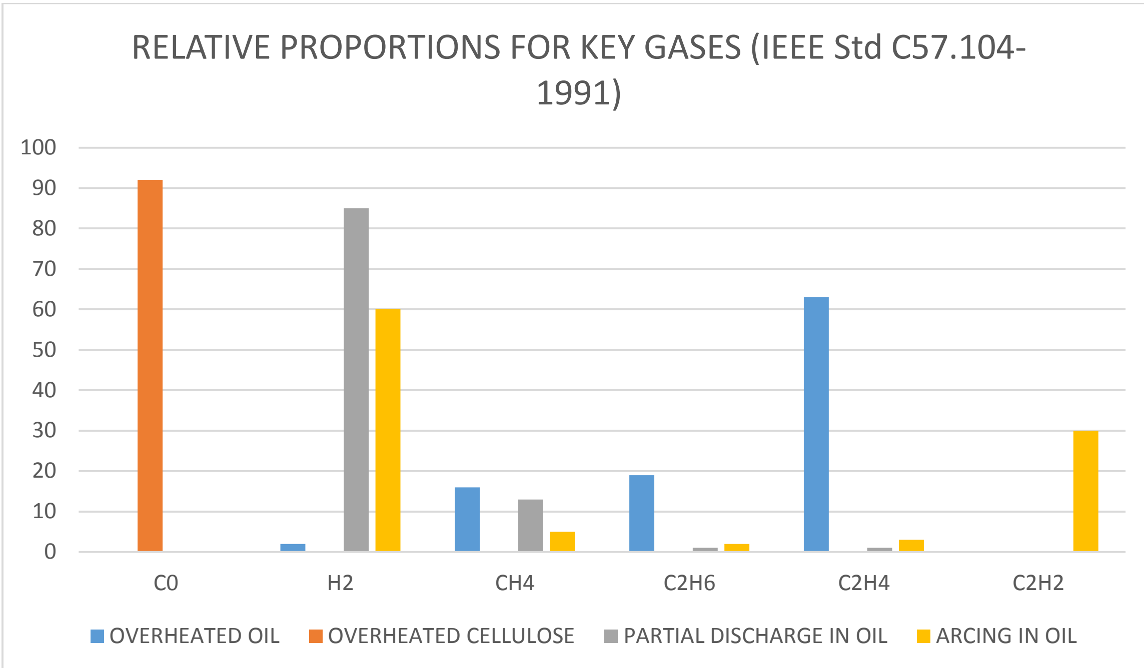

Figure 2.1 : Relative proportions for key gases (IEEE Std C57.104-1991) [11]

2.3 Doernenburg Ratio Method (DRM)

Doernenburg Ratio Method (DRM) is created due to thermal degradation principle in 1970 [13]. This technique measures the proportion of gas concentration to detect fault types. There are several type of faults occur due to thermal stress such partial discharge, arcing and thermal decomposition. When the fault happened, there are also several gases are released. The gases are hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2) [14].

There are four ratio of gases are set to determine the faults [14]. The ratios are

- Ratio 1 = CH_4 / H_2
- Ratio 2 = C_2H_2 / C_2H_4
- Ratio 3 = C_2H_6 / C_2H_2
- Ratio 4 = C_2H_2 / CH_4

The concentration of one of key gases in the four ratios stated above must surpass twice at least to determine correct result using DRM [15]. This method consider gas concentration limit (L1) to differentiate faults. The limit specification (L1) shows in table 1.

Table 2.2 : Limit Specification (L1) for Doernenburg Ratio Method [15]

Gas	**Concentration L1 (ppm)**
Hydrogen (H_2)	100
Methane (CH_4)	120
Carbon Monoxide (CO)	350
Acetylene (C_2H_2)	35
Ethylene (C_2H_4)	50
Ethane (C_2H_6)	65

2.4 Rogers Ratio Method (RRM)

Rogers Ratio Method (RRM) is the most common gas ratio used to detect fault compared to the Doernenburg Ratio Method (DRM) [13] [16]. RRM used to discover more thermal fault types. Fault are determined based on a simple range of ratio. This technique measures four conditions of an oil insulated transformer which are normal condition, partial discharge, arcing, thermal with low temperature, thermal less than 700°C and thermal exceeding 700°C [14]. There are several gases involved in RRM are hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2).

RRM is quite similar to DRM but with some modification and adjustment in order to improve the weakness of DRM [13]. There is some requirement for DRM in order to get the diagnostic fault to be valid while RRM can be utilized with any individual gases surpass its normal limit and does not rely on specific gas concentrations [15]. At first, RRM uses four ratio which is C_2H_6/CH_4, C_2H_2/C_2H_4, CH_4/H_2, and C_2H_4/C_2H_6 and have twelve diagnosis faults. This method provides more interpretation details based on temperature range for thermal faults. However, the ratio for C_2H_6/CH_4 can only trigger a limited temperature range of decomposition and do not assist in further identification [13] [17]. Therefore based on IEEE Standard C57.104-1991, RRM analysis is modified and the ratio for C_2H_6/CH_4 is excluded from RRM and the modified RRM perform only six diagnosis faults.

The new three ratio of gases are set to determine the faults. The ratios are

- Ratio 1 = CH_4 / H_2
- Ratio 2 = C_2H_2 / C_2H_4
- Ratio 5 = C_2H_4 / C_2H_6

RRM is consider more effective compared to DRM because it reflect more failure investigations with the gas analysis of each case. However, the result are inconsistent because it does not consider normal concentration below and lead to invalid codes.

2.5 IEC Ratio Method (IRM)

IEC Ratio Method (IRM) is quite similar to RRM because it use three similar ratio same with RRM. IRM was implemented in 1978 as a development of RRM [13]. The fault discover by IRM is quite similar from RRM but the thermal faults is more specific than RRM. There are several gases involved in IRM are hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2).

At first, IRM introduced nine type of faults with different temperatures ranges from partial discharge of low energy density up to thermal fault more than 700°C [13]. Then, IRM has been modified in IEC Publication 60599 from past publication IEC 599 [7]. Therefore, six type of faults that have been found in electrical equipment. The six faults that have been modified are partial discharge, discharges of low or high energy and thermal faults of temperature less than 300°C, temperature between 300°C to 700°C, or temperature more than 700°C [18].

The new three ratio of gases are set to determine the faults. The ratios are

- Ratio 1 = CH_4 / H_2
- Ratio 2 = C_2H_2 / C_2H_4
- Ratio 5 = C_2H_4 / C_2H_6

2.6 Duval Triangle Method (DTM)

Duval Triangle Method (DTM) was implement by Michel Duval [7]. It was created based on an innovation developed by IEC 60599 Ratio Method [7]. There are several gases involved in DTM which is methane (CH_4), acetylene (C_2H_2) and ethylene (C_2H_4). Concentration of gases for DTM which is methane (CH_4), acetylene (C_2H_2) and ethylene (C_2H_4) are expressed as percentage for total amount of gases. It is plotted as a point in a triangular coordinate system which have been divided into fault zones. The triangle represent with various type of faults which is:

- PD: Partial discharge
- Tl: Low-range thermal fault (below 300 °C)
- T2: Medium-range thermal fault (300-700 °C)
- T3: High-range thermal fault (above 700 °C)
- Dl: Low-energy electrical discharge
- D2: High-energy electrical discharge
- DT: Indeterminate - thermal fault or electrical discharge.

Duval Triangle Method (DVM) provides better result compare to others according to some papers [6]. However, many people are not familiar with the use of triangle coordinates. Therefore, inconsiderate implementation prompts to wrong findings. Furthermore DVM does not incorporate ordinary zone so that it cannot be utilized to recognize incipient faults. [7].

2.7 Summary

This chapter explains about basic interpretation method for DGA that have been used over many years which include the advantages and disadvantages of every method. Every method explain about type of faults involved and the gas involved.

Table 2.3 : Diagnosis suummary [5]

Type	Fault Types	Gases Involved
KGM	PD, Arcing, Overheated oil, Overheated cellulose.	Hydrogen (H_2), Methane (CH_4), Ethane (C_2H_6), Ethylene (C_2H_4), Acetylene (C_2H_2) and carbon dioxide (CO_2)
DRM	Thermal decomposition, PD, Arcing	Hydrogen (H_2), Methane (CH_4), Ethane (C_2H_6), Ethylene (C_2H_4), Acetylene (C_2H_2) and carbon dioxide (CO_2)
RRM	PD, Arcing, Low temperature, Thermal<700°C, and >700°C	Hydrogen (H_2), Methane (CH_4), Ethane (C_2H_6), Ethylene (C_2H_4), Acetylene (C_2H_2) and carbon dioxide (CO_2)
IRM	PD, Low energy discharge, High energy discharge, Thermal(T) fault T<300°C , 300<T<700°C, and T>700°C	Hydrogen (H_2), Methane (CH_4), Ethane (C_2H_6), Ethylene (C_2H_4), Acetylene (C_2H_2) and carbon dioxide (CO_2)