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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Firstly, I would like to offer my gratitude to Allah S.W.T for the mercy and grace, I finally able to complete a report for the Final Year Project (FYP) based on the specified 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

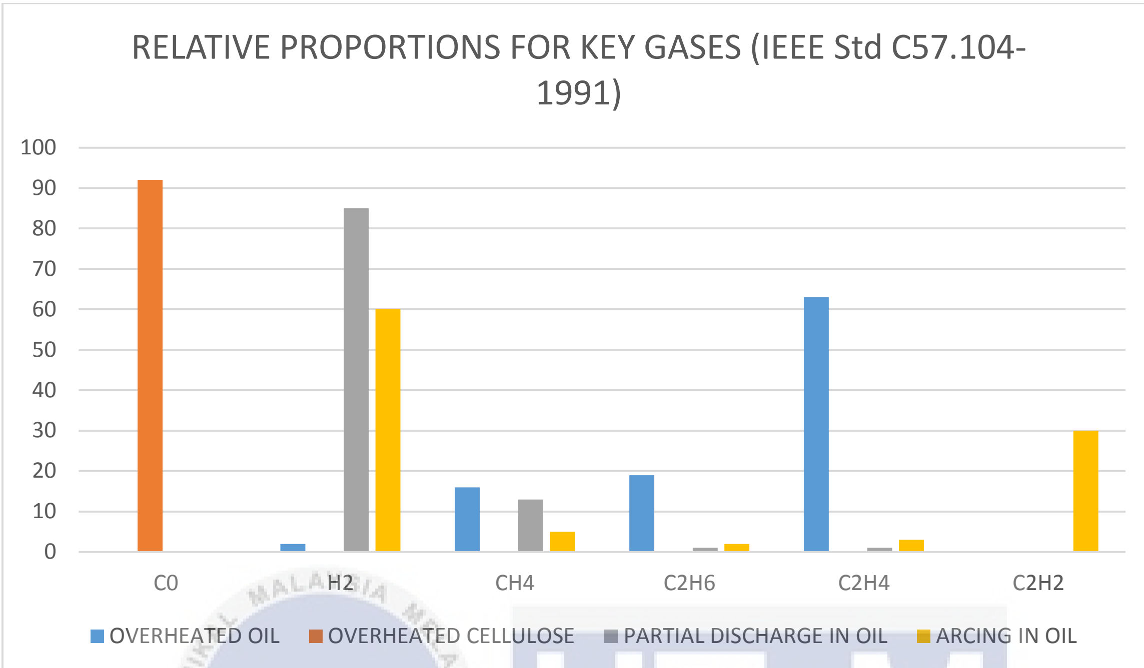


Figure 2.1 : Relative proportions for key gases (IEEE Std C57.104-1991) [11]

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)

DTM	PD, Low energy discharge, High energy discharge, Thermal fault <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)
AI	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)

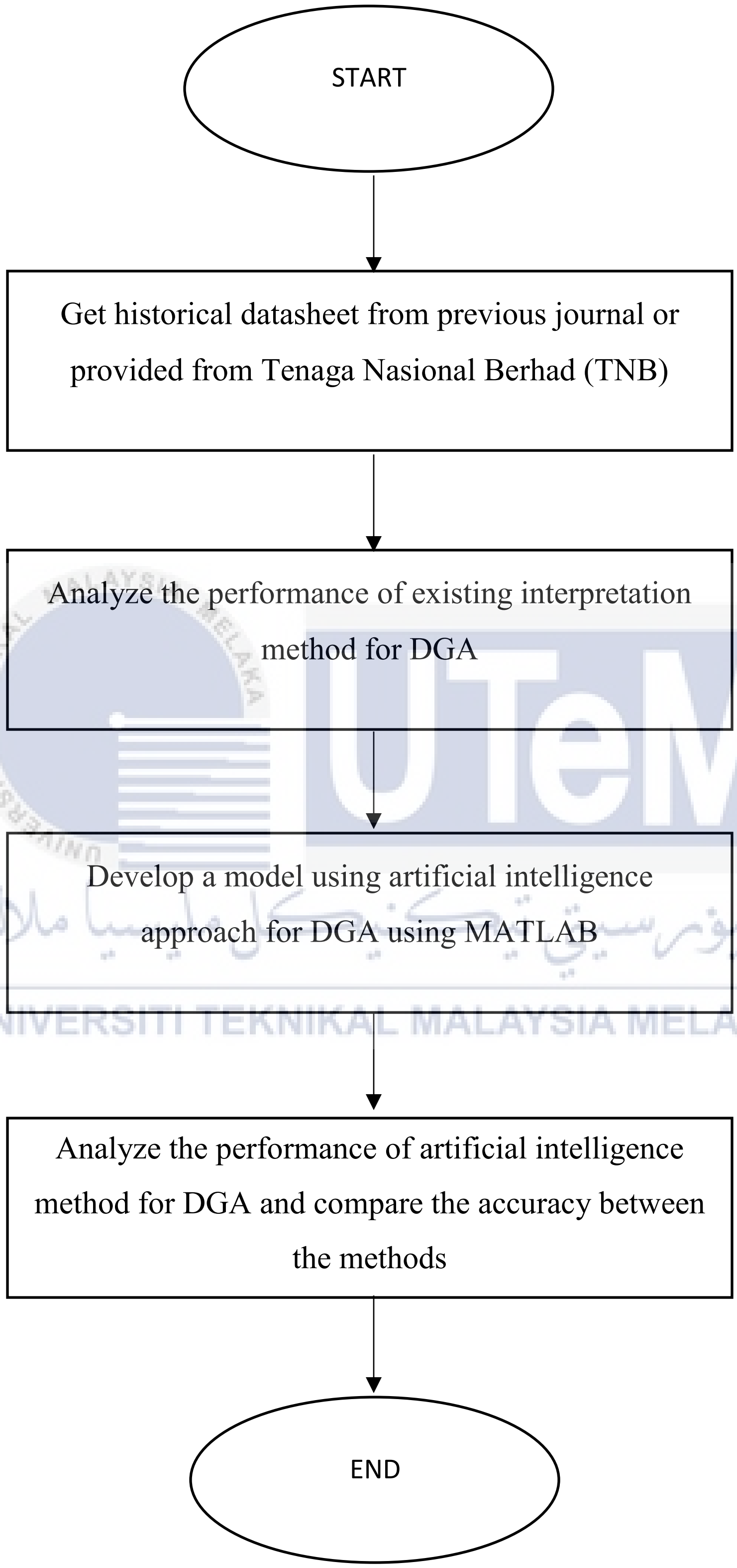
CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

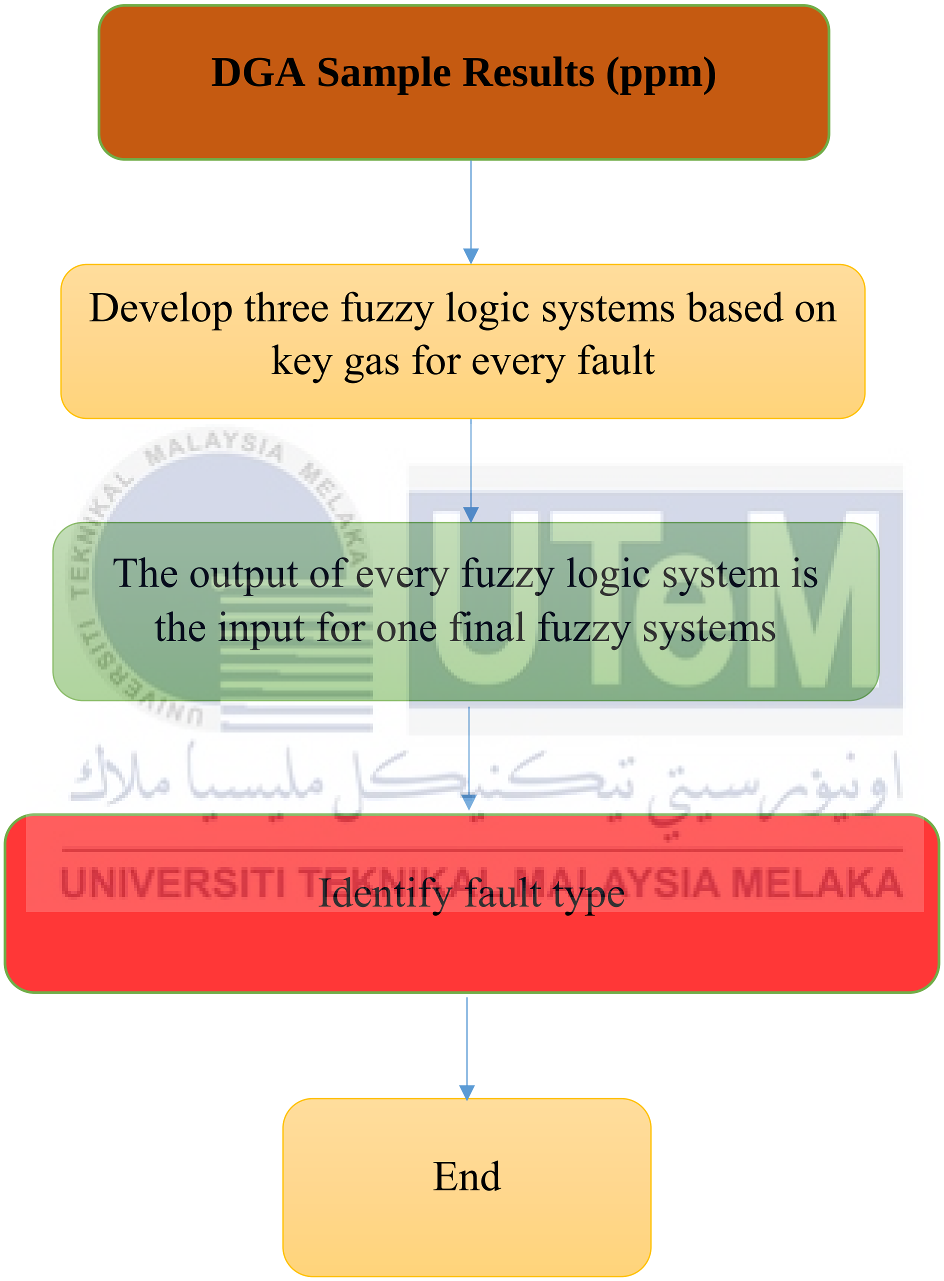
In this chapter will explains about the process of interpretation method for Dissolved Gas Analysis (DGA). There are some specification and standard that have been used to analyse every interpretation method. Basic flowchart and procedure will be presented to give overall view about the project. Every interpretation techniques procedure will be explained detail on how it works to get accurate result.

3.2 Flow Chart



Flowchart 3.1: Interpretation Method for DGA

3.3 Flowchart of Project Method



Flowchart 3.2: Project Methodology

3.4 Artificial Intelligence (Fuzzy Logic Method)

Although DGA has been extensively used in the industry, in some cases, the conventional methods fail to diagnose. This normally happens for those transformers which have multiple types of faults. In such a case the relation between different gases becomes too complicated that they may not match the codes pre-defined. To overcome these limitations, fuzzy approach is coordinate with key gas methods. Fuzzy Logic provides an approximate but effective means of describing the behavior of systems that are too complex or not easily analyzed. It differs from classical logic in that statements can take on any real value between 0 and 1, representing the degree to which an element belongs to a given set. Results obtained will revealed that Fuzzy technique is a feasible approach in addressing fault classification in a transformer. Fuzzy Logic was developed using MATLAB to automate the evaluation of both methods. The proposed FIS Editor prepared using MATLAB Fuzzy Logic Toolbox is shown below. There are four set of fuzzy that have been used in this method. The design of each fuzzy are shown below.

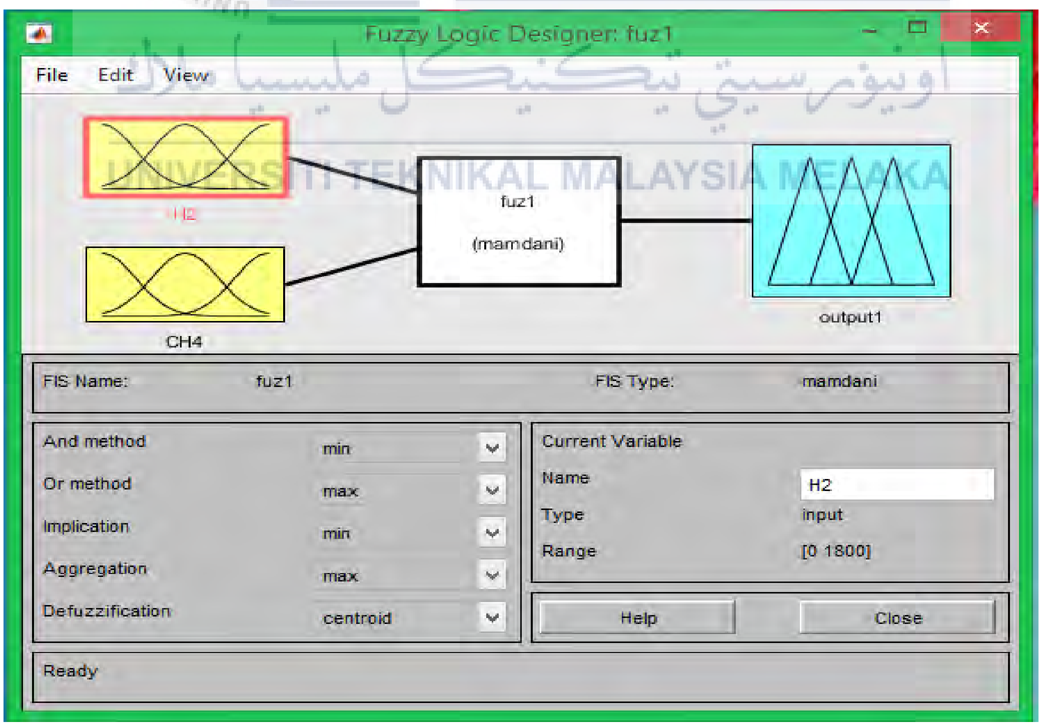


Figure 3.3: Fuzzy logic 1 using MATLAB

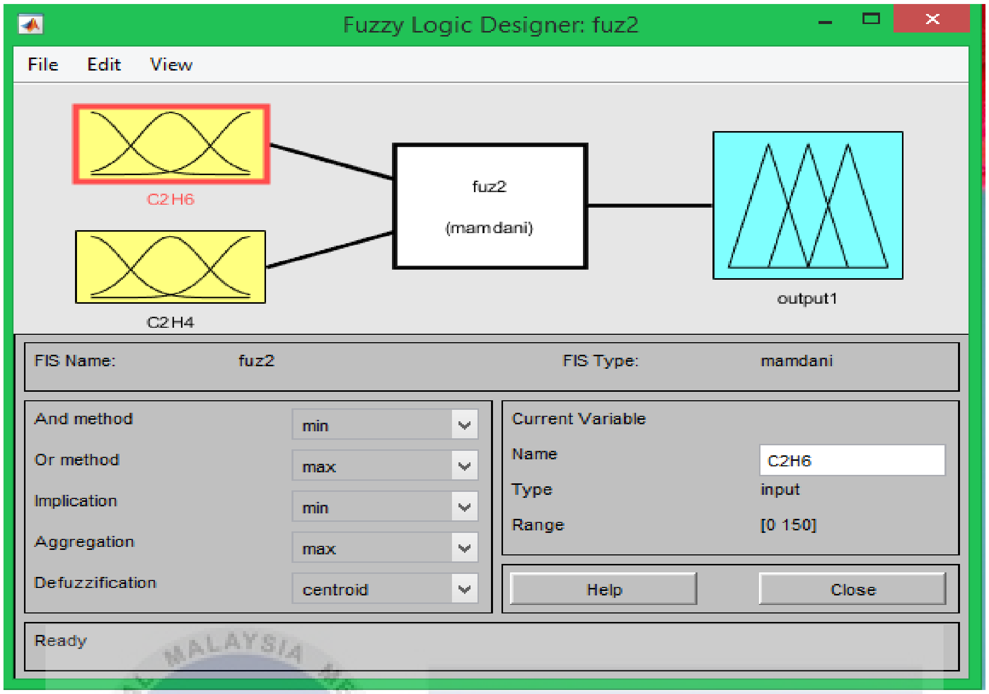


Figure 3.4.1: Fuzzy logic 2 using MATLAB

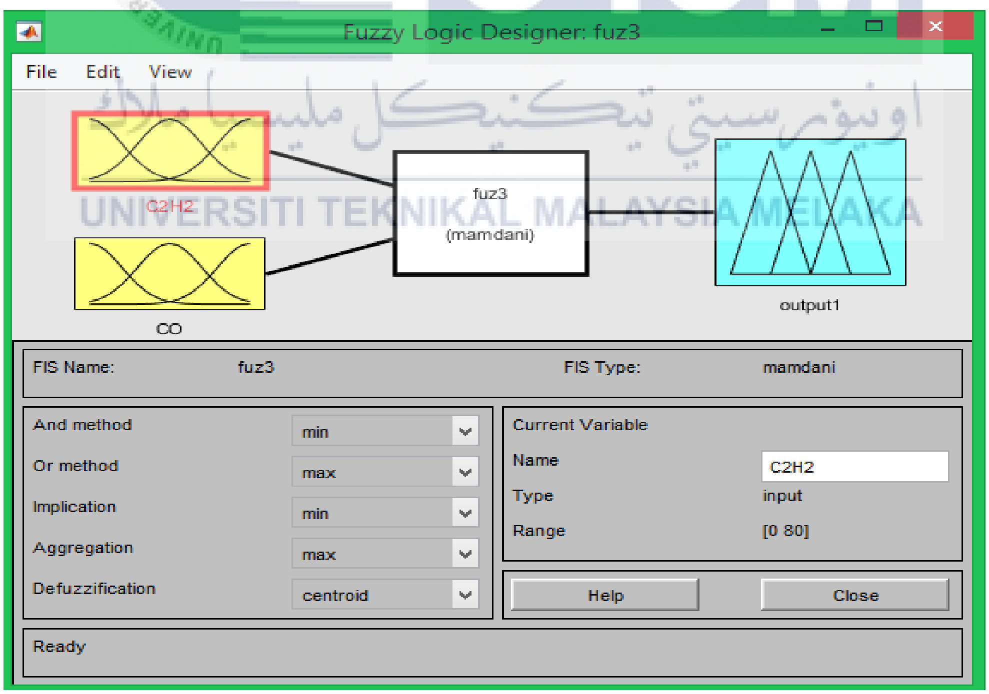


Figure 3.4.2: Fuzzy logic 3 using MATLAB

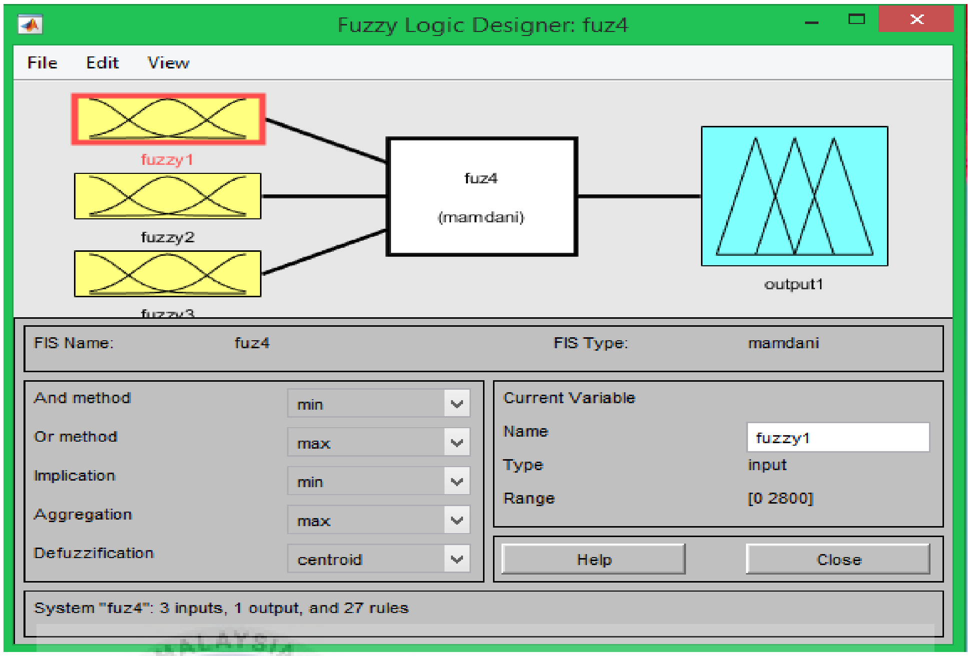


Figure 3.4.3: Fuzzy logic 4 using MATLAB

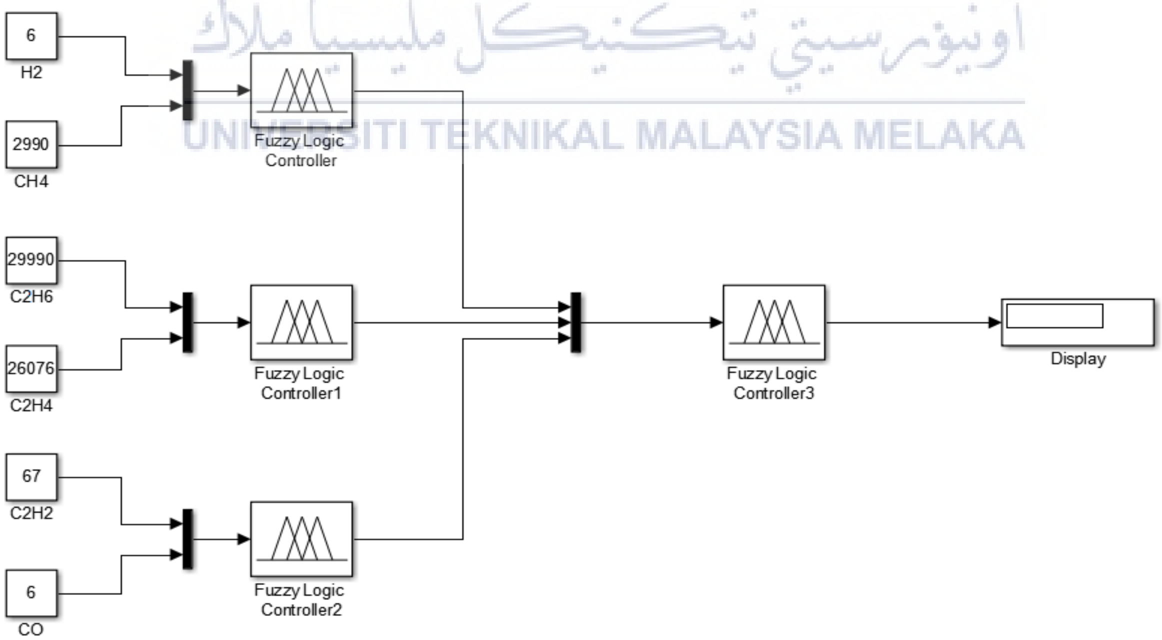


Figure 3.4.4: The design for the system in Simulink MATLAB

There are 50 historical data of to evaluate the method. There are three membership function for each fuzzy logic. The membership function for fuzzy logic 1, fuzzy logic 2 and fuzzy logic 3 are low, moderate and danger. Each of the fuzzy system comprises of one output that are arranged to each fault. For fuzzy logic 1 is for partial discharge. For fuzzy logic 2 is for thermal fault. For fuzzy logic 3 is for arcing. The output of each fuzzy will be the input of fuzzy logic 4. There are also three membership function for fuzzy logic 4. For the final output for fuzzy logic 4 is divided into three cases. The three cases are explained in chapter 4. The block diagram for the system are shown above.

The first step of applying the Fuzzy Logic method is to determine the input and output variables by examining the relation of the key gases with the fault type. The quantization step is to define the threshold values for all the 6 input gases for 3 fuzzy logic systems.

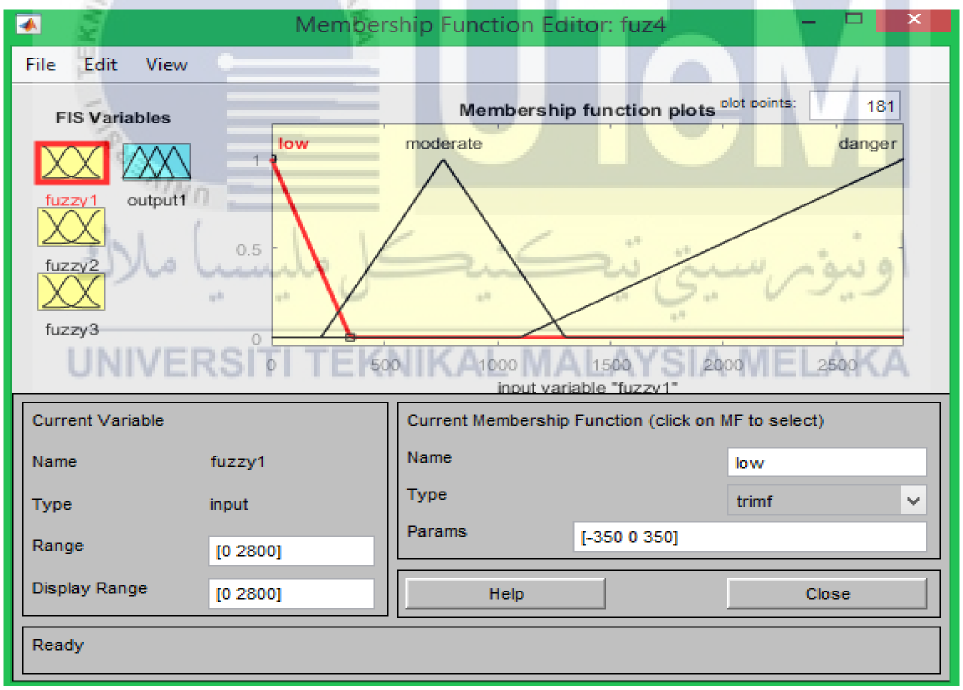


Figure 3.4.5: Example of membership function for input fuzzy 1

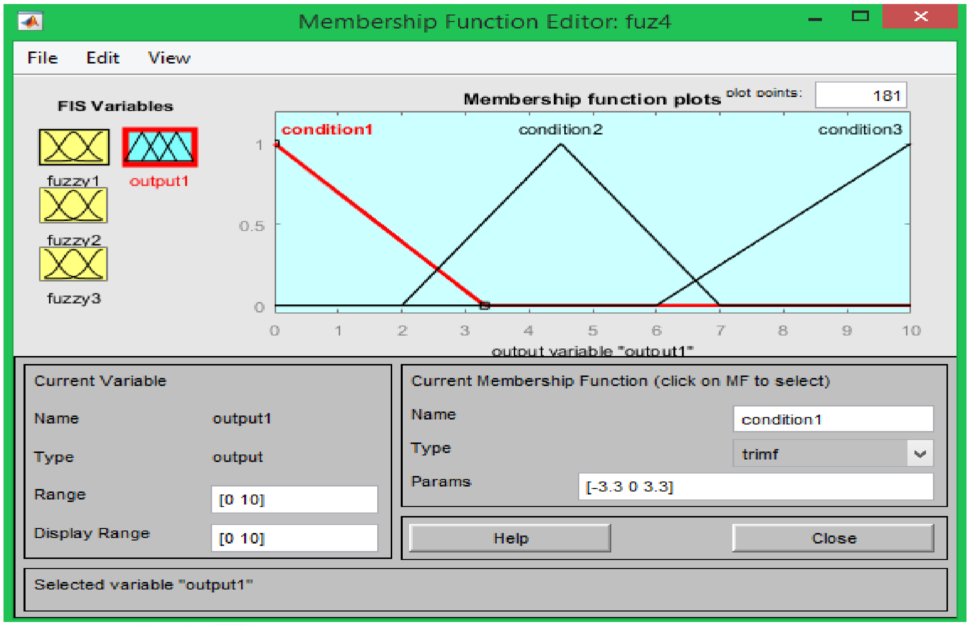


Figure 3.4.6: Membership function of output final fuzzy 4

Referring to the three-level criterion to classify risks to transformers (Table 4), three fuzzy codes Low, Moderate and Danger are selected for 6 input parameters (H2, CO, C2H2, C2H4, C2H6 and CH4) to be used to determine 3 outputs. Due to uncertainty in measurements of gas concentrations by gas analyzers, 10% overlaps between two consecutive codes are apply. All parameters are set based on total dissolved combustible gas (TDCG).

It is suggested a four-level criterion to classify risks to transformers when there is no previous dissolved gas history as follow:

Condition 1: TDGC below this level indicates the transformer is operating satisfactorily.

Condition 2: TDGC within this range indicates greater than normal combustible level. Action should be taken to establish a trend.

Condition 3: TDGC within this range indicates a high level of decomposition. Immediate action should be taken to establish a trend.

Condition 4: TDGC within this range indicates excessive decomposition. Continued operation could result in failure of the transformer.

If any of the individual combustible gas exceeds specified levels, further investigation should be done. Table below lists the dissolved gas concentrations for the individual gases and TDGC for Condition 1-4. According the various levels of TDGC, it is indicated the recommended initial sampling intervals and operation procedures.

Table 3.1: Dissolved Gas Concentration

Status	H2	CH4	C2H2	C2H4	C2H6	CO	TDCG
C1	<100	<120	<35	<50	<65	<350	<720
C2	101-700	121-400	36-50	51-100	66-100	351-570	721-1920
C3	701-1800	401-1000	51-80	101-200	101-150	571-1400	1921-4630
C4	>1800	>1000	>80	>200	>150	>1400	>4630

In the Fuzzy Logic diagnostic method, the fuzzy inference rules derived from dissolved gas concentration are 9 rules for single fault type based on the IEEE Standard guide according IEEE Std C57.104-1991. The minimum fuzzy rules are shown below.

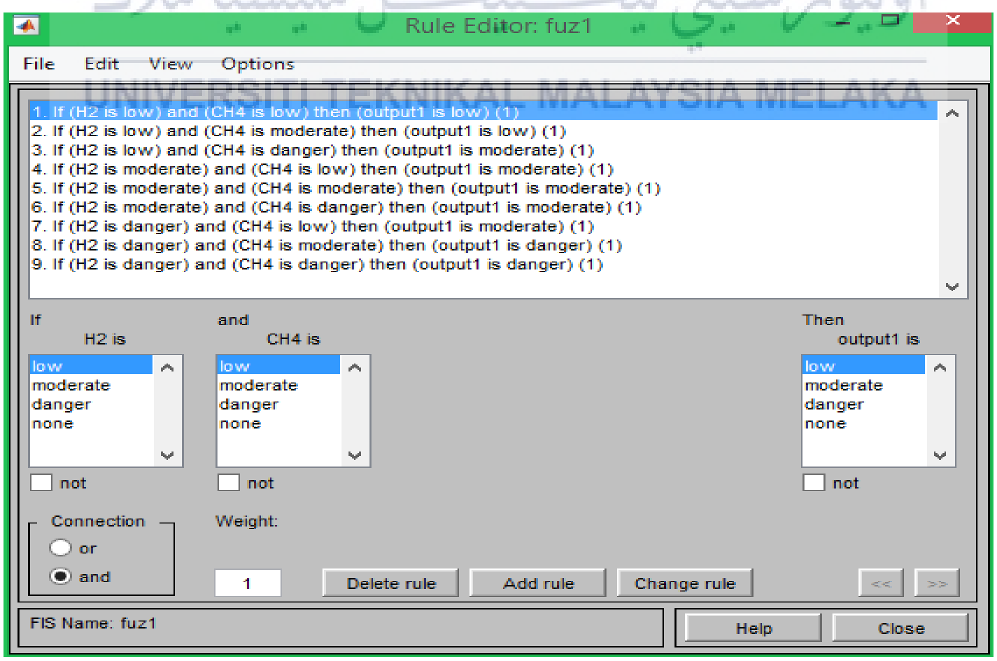
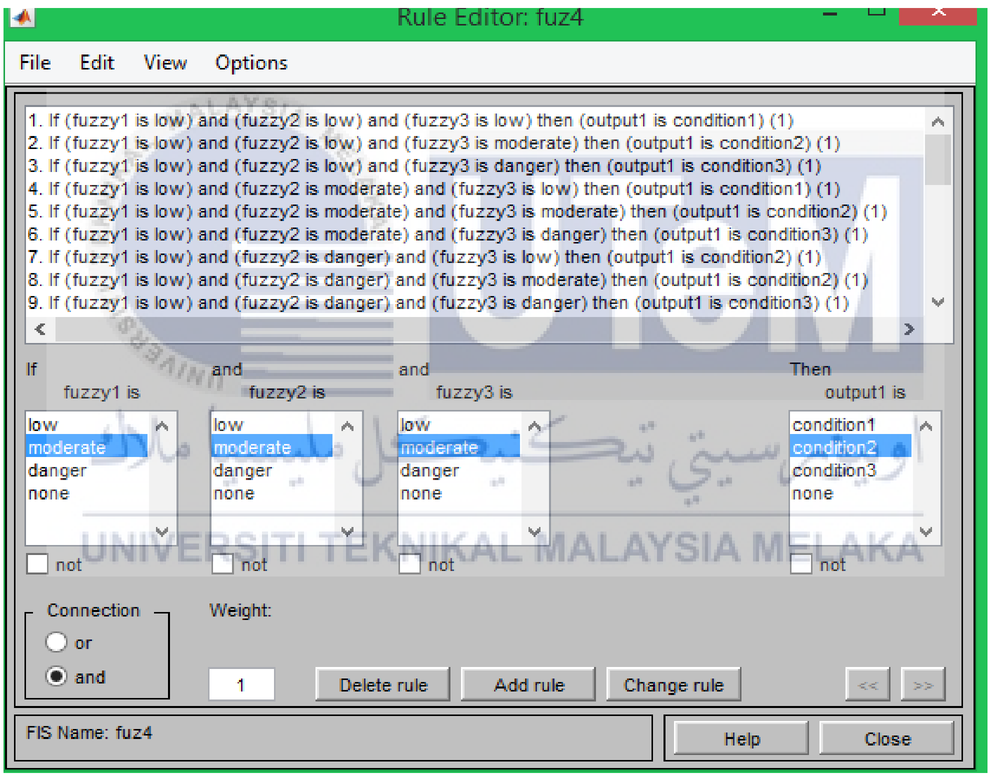


Figure 3.4.7: The minimum Fuzzy Inference Rules

Based on the IEEE Standard guide, the data suggested the 27 fuzzy inference rules for multiple faults. Each rule consists of two components, which are the antecedent (IF part), and the consequent (THEN part). With the fuzzy logic technique, the partial membership may improve the number of matched cases as compared to the ordinary crisp theory. For the fuzzy logic control, Mamdani's, Min composition technique is used. FIS derives output fuzzy sets from judging all the fuzzy rules by finding the weighted average of all 27 fuzzy rules output. In the Fuzzy Logic diagnostic method with 27 fuzzy inference rules we take more accurate results. The fuzzy rules for each dissolved gas are given in below.



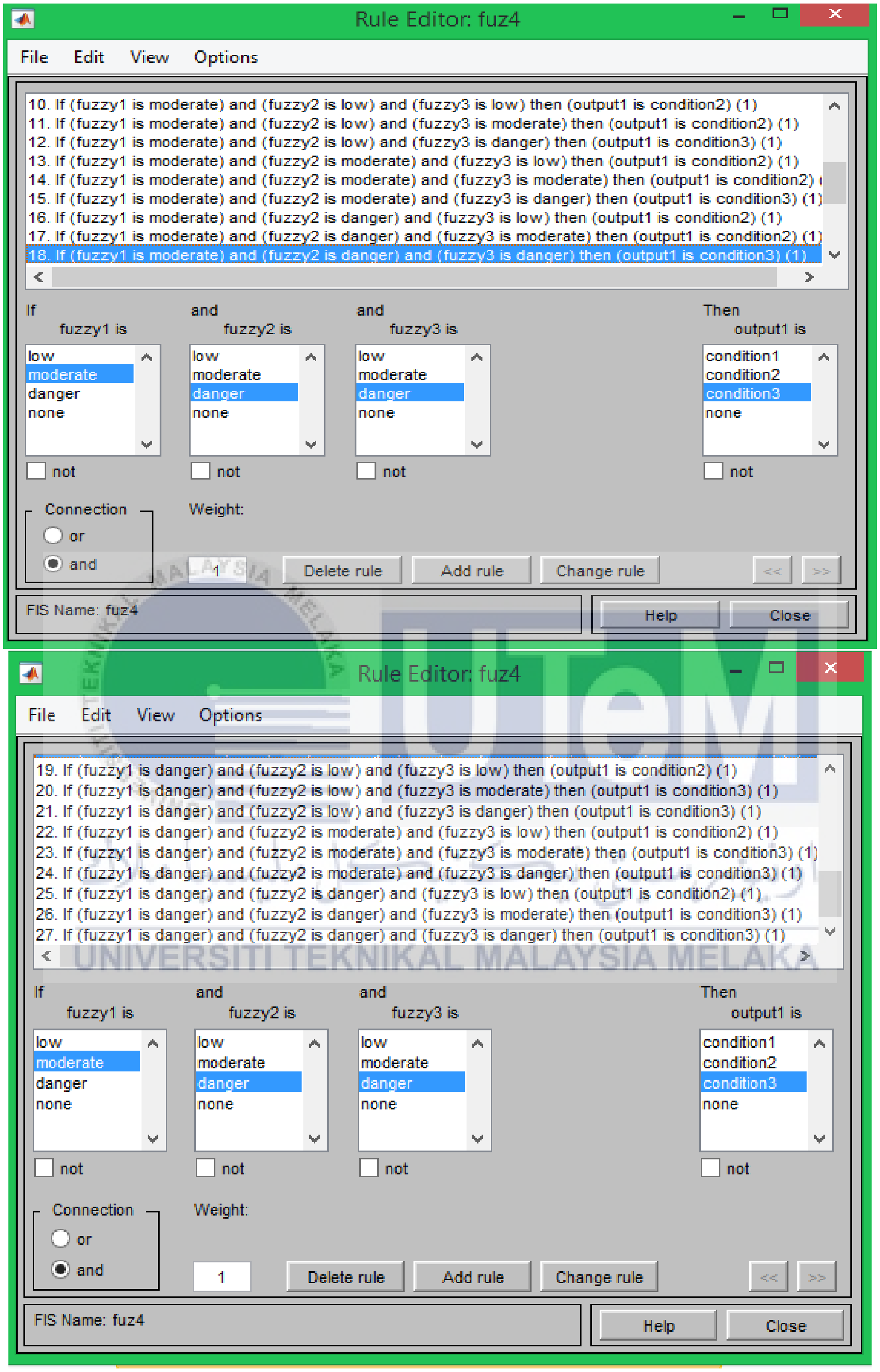
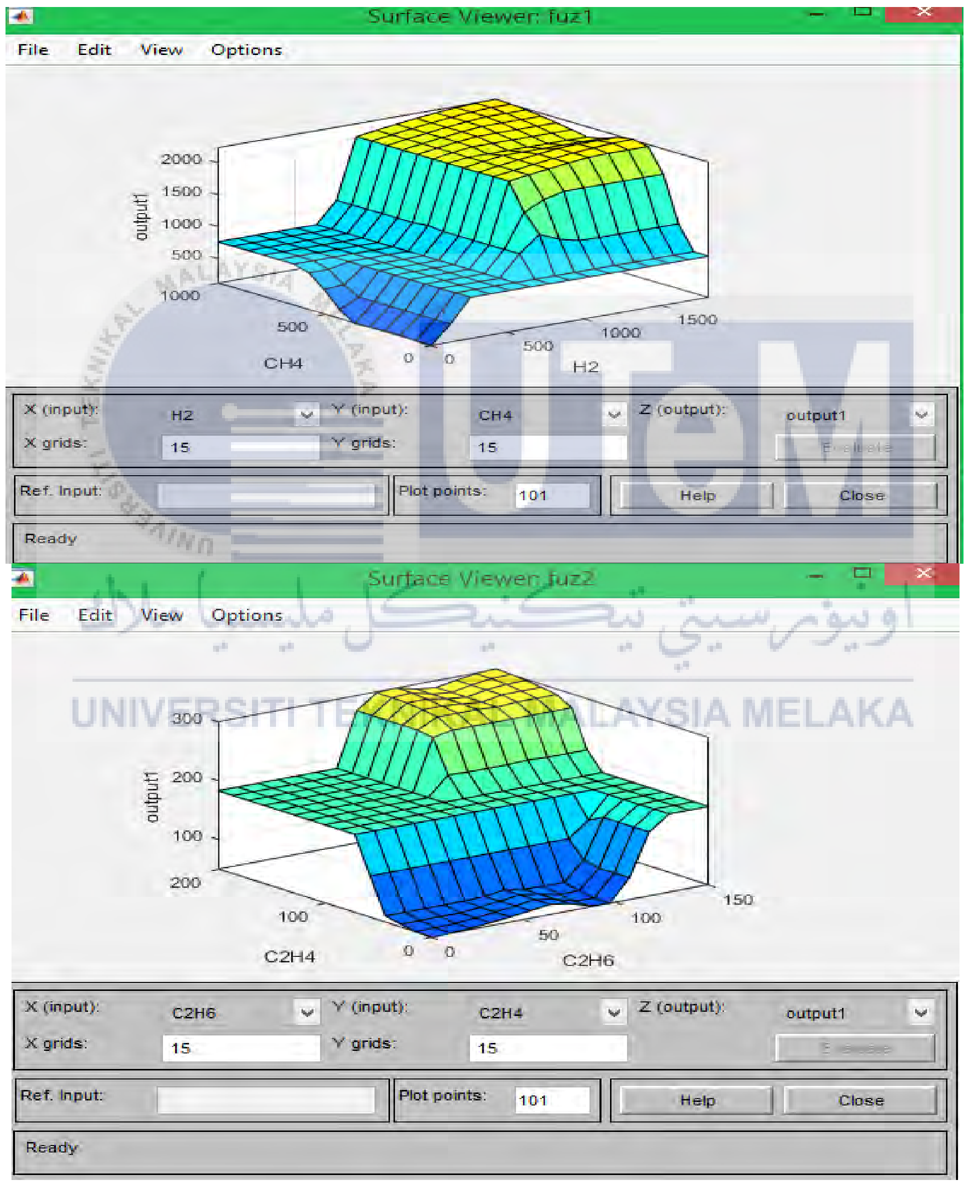


Figure 3.4.8: Fuzzy Inference Rules

In the Fuzzy Logic diagnostic method, the method that have been used is the Centroid defuzzification process. The result of the prediction analyses done to test the accuracy of the method using the date of shows an improvement of accuracy compared to the individual method. Figure 3.9.2 represents the influence of different Key Gases to the type of fault for Fuzzy Logic diagnostic method with 27 fuzzy inference rules used Mamdani's, Min composition technique.



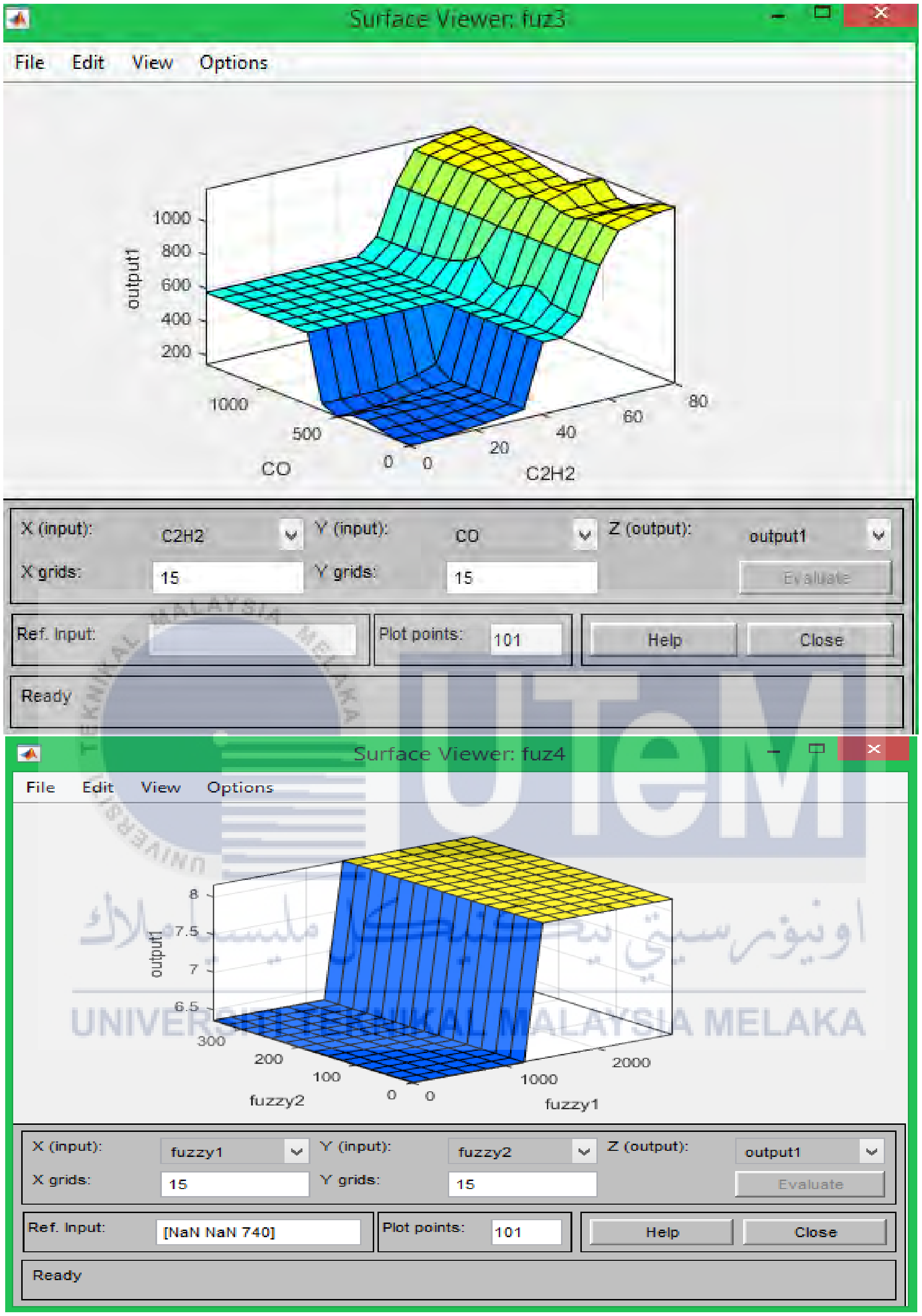


Figure 3.4.9: The influence of different Key Gases to the type of fault for Fuzzy Logic diagnostic method with 27 fuzzy inference rules

3.5 Key Gas Method Procedure

Key Gas Method (KGM) is a technique which consider on the amount of individual gases discharged. In this technique, the concentration of single gas is considered rather than using ratio method to determine faults. For KGM there are four significant faults. The faults are partial discharge, arcing, overheated of oil and overheated of cellulose.

- **Partial Discharge (PD)**

  The initial fault type that can measure using KGM is partial discharge (PD). Partial discharge occur in insulating oil of transformer. The key gas for PD is hydrogen (H_2) because hydrogen (H_2) has the biggest concentration among other gases. Therefore, (H_2) gas is a sign for partial discharge fault. Based on the chart below, hydrogen (H_2) produce during fault is 85% while methane (CH_4) is 13%, ethane (C_2H_6) and ethylene (C_2H_4) is 1%. The relative proportions for partial discharge is shown in the chart below.

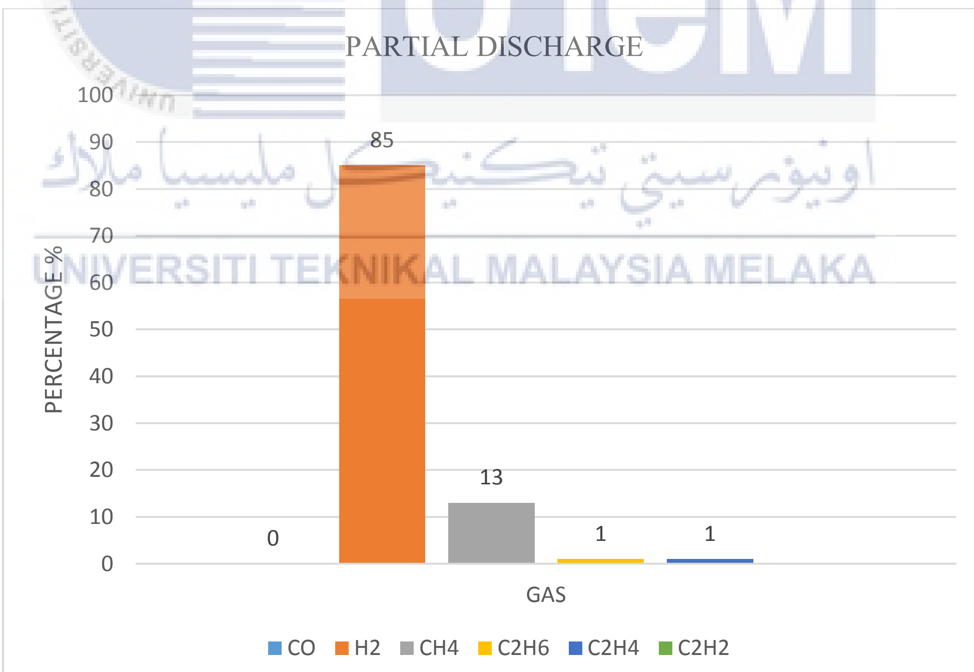


Figure 3.5 : Concentration of Gases for Partial Discharge

- **Arcing**

In arcing, acetylene (C_2H_2) will form when the temperature rising up to 700°C and arcing can deliver temperature starting from 2000°C up to 3000°C. Meanwhile, acetylene (C_2H_2) is produce twice as hydrogen (H_2) as the ratio is 2:1 because of the chemical reaction taken place. The amount of hydrogen (H_2) approximately is 60% while acetylene (C_2H_2) is 30%. Therefore, acetylene (C_2H_2) is the key gas arcing and the value of acetylene (C_2H_2) must below twice hydrogen (H_2). The relative proportions of arcing is shown in the chart below.

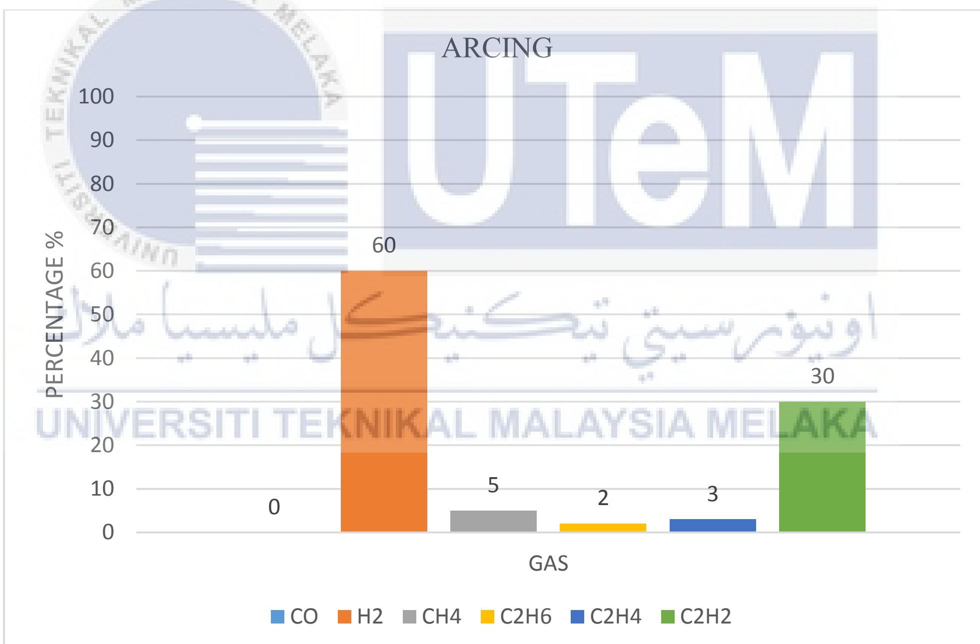


Figure 3.6 : Concentration of Gases for Arcing

- **Overheated Oil**

Overheating in oil will produce acetylene (C_2H_2) if the temperature is rising up to 700°C. When the temperature is about 300°C, ethylene (C_2H_4) will start to form. Therefore, ethylene (C_2H_4) is the key gas of overheated in oil with the small presence of methane (CH_4) and ethane (C_2H_6). The relative proportions of overheated in oil is shown in the chart below.

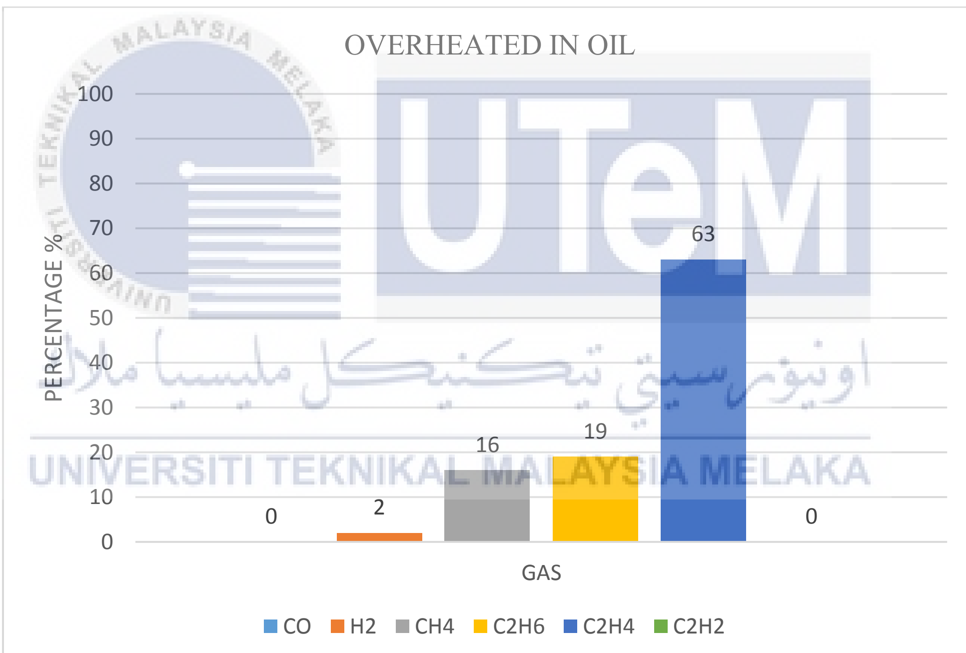


Figure 3.7 : Concentration of Gases for Overheated in Oil

- **Overheated Cellulose**

Overheating in cellulose created large amount of carbon monoxide (CO) and carbon dioxide (CO_2). Therefore, carbon monoxide is the key gas for overheating in cellulose. Carbon dioxide is not include because it is not a combustible gas. The percentage of carbon monoxide produce is about 93%. The relative proportions of overheated cellulose shown in the chart below.

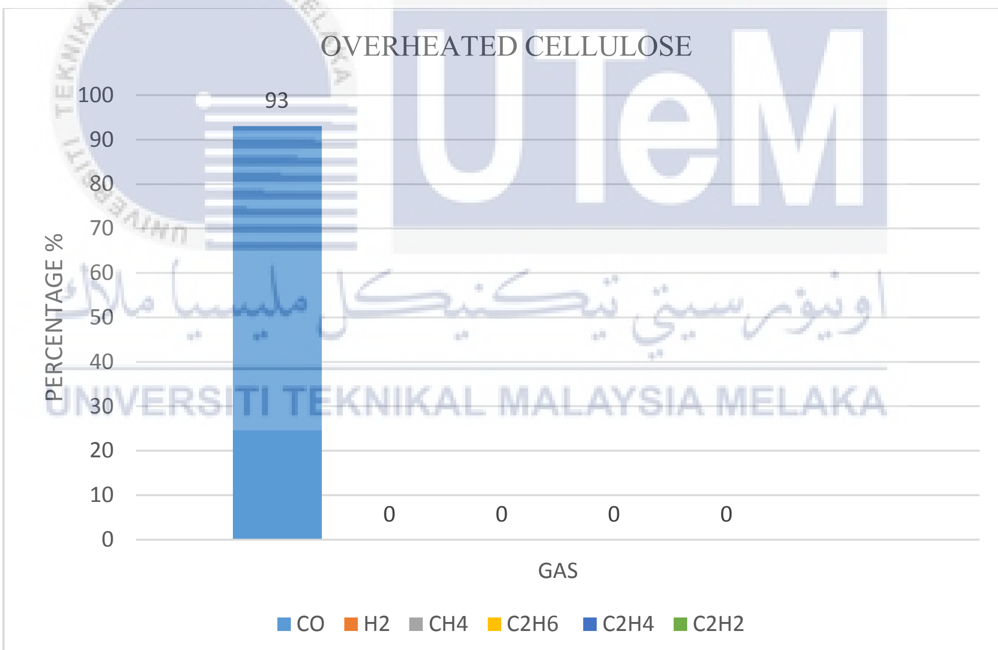


Figure 3.8 : Concentration of Gases for Overheated in Cellulose

3.6 Doernenburg Ratio Method (DRM) Procedure

Doernenburg Ratio Method (DRM) is created due to thermal degradation principle in 1970. 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 involved in DRM are hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2). There are four ratio of gases are set to determine the faults. The ratios use are :

- Ratio 1 = CH_4 / H_2
- Ratio 2 = C_2H_2 / CH_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. This method consider gas concentration limit (L1) to differentiate faults. The limit specification (L1) shows in table 3.1.

Key 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

Table 3.2: Limit Specification for Doernenburg Ratio Method (DRM)

In order to diagnose fault using DRM method, the procedure is provided below:

1. The centralization of gases are acquired by removing the gases and isolating them by chromatograph.
2. The concentration of one gases in each ratio must exceeds twice the value of limit specification L1 and if one of three gases exceeds the value for L1, the unit is considered faulty.
3. After checking the gas concentration limit L1, then proceed to determine the validity of ratio procedure. At least, one of the gas ratio exceeds limit L1, the ratio procedure is valid. Otherwise, the ratios are not significant and the value of the gases can be investigated by other methods.
4. Assuming the ratio is valid, each successive ratio is calculated and compared to the value in table 2 below. If all the ratios meet the criteria stated in table 2 then suggested diagnosis is valid.

Suggested diagnostic fault	Ratio 1 (R1) CH_4 / H_2	Ratio 2 (R2) C_2H_2 / CH_4	Ratio 3 (R3) C_2H_6 / C_2H_2	Ratio 4 (R4) C_2H_2 / CH_4
Thermal Decomposition	>1	<0.75	<0.3	>0.4
Partial Discharge (low intensity)	<0.1	Not significant	<0.3	>0.4

Arcing (high intensity)	>0.1 to <1	>0.75	>0.3	<0.4

Table 3.3 : Ratio Interpretation for Doernenburg Ratio Method (DRM)

3.7 Rogers Ratio Method (RRM) Procedure

RRM apply three gas ratios to detect fault and used to discover more thermal fault types. Fault are determined based on a simple range of ratio. RRM measures four conditions of faults. The faults are normal condition, partial discharge, arcing, thermal with low temperature, thermal less than 700°C and thermal exceeding 700°C. There are several gases involved in RRM. The gases are hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2).

The new three ratios 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

In order to diagnose fault using DRM method, the procedure is provided below:

5. The centralization of gases are acquired by removing the gases and isolating them by chromatograph.
6. After obtained the value of the gases, calculate the gas ratio referring table 3.
7. If the value of ratio 1 in between 0.1 to l, ratio 2 is less than 0.1 and ratio 5 is less than 1 then it is normal condition.
8. If the value of ratio 1 and ratio 2 is less than 0.1 while the value of ratio 5 is less than 1 then it indicates partial discharge with low energy density arcing.
9. If the value of ratio 1 in between 0.1 and 3, ratio 2 is in between 0.1 to 1 and ratio 5 is greater than 3 then it indicates arcing with high energy discharge.

10. If the value of ratio 1 is less than 0.1, ratio 2 is in between 0.1 to 1 and the value of ratio 5 is in between 1 to 3 then it indicates thermal with temperature.
11. If the value of ratio 1 is less than 0.1, ratio 2 is greater than 1 and ratio 5 is in between 1 to 3 then it indicates thermal less than 700°C.
12. If the value of ratio 1 is less than 0.1, ratio 2 is greater than 1 and ratio 5 greater than 3 then it indicates thermal less than 700°C.

Suggested Diagnostic Fault	Ratio 2 C_2H_2 / C_2H_4	Ratio 1 CH_4 / H_2	Ratio 5 C_2H_4 / C_2H_6
Normal	<0.1	>0.1 to <1	<1
PD - Low energy density arcing	<0.1	<0.1	<1
Arcing - High energy discharge	0.1 to 3	0.1 to 1	>3
Low temperature thermal	<0.1	>0.1 to <1	1 to 3
Thermal less than 700°C	<0.1	>1	1 to 3
Thermal exceeding 700°C	<0.1	>1	>3

Table 3.4 : Ratio Interpretation for Rogers Ratio Method (RRM)

3.8 IEC Ratio Method (IRM) Procedure

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. 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). 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.

In order to diagnose fault using DRM method, the procedure is provided below:

1. The centralization of gases are acquired by removing the gases and isolating them by chromatograph.
2. If ratio 1 is less than 0.1 and ratio 5 is less than 0.2 then it indicates partial discharge.
3. If ratio 1 is in between 0.1 to 5, ratio 2 is greater than 1 and ratio 5 is greater than 1 then it indicates discharge with low energy.
4. If ratio 1 is in between 0.1-0.5, ratio 2 is in between 0.6-2.5 and ratio 5 is greater than 2 then it indicates discharge with high energy.
5. If ratio 1 is greater than 1, ratio 5 is less than 1 it indicates thermal faults not more than 300°C.
6. If ratio 1 is greater than 1, ratio 2 is less than 0.1 and ratio 5 is in between 1 to 5 then it indicates thermal faults more than 300°C but not exceeding 700°C.

7. If ratio 1 is greater than 1, ratio 2 is less than 0.2 and ratio 5 is greater than 4 then it indicates thermal faults exceeding 700°C

Case	Suggested Diagnosis Fault	Ratio 2 C_2H_2 / C_2H_4	Ratio 1 CH_4 / H_2	Ratio 5 C_2H_4 / C_2H_6
PD	Partial Discharge	NS	<0.1	<0.2
D1	Discharge with low energy	>1	0.1-0.5	>1
D2	Discharge with high energy	0.6-2.5	0.1-1	>2
T1	Thermal faults not exceeding 300°C	NS	>1 but NS	<1
T2	Thermal faults exceeding 300°C but not exceeding 700°C	<0.1	>1	1-4
T3	Thermal faults exceeding 700°C	<0.2	>1	>4
NS = Non-significant whatever the value				

Table 3.5 : Ratio Interpretation for IEC Ratio Method (IRM)

3.9 Duval Triangle Method (DTM) Procedure

Duval Triangle Method (DTM) was implement by Michel Duval. It was created based on an innovation developed by IEC 60599 Ratio Method. 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: Combination of thermal faults and discharges

In order to diagnose fault using DTM, the procedure is provided below:

1. The centralization of gases are acquired by removing the gases and isolating them by chromatograph.
2. The three gas are (CH4) = A, (C2H4) = B and (C2H2) = C, in ppm.
3. Calculate the sum of this three gases (CH4 + C2H4 + C2H2) = S, in ppm.

4. After that, calculate the relative proportion of the three gases, in percentage. X = % CH4 = 100 (A/S), Y = % C2H4 = 100 (B/S), Z = % C2H2 = 100 (C/S).
5. Then, X, Y and Z are necessarily between 0 and 100%, and (X + Y + Z) should always = 100 %.
6. Plotting X, Y and Z in the Triangle provides only one point in the Triangle.

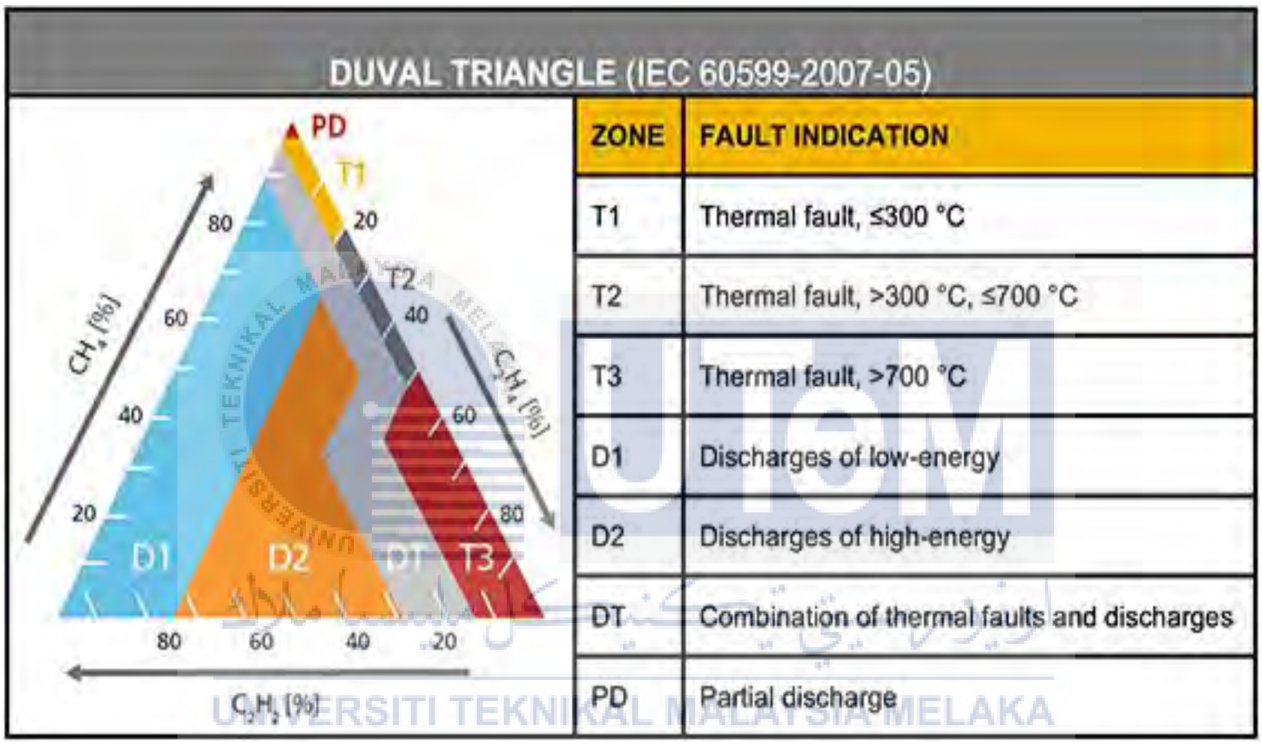


Figure 3.7 : Duval Triangle (IEC 60599-2007-05)

4.0 Gantt Chart

This project is planned from starting until the end of Final Year Project 1. It is required to ensure the planning activities will be accomplished based on the deadline. The project timeline is planned as shown in Table 3.1

Task	Weeks					
	1-2	3-4	5	6-12	13	14
Introduction and executive briefing about Final Year Project 2						
Discussing with supervisor about the project and set up meeting with him						
Collect any information that related on how to do simulation from MATLAB						
Designing the simulation of the project						

Presentation of FYP 2						
Submit Progress Report						

Table 3.6 : FYP 2 Gantt chart

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

There are 50 historical data were taken from previous journal and an analysis of each data was used to analyse the performance for basic interpretation method for DGA such as KGM, DRM, RRM, IRM and DTM. The performance of each method were compared and an analysis of the results were made.

4.2 RESULT AND DISCUSSION

All interpretation method for DGA are classify due to the type of faults that is stated in table 4.1. F1 code represents normal condition. F2 code represents thermal fault while F3 code represents partial discharge condition. F4 code states for arcing while F5 is out of code. All 50 historical data taken from previous journal were analyze and the result shows in table 4.2. To get the acuracy of each interpretation method for DGA is number succesful prediction divided by actual number of fault. Then the accuracy of each method is been compared.

Table 4.1 : Fault type for various DGA interpretation method

Types	F1	F2	F3	F4	F5
KGM	Normal	Overheated cellulose, overheated oil	PD	Arcing	Out of code
DRM	Normal	Thermal decomposition	PD	Arcing	Out of code
RRM	Normal	Low temperature thermal fault, Thermal<700°C, and >700°C	Low energy density-PD	Arcing	Out of code
IRM	Normal	Thermal(T) fault T<300°C , 300<T<700°C, and T>700°C	PD	Low energy discharge, High energy discharge	Out of code
DTM	Normal	Thermal(T) fault T<300°C , 300<T<700°C, and T>700°C	PD	Low energy discharge, High energy discharge	Out of code

The formula to calculate accuracy for DGA diagnostic are given below:

$$\text{Accuracy} = \frac{\text{succesful prediction}}{\text{actual number}} \times 100 \qquad [10]$$

Table 4.2 : The range of AI method output

Fault code	Range
F1	0 - 3.00
F2	8.25 - 10.00
F3	3.10 - 6.00
F4	6.10 - 8.24
F5	10.00 – 15.00

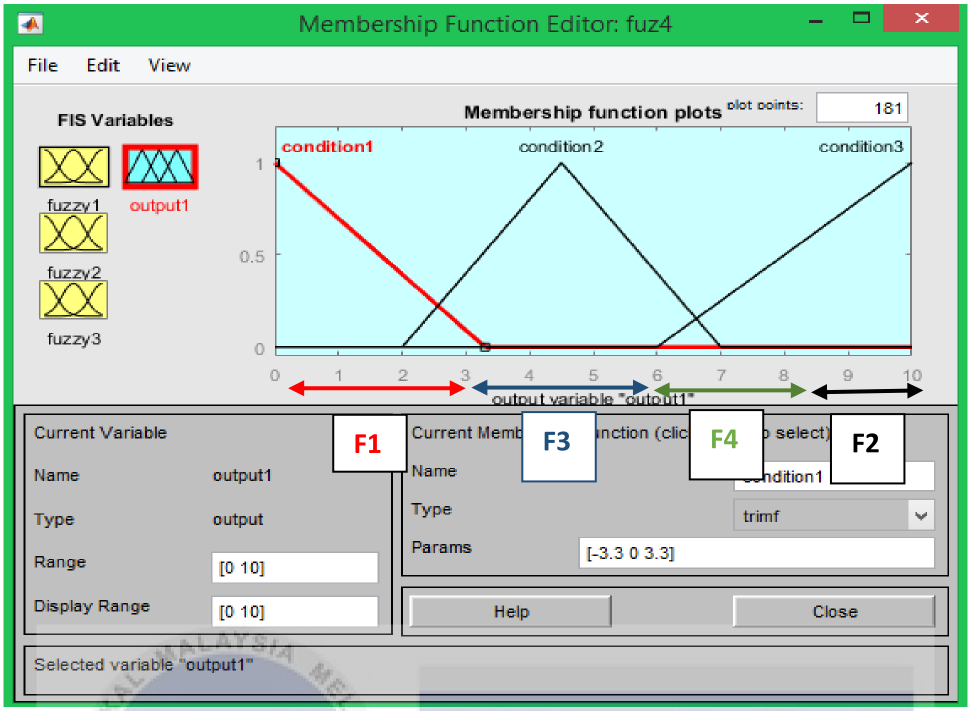


Figure 4.1 : The range of output of Fuzzy Logic Method

The range of AI method output that have been developed is from 0.00 until 15.00 which is classify into five ranges. The range for F1 code is from 0 until 3.00 which is the condition of the transformer is consider safe and operate in normal operation. While the range for F2 code is from 8.25 until 10.00 which consider thermal fault. The range of for F3 code is from 3.10 until 6.00 and fault is partial discharge. For F4 code, the range is from 6.10 until 8.24 which the fault is arcing. For F5 is from 10.00 until 15.00 which is wrong interpretation. The output of Fuzzy Logic method is shown above

This table below stated the analysis between six interpretation method based on the actual number of fault and the succesful prediction based on each interpretation method. All interpretation method for DGA are classify due to the type of faults that is stated in table 4.1. The result shows that KGM provide 51% of correct diagnoses, 10% unresolved diagnoses and 39% wrong diagnoses. DRM and RRM produce 65% and 42% correct diagnoses, 34% and 55% unresolved diagnoses while the rest is wrong diagnoses. IRM provides 63% correct diagnoses, 28% unresolved diagnoses and 9% wrong diagnoses. DTM procduce 90% correct diagnoses which is the second highest among the method and only 10% wrong diagnoses. AI method produce the highest accuracy which is 94% correct diagnoses, and only 6% wrong diagnoses.

Table 4.3 : Accucary for various DGA interpretation method

Method	**Fault Code**	**Actual Number**	**Successful Prediction**	**Accuracy (%)**

KGM	F2	20	9	45
	F3	9	8	88.9
	F4	20	8	40
	F5	0	5	0
DRM	F2	20	12	60
	F3	9	2	22.22
	F4	20	18	90
	F5	0	17	0
RRM	F2	20	11	55
	F3	9	1	11.11
	F4	20	9	45
	F5	0	27	0
IRM	F2	20	14	70
	F3	9	3	33.33
	F4	20	14	70
	F5	0	14	0
DTM	F2	20	15	75
	F3	9	9	100
	F4	20	20	100
	F5	0	0	100
AI	F2	20	17	85
	F3	9	10	100
	F4	20	20	100
	F5	0	0	100

Table 4.4: Overall performance for various DGA interpretation method

Types	Correct diagnoses %	Unresolved diagnoses %	Wrong diagnoses %
KGM	51 %	10 %	39 %
DRM	65 %	34 %	1 %
RRM	42 %	55 %	3 %
IRM	63 %	28 %	9 %
DTM	90 %	0	10 %
AI	94 %	0	6%

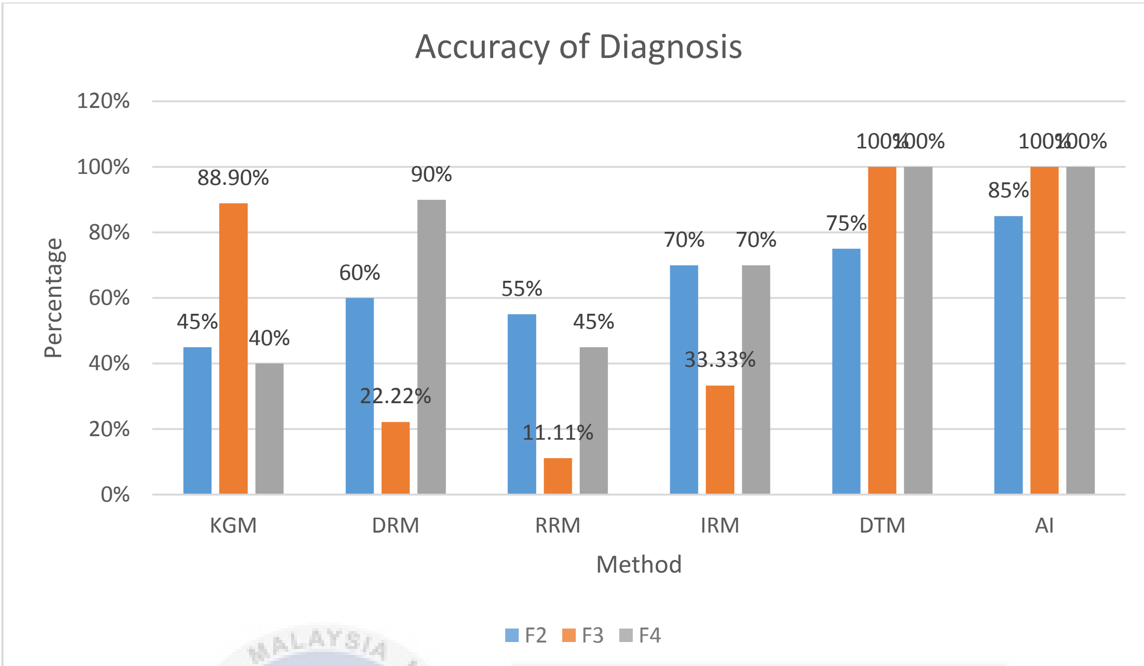


Figure 4.2 : Comparison between accuracy of each interpretation method

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

For conclusion, there are several DGA interpretation methods are discussed and compared in this project. Based on analysis that have been made, DTM is the most effective method compare to other method which is 90% accuracy and only 10% wrong diagnosis.

However inconsiderate implementation leads to wrong diagnoses. Furthermore, DTM method only can detect fault after the fault already occur. Therefore, artificial intelligence method has been developed to solve this problem. Artificial intelligence method is design using MATLAB software which can use to analyze and develop algorithm which considered one of the most expert system due to the capability in s and in decision making. After several analysis have been done, AI method is the most accurate and precise technique compared to others which is 93% accuracy. In addition, AI method can also be used to detect SF6 gas which other method cannot detect it. The most crucial part in this project which is AI method can be used to detect before the fault occur which is vital to monitor the life of transformer.

5.2 Recomendation

To increase the accuracy of this diagnosis method a combination of method maybe can improve the accuracy of the diagnosis. Maybe there is some other technique that have not been used widely that can perform better accuracy and precise result. AI method have been divided into two technique which is neural network and fuzzy logic. Maybe combination of these two techniques can increase the percentage of the accuracy. There is very important to perform better diagnosis because any wrong diagnosis can lead to failure of the transformer.

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APPENDIX A

DGA Samples for 50 cases

Data of Gases Using Key Gas Method (KGM)

H2	CH4	C2H2	C2H4	C2H6	CO	CO2	KGM
32930	2397			157	313	560	F3
37800	1740	8	8	249	56	197	F3
92600	10200				6400	103151	F3
8266	1061			22	107	498	F3
9340	995	7	6	60	60	620	F3
620	4704	10	5	554	6	347	F5
33046	619		2	58	51	1	F3
40280	1069	1	1	1060	1		F3
26788	18342		27	2111	704		F3

78	20	28	13	11		784	F3
305	100	541	161	33	440	3700	F2
35	6	482	26	3	200	2240	F2
543	120	1880	411	41	76	2800	F2
230	163	692	233	27	130	115	F5
645	86	317	110	13	74	114	F4
60	10	4	4	4	780	7600	F2
95	10	39	11		122	467	F5
6870	1028	5500	900	79	29	388	F4
10092	5399	37565	6500	530	42	413	F5
650	81	270	51	170	380	2000	F2
440	89	757	304	19	299	1190	F2
210	43	187	102	12	167	1070	F2
2850	1115	3675	1987	138	2330	4330	F4
7020	1850	4410	2960		2140	1000	F4
545	130	239	153	16	660	2850	F4
7150	1440	1760	1210	97	608	2260	F4
620	325	244	181	38	1480	2530	F4
120	31	94	66		48	271	F4
755	229	460	404	32	845	5580	F4
1270	3450	8	1390	520	483	4450	F5
3420	7870	33	6990	1500	573	4640	F2
360	610	9	260	259	12000	74200	F5
1	27	1	4	49	53	254	F5
3675	6392	5	7691	2500	101	833	F2
48	610		10	29	1900	970	F2
12	18		4	4	559	1710	F2
66	60		7	2	76	90	F5
1450	940	61	322	211	2420	3560	F5
	18900	330	540	410	3900	710	F5
8800	64064		95650	72128	290	90300	F2
6709	10500	750	1770	1400	290	1500	F5
1100	1600	26	2010	221		1430	F2
290	966	57	1810	299	72	756	F2
2500	10500	6	13500	4790	530	2310	F2
1860	4980	1600	10700		158	1300	F2
860	1670	40	2050	30	10	690	F5
150	22	11	60	9			F5
400	940	24	820	210	390	1700	F5

6	2990	67	26076	29990	6	26	F2

Data of Gases Using Doernenburg Ratio Method (DRM)

H2	CH4	C2H2	C2H4	C2H6	CO	CO2	DRM
32930	2397			157	313	560	F5
37800	1740	8	8	249	56	197	F3
92600	10200				6400	103151	F5
8266	1061			22	107	498	F5
9340	995	7	6	60	60	620	F5
620	4704	10	5	554	6	347	F5
33046	619		2	58	51	1	F5
40280	1069	1	1	1060	1		F3
26788	18342		27	2111	704		F5
78	20	28	13	11		784	F4
305	100	541	161	33	440	3700	F4
35	6	482	26	3	200	2240	F4

543	120	1880	411	41	76	2800	F4
`230	163	692	233	27	130	115	F4
645	86	317	110	13	74	114	F4
60	10	4	4	4	780	7600	F5
95	10	39	11		122	467	F4
6870	1028	5500	900	79	29	388	F4
10092	5399	37565	6500	530	42	413	F4
650	81	270	51	170	380	2000	F5
440	89	757	304	19	299	1190	F4
210	43	187	102	12	167	1070	F4
2850	1115	3675	1987	138	2330	4330	F4
7020	1850	4410	2960		2140	1000	F4
545	130	239	153	16	660	2850	F4
7150	1440	1760	1210	97	608	2260	F4
620	325	244	181	38	1480	2530	F4
120	31	94	66		48	271	F4
755	229	460	404	32	845	5580	F4
1270	3450	8	1390	520	483	4450	F2
3420	7870	33	6990	1500	573	4640	F2
360	610	9	260	259	12000	74200	F2
1	27	1	4	49	53	254	F2
3675	6392	5	7691	2500	101	833	F2
48	610		10	29	1900	970	F5
12	18		4	4	559	1710	F5
66	60		7	2	76	90	F5
1450	940	61	322	211	2420	3560	F5
	18900	330	540	410	3900	710	F5
8800	64064		95650	72128	290	90300	F5
6709	10500	750	1770	1400	290	1500	F2
1100	1600	26	2010	221		1430	F2
290	966	57	1810	299	72	756	F2
2500	10500	6	13500	4790	530	2310	F2
1860	4980	1600	10700		158	1300	F5
860	1670	40	2050	30	10	690	F2
150	22	11	60	9			F5
400	940	24	820	210	390	1700	F2
6	2990	67	26076	29990	6	26	F2

Data of Gases Using Rogers Ratio Method (RRM)

H2	CH4	C2H2	C2H4	C2H6	CO	CO2	RRM
32930	2397			157	313	560	F5
37800	1740	8	8	249	56	197	F5
92600	10200				6400	103151	F5
8266	1061			22	107	498	F5
9340	995	7	6	60	60	620	F5
620	4704	10	5	554	6	347	F5
33046	619		2	58	51	1	F3
40280	1069	1	1	1060	1		F5
26788	18342		27	2111	704		F1
78	20	28	13	11		784	F5
305	100	541	161	33	440	3700	F5
35	6	482	26	3	200	2240	F5

543	120	1880	411	41	76	2800	F5
`230	163	692	233	27	130	115	F4
645	86	317	110	13	74	114	F4
60	10	4	4	4	780	7600	F5
95	10	39	11		122	467	F5
6870	1028	5500	900	79	29	388	F5
10092	5399	37565	6500	530	42	413	F5
650	81	270	51	170	380	2000	F5
440	89	757	304	19	299	1190	F4
210	43	187	102	12	167	1070	F4
2850	1115	3675	1987	138	2330	4330	F4
7020	1850	4410	2960		2140	1000	F5
545	130	239	153	16	660	2850	F4
7150	1440	1760	1210	97	608	2260	F4
620	325	244	181	38	1480	2530	F4
120	31	94	66		48	271	F5
755	229	460	404	32	845	5580	F4
1270	3450	8	1390	520	483	4450	F2
3420	7870	33	6990	1500	573	4640	F2
360	610	9	260	259	12000	74200	F2
1	27	1	4	49	53	254	F5
3675	6392	5	7691	2500	101	833	F5
48	610		10	29	1900	970	F5
12	18		4	4	559	1710	F2
66	60		7	2	76	90	F5
1450	940	61	322	211	2420	3560	F2
	18900	330	540	410	3900	710	F2
8800	64064		95650	72128	290	90300	F2
6709	10500	750	1770	1400	290	1500	F5
1100	1600	26	2010	221		1430	F2
290	966	57	1810	299	72	756	F2
2500	10500	6	13500	4790	530	2310	F2
1860	4980	1600	10700		158	1300	F5
860	1670	40	2050	30	10	690	F2
150	22	11	60	9			F5
400	940	24	820	210	390	1700	F2
6	2990	67	26076	29990	6	26	F2

Data of Gases Using IEC Ratio Method (IRM)

H2	CH4	C2H2	C2H4	C2H6	CO	CO2	IRM
32930	2397			157	313	560	F5
37800	1740	8	8	249	56	197	F3
92600	10200				6400	103151	F5
8266	1061			22	107	498	F5
9340	995	7	6	60	60	620	F2
620	4704	10	5	554	6	347	F2
33046	619		2	58	51	1	F3
40280	1069	1	1	1060	1		F3
26788	18342		27	2111	704		F2
78	20	28	13	11		784	F4
305	100	541	161	33	440	3700	F4
35	6	482	26	3	200	2240	F4

543	120	1880	411	41	76	2800	F4
`230	163	692	233	27	130	115	F4
645	86	317	110	13	74	114	F5
60	10	4	4	4	780	7600	F4
95	10	39	11		122	467	F4
6870	1028	5500	900	79	29	388	F5
10092	5399	37565	6500	530	42	413	F4
650	81	270	51	170	380	2000	F2
440	89	757	304	19	299	1190	F4
210	43	187	102	12	167	1070	F4
2850	1115	3675	1987	138	2330	4330	F4
7020	1850	4410	2960		2140	1000	F5
545	130	239	153	16	660	2850	F4
7150	1440	1760	1210	97	608	2260	F4
620	325	244	181	38	1480	2530	F4
120	31	94	66		48	271	F5
755	229	460	404	32	845	5580	F4
1270	3450	8	1390	520	483	4450	F2
3420	7870	33	6990	1500	573	4640	F2
360	610	9	260	259	12000	74200	F2
1	27	1	4	49	53	254	F2
3675	6392	5	7691	2500	101	833	F2
48	610		10	29	1900	970	F2
12	18		4	4	559	1710	F2
66	60		7	2	76	90	F5
1450	940	61	322	211	2420	3560	F5
	18900	330	540	410	3900	710	F5
8800	64064		95650	72128	290	90300	F2
6709	10500	750	1770	1400	290	1500	F5
1100	1600	26	2010	221		1430	F2
290	966	57	1810	299	72	756	F2
2500	10500	6	13500	4790	530	2310	F2
1860	4980	1600	10700		158	1300	F5
860	1670	40	2050	30	10	690	F2
150	22	11	60	9			F5
400	940	24	820	210	390	1700	F2
6	2990	67	26076	29990	6	26	F2

Data of Gases Using Duval Triangle Method (DTM)

H2	CH4	C2H2	C2H4	C2H6	CO	CO2	DTM
32930	2397			157	313	560	F3
37800	1740	8	8	249	56	197	F3
92600	10200				6400	103151	F3
8266	1061			22	107	498	F3
9340	995	7	6	60	60	620	F3
620	4704	10	5	554	6	347	F3
33046	619		2	58	51	1	F3
40280	1069	1	1	1060	1		F3
26788	18342		27	2111	704		F3
78	20	28	13	11		784	F4
305	100	541	161	33	440	3700	F4
35	6	482	26	3	200	2240	F4

543	120	1880	411	41	76	2800	F4
`230	163	692	233	27	130	115	F4
645	86	317	110	13	74	114	F4
60	10	4	4	4	780	7600	F4
95	10	39	11		122	467	F4
6870	1028	5500	900	79	29	388	F4
10092	5399	37565	6500	530	42	413	F4
650	81	270	51	170	380	2000	F4
440	89	757	304	19	299	1190	F4
210	43	187	102	12	167	1070	F4
2850	1115	3675	1987	138	2330	4330	F4
7020	1850	4410	2960		2140	1000	F4
545	130	239	153	16	660	2850	F4
7150	1440	1760	1210	97	608	2260	F4
620	325	244	181	38	1480	2530	F4
120	31	94	66		48	271	F4
755	229	460	404	32	845	5580	F4
1270	3450	8	1390	520	483	4450	F2
3420	7870	33	6990	1500	573	4640	F2
360	610	9	260	259	12000	74200	F2
1	27	1	4	49	53	254	F2
3675	6392	5	7691	2500	101	833	F2
48	610		10	29	1900	970	F3
12	18		4	4	559	1710	F2
66	60		7	2	76	90	F2
1450	940	61	322	211	2420	3560	F4
	18900	330	540	410	3900	710	F2
8800	64064		95650	72128	290	90300	F2
6709	10500	750	1770	1400	290	1500	F4
1100	1600	26	2010	221		1430	F2
290	966	57	1810	299	72	756	F2
2500	10500	6	13500	4790	530	2310	F2
1860	4980	1600	10700		158	1300	F2
860	1670	40	2050	30	10	690	F2
150	22	11	60	9			F2
400	940	24	820	210	390	1700	F2
6	2990	67	26076	29990	6	26	F2

Data of Gases Using Artificial Intelligence Method (AI)

H2	CH4	C2H2	C2H4	C2H6	CO	CO2	AI	AI	Range
32930	2397			157	313	560	F3	C2	4.5
37800	1740	8	8	249	56	197	F3	C2	4.5
92600	10200	2	3	30	640	103151	F3	C2	4.5
8266	1061			22	107	498	F3	C2	4.5
9340	995	7	6	60	60	620	F3	C2	4.5
620	4704	10	5	554	6	347	F3	C2	4.5
33046	619		2	58	51	1	F3	C2	4.5
40280	1069	1	1	1060	1		F3	C2	4.5
26788	18342		27	2111	704		F3	C2	4.5
7600	1230	1560	836	318	4970	4080	F4	C3	8.162
305	100	541	161	33	440	3700	F4	C3	6.356
35	6	482	26	3	200	2240	F4	C3	6.356
543	120	1880	411	41	76	2800	F4	C3	6.356
230	163	692	233	27	130	115	F4	C3	6.356

645	86	317	110	13	74	114	F4	C3	6.356
60	10	244	89	9	524	2100	F4	C3	6.356
8		101	43		192	4067	F4	C3	8.524
6870	1028	5500	900	79	29	388	F4	C3	8.162
10092	5399	37565	6500	530	42	413	F4	C3	8.162
650	81	270	51	170	380	2000	F4	C3	6.356
440	89	757	304	19	299	1190	F4	C3	6.356
210	43	187	102	12	167	1070	F4	C3	6.356
2850	1115	3675	1987	138	2330	4330	F4	C3	8.162
7020	1850	4410	2960		2140	1000	F4	C3	8.162
545	130	239	153	16	660	2850	F4	C3	6.356
7150	1440	1760	1210	97	608	2260	F4	C3	8.162
620	325	244	181	38	1480	2530	F4	C3	6.356
120	31	94	66		48	271	F4	C3	8.222
755	229	460	404	32	845	5580	F4	C3	6.356
290	966	57	1810	299	72	756	F2	C3	8.378
280	950	60	1900	303	68	800	F2	C2	8.529
360	610	9	260	259	12000	74200	F2	C2	8.378
1	27	1	4	49	53	254	F1	C1	1.202
3675	6392	5	7691	2500	101	833	F2	C2	8.378
48	610		10	29	1900	970	F2	C2	8.378
12	18		4	4	559	1710	F1	C1	1.165
66	60		7	2	76	90	F1	C1	1.168
1450	940	61	322	211	2420	3560	F2	C2	8.378
	18900	330	540	410	3900	710	F2	C2	8.529
8800	64064		95650	72128	290	90300	F2	C2	8.529
6709	10500	750	1770	1400	290	1500	F2	C2	8.378
1100	1600	26	2010	221		1430	F2	C2	8.378
2500	10500	6	13500	4790	530	2310	F2	C2	8.378
1860	4980	1600	10700		158	1300	F2	C2	8.529
860	1670	40	2050	30	10	690	F2	C2	8.378
150	22	11	60	9			F2	C2	8.378
400	940	24	820	210	390	1700	F2	C2	8.378
6	2990	67	26076	29990	6	26	F2	C3	8.529
1270	3450	8	1390	520	483	4450	F2	C2	8.378
3420	7870	33	6990	1500	573	4640	F2	C2	8.378