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LAPORAN PROJEK
SARJANA MUDA

THE CREATION OF DUVAL TRIANGLE BY SOFTWARE IMPLEMENTATION FOR DISSOLVED GAS ANALYSIS

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Bachelor of Electrical Engineering (Industrial Power)

June 2014

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" I hereby declare that I have read through this report entitle "The Creation of Duval Triangle by Software Implementation for Dissolved Gas Analysis" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power) "

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Date : 18 June 2014

THE CREATION OF DUVAL TRIANGLE BY SOFTWARE IMPLEMENTATION FOR DISSOLVED GAS ANALYSIS

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A report submitted in partial fulfillment of the requirements for the degree of

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JUNE 2014

I declare that this report entitle "*The Creation of Duval Triangle by Software Implementation for Dissolved Gas Analysis*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ______________________________

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Date : 18 June 2014

Special dedicated to my beloved father, mother, brothers, sisters and friends who always give me strength guided, encouraged throughout my journey of education.

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ABSTRACT

The transformer is one of the most important and expensive components of the electric power system network. The major faults can cause damage to the power transformer, which are not only disturbing the electrical network, but also resulting in large losses. It is difficult to classify the incipient faults that occur in the power transformer if there is no suitable analysis being used. Deep studies about Dissolved Gas Analysis (DGA) found that Duval Triangle method and other techniques can be used to analyse the fault that will occur in the power transformer. Nowadays, Tenaga Nasional Berhad (TNB) is using Microsoft Excel software related to Duval Triangle method to analayze the power transformer. Research found that the Duval Triangle method of DGA gives the accurate result more than 88% compared to other techniques. Microsoft Excel is licensed software and the users need to buy at a high price to get the full licensed software. Java programming is used in the developing new Duval Triangle in Eclipse software. As the Eclipse software is open-source software and the licensed is free, therefore the license issue can be solved. The results from the new developed Duval Triangle software will be compared with the results from the existing software in order to proof that the new developed Duval Triangle software is valid to be used.

ABSTRAK

Alat ubah adalah salah satu komponen yang paling penting dan mahal dalam rangkaian sistem kuasa elektrik. Permasalahan utama boleh menyebabkan kerosakan kepada alat ubah, bukan sahaja mengganggu rangkaian elektrik, tetapi juga mengakibatkan kerugian besar. Situasi akan menjadi sukar untuk mengelaskan permasalahan yang akan berlaku dalam alat ubah kuasa jika tiada analisis sesuai yang boleh digunakan. Kajian yang mendalam berkaitan "Dissolved Gas Analysis" (DGA) mendapati "Duval Triangle" dan teknik-teknik lain boleh digunakan untuk menganalisis permasalahan yang akan berlaku di dalam alat ubah kuasa. Pada masa kini, Tenaga Nasional Berhad (TNB) menggunakan perisian "Microsoft Excel" yang berkaitan dengan kaedah "Duval Triangle" untuk menganalisa alat ubah kuasa. Kajian mendapati bahawa kaedah "Duval Segitiga" memberikan keputusan 88% lebih tepat berbanding dengan teknik-teknik lain. "Microsoft Excel" adalah perisian berlesen dan pengguna perlu membeli pada harga yang tinggi untuk mendapatkan perisian berlesen penuh. Pengaturcaraan Java digunakan dalam membangunkan "Duval Triangle" baru dalam perisian Eclipse. Perisian Eclipse adalah perisian sumber terbuka dan lesen adalah percuma, maka isu lesen boleh diselesaikan. Keputusan daripada perisian "Duval Triangle" baru akan dibandingkan dengan keputusan daripada perisian yang sedia ada bagi membuktikan bahawa "Duval Triangle" perisian baru adalah sah untuk digunakan.

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LIST OF ABBREVIATIONS

DGA	Dissolved Gas Analysis
TNB	Tenaga Nasional Berhad
FYP	Final Year Project
O_2	Oxygen
H_2	Hydrogen
NO_2	Nitrogen
CH_4	Methane
C_2H_6	Ethane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
FRA	Frequency Response Analysis
PDC	Polarization and Depolarization Current
RVM	Recovery Voltage Methods
FDS	Frequency Dielectric Spectroscopy
PD	Partial Discharge
DAC	Digital to Analog
C_2H_4	Ethylene
C_2H_2	Acetylene

ppm	parts per million
JVM	Java Virtual Machine
LTC	Load Tap Changer
IEEE	Institute of Electrical and Electronics Engineers
IBM	International Business Machines
IDE	Integrated Development Environment
UI	User Interface
ADT	Android Development Tools
AVD	Android Virtual Device

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Transformer is one of the most important and critical components in the electric power system network. The main function is to transfer the electric power from the power station to the consumer center by step up or step down the voltage value. For many years, the power transformer has been in maintenance under different environmental, electrical and mechanical condition. As it is the most important and critical component in the electric power system network, the predicting diagnosis method analyzing and condition monitoring system are focused on the power transformer [1]. Nowadays, electric utilities from all around the world make efforts on the power transformer for extended transformer lifespan, prevent tripping due to breakdown of the transformer, prevent or reduce damage on the equipment and lastly demand for a higher productivity increase.

There are few general reasons of power transformer failures such as overheating, lightning surges, overload, line surges, etc. One of the main reason breakdowns in the power transformer is overheated, which are caused by some factors such as overload, copper losses, core losses, hysteresis, Eddy current, cooling system failure, etc. Overheating in a power transformer gives the bad effects that reduce the function and character of a good insulation system either oil or paper insulator [2]. It is a very important issue for electric utilities to prevent the failures and to keep the power transformer in best-performing condition. Hence, a better monitoring and analyzing life assessment or diagnostics will help to increase the lifespan of the power transformers. There are many types of diagnostic techniques have been used by electric utilities. The methods that usually used are chemical, electrical, mechanical, optical and thermal diagnostics [3, 4]. Dissolved Gas Analysis (DGA) has been found that to be the best method of the diagnostic amount of gases dissolved in the power transformers [5-7].

1.2 Project Motivation

The analysis of oil sample from the power transformer is very effective, predictive and efficient for determining the health of the transformer. By using DGA, the oil sample will be tested to assess the health of the power transformer. The failure of the function electrical insulation and other related parts inside a power transformer will generate gases inside the transformer. DGA methods are available for identification of the faults such as arcing, corona or hot spot. The gases that generated are identified and will give useful information on the preventive maintenance program. Moreover, DGA can provide advance warning of the existence of faults and monitor the rate of fault development [8]. Therefore, DGA method can minimize the risk of the power transformer from damage.

Java language is now the most popular programming in all around the world. Besides, Java language is easier to understand and usually used in developing graphical method. Moreover, Java language can be run on the various of open-source software such as Eclipse software. As the Eclipse software is open-source software and the licensed is free, therefore the users no longer need to worry about the licensed issues. In addition, the installer size of Eclipse software is smaller compared to MATLAB and Microsoft Office software. Apart from that, this Java language also can be used in developing new Android application. A hundred million of mobile devices are powered by the Android platform in more than 190 countries. The applications available for the Android seem to grow faster in the Play Store. The lack of problems, more friendly and being an open-source platform is making it number one in the industry. Furthermore, Android gives developers to create new application and games for Android users everywhere. Android devices come in all kinds of sizes and with all sorts of features and prices [9].

Nowadays, with the evolution of growth and development throughout the world, DGA diagnostic system should be built more impressions and fast way. DGA diagnostic systems developer must be developed this system in line with characteristic of the local power transformer to achieve the best performance. However, countries that have the same environmental conditions and characteristics of the power transformer may find this diagnostic system very useful to them and suitable with a minor modification. Hence, it can help local manufacturers by developed diagnostic system as to save on maintenance costs of the power transformer [10].

1.3 Problem Statement

The power transformer is a major part and a highly expensive component of an electric power system network. There are more than one thousand of the power transformers serviced under Tenaga Nasional Berhad (TNB). The failure in these power transformers may give interruption of the power supply to industries and residents. Hence, preventive maintenance technique for detection of faults in these power transformers is introduced. DGA is the most important tool in determining the fault condition within the oil-filled power transformer. The most frequent technique that has used in DGA is a Duval Triangle method. This method has satisfied the fault diagnosis more than 88% accurate than any other method of diagnosis [6]. Moreover, the types of hydrocarbon gases that filled in the power transformer are difficult to be categorizing to produce the results. Duval Triangle will use three hydrocarbon gases to calculate and identified the types of faults occur in power transformers.

The latest software of Duval Triangle that being used for diagnostic in the power transformer is Microsoft Excel Duval Triangle Calculator. This file will be run using

Microsoft Office software. Besides, Microsoft Office is licensed software and the users need to buy at a high price to get the full license software. Java language is easier to understand and usually used in developing graphical method. Moreover, Java language can be run on the various of open-source software such as Eclipse software. As the Eclipse software is open-source software and the licensed is free, hence the users no longer need to worry about the licensed issues. In addition, the installer size of Eclipse software is smaller compared to Microsoft Office software.

1.4 Objectives

The objectives of this project are:

i. To analyze various DGA methods applied for power transformer specifically Duval Triangle method.
ii. To develop new software via Eclipse software for the simplification of Duval Triangle analysis.
iii. To verify the new developed software via Eclipse software with the existing hardware (Microsoft Excel Duval Triangle Calculator) for the simplification of Duval Triangle analysis by using the actual data from TNB.

1.5 Scope of Research

The scope of this project is study, understand and investigate the methods that are used in DGA to diagnose the types of faults that occurred in the power transformers. Hence, the investigation is focusing on the Duval Triangle method via implementation of AutoCAD and Eclipse software to visualize the difference types of faults that occurred inside the power transformers. Once the process completed, the development of new software will be implemented. In addition, this new developed software will be based on the characteristics according to the different fault classifications on triangular map using Java language. Lastly, the validation process will take place. A real DGA data from TNB will be inserted into both of software; existing software using Microsoft Excel and new developed Duval Triangle software. Hence, the results from the new developed software will be compared with the results from the existing software in order to prove that the new developed software is valid to be used.

1.6 Outline of Report

This report consists of five chapters. Chapter 1 describes the overview of project, motivation of project, problem statements, objectives, scope and outline of a report. Furthermore, Chapter 2 explains the literature review related for this project, including theory of the transformer, DGA analysis, Java language, Eclipse software, etc. Chapter 3 explains the methodology of the project starting from finding information, study and understanding until procedure to develop Duval Triangle software using Eclipse software. Chapter 4 discusses of final results and an analysis. Lastly, in Chapter 5 is conclusion and recommendation from the finding research that have been made.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chapter 2 will describe all the related research as the studies about to this project. It is including all the important studies, thesis, and research about the diagnosis method in the transformer, which have been performed previously by other research work of IEEE journal, thesis and information from the Internet. In Section 2.2, it will discuss the general methods used in diagnosis the transformer condition, which are chemical, electrical, optical, mechanical and thermal methods. Besides, Section 2.3 explain about DGA with the different types of method in DGA includes Roger Ratio, IEC Ratio, Doernenburg Ratio, Key Gases and Duval Triangle method. Next, the basic principle of the Duval Triangle method is elaborate in Section 2.4. In addition, Section 2.5 presents the Java programming that being used in this project. Lastly, there are some reviews of previous work about the Duval Triangle software in Section 2.6.

2.2 Diagnosis Fault in Transformer

The failures in the power transformer either minor or major problems may bring the transformer into the breakdown. Hence, diagnosis in the power transformer is very important to overcome the problems. There are five different types of transformer diagnosis method can be applied in the transformer, which are chemical, electrical, optical, mechanical and thermal methods [3, 4].

2.2.1 Chemical Diagnostic Methods

There are two chemicals diagnostic methods, which are oil analysis and DGA as shown in Figure 2.1. From the Figure 2.1, the common DGA diagnosis technique used are IEC Ratio, Roger Ratio, Doernenburg Ratio, Duval Triangle and Key Gases. For oil analysis, this method is used for determination of the oil humidity by using Furan Values, Moisture and Neutralization Value techniques [3, 4]. DGA is the most efficient way for the determination and classification of thermal and electric failures compared to the oil analysis methods [5-7].

Every type of faults produces typical gases that dissolved in oil. By using DGA, the typical failures such as local oil breakdowns, overheating and partial discharge can be recognized in the power transformer. Hence, these failures will produce oxygen (O_2), hydrogen (H_2), nitrogen (NO_2) and lower molecular hydrocarbon compound such as methane (CH_4), ethane (C_2H_6), carbon monoxide (CO) or carbon dioxide (CO_2). With a rapid growth of technology, a new diagnosis apparatus for online detecting gases dissolved in the power transformer oil are developed [4, 8].

Figure 2.1 shows a summary of chemical diagnostic method that used to diagnose the power transformer. The chemical diagnostic method divided by two parts, which are oil analysis and DGA methods.

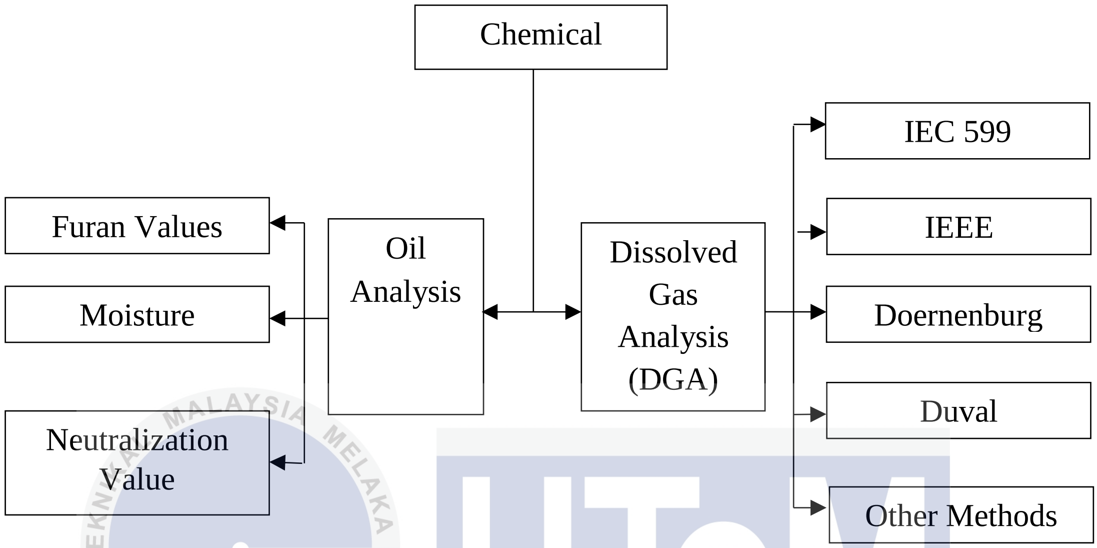


Figure 2.1: Chemical Diagnostic Method [3, 4]

2.2.2 Electrical Diagnosis Methods

One possible way to diagnose an insulation condition in the power transformer is the measurement and evaluation of the dielectric response. The dielectric properties of oil insulation systems influenced by the moisture and ageing. Measurement of resistance on the windings can give a result about faults or breaks occur in the power transformers. Oil breakdown voltage is one of the most famous and popular electrical methods for evaluation of the oil condition. This method is standardized and delivers the resistibility of the oil against alternating voltage [4].

For signal analysis, Frequency Response Analysis (FRA) is mainly used in detection of deformation or movement of transformer windings. Hence, winding response are recorded when a high-frequency signal is applied at the winding of the transformer. The impulse test allows the measurement of the impedance or its transfer function. There are two methods to measure the low-frequency response of the transformers which are swept frequency method and low voltage impulse. With a modern technique now, the low-voltage impulse method which is more sensitive and high speed to detect winding clamping looseness and small winding movement [4].

For the insulation method, Polarization and Depolarization Current analysis (PDC) are one of a non-destructive dielectric testing method for testing transformer. The conductivity and moisture content in a transformer can be measured by using this method. Besides, the Recovery Voltage Methods (RVM) is another technique in insulation method. This method based on the polarization of oil paper. By using this method, it can determine the moisture content in the insulation and at the same time the strength of dielectric, loading capacity and life span can be estimated [4]. In addition, Frequency Dielectric Spectroscopy (FDS) is same as RVW, which is to examine in determining system humidity [12].

A partial discharge (PD) is a small electrical discharge or spark that occurs within a minuscule portion of the insulation between two conducting electrodes of medium and high-voltage equipment. The insulation degradation is the most activity by PD and will affect to the insulation system. PD method is normally used for detection and localization a weak spot in the insulation system. There are four different types of technique that can detect the PD such as PD Evaluation, Digital to Analog (DAC), PD measurement and PD localization [4].

Lastly, by using oil analysis method, it can give the result of resistibility of oil against alternating voltage. The result is influenced basically from the water, particle and gas content of the oil. The aging of the condition of the oil can identify by measuring the loss factor. As the aging products in the oil increase, the loss factor and resistivity of oil will affect. Moisture and ageing can affect the dielectric properties of oil insulation systems [4].

Figure 2.2 shows the common techniques that used in the electrical diagnosis method for diagnosing the fault in power transformer. The electrical diagnostic method divided by four parts, which are partial discharge, insulation, signal analysis and oil analysis.

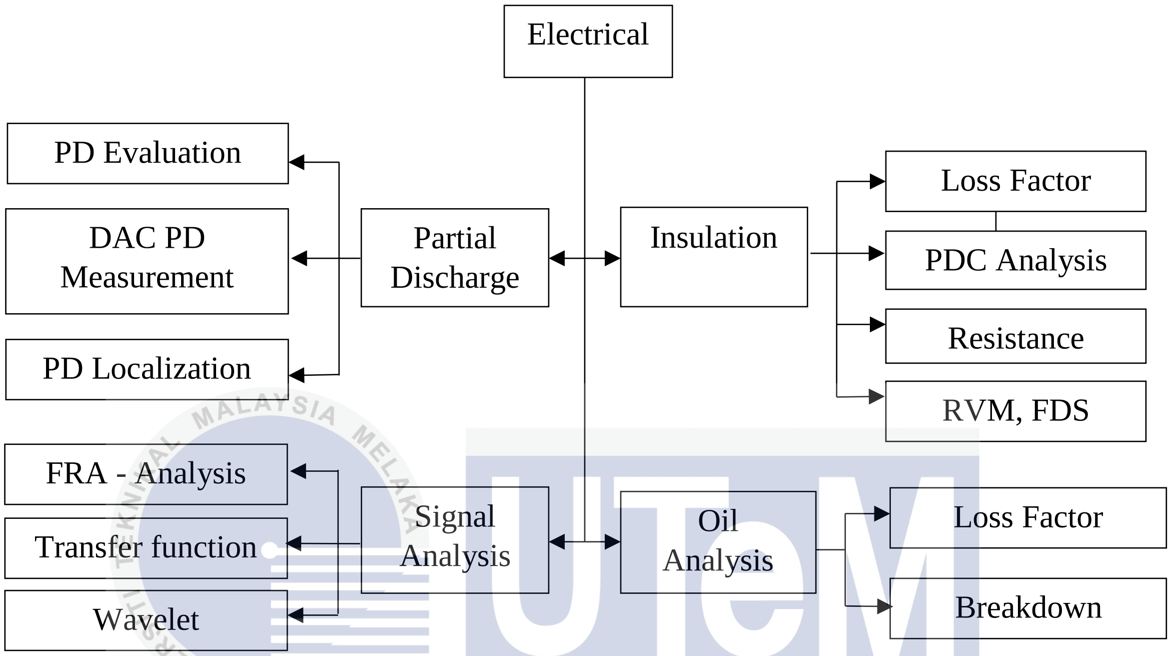


Figure 2.2: Electrical Diagnostic Methods [3, 4]

2.2.3 Thermal/Optical Diagnosis Methods

Figure 2.3 shows an overview about the thermal/optical diagnosis method that used for diagnosing the fault in the power transformers. This method divided into two parts, which are operating temperature and visual. By using the electromagnetic spectrum from 10^4 Hz up to 10^{16} Hz, both thermal and optical diagnosis methods can give information about the failure of the transformer [4].

The thermal problems can be detected by the implementation of the fibre optic sensing element and micro controller based on signal processing hardware [13]. Besides, thermography method can be used to identify the location of electrical connection problems and also a hot spot that presented in the transformer. In temperature monitoring part, it can detect the hot spot problems in the transformer that can cause to serious equipment broken [4].

The summary of classification of the heating scans as shown in Table 2.1. Each classification of heat has been assigned with their own range of temperature starting from 0 ˚C up to 50 ˚C.

Table 2.1: Classification of the heating scans [14]

Classification	Temperature Excess
Attention	0 – 9 ˚C
Intermediate	10 – 20 ˚C
Serious	21 – 49 ˚C
Critical	> 50 ˚C

Optical methods are the method that used human eye to do an inspection. Endoscopy means observes inside and typically refers to look inside the human body for medical reasons using an instrument. In these cases, the human body is replacing with the transformer. This method allows the investigation and observation by using a fibre optic endoscope inside the transformer [15]. This method will assure all the internal parts of a transformer in a good condition, economic and strategic sense.

Figure 2.3 shows the common techniques that used in the thermal/optical diagnosis method for diagnosing the fault in power transformer. The electrical diagnostic method divided by two parts, which are operating temperature and visual.

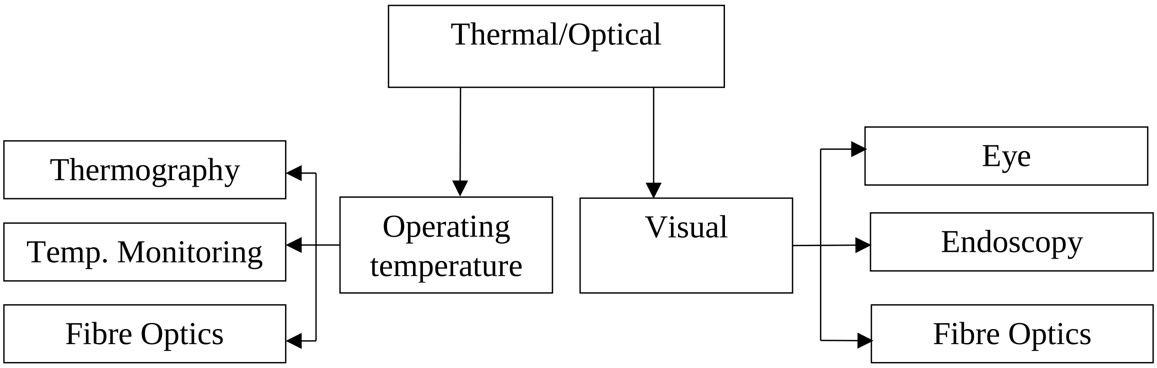


Figure 2.3: Thermal/Optical Diagnostic Methods [3, 4]

2.2.4 Mechanical Diagnosis Methods

Lastly, the diagnosis method applied in the transformer is mechanical diagnosis methods, which are divided into two parts as shown in Figure 2.4. For oil stream analysis under dynamic part, this method can control the cooling system of the transformer. The mechanical deformation by short circuit also can be detected. Besides, the transient oil pressure can be applied to monitoring the faults by applying a current surge. In the acoustic part, it is the most important method to detect the localization of partial discharge by using PD detection and operating noise method [4].

Figure 2.4 shows a summary of mechanical diagnostic method that used to diagnose the power transformer. The chemical diagnostic method divided by two parts, which are acoustics and dynamics.

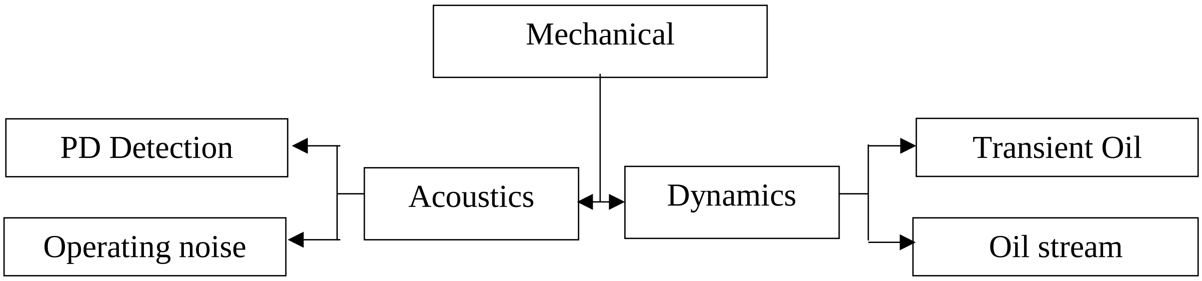


Figure 2.4: Mechanical Diagnostic Methods [3, 4]

2.3 Dissolved Gas Analysis (DGA)

DGA is one of the most important, sensitive and reliable tools for detection of a fault condition within an oil-immersed transformer [5- 7]. This method is widely used to identify the incipient faults in the transformer [3, 6, 16]. The researchers have shown that DGA can detect and gives warning of 70% of the common faults in the power transformer [17]. DGA is potential to differentiate faults in transformer such as partial discharge (corona), overheating and arcing. Each of faults will produce the different ratio of gases in the oil-filled transformer. There are different types of methods develop to diagnosis these gases. The common DGA diagnostic techniques are Key Gases, Roger Ratio, Doernburg Ratio, IEC Ratio and Duval Triangle [3, 6, 16]. The Duval Triangle is one of the diagnostic methods in the DGA. This method is better in predicting incipient faults and use in many years and also become more famous in the industry [7, 18]. There are five main fault gases analyzed in DGA which are Hydrogen (H_2), Methane (CH_4), Ethane (C_2H_6), Ethylene (C_2H_4) and Acetylene (C_2H_2) [5, 6, 8].

Table 2.2 shows the result of the comparison of DGA diagnosis method in detecting faults inside the power transformer. From Table 2.2, Duval Triangle gives the low percentage of wrong result and that is why Duval Triangle more popular nowadays.

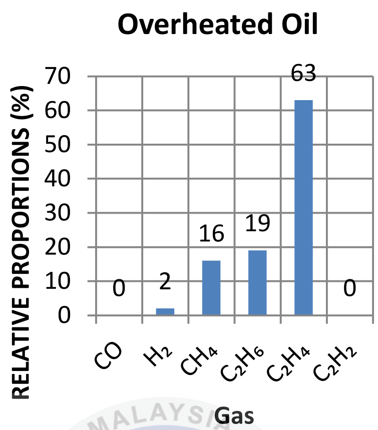
Table 2.2: Comparison of Diagnostic Method [16]

Test Methods	% Unresolved Diagnoses	% Wrong Diagnoses	% Total
Key Gases	0	58	58
Rogers	33	5	38
Doernenburg	26	3	29
IEC	15	8	23
Duval Triangle	0	4	4

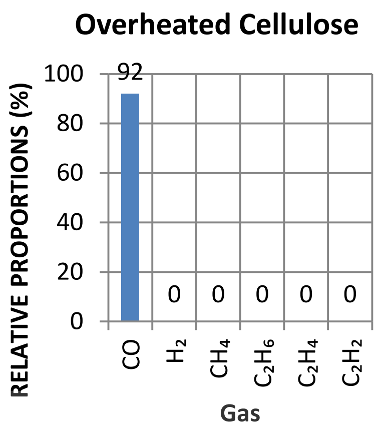
2.3.1 Key Gases Method

The Key Gases analysis is a method based on analyzing the levels of combustible gases where release by increasing of temperature in insulation oil. The fault of gases depends on the heat energy that will break the molecular bonding of the insulating oil chemical. In order to identify faults, Key Gases method used the individual gas rather than the calculation of a gas ratio [6].

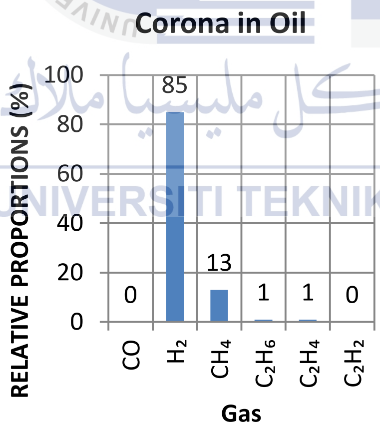
Figure 2.5 shows the relative proportions for four general fault types in Key Gases method. The types of gas that related to this method are ethylene (C_2H_4), methane (CH_4), ethane (C_2H_6), carbon monoxide (CO), hydrogen (H_2) and acetylene (C_2H_2).



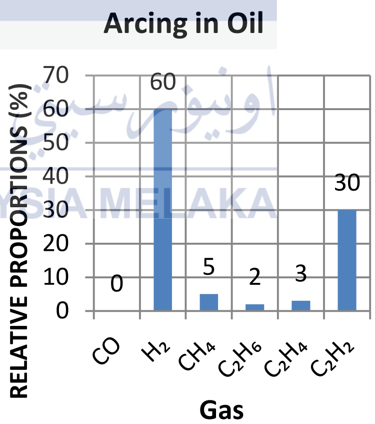
(a) Principal Gas: Ethylene



(b) Principle Gas: Carbon Monoxide



(c) Principle Gas: Hydrogen



(d) Principle Gas: Acetylene

Figure 2.5: Key Gases Diagnosis; (a) overheated oil, (b) overheated cellulose, (c) corona in oil, (d) arcing in oil [6]

The faults in the transformer have been assigned with their own specific gases in Key Gases method. The main specific of the gas problem by analyzing are overheated oil, overheated cellulose, corona in oil and arcing in oil. The arcing fault happened when a large amount of hydrogen and acetylene present with the minor amount of ethylene and methane. For corona fault, the amount of hydrogen is bigger than any gases. Moreover, the overheating of oil fault caused by the present larger amount of ethylene gas in the transformer. Lastly, the overheating of cellulose fault appears when a large amount of carbon monoxide gas in the transformer [18].

Table 2.3 shows the summary of diagnostic criteria of the Key Gases method. The mixture of two gases appoints different kind of fault occur in the transformers.

Table 2.3:Diagnostic criteria of key gas method [18]

Fault	Key gas	Criteria	Gas percent amount
Arcing	Acetylene (C_2H_2)	Large amount of H_2 and C_2H_2, and minor quantities of CH_4 and C_2H_4. CO and CO_2 may also exist if cellulose is involved.	H_2: 60% C_2H_2: 30%
Corona (PD)	Hydrogen (H_2)	Large amount of H_2, some CH_4, with small quantities of C_2H_6 and C_2H_4. CO and CO_2 may be comparable if cellulose is involved.	H_2: 85% CH_4: 13%
Overheating of oil	Ethylene (C_2H_4)	Large amount of C_2H_4, less amount of C_2H_6, some quantities of CH_4 and H_2. Traces of CO	C_2H_4: 63% C_2H_6: 20%

Overheating of cellulose	Carbon monoxide (CO)	Large amount of CO and CO_2. Hydrocarbon gases may exist.	CO: 92%

2.3.2 Duval Triangle

The Duval Triangle developed by Dr Michel Duval used for oil-insulated equipment of high voltage that mostly focused on the transformer. The three hydrocarbon gases that are methane (CH_4), ethylene (C_2H_4) and acetylene (C_2H_2) are corresponding to the increasing of the amount of this gas in transformer [6, 7, 11]. The percentage of each gas will plot on Duval Triangle where this triangle is divided into seven types of faults.

Table 2.4 shows the key faults of Duval Triangle that occur in the power transformer. There are seven kinds of faults that can be detected in the power transformers by using the Duval Triangle method.

Table 2.4: Key faults in power transformer [16, 18]

Symbol	Faults	Examples
PD	Partial discharges	Discharge of the cold plasma (corona) type in gas bubbles or voids, with the possible formation of X-wax in paper
D1	Discharges of low energy	Partial discharges of the sparking type, inducing pinholes, carbonized punctures in paper Low energy arcing inducing carbonized perforation or surface tracking of paper or the formation of carbon particles in oil

D2	Discharges of high energy	Discharges in paper or oil, with power follow through, resulting in extensive damage to paper or large formation of carbon particles in oil, metal fusion, tripping of the equipment and gas alarms
DT	Thermal and electrical faults	Mixture of thermal and electrical faults
T1	Thermal faults, T<300˚C	Evidenced by paper turning brownish (>200˚C) or carbonized (>300˚C)
T2	Thermal fault, 300<T<700˚C	Carbonization of paper, formation of carbon particles in oil
T3	Thermal fault, T>700˚C	Extensive formation of carbon particles in oil, metal coloration (800˚C) or metal fusion (>1000˚C)

2.3.3 Roger Ratio Method

Roger Ratio method is based on the four-digit code ratios that generated from the five fault gases, which are hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4) and acetylene (C_2H_2) [6, 18]. From the combination of the Roger's Ratio codes, it gives 12 different types of transformer faults. These methods used simple coding scheme based on predetermined ratio range for fault diagnosis [6, 18]. In addition, the Roger Ratio method used two tables to indicate the faults; firstly, code definition of Roger's refined ratio and secondly diagnosis of Rogers refined ratio method as shown in Table 2.5 and Table 2.6 [6, 18].

Table 2.5 shows the gas ratio codes that used in Roger Ratio method. These methods consist of four gases ratio. There are CH_4/H_2, C_2H_6/CH_4, C_2H_4/C_2H_6 and C_2H_2/C_2H_4.

Table 2.5: Code definition of Rogers refined ratio method [6, 18]

Gas Ratio	Range	Code
CH_4/H_2 (R1)	Not greater than 0.1	5
	Between 0.1 and 1.0	0
	Between 1.0 and 3.0	1
	Not less than 3.0	2
C_2H_6/CH_4 (R4)	Less than 1.0	0
	Not less than 1.0	1
C_2H_4/C_2H_6 (R5)	Less than 1.0	0
	Between 1.0 and 3.0	1
	Not less than 3.0	2
C_2H_2/C_2H_4 (R2)	Less than 0.5	0
	Between 0.5 and 3.0	1
	Not less than 3.0	2

Table 2.6 shows the classification of diagnosis result based on the Roger's Ratio codes. The result comes out from the combination of gas ratio code from Table 2.5.

Table 2.6: Diagnosis of Rogers refined ratio method [6, 18]

R1	R4	R5	R2	Diagnosis
0	0	0	0	Normal deterioration
5	0	0	0	Partial discharge
1 or 2	0	0	0	Slight overheating – below overheating 150 ˚C
1 or 2	1	0	0	Slight overheating – 150 ˚C-200 ˚C
0	1	0	0	Slight overheating – 200 ˚C-300 ˚C
0	0	1	0	General conductor overheating
1	0	1	0	Winding circulating currents
1	0	2	0	Core and tank circulating currents, overheated joints
0	0	0	1	Flashover without power follow through
0	0	1 or 2	1 or 2	Arc with power follow through
0	0	2	2	Continuous sparking to floating potential
5	0	0	1 or 2	Partial Discharge with tracking(note CO)

2.3.4 IEC Ratio Method

For IEC Ratio method, it is the same with the Roger Ratio method, but the ratio gas of C_2H_6/CH_4 is ignored. The combinations of three ratios gases give the new different ranges of code as shown in Table 2.7. Compared to Roger Ratio method, the IEC Ratio method gives nine different type transformer faults as shown in Table 2.8 [6, 19].

Table 2.7 shows the new three gas ratios that have different ranges of code compared to Roger Ratio method.

Table 2.7: MSZ-09-00.0352 Standard's Ratio for Key Gases [6, 19]

Ratio limits	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6
	Ratio codes		
<0,1	0	1	0
≥0,1…1≤	1	0	0
>1…3≤	1	2	1
>3	2	2	2

Table 2.8 shows the classification of fault based on IEC Ratio codes from Table 2.8. There are nine characteristic faults can be determined in the transformer by using this method.

Table 2.8: Fault Diagnosis [6, 19]

Case	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6	Suggested fault diagnosis
0	0	0	0	Normal
1	0	1	0	Partial discharge of low-energy
2	1	1	0	Partial discharge of high-energy
3	1 – 2	1	1 – 2	Arcing-discharge of low-energy
4	1	0	2	Arcing-discharge of high-energy
5	0	0	1	Thermal fault (110 ˚C …150 ˚C)
6	0	2	0	Thermal fault 150 ˚C …300 ˚C
7	0	2	1	Thermal fault (300 ˚C …700 ˚C)
8	0	2	2	Thermal fault (>700 ˚C)

2.3.5 Doernenburg Ratio Method

Doernenburg Ratio Method used the gas concentration from the ratio of CH_4/H_2, C_2H_2/CH_4, C_2H_4/C_2H_6 and C_2H_2/C_2H_4. This method able to detect three of general fault types in the transformer, which are Thermal Decomposition, Corona (Low Intensity Partial Discharge), Arcing (High Intensity Partial Discharge) as shown in Table 2.10. The concentration L1 of gas must exceed first to know if there is really a problem with the transformer. Table 2.9 shows the concentration L1 and their key gases. There are five steps procedure needs to be following to diagnose faults using this method [6].

Descriptions of the steps to diagnose faults using Doernenburg ratio method are as follows [6].

1. The concentration of each gas obtained by extracting the gases and separating them by the chromatograph.
2. The next step can proceed if at least one of the gas concentrations (in ppm) for H_2, CH_4, C_2H_2 and C_2H_4 exceeds twice the values for limit L1 as shown in Table 2.9.
3. The ratio procedure is valid if at least one of the gases in each ratio CH_4/H_2, C_2H_2/CH_4, C_2H_2/CH_4 and C_2H_6/C_2H_2 exceed the limit L1. Otherwise, the ratios are not significant the gas will diagnose by alternative methods.
4. Assuming the ratio analysis is valid; the value obtained from each ratio compared to the values from Table 2.10 in the order of ratio CH_4/H_2, C_2H_2/CH_4, C_2H_2/CH_4 and C_2H_6/C_2H_2.
5. The result of diagnosis is valid if all the ratios for each fault type fall within the values in Table 2.10.

Table 2.9 shows the key gases and their concentration L1 to be used to get the result of diagnosis.

Table 2.9: Concentration L1 for Doernenburg Ratio Method [6]

Key Gas	Concentrations 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 2.10 shows the fault diagnosis for Doernenburg Ratio method that occurs in the transformer. There are three common faults can detect by using this method.

Table 2.10: Fault Diagnosis for Doernenburg Ratio Method [6]

Suggested Fault Diagnosis	Ratio 1 (R1) CH_4/H_2 Extracted From Oil Gas Space	Ratio 2 (R2) C_2H_2/C_2H_4 Extracted From Oil Gas Space	Ratio 3 (R3) C_2H_2/CH_4 Extracted From Oil Gas Space	Ratio 4 (R4) C_2H_6/C_2H_2 Extracted From Oil Gas Space
1 – Thermal Decomposition	> 1.0 >0.1	<0.75 <1.0	<0.3 <0.1	>0.4 >0.2

2 – Corona (Low intensity PD)	<0.1 <0.01	Not significant	<0.3 <0.1	>0.4 >0.2
3 – Arching (High Intensity PD)	> 1.0 >0.01 <0.1 <0.1	>0.75 >1.0	>0.3 >0.1	<0.4 <0.2

2.4 Types of Duval Triangle

The Duval Triangle diagnosis was developed by Dr Michel Duval in 1974. The triangle divided into seven zones and each type of zone shows to a certain type of fault. This method always provides the diagnosis with very low percentages of the wrong results [19]. It used three hydrocarbon gases only, which are methane (CH_4), ethylene (C_2H_4), and acetylene (C_2H_2) to determine the fault of the transformer [7, 11, 20]. The Duval Triangle method diagnosis is used in equipment filled mineral oil, load tap changer (LTC) of oil type, equipment filled non-mineral such as synthetic or natural ester and low temperature faults in transformer [21].

2.4.1 The Duval Triangle 1 for Transformer Filled Mineral Oil

The Duval Triangle 1 for mineral oil-filled power transformer concentrates on three gases, which are methane (CH_4), ethylene (C_2H_4) and acetylene (C_2H_2) corresponding to the increasing energy levels of gas formation [7, 11, 20]. The relative proportions of the three gases are from 0% to 100% for each gas. Each of gas is converted to percentage in order to identify the coordinate of line intersection.

Figure 2.6 shows the Duval Triangle 1 method that used in detect incipient fault occur in mineral oil-filled power transformer.

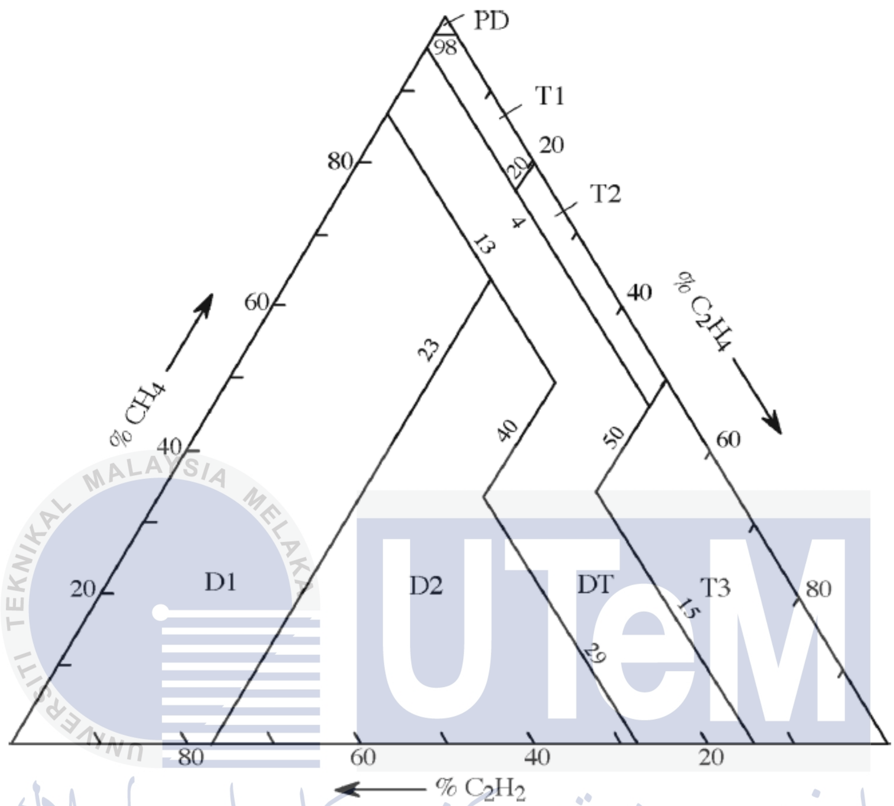


Figure 2.6: The Duval Triangle 1 for transformers filled with mineral oils [21]

Table 2.11 shows the seven types of faults that can detects using a Duval Triangle 1 method such as partial discharge, discharge of low energy, discharge of high energy, thermal and electrical faults, thermal fault below than 300 ˚C, thermal fault between 300 ˚C until 700 ˚C and lastly thermal fault over 700 ˚C. Each of fault assigns their own definition of fault occurs in the transformer.

Table 2.11: Key faults in power transformer [11]

Symbol	Faults	Examples
PD	Partial discharges	Discharge of the cold plasma (corona) type in gas bubbles or voids, with the possible formation of X-wax in paper
D1	Discharges of low energy	Partial discharges of the sparking type, inducing pinholes, carbonized punctures in paper Low energy arcing inducing carbonized perforation or surface tracking of paper or the formation of carbon particles in oil
D2	Discharges of high energy	Discharges in paper or oil, with power follow through, resulting in extensive damage to paper or large formation of carbon particles in oil, metal fusion, tripping of the equipment and gas alarms
DT	Thermal and electrical faults	Mixture of thermal and electrical faults
T1	Thermal faults, T<300˚C	Evidenced by paper turning brownish (>200˚C) or carbonized (>300˚C)
T2	Thermal fault, 300<T<700˚C	Carbonization of paper, formation of carbon particles in oil
T3	Thermal fault, T>700˚C	Extensive formation of carbon particles in oil, metal coloration (800˚C) or metal fusion (>1000˚C)

2.4.2 The Duval Triangle 2 for Load Tap Changer (LTC) Of Oil Type

The percentage of transformer failure due to LTC is very high. During a normal operation of LTC, there are interferences of gases produced. To determine the faults in LTC, the normal operation of the transformer must be identified precisely. This method has been used in investigating of LTC involves arcing between contacts and/or heating in transition resistors [21]. Duval Triangle is based on the use of three gases, which are methane (CH_4), ethylene (C_2H_4) and acetylene (C_2H_2) in calculations to determine the fault [21].

Figure 2.7 shows the Duval Triangle 2 method that used in detect incipient fault occur for LTC of oil type.

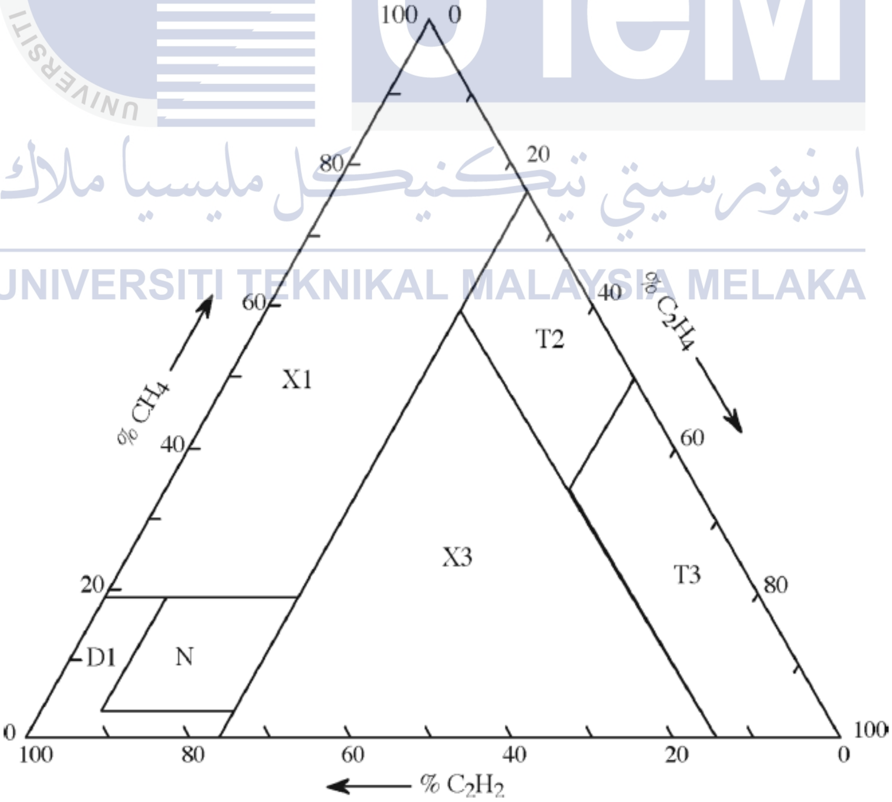


Figure 2.7: The Duval Triangle 2 for LTC of oil type [21]

Table 2.12 shows the six types of faults that can detect using a Duval Triangle 2 method in LTC of oil type.

Table 2.12: Identification of fault zones for LTC of oil type [21]

Zone	Identification	Recommended actions
N	Normal operation	
T3	Severe thermal fault T3 ($T>700^{\circ}C$), heavy coking	Change the oil inspect the LTC for cooking of contacts
T2	Severe thermal fault T2 ($300^{\circ}C < T < 700^{\circ}C$)	Test or inspect the LTC for signs of light coking or resistance of contacts, or of severe arcing
X3	Fault T3 or T2 in progress (mostly) with light coking or increased resistance of contact. Or, severe arcing D2.	Test or inspect the LTC for signs of light coking or resistance of contacts, or of severe arcing.
D1	Abnormal arcing D1 (outside of zone N)	Inspect the LTC for small signs of arcing
X1	Abnormal arcing D1 or thermal fault in progress	Area still under investigation

2.4.3 The Duval Triangle 3 for Non-Mineral Oils

The non-mineral oils are less used in electrical equipment compare with mineral oil that widely used as an insulating in electrical equipment. The examples of non-mineral oils are silicone oil, synthetic ester (Midel) and natural ester/ vegetable oil (FR3 and BioTemp) [21]. Nowadays, the non-mineral oils are ever more used because they are more environmental friendly as it is less flammable. The Duval Triangle 1 for mineral oil can be used in non-mineral oil by adjusting the boundaries to create a Duval Triangle 3 for each of the non-mineral oils as shown in Figure 2.8 [21].

Figure 2.8 shows the Duval Triangle 3 for non-mineral oil. The zone for Duval Triangle 1 for mineral oil is same as the Duval Triangle 3 for non-mineral except for zones T1/T2, T2/T3 and D1/D2 in boundaries (%C_2H_4). Zone boundaries specific for each non-mineral oil are in color. Those in black are the same as Duval Triangle 1 for mineral oil [21].

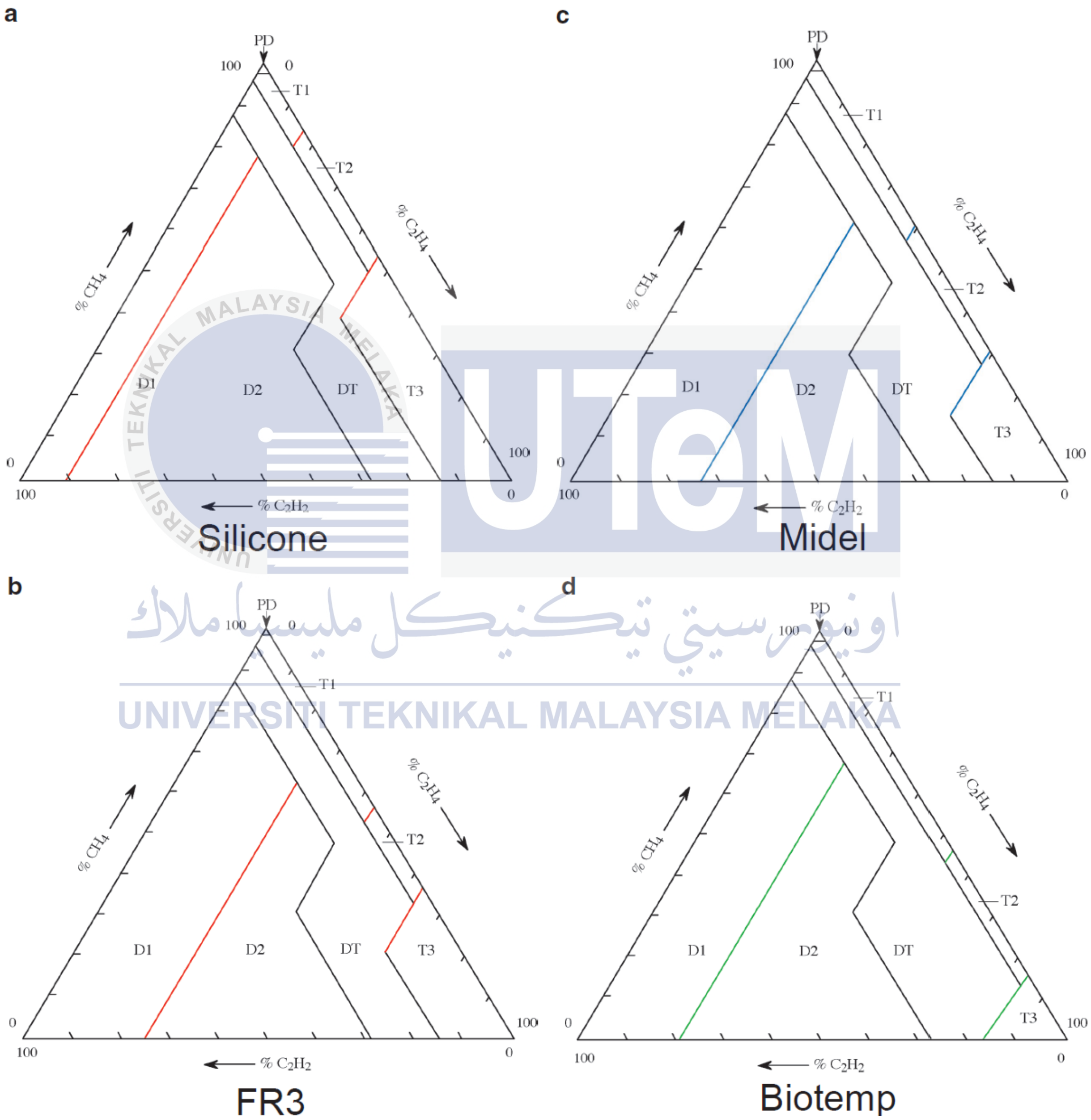


Figure 2.8: The Duval Triangle 3 for non-mineral oils; (a) Silicone, (b) Midel, (c) FR3, (d) BioTemp [21]

2.4.4 The Duval Triangle 4 and 5 for Low Temperature Fault in Transformer

The Duval Triangle 4 used three gases called low-energy gases, which are hydrogen (H_2), methane (CH_4) and ethane (C_2H_6) while for the Duval Triangle 5, it used three gases called temperature gases, which are ethylene (C_2H_4), methane (CH_4) and ethane (C_2H_6). Both methods based on the inspected cases of transformer faults and stray gassing test results in the laboratory [21]. This method is very efficient way to detect the type of fault in the transformer (D1, D2, T1, T2, T3 and PD) [21]. If the faults close to the zone of boundary PD and T1, it might be difficult to differentiate between these two types of faults. The present of stray gases in the PD, T1 or T2 zone may be interfering of identification of fault in the transformer. Hence, the Duval Triangle for low temperature has been developed to overcome this problem [21].

Figure 2.9 shows the Duval Triangle 4 for low temperature faults in the transformers filled with mineral oil. There are five types of fault can detect in the transformer.

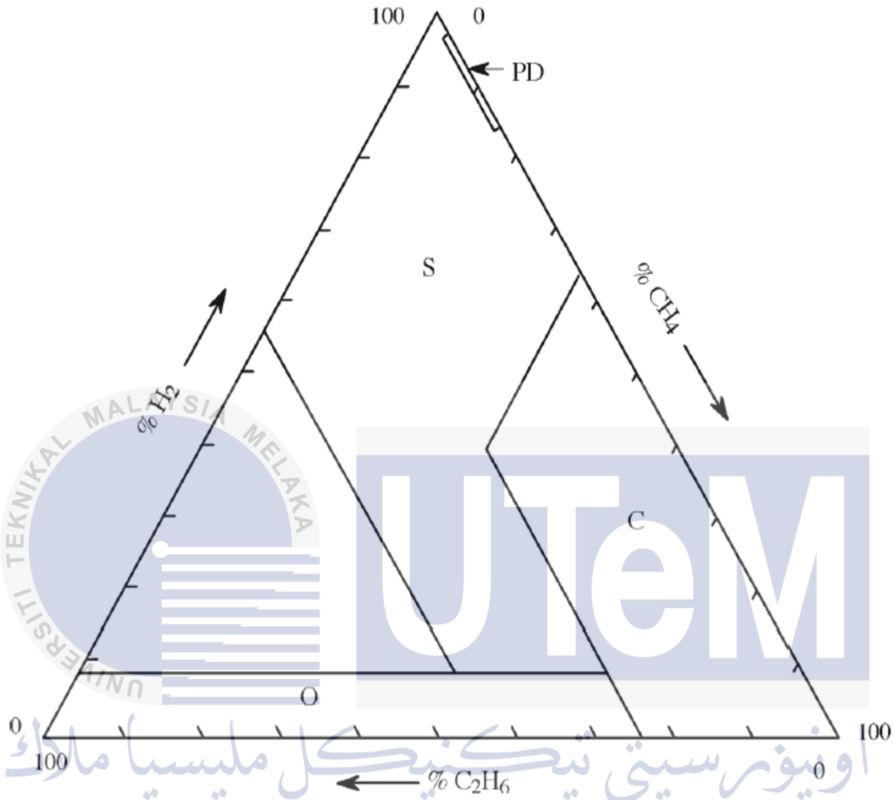


Figure 2.9: The Duval Triangle 4 for low-temperature faults in transformers filled with mineral oil [21]

Figure 2.10 shows the Duval Triangle 5 for low temperature faults in the transformers filled with mineral oil. There are seven types of fault can detect in the transformer.

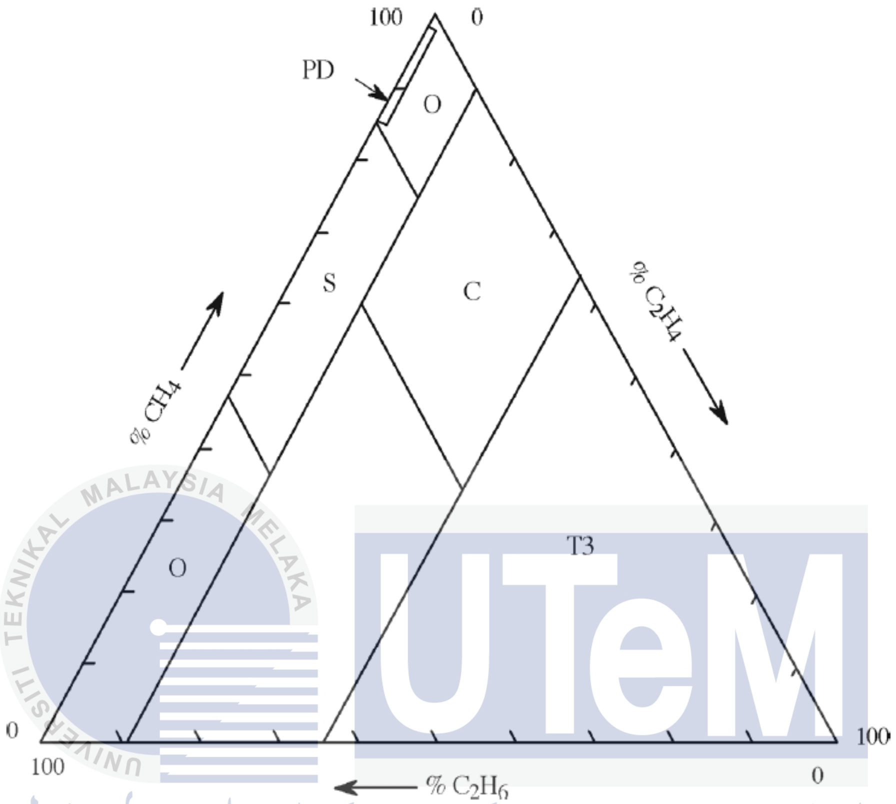


Figure 2.10: The Duval Triangle 5 for low temperature faults in transformers filled with mineral oil [21]

Table 2.13 shows the identification of fault zones that can detect using Duval Triangle 4 and 5 in the transformers.

Table 2.13: Identification of fault zones [21]

PD	Corona Partial Discharges
S	Stray gassing of mineral oil
C	Hot spots with carbonization of paper (T > 300 ˚C)
O	Overheating (T > 250 ˚C)

2.5 Java

Java is an example of a high-level language. This programming language differs from the other programming language in a couple of significant ways. Programmer enables to write based command of Java programming using English instead of having to write in numerical coding. Most Java compilers produce machine language for a hypothetical machine and well-known as Java Virtual Machine (JVM). To run a Java program on a particular machine, the JVM machine code must be translated into the machine code on that machine. Small Java applications are called Java applet function as an interface to Java. A graphical can be running in this applet [22, 23]. As the Duval Triangle is a graphical method, this triangle can be plotted using Java. The mathematical equation also can be expressed in Java programming. Hence, Java is one of the programming that can be developed Duval Triangle software.

2.6 Reviews of Previous Related Works

Reference [7], Akbari, Setayeshmehr, Borsi, and Gockenbach have published a paper on the software implementation of the Duval Triangle method. In this paper, the researchers discussed the procedures on how to develop new Duval Triangle software using Java programming. The triangles coordinates need to be converted into the Cartesian coordinate using the trigonometry concept in order to plot Duval Triangle. As the Duval Triangle has seven faults zone boundaries, the researchers need to determine a polygon for each zone. The researchers implement Java programming because of its importance in modern application and also become famous for the software engineers. Besides, there is a lot of a free tool or compiler for Java. All the seven zones can be defined using Java *Polygon()* function, while Java *addpoint()* function used to add each of the single Cartesian coordinates to a single polygon. To determine the fault in the Duval Triangle, a Java *contains()* function is used for defining the fault. Lastly, the conversion from Cartesian coordinates to the graphic coordinates is needed to display the Duval Triangle and polygon inside it. The concept of graphic coordinates is vice versa to the Cartesian coordinate which is the coordinates increasing down and to the right.

Reference [11], Sukhbir Singh, Dheeraj Joshi and M.N. Bandyopadhyay have published a paper on the software implementation of the Duval Triangle technique for DGA in the power transformer. The researchers explained the implementation of MATLAB programming in developing new Duval Triangle software. Firstly, the polygon coordinates for zone boundaries of faults have been converted in terms of percentage of CH_4, C_2H_4 and C_2H_2 from 0% to 100% respectively. Then, three sides of the triangle plotted to 60˚ at each side. Next, the Duval Triangle plotted by referred to the new coordinates in terms of percentage. To spot any point in the triangle, such as to calculate Cartesian coordinate of point $R(R_x, R_y)$ which is collected from the ratio of the three gases, the researchers used a simple mathematics equation as Equation 2.1 and Equation 2.2.

$$R_x = 0 + CH_4 * \cos 30^\circ \tag{2.1}$$

$$R_y = 0 + (C_2H_4 + CH_4 * 0.5) \tag{2.2}$$

There are a lot of advantages of using Java language compared to MATLAB in designing the Duval Triangle method. Java language is easier to understand and used in developing graphical method. Moreover, Java language can be run on the various of open-source software such as Eclipse software, which can be downloaded free on the Internet. In addition, the MATLAB software is licensed software which the users need to buy the software at expensive prices. Apart from that, the installer size for MATLAB is bigger compared to the Java open-source software.

Up to present, according to the reviews that have been done previously, there is no application of Eclipse software in power transformer diagnostics that have been proposed until now. Hence, by considering the advantages and disadvantages of both methods in previous researches, the usage of Java language that runs in Eclipse software is proposed. Therefore, this project is proposed for new developed Duval Triangle software using Eclipse software.

2.7 Summary

In these chapters, there were seven sections included the summary of this chapter. This chapter starts to describe of overview the content in literature review regarding from other research works. The general information on diagnosis in the transformer conditions which are chemical, electrical, mechanical, optical and thermal methods and more details of these five methods were discussed in Section 2.2. Then, in Section 2.3 explained about DGA with the different types of method in DGA includes Roger Ratio, IEC Ratio, Doernenburg Ratio, Key Gases and Duval Triangle method. Next, the basic principle of the Duval Triangle method was elaborated in Section 2.4, which is one of the methods in the

DGA. More detail on methodology for developing the Duval Triangle via Eclipse software present in the Chapter 3. A simple briefed about Java programming in Section 2.5 as it is used in this project. Lastly, there were some reviewed of previous work about Duval Triangle software in Section 2.6.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Chapter 3 will describes the method of experimental procedure and task of planning in developing Duval Triangle software. AutoCAD and Eclipse software is used as the tool to develop Duval Triangle software to diagnose the types of fault. This chapter will describe nine sections include the summary of this chapter. Section 3.2 explains the flowchart of methodology of this project. Then, in Section 3.3 will elaborate the plotting of fault zones in the Duval Triangle by using the coordinates of fault zones while, in Section 3.4 presents the setup of Duval Triangle using AutoCAD software. Furthermore, in Section 3.5 presents the setup of Duval Triangle using Eclipse software. A part from that, in Section 3.6 will describes on the Java programming that used to develop new Duval Triangle software. Moreover, in Section 3.7 will discuss on the result display in the Eclipse software. Lastly, the validation procedures take place on the new developed Duval Triangle software with Microsoft Excel Duval Calculator in Section 3.8.

3.2 Flowchart of Methodology

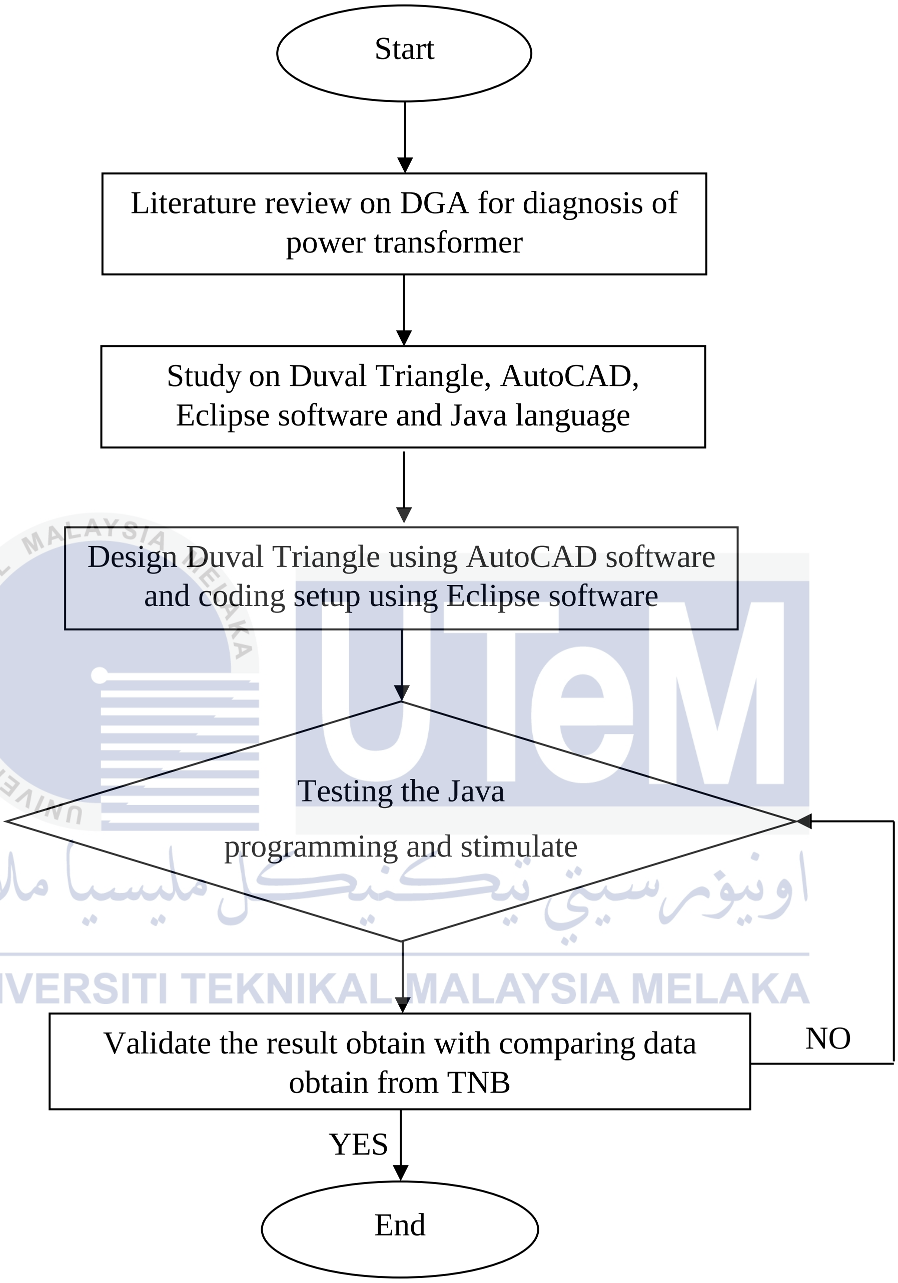


Figure 3.1: The flowchart of the methodology

Figure 3.1 presents the flowchart of project methodology, which took about a year to complete. Basically, the methodology for this project divided into four stages of the process. Stage one is about a detailed study of research on DGA. Stage two is the study of the software that used in the design Duval Triangle. Stage three is designs the Duval

Triangle by using AutoCAD and Eclipse software. Stage four is validation data of the result obtained. A clear explanation of each stage presented as follows:

i. Literature review on DGA

The literature reviews regarding on previous researchers work in identifying any important issue about the DGA method from IEEE journals, articles, books, etc. This stage more involved study of the concept of DGA methods to detect the incipient faults, studies on fault occur in the power transformer and a method of the DGA to interpret the fault gases. Besides, the research on previous work that related to the Duval Triangle method used as a reference in this project. In addition, the information about Java, Eclipse and AutoCAD is required as it is important in the development Duval Triangle.

ii. Study on Duval Triangle, AutoCAD, Eclipse software and Java language

Before developing the Duval Triangle software, there needs a study on the triangle in detail so that it will be easier to plot the triangle. Besides, the study of AutoCAD software also important because to get the coordinates of each zone boundary in the triangle. All the coordinates will use in Java programming. Eclipse software is software that will run the Java programming. In the Java programming will specify on the designing of the triangle, stimulate calculating the mathematical and the design of graphical of the Duval Triangle software. This stage included revising the tutorial from the Internet, articles, journal and books.

iii. Design and Coding Setup Duval Triangle using Eclipse Software

This new developed of Duval Triangle software is based on the graphic coordinate system that running on the Eclipse software by using Java programming. Firstly, by using

AutoCAD software, the polygon coordinates for the numerical zone boundaries of seven key faults of Duval Triangle has been converted in terms of percentages of methane (CH_4), ethylene (C_2H_4) and acetylene (C_2H_2) from 0% to 100% respectively. Then, the coordinate (x, y) of the polygon at AutoCAD software is reused in Java programming. In Java programming, the coordinates of each zone must be put correctly. This can avoid in wrong design of the triangle. To plot a line, the coordinates at the initial and final point is used with a help of line command. As the Duval Triangle has seven polygons triangle, the polygons need to plot one by one until the Duval Triangle completed.

iv. Research Validation Data

If the Duval Triangle built successfully, the next step is validation data in which compared with the results from existing software by applying the real data of DGA from TNB with this new developed Duval Triangle software. The Duval Triangle software must be deal with the real data gathering from TNB. If there any problem while developing the software, the revisions are required. It is included revising the tutorial from Eclipse help or obtaining the tutorial from the Internet and books.

3.3 Duval Triangle Fault Zones Coordinates

The Duval Triangle concentrates on the three gases, which are methane (CH_4), ethylene (C_2H_4) and acetylene (C_2H_2). The relative proportion of the three gases is from 0% to 100% for each gas. Each of the gases is converted to percentage in order to identify the coordinate of line intersection. The different values of gas assign the different kind of fault that occurs in the power transformer. There is seven boundaries area of fault in the Duval Triangle and each of boundary area has been appointed with their own coordinates. The seven boundaries area of fault can be determined according to Figure 3.2. To develop the Duval Triangle, a simple trigonometry method can be applied to create polygon in triangular map. By using AutoCAD software and the information of coordinates of the polygon in triangular map, the Duval Triangle can plot easily. Table 3.1 shows a polygon coordinates for the numerical zone boundaries of seven key faults of Duval Triangle.

Figure 3.2 shows the seven different zone boundaries in the Duval Triangle. Each of zones indicates the types of faults occur in the power transformer.

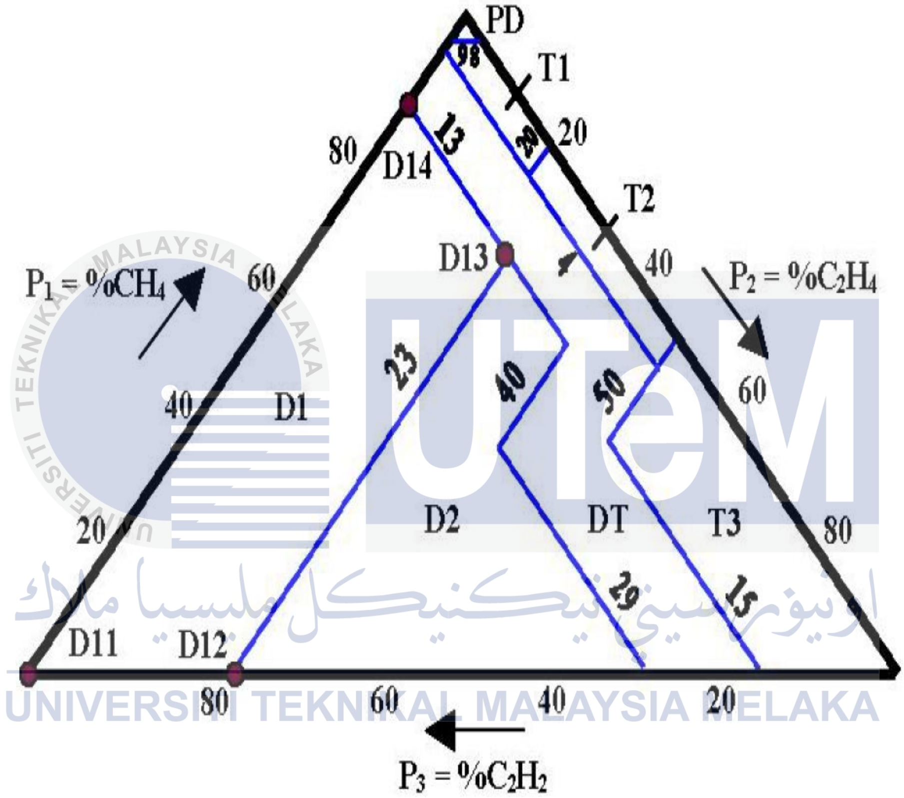


Figure 3.2: Different fault zone inside the triangle [7]

Table 3.1 shows a polygon coordinates for the numerical zone boundaries of seven key faults of Duval Triangle. The coordinates have been converted to percentage as to ease to plot the triangle.

Table 3.1: Triangular coordinates for Duval Triangle 1 Zones [4, 11]

Area	Points	% CH_4	% C_2H_4	% C_2H_2
PD	PD1	98	2	00
	PD2	100	00	00
	PD3	98	00	2
D1	D11	0	0	100
	D12	0	23	77
	D13	64	23	13
	D14	87	00	13
D2	D21	00	23	77
	D22	0	71	29
	D23	31	40	29
	D24	47	40	13
	D25	64	23	13
DT	DT1	00	71	29
	DT2	00	85	15
	DT3	35	50	15
	DT4	46	50	4
	DT5	96	00	4
	DT6	87	00	13
	DT7	47	40	13
	DT8	31	40	29
T1	T11	76	20	4
	T12	80	20	00
	T13	98	2	00
	T14	98	00	2
	T15	96	00	4

T2	T21	46	50	4
	T22	50	50	00
	T23	80	20	00
	T24	76	20	4
T3	T31	00	85	15
	T32	00	100	00
	T33	50	50	00
	T34	35	50	15

3.4 Duval Triangle Software Setup using AutoCAD Software

AutoCAD is a two-dimensional and three-dimensional computer-aided drafting software application used in architecture, construction and manufacturing to help in the preparation of blueprints and other engineering plans. AutoCAD is used mainly by drafters, as well as engineers, surveyors and architects also need to use the software from time to time.

Duval Triangle has seven zone fault boundaries in the equivalent triangle. This tool very suitable to plot the Duval Triangle to get the coordinates that will be used in the Java programming. Hence, this tool can help in plotting the Duval Triangle. By using the line command in this software and referring to coordinate in Table 3.1, it is eased to plot the Duval Triangle in AutoCAD software. The Figure 3.3 shows the Duval Triangle in AutoCAD software.

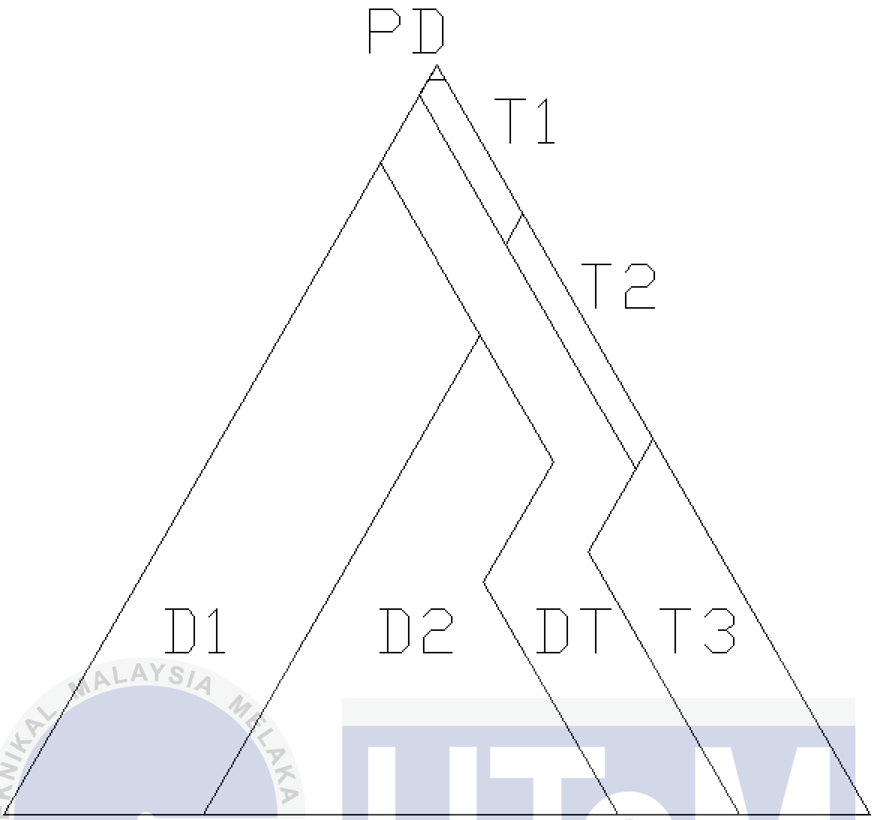


Figure 3.3: A new developed Duval Triangle region using AutoCAD

3.5 Duval Triangle Software Setup using Eclipse Software

Eclipse is a Java-based open-source platform supported by IBM that allows developers to create a customized Integrated Development Environment (IDE) from plug-in components built by Eclipse members. It is popular for Java application development (Java SE and Java EE) and Android apps. Moreover, Eclipse also supports C/C++, PHP, Python, Perl and other web project development via extensible plug-ins. Eclipse provides a common user interface (UI) model for working with tools. Java programming is suitable for visualization, analyze data, develop mathematical algorithms and create models and applications.

Besides MATLAB, Java programming also can make the users analyze their own mathematical algorithms and developed applications or models quickly. Thus, the main reasons of choosing Eclipse software and Java programming as a tool to implementation the Duval Triangle because the language of programming is simple and easy to understand. Google has created the Android Development Tools (ADT) plug-in for Eclipse and Android Virtual Device (AVD) Manager, which act as a virtual device management in Eclipse software. AVD Manager is a simple user interface for managing configuration of the AVD (Android virtual device).

Moreover, an AVD is a device configuration for the Android emulator which allows to model different configurations of Android devices. In a simple word, the Java programming not only build, but it must be tested by emulators (virtual device) to show how the coding will run in a certain uniform Android device. As a conclusion, by inserting the values of the three gases in parts per million (ppm) units, the software will run the calculation for the user and calculate the ratio of each gas. Then, the software will decide the types of faults that occur in the power transformer.

Figure 3.4 shows the full flow operations of new developed Duval Triangle software by using Eclipse software and Java programming.

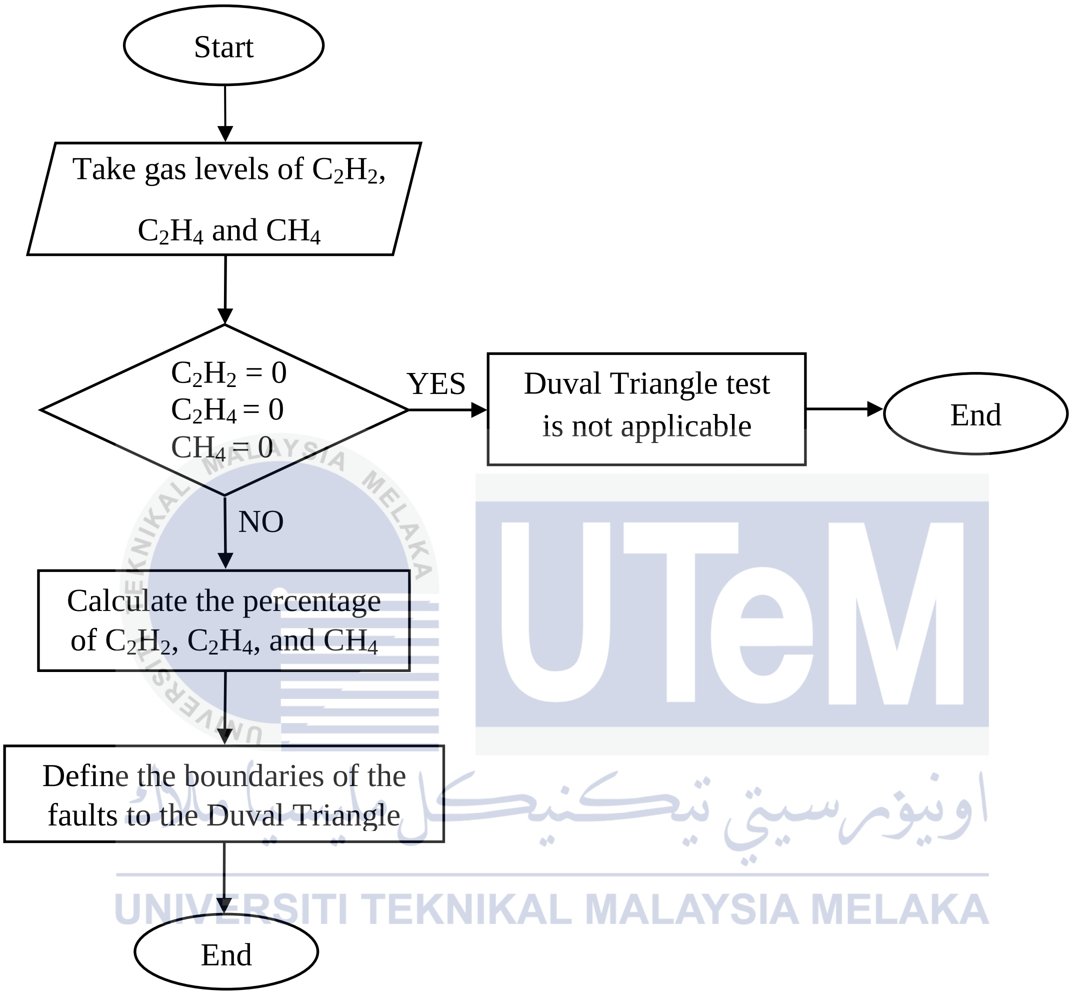


Figure 3.4: A flow operations of new developed Duval Triangle

3.6 Java Programming

This section gives the explanations on the modeling or plotting the Duval Triangle in triangular coordinates and mathematical equation used for identifying faults using Java programming. The implementation of Duval Triangle can be presented in triangular coordinates to visualize the diagnostic results. There are three main parts of programming to be done to complete the creation of new software Duval Triangle. The first part is modeling or plotting the Duval Triangle, the second part is calculating the ratio of the three gases, and the final part is a mathematical equation to identifying the types of faults occur in the power transformer. Thus, the output of the coding will appear on AVD.

Step 1: Plotting the Duval Triangle

Before plotting the Duval Triangle using Java programming, there is a method that must be taken first. The method mention is plotting Duval Triangle using AutoCAD software. By referring triangular coordinate in Section 3.3, the seven zones of the boundaries of a triangle can be plotted easily. After the complete plot the triangle, the coordinate (x, y) of the polygon at AutoCAD software is transferred into Java programming. In Java programming, the coordinates of each zone must be put correctly. This can avoid in wrong design of the triangle. To plot a line, the coordinate at the initial and final point is used with a help of line command. As the Duval Triangle has seven polygons triangle, the polygons need to plot one by one until the Duval Triangle completed.

Figure 3.5 and Figure 3.6 shows a part of Java programming used to plot a complete Duval Triangle. In Figure 3.5, this coding used to plot a seven boundaries in the Duval Triangle, while in Figure 3.6 this coding for colouring the seven regions in the Duval Triangle. For a table of fault, parameters of the power transformer, faults detected and other criteria have their own coordinates. It is important to make sure that it not intersects with the triangle.

```
//Large triangle
canvas.drawLine( (int) 30, (int) 430, (int) 230, (int) 83.59, paint);
canvas.drawLine( (int) 430, (int) 83.59, (int) 430, (int) 430, paint);
canvas.drawLine( (int) 430, (int) 430, (int) 30, (int) 430, paint);

// D1 region
canvas.drawLine( (int) 122, (int) 430, (int) 250, (int) 208.2976, paint);
canvas.drawLine( (int) 250, (int) 208.3976, (int) 204, (int) 128., paint);

// D2 and DT region
canvas.drawLine( (int) 314, (int) 430,        (int) 252, (int) 322.64, paint);
canvas.drawLine( (int) 252, (int) 322.64, (int) 284, (int) 267.1872, paint)
canvas.drawLine( (int) 284, (int) 267.1872, (int) 250, (int) 208.2976, paint);

// T3 region
canvas.drawLine( (int) 370, (int) 430,        (int) 300, (int) 308.7564, paint);
canvas.drawLine( (int) 300, (int) 308.7564, (int) 330, (int) 256.7948, paint);

// T1 and T2 region
canvas.drawLine( (int) 322, (int) 270.6512, (int) 222, (int) 97.4464, paint);
canvas.drawLine( (int) 262, (int) 166.7284, (int) 270, (int) 152.872, paint);

// PD region
canvas.drawLine( (int) 226, (int) 90.518,(int) 234, (int) 90.518, paint);
```

Figure 3.5: Java programming to plot Duval Triangle in Eclipse software

Figure 3.6 shows a coding used to colouring the seven regions in the Duval Triangle. Each of the regions in the Duval Triangle differentiates with different colours.

```
//Large triangle
paint3.setStyle(Paint.Style.FILL);
paint3.setColor(Color.TRANSPARENT);
Path path8 = new Path();
path8.moveTo(30, 430); path8.lineTo(230, 84); path8.lineTo(430, 430); path8.close();
canvas.drawPath(path8, paint3);

//D1 region
paint1.setStyle(Paint.Style.FILL); paint1.setColor(Color.CYAN);
Path path4 = new Path(); Path path41 = new Path(); path4.moveTo((int)x1, (int)y1);
path4.lineTo(122, 430); path4.lineTo(250, 209); path4.lineTo(204, 128);
path41.moveTo((int)x1-1, (int)y1); path41.lineTo(122+1, 430); path41.lineTo(250+1,
209); path41.lineTo(204+1, 128+1); path4.close();path41.close();
canvas.drawPath(path4, paint1);

//D2 region
paint1.setStyle(Paint.Style.FILL);
paint1.setColor(Color.BLUE);
Path path1 = new Path();Path path11 = new Path();
path1.moveTo(122, 430); path1.lineTo(314,430); path1.lineTo(252, 323);
path1.lineTo(284, 267); path1.lineTo(250, 209);
path11.moveTo(122+1, 430); path11.lineTo(315,430); path11.lineTo(253+1, 324);
path11.lineTo(285+1, 268); path11.lineTo(250+1, 209);
path1.close();path11.close();
canvas.drawPath(path1, paint1);

//DT region
paint3.setStyle(Paint.Style.FILL);
paint3.setStrokeWidth(2);
```

```
paint3.setColor(Color.MAGENTA);
Path path7 = new Path();
Path path71 = new Path();
path7.moveTo(314, 430); path7.lineTo(370, 430); path7.lineTo(300, 309); path7.lineTo(322, 271); path7.lineTo(222, 97); path7.lineTo(204, 128);path7.lineTo(284, 267); path7.lineTo(252, 323);
path71.moveTo(314+1, 430); path71.lineTo(370-1, 430); path71.lineTo(300-1, 308); path71.lineTo(322, 270); path71.lineTo(222, 97); path71.lineTo(204+1, 128-1);path71.lineTo(284+1, 267); path71.lineTo(252+1, 323);
path7.close();path71.close();
canvas.drawPath(path7, paint3);

//T1 region
paint3.setStyle(Paint.Style.FILL);
paint3.setColor(Color.GRAY);
Path path5 = new Path();Path path51 = new Path();
path5.moveTo(270, 152); path5.lineTo(262, 167); path5.lineTo(222, 97); path5.lineTo(226, 91); path5.lineTo(234, 91);
path51.moveTo(270+1, 152+1); path51.lineTo(262, 167); path51.lineTo(222, 97); path51.lineTo(226-2, 91+1); path51.lineTo(234+2, 91+1);
path5.close();path51.close();
canvas.drawPath(path5, paint3);

//T2 region
paint3.setStyle(Paint.Style.FILL);
paint3.setColor(Color.GREEN);
Path path3 = new Path();Path path31 = new Path();
path3.moveTo(330, 257); path3.lineTo(322, 270); path3.lineTo(262-1, 167-1); path3.lineTo(270, 152);
path31.moveTo(330, 257); path31.lineTo(322-1, 270); path31.lineTo(262-1, 167); path31.lineTo(270+1, 152+1);
path3.close();path31.close();
canvas.drawPath(path3, paint3);
```

```
//T3 region
paint2.setStyle(Paint.Style.FILL);
paint2.setColor(Color.RED);
Path path2 = new Path();Path path21 = new Path();
path2.moveTo((int)x3, (int)y3); path2.lineTo(370, 430); path2.lineTo(300, 309);
path2.lineTo(330, 257);
path21.moveTo((int)x3+1, (int)y3); path21.lineTo(370-1, 430); path21.lineTo(300-1,
309); path21.lineTo(330-1, 257-1);
path2.close();path21.close();
canvas.drawPath(path2, paint2);

//PD region
paint3.setStyle(Paint.Style.FILL);
paint3.setColor(Color.parseColor("#FFA500"));
Path path6 = new Path();Path path61 = new Path();
path6.moveTo(230, 84-1); path6.lineTo(226, 91); path6.lineTo(234, 91);
path61.moveTo(230, 84-2); path61.lineTo(226-2, 91+1); path61.lineTo(234+2, 91+1);
path6.close();path61.close();
canvas.drawPath(path6, paint3);
```

Figure 3.6: Java programming to colouring Duval Triangle in Eclipse software

Step 2: Calculation the ratio of three gases

The three sides of the Duval Triangle are expressed in triangular coordinates (a1, b1, c1) representing the relative proportions of CH_4, C_2H_4 and C_2H_2 from 0% to 100% for each gases. In order to display a DGA result in the Duval Triangle method, then it must start with the concentration of the three gases, CH_4, C_2H_4 and C_2H_2 in ppm unit. The DGA by Duval Triangle method involves the percentage of gas (CH_4, C_2H_4 and C_2H_2) ratios in graphical presentation. Equation 3.1, Equation 3.2 and Equation 3.3 represent the formula used to calculate the relative percentage (%) of the three gases. Each of the three sides is necessarily between 0% until 100% and (a1 + b1 + c1) should always = 100%.

$$\%CH_4\ (a1) = \frac{CH_4}{CH_4+C_2H_4+C_2H_2}\ X\ 100\% \quad (3.1)$$

$$\%C_2H_4\ (b1) = \frac{C_2H_4}{CH_4+C_2H_4+C_2H_2}\ X\ 100\% \quad (3.2)$$

$$\%C_2H_2\ (c1) = \frac{C_2H_2}{CH_4+C_2H_4+C_2H_2}\ X\ 100\% \quad (3.3)$$

Table 3.2 represents an example of calculation to finding the percentage every type of gases by using Equation 3.1, Equation 3.2 and Equation 3.3. The volume of three gases are choosing which is CH_4 = 180 ppm, C_2H_4 = 110 ppm and C_2H_2 = 135 ppm and represent as a1, b1 and c1.

Table 3.2: Calculation the ratio of gases in percentages

Gases	Volume (ppm)	Percentages of Gases
CH_4 (a1)	180	42.35 %
C_2H_4 (b1)	110	25.88 %
C_2H_2 (c1)	135	31.76 %
Total	425	100 %

Step 3: Identification of range of three gases

Before the new developed Duval Triangle software did the simulation, the user has to insert the value of three gases as an input to the programming. The limit of the percentages the three of gases will be read by the Java programming and the programming will command for expression while running. From the example of Table 3.2, the percentage of gases CH_4 (a1), C_2H_4 (b1) and C_2H_2 (c1) are 42.35 %, 25.88 % and 31.76 %. This will indicate that the appropriate range of faults falls at “D2 – Electrical Discharge of

High Energy". This input will be processed by the Java programming as shown in Figure 3.7. In addition, the further programming attached in Appendix A.

Figure 3.7 shows a part of Java programming that used to detect the faults that occur in the power transformer. The red box shows the identification of fault in the Java programming which fault at D2 region. Each of zone boundaries has been set according to the triangular coordinates in Section 3.3.

```
if (u1==0 && u2==0){
      l1.tfault.setText("D1 ELectrical Discharges of Low Energy");
    }
    else if(u2==0 && u3==0){
      l1.tfault.setText("PD Corona Partial Discharge");
      }
    else if(u1==0 && u3==0){
      l1.tfault.setText("T3 Thermal Faults, T>700˚C");
      }
    else if ((Double.isNaN(u1))){
      l1.tfault.setText("Error Fault");
    }

    else if (l1.a1>=98 && l1.b1<=2 && l1.c1<=2){
      l1.tfault.setText("   PD Corona Partial Discharge  ");
    }

    else if (l1.a1<=98 && l1.a1>=96 && l1.b1<=20 && l1.b1>=2 && l1.c1<=4){
      l1.tfault.setText("   T1 Thermal Faults of Temperature T<300˚C  ");
    }

    else if (l1.a1<=98 && l1.a1>=76 && l1.b1<=20 && l1.b1>=2 && l1.c1<=4){
      l1.tfault.setText("   T1 Thermal Faults of Temperature T<300˚C  ");
    }
```

```
else if (l1.a1<=98 && l1.a1>=76 && l1.b1<=20 && l1.b1>=0 && l1.c1<=4){
    l1.tfault.setText("   T1 Thermal Faults of Temperature T<300˚C  ");
}

else if  (l1.a1<=50  && l1.b1>=50 && l1.c1<=15)     {
    l1.tfault.setText("  T3 Thermal Faults, T>700˚C  ");
}

else if (l1.a1>=46 && l1.a1<=80 && l1.b1<=50 && l1.b1>=20 && l1.c1<=4){

    l1.tfault.setText("  T2 Thermal Faults, 300˚C<T<700˚C  ");
}

else if (l1.c1== 4 && l1.a1 >= 76 && l1.b1 <= 20){
    l1.tfault.setText("  D2 ELectrical Discharges of High Energy   ");
}

else if (l1.c1== 29 && l1.a1 <= 35 && l1.b1 >= 50){
    l1.tfault.setText("  D2 ELectrical Discharges of High Energy   ");
}

else if( l1.a1<=87 && l1.b1<=23 && l1.c1>=13){
    l1.tfault.setText("  D1 ELectrical Discharges of Low Energy   ");
}

else if (l1.a1<=45 && l1.b1>=23 && l1.c1>=29 && l1.c1<=77){
    l1.tfault.setText("   D2 ELectrical Discharges of High Energy  ");
}

else if (l1.a1<=64 && l1.a1 >=45 && l1.b1<=40 && l1.b1>=23 && l1.c1<=29
&& l1.c1>=13){
    l1.tfault.setText("  D2 ELectrical Discharges of High Energy   ");
}
```

```
            else if (l1.a1<=47 && l1.a1 >=31 && l1.b1<=40 && l1.b1>=23 &&
l1.c1<=29 && l1.c1>=13){
         l1.tfault.setText("  D2 ELectrical Discharges of High Energy  ");
      }

      else if ( l1.a1<=35 && l1.b1>=50 && l1.c1>=15 && l1.c1<=29){
         l1.tfault.setText("   DT Mixtures of Electical & Thermal Faults  ");
      }

      else if (l1.a1>=20 && l1.a1<=55 && l1.b1>=40 &&  l1.b1<=50 && l1.c1>=4 &&
l1.c1<=29){
         l1.tfault.setText("   DT Mixtures of Electical & Thermal Faults  ");
      }

      else if  (l1.a1>=47 && l1.a1<=96 && l1.b1<=40 && l1.c1<=13 && l1.c1>=4){
         l1.tfault.setText("  DT Mixtures of Electical & Thermal Faults   ");
      }
```

Figure 3.7: Java programming to detect faults occurs in the power transformer

3.7 Display Results in Eclipse Software

The function of an Android Virtual Device (AVD) Manager is to configure the emulator that allows users to model an actual device by specifying hardware and software option. The output result of Java programming will be shown at AVD. It will show the coding running smoothly or not. Here, the user needs to insert the input of the three gases, and then the result will be shown of incipient fault occur in the transformer. Various virtual buttons can be used at AVD such as hardware button, D-pad button and basic control. Figure 3.8 shows the interface of AVD in Eclipse software.

The new developed Duval Triangle software will be displayed at the AVD. Here, the users need to key in all the parameters of the power transformer. Then, this new software will calculate the ratio of each gas. After all calculations were done, the result of fault that occurs in the power transformer will be displayed.

Figure 3.8: The interface of Android Virtual Device (AVD) in Eclipse software

3.8 Research Validation from Java Programming with Excel

The validation of this new software is the most important part in developing this new Duval Triangle. After developing the Duval Triangle via Eclipse software, the results of diagnosis will be compared with the existing software that used by TNB. The existing software has been developed via Microsoft Excel from other developers in order to detect the incipient fault in the power transformer using the Duval Triangle method. By inserting the real data of DGA getting from TNB into Microsoft Excel Duval Calculator, the results from Excel must be deal with the result by new developed Duval Triangle software.

3.9 Summary

In Chapter 3, there are nine sections discuss included the summary in this chapter. This chapter started with the flowchart of project methodology in Section 3.2. Section 3.3 described the plotting faults zones in the triangular map by using the coordinates of faults zones. In addition, Section 3.4 explained the Duval Triangle software setup using AutoCAD software while in Section 3.5 presented the Duval Triangle software setup using Eclipse software. In Section 3.6 described on the Java programming that used to created new Duval Triangle. Moreover, in Section 3.7 discussed on the display result of Duval Triangle in Eclipse software. Lastly, the validation procedure on the new developed Duval Triangle software with Microsoft Excel Duval Calculator was discussed in Section 3.8.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Chapter 4 will discuss the results obtained from the new developed Duval Triangle software designed by using Eclipse software. The new Duval Triangle is created via the Eclipse software in order to identify the types of faults occur in the power transformer. There are six sections explain included the summary in this chapter. In Section 4.2, Selangor Transformer, 2009 data are used for interpretation of DGA using Duval Triangle method. The simulation results from both of software will be presents in Section 4.3. Moreover, in Section 4.4 explains the validation result of new developed Duval Triangle software with the existing software, Microsoft Excel Duval Calculator. Lastly, in Section 4.5 elaborates on the critical points exist in the Duval Triangle.

4.2 DGA Samples

Table 4.1 shows the real data obtained from TNB used to interpret DGA using the Duval Triangle method. There are 34 oil samples were used to test the performance of new developed Duval Triangle software to classify the types of fault occur in the power transformer. This data is getting from TNB which all information received is strictly confidential and is only used for this study. According to the data given, the power transformers were used for the interpretation of the DGA is a transformer with 33/11 kV, which carries a load under 30 MVA. The Duval Triangle method just used three main gases, which are methane (CH_4), ethylene (C_2H_4) and acetylene (C_2H_2) in order to perform an analysis. The gases contained in the power transformer playing a main role in determining the type of fault occur in the transformer.

Table 4.1: DGA samples

No.	Site	Load (MVA)	TX No.	Maker	Gases (ppm)			Gases (%)		
					CH_4	C_2H_4	C_2H_2	$\%CH_4$	$\%C_2H_4$	$\%C_2H_2$
1	Bandar Sunway	30	T1	Hefei China	4	53	16	5.48	72.60	21.92
2	Bandar Sunway	30	T2	Hefei China	3	77	7	3.45	88.51	8.05
3	MBF Spring Crest	30	T2	MTM	6	105	9	5.00	87.50	7.50
4	MBF Spring Crest	30	T1	MTM	4	98	17	3.36	82.35	14.29
5	Batu Tiga	30	T1	Electroputere Romania	4	77	0	4.94	95.06	0.00
6	Batu Tiga	30	T2	Electroputere Romania	181	56	2	75.73	23.43	0.84
7	Central Klang	30	T1	MTM	9	57	6	12.50	79.17	8.33
8	Commerce Square	30	T1	Liaoyang China	21	124	5	14.00	82.67	3.33
9	Istimewa Ria	30	T1	MTM	15	92	73	8.33	51.11	40.56
10	Istimewa Ria	30	T2	MTM	9	57	27	9.68	61.29	29.03
11	Bandar Tun Hussein Onn	30	T1	Wilson Australia	11	71	14	11.46	73.96	14.58

12	Bangi Lama	15	T2	MTM	130	18	4	85.53	11.84	2.63
13	Motorola	30	T1	MTM	14	170	24	6.73	81.73	11.54
14	New Town Port	30	T1	Bharat India	6	79	18	5.83	76.70	17.48
15	Pulau Indah	30	T1	Electroputere Romania	6	109	23	4.35	78..99	16.67
16	Pulau Indah	30	T2	Electroputere Romania	6	210	16	2.59	90.52	6.90
17	Sek 23 Shah Alam	30	T2	Hefei China	83	106	254	18.74	23.93	57.34
18	Sek 9 Bangi	15	T2	MTM	181	55	6	74.79	22.73	2.48
19	Serendah	15	T2	MTM	376	557	4	40.13	59.45	0.43
20	Sime Darby	15	T2	MTM	6	106	4	5.17	91.38	3.45
21	Subang Hitech	30	T2	Electroputere Romania	152	41	3	77.55	20.92	1.53
22	Sungai Manggis	15	T1	ACEC Belgium	7	180	19	3.40	87.38	9.22
23	Sungei Way	15	T1	MTM	7	39	59	6.67	37.14	56.19
24	Taman Klang Utama	30	T2	Electroputere Romania	109	67	23	54.77	33.67	11.56
25	Tanjung Rhu	7.5	T2	ACEC Belgium	4	99	26	3.10	76.74	20.16
26	Wanderful	30	T2	MTM	6	16	36	10.34	27.59	62.07

27	Pearl Point TX1	15	T1	Bonar Long	8	18	226	3.17	7.14	89.68
28	Berjaya Golf Tx2	30	T2	MTM	725	613	6347	9.43	7.98	82.59
29	Sogo TX1	30	T1	Electroputere Romania	840	2535	4748	10.34	31.21	58.45
30	Sogo TX2	30	T2	Bharat India	440	459	3249	10.61	11.07	78.33
31	Sri Hartamas TX1	30	T1	Shenyang China	947	770	40	53.90	43.82	2.28
32	Sri Hartamas TX2	30	T2	Shenyang China	4	63	5	5.56	87.50	6.94
33	Sentul Raya TX1	30	T1	MTM	178	146	2037	7.54	6.18	86.28
34	Sungai Pusu TX2	30	T1	MTM	98	91	1052	7.90	7.33	84.77

4.3 Simulation Result

The analysis of case studies was chosen from the DGA information in the Table 4.1. There were three examples of DGA data selected for analysis. The results of simulation are done by using two software designs by Microsoft Excel and Eclipse. The results of analysis from both of software are shown in Section 4.3.1, Section 4.3.2 and Section 4.3.3 and there are more results of visualizing Duval Triangle software via Eclipse and Microsoft Excel Duval Calculator was attached in Appendix B.

4.3.1 Case 1

In case study 1, a power transformer located in Bandar Sunway was selected. According to information in Table 4.1, the volume of the three gases is CH_4 = 4 ppm, C_2H_4 = 53 ppm and C_2H_2 = 16 ppm. By inserting the value of the three gases in new developed Duval Triangle software and Microsoft Excel Duval Triangle Calculator, the result appears as shown in Figure 4.1 and Figure 4.2.

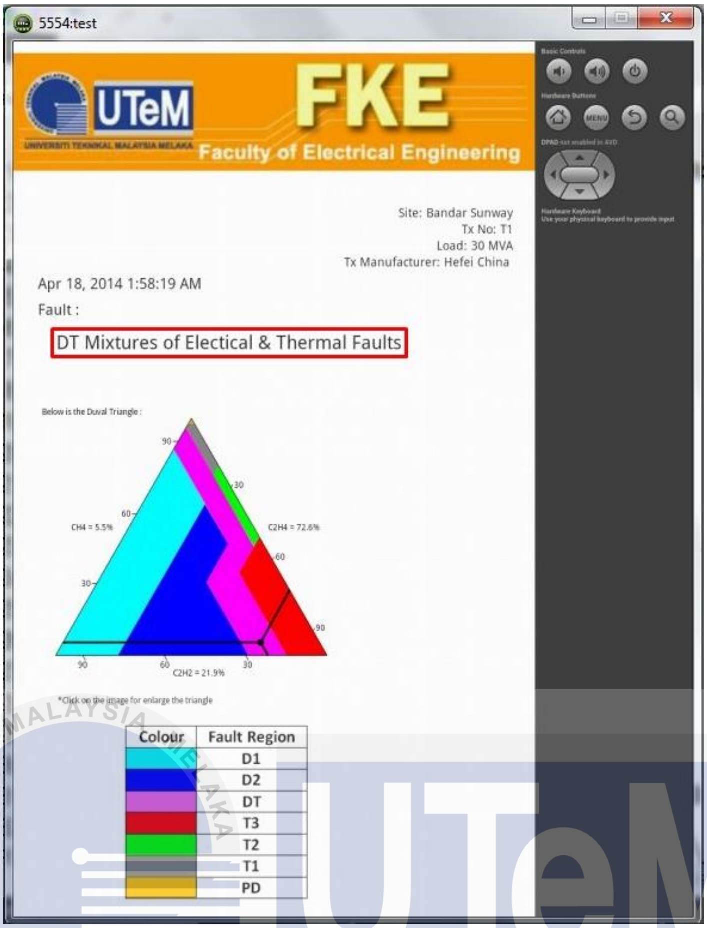


Figure 4.1: Result simulation for case study 1 via new developed Duval Triangle software

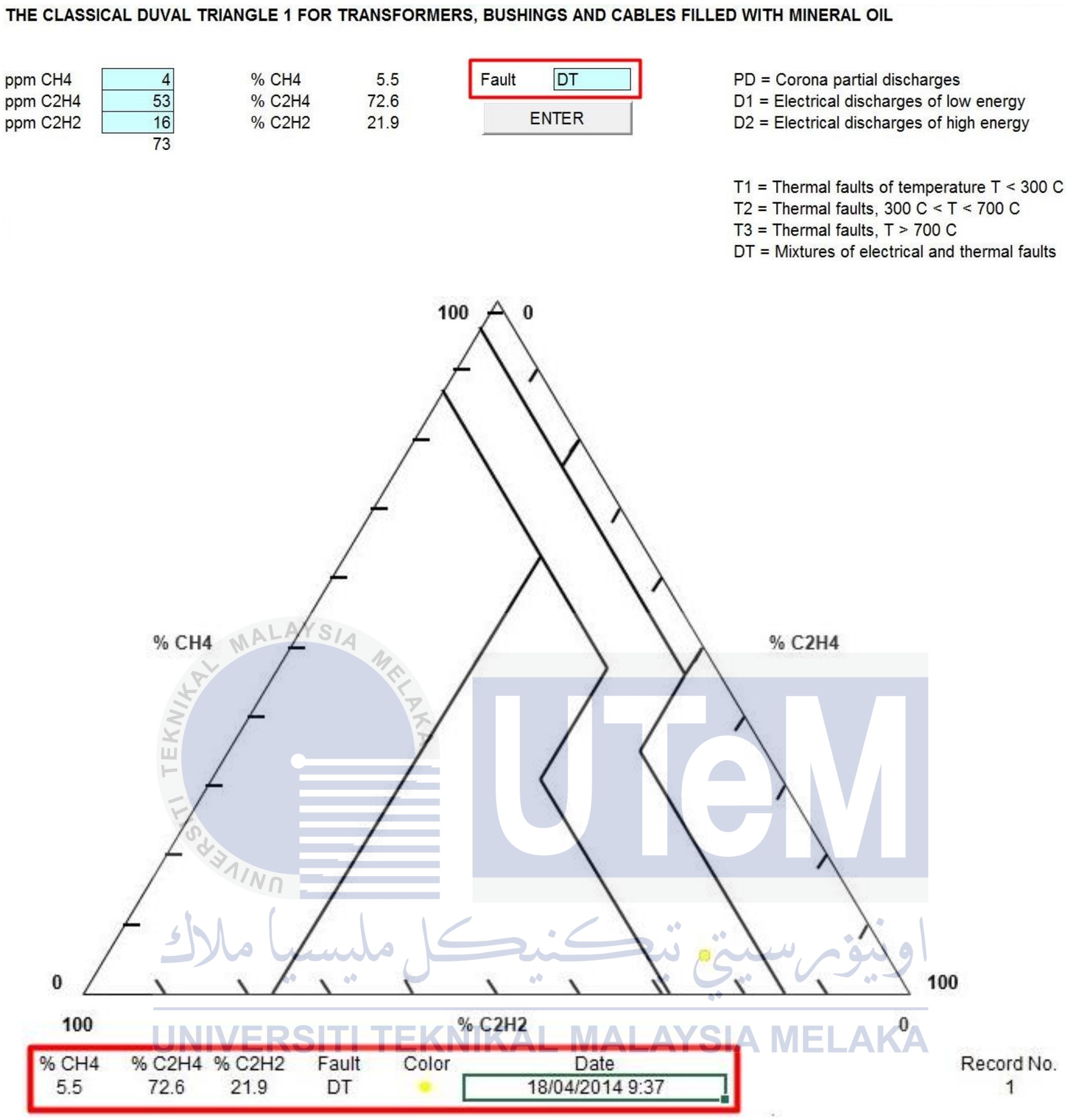


Figure 4.2: Result simulation for case study 1 via Microsoft Excel Duval Triangle Calculator

From the result obtain on simulation via new developed Duval Triangle and Microsoft Excel Duval Calculator software, the types of fault detected from both of these software is "DT – Mixtures of electrical and thermal faults".

4.3.2 Case 2

In case study 2, a power transformer located in MBF Spring Crest was selected. According to information in Table 4.1, the volume of the three gases is CH_4 = 6 ppm, C_2H_4 = 105 ppm and C_2H_2 = 9 ppm. By inserting the value of the three gases in new developed Duval Triangle software and Microsoft Excel Duval Triangle Calculator, the result appears as shown in in Figure 4.3 and Figure 4.4.

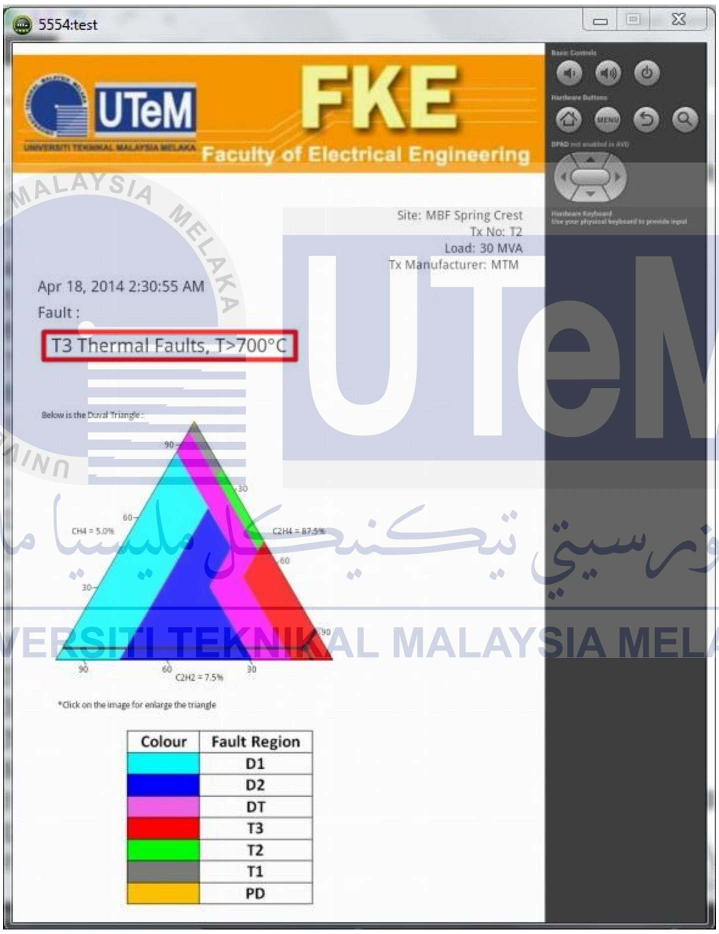


Figure 4.3: Result simulation for case study 2 via new developed Duval Triangle software

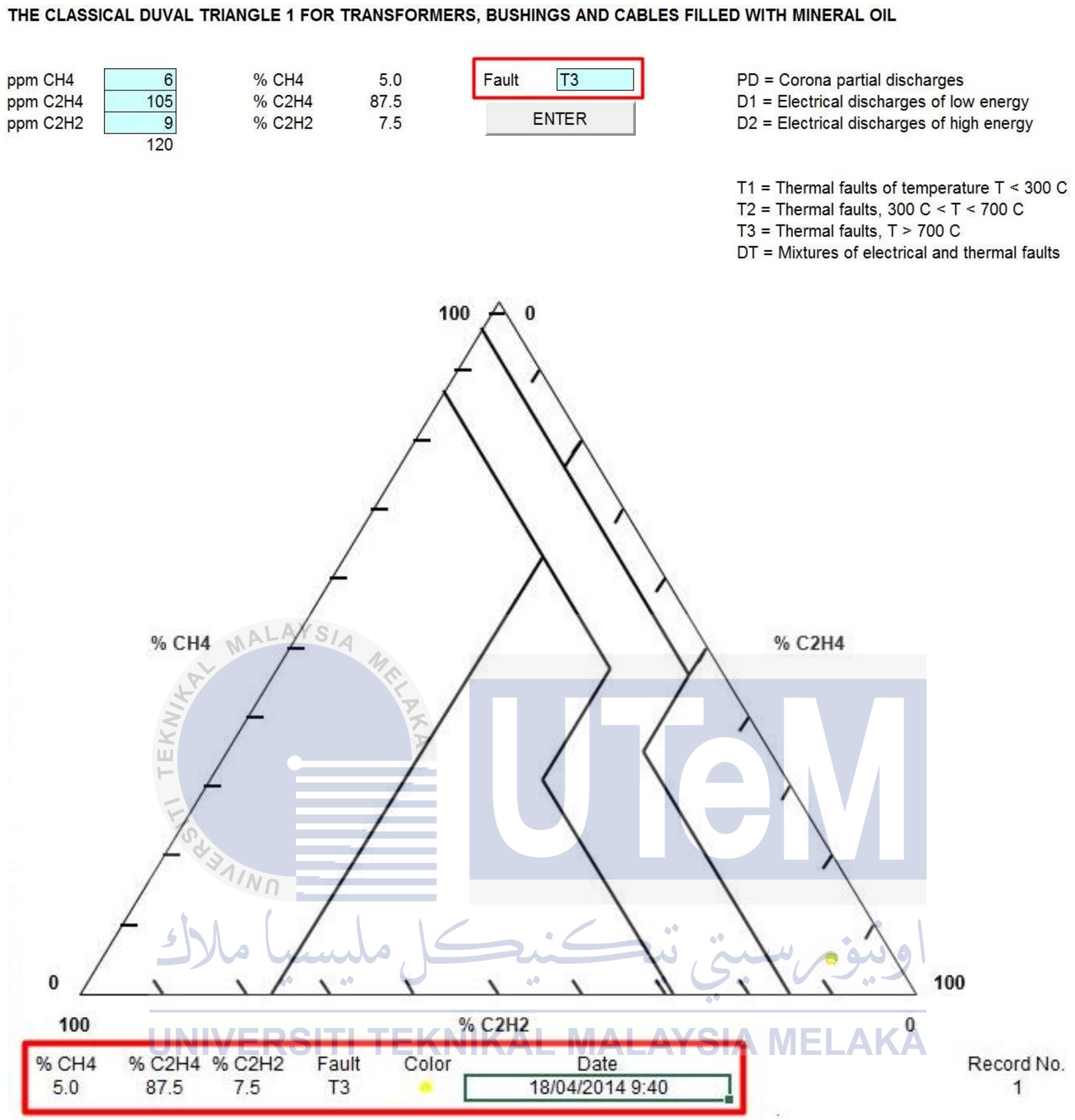


Figure 4.4: Result simulation for case study 2 via Microsoft Excel Duval Triangle Calculator

From the result obtain on simulation via new developed Duval Triangle and Microsoft Excel Duval Calculator software, the types of fault detected from both of these software is “T3 - Thermal Fault >700 Deg ˚C”.

4.3.3 Case 3

In case study 3, a power transformer located in Batu Tiga was selected. According to information in Table 4.1, the volume of the three gases is CH_4 = 181 ppm, C_2H_4 = 56 ppm and C_2H_2 = 2 ppm. By inserting the value of the three gases in new developed Duval Triangle software and Microsoft Excel Duval Triangle Calculator, the result appears as shown in in Figure 4.5 and Figure 4.6.

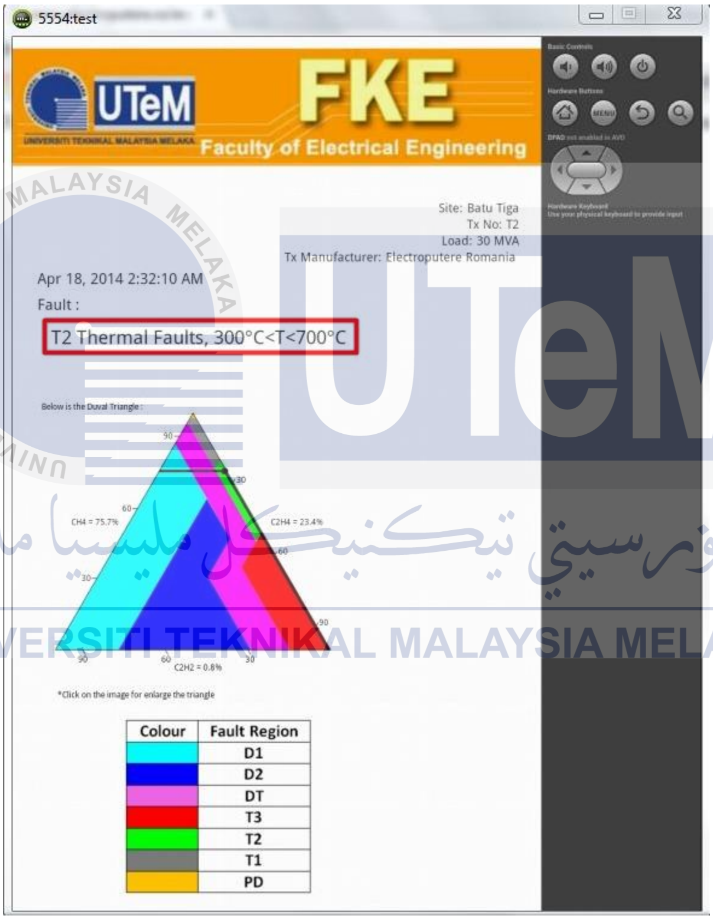


Figure 4.5: Result simulation for case study 3 via new developed Duval Triangle software

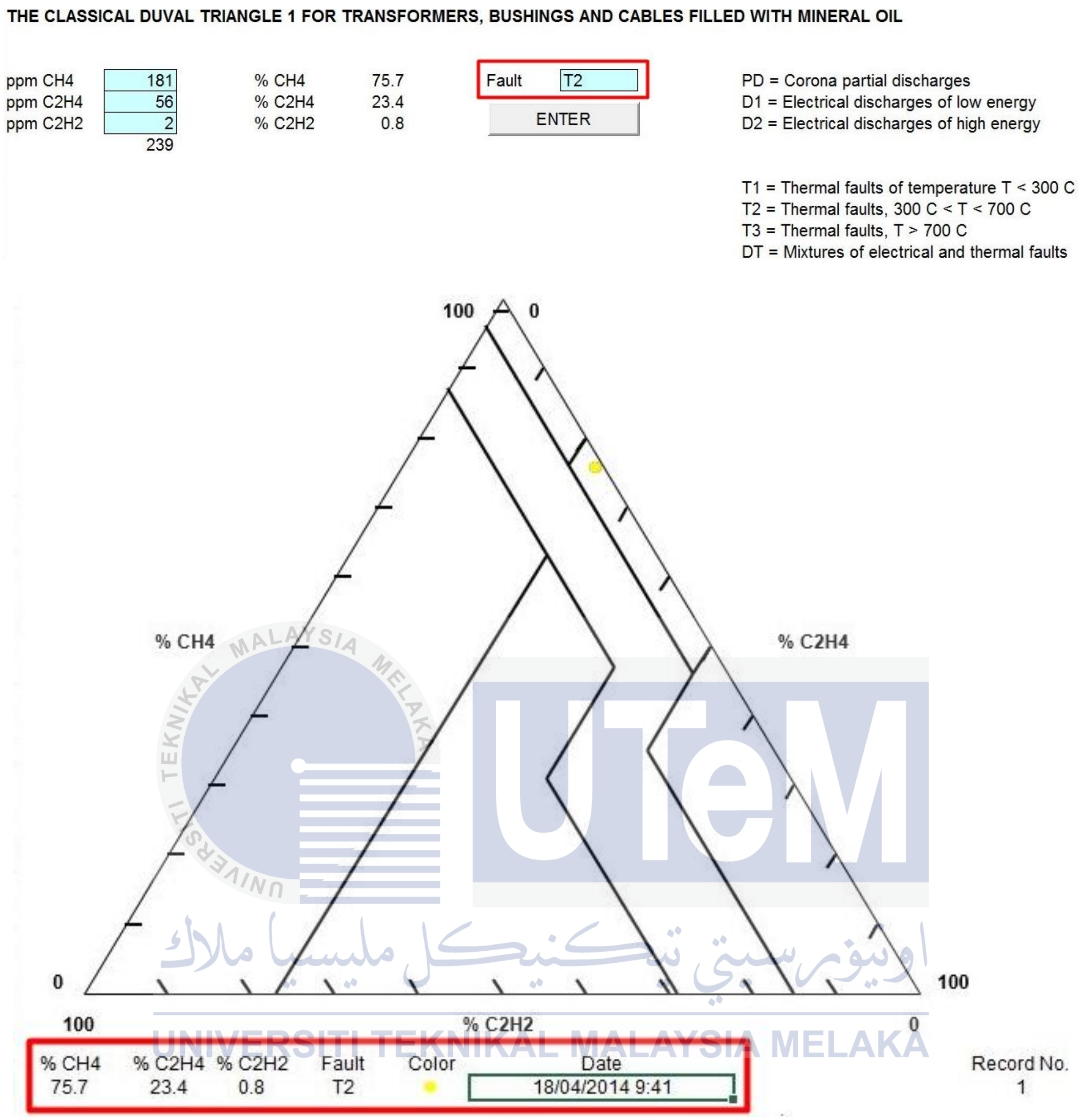


Figure 4.6: Result simulation for case study 3 via Microsoft Excel Duval Triangle Calculator

From the result obtain on simulation via new developed Duval Triangle and Microsoft Excel Duval Calculator software, the types of fault detected from both of these software is “T2 - Thermal Fault 300-700 Deg ˚C”.

4.4 Validation Result of New Developed Duval Triangle Software with Microsoft Excel Duval Calculator

This section shows the results obtained from the new developed Duval Triangle software with the Microsoft Excel Duval Calculator. There were 34 real data from TNB was selected and have been tested by using both of software. By using the Duval Triangle method, there are seven types of faults can be detected in the power transformer which are PD, D1, D2, DT, T1, T2 and T3. The Duval Triangle method just used three hydrocarbon gases, which are CH_4, C_2H_4 and C_2H_2. The user needs to insert the value of these gases in the software and the software will give the incipient types of fault that occur in the power transformer. In the Java programming, the condition to identify the types of faults has been set manually. By inserting the value of these three gases, the Java programming will identify the types of faults that occur in the power transformer according to the condition that has been set previously.

Table 4.2 shows the summary of the results comparison between new developed Duval Triangle software and Microsoft Excel Duval Triangle Calculator for 34 cases of data. Both of software give the same results of fault occur in the oil-filled power transformer. The results obtained showed that this new software can be used in industries worldwide. Hence, the objectives of Section 1.4 are achieved completely.

Table 4.2: Comparison by both of software

No.	Site	Load (MVA)	TX No.	Maker	Gases (ppm)			Gases (%)			Result obtained from both software	
					CH_4	C_2H_4	C_2H_2	%CH_4	%C_2H_4	%C_2H_2	New Developed Duval Triangle Software	Microsoft Excel Duval Triangle Calculator
1	Bandar Sunway	30	T1	Hefei China	4	53	16	5.48	72.60	21.92	DT – Mixtures of Electrical and Thermal Faults	DT – Mixtures of Electrical and Thermal Faults
2	Bandar Sunway	30	T2	Hefei China	3	77	7	3.45	88.51	8.05	T3 - Thermal Fault, T >700 ˚C	T3 - Thermal Fault, T >700 ˚C
3	MBF Spring Crest	30	T2	MTM	6	105	9	5.00	87.50	7.50	T3 - Thermal Fault, T >700 ˚C	T3 - Thermal Fault, T >700 ˚C
4	MBF Spring Crest	30	T1	MTM	4	98	17	3.36	82.35	14.29	T3 - Thermal Fault, T >700 ˚C	T3 - Thermal Fault, T >700 ˚C
5	Batu Tiga	30	T1	Electroputere Romania	4	77	0	4.94	95.06	0.00	T3 - Thermal Fault, T >700 ˚C	T3 - Thermal Fault, T >700 ˚C
6	Batu Tiga	30	T2	Electroputere Romania	181	56	2	75.73	23.43	0.84	T2 - Thermal Fault 300-700 ˚C	T2 - Thermal Fault 300-700 ˚C
7	Central Klang	30	T1	MTM	9	57	6	12.50	79.17	8.33	T3 - Thermal Fault, T >700 ˚C	T3 - Thermal Fault, T >700 ˚C

8	Commerce Square	30	T1	Liaoyang China	21	124	5	14.00	82.67	3.33	T3 - Thermal Fault, T >700 ˚C	T3 - Thermal Fault, T >700 ˚C
9	Istimewa Ria	30	T1	MTM	15	92	73	8.33	51.11	40.56	D2 – Electrical Discharges of High Energy	D2 – Electrical Discharges of High Energy
10	Istimewa Ria	30	T2	MTM	9	57	27	9.68	61.29	29.03	D2 – Electrical Discharges of High Energy	D2 – Electrical Discharges of High Energy
11	Bandar Tun Hussein Onn	30	T1	Wilson Australia	11	71	14	11.46	73.96	14.58	T3 - Thermal Fault, T >700 ˚C	T3 - Thermal Fault, T >700 ˚C
12	Bangi Lama	15	T2	MTM	130	18	4	85.53	11.84	2.63	T1 - Thermal Fault, T <700 ˚C	T1 - Thermal Fault, T <700 ˚C
13	Motorola	30	T1	MTM	14	170	24	6.73	81.73	11.54	T3 - Thermal Fault, T >700 ˚C	T3 - Thermal Fault, T >700 ˚C
14	New Town Port	30	T1	Bharat India	6	79	18	5.83	76.70	17.48	DT – Mixtures of Electrical and Thermal Faults	DT – Mixtures of Electrical and Thermal Faults
15	Pulau Indah	30	T1	Electroputere Romania	6	109	23	4.35	78..99	16.67	DT – Mixtures of Electrical and Thermal Faults	DT – Mixtures of Electrical and Thermal Faults
16	Pulau Indah	30	T2	Electroputere Romania	6	210	16	2.59	90.52	6.90	T3 - Thermal Fault, T >700 ˚C	T3 - Thermal Fault, T >700 ˚C

17	Sek 23 Shah Alam	30	T2	Hefei China	83	106	254	18.74	23.93	57.34	D2 – Electrical Discharges of High Energy	D2 – Electrical Discharges of High Energy
18	Sek 9 Bangi	15	T2	MTM	181	55	6	74.79	22.73	2.48	T2 - Thermal Fault 300-700 ˚C	T2 - Thermal Fault 300-700 ˚C
19	Serendah	15	T2	MTM	376	557	4	40.13	59.45	0.43	T3 - Thermal Fault, T >700 ˚C	T3 - Thermal Fault, T >700 ˚C
20	Sime Darby	15	T2	MTM	6	106	4	5.17	91.38	3.45	T3 - Thermal Fault, T >700 ˚C	T3 - Thermal Fault, T >700 ˚C
21	Subang Hitech	30	T2	Electroputere Romania	152	41	3	77.55	20.92	1.53	T2 - Thermal Fault 300-700 ˚C	T2 - Thermal Fault 300-700 ˚C
22	Sungai Manggis	15	T1	ACEC Belgium	7	180	19	3.40	87.38	9.22	T3 - Thermal Fault, T >700 ˚C	T3 - Thermal Fault, T >700 ˚C
23	Sungei Way	15	T1	MTM	7	39	59	6.67	37.14	56.19	D2 – Electrical Discharges of High Energy	D2 – Electrical Discharges of High Energy
24	Taman Klang Utama	30	T2	Electroputere Romania	109	67	23	54.77	33.67	11.56	DT – Mixtures of Electrical and Thermal Faults	DT – Mixtures of Electrical and Thermal Faults
25	Tanjung Rhu	7.5	T2	ACEC Belgium	4	99	26	3.10	76.74	20.16	DT – Mixtures of Electrical and Thermal Faults	DT – Mixtures of Electrical and Thermal Faults

26	Wanderful	30	T2	MTM	6	16	36	10.34	27.59	62.07	D2 – Electrical Discharges of High Energy	D2 – Electrical Discharges of High Energy
27	Pearl Point TX1	15	T1	Bonar Long	8	18	226	3.17	7.14	89.68	D1 – Electrical Discharges of Low Energy	D1 – Electrical Discharges of Low Energy
28	Berjaya Golf Tx2	30	T2	MTM	725	613	6347	9.43	7.98	82.59	D1 – Electrical Discharges of Low Energy	D1 – Electrical Discharges of Low Energy
29	Sogo TX1	30	T1	Electroputere Romania	840	2535	4748	10.34	31.21	58.45	D2 – Electrical Discharges of High Energy	D2 – Electrical Discharges of High Energy
30	Sogo TX2	30	T2	Bharat India	440	459	3249	10.61	11.07	78.33	D1 – Electrical Discharges of Low Energy	D1 – Electrical Discharges of Low Energy
31	Sri Hartamas TX1	30	T1	Shenyang China	947	770	40	53.90	43.82	2.28	T2 - Thermal Fault 300-700 ˚C	T2 - Thermal Fault 300-700 ˚C
32	Sri Hartamas TX2	30	T2	Shenyang China	4	63	5	5.56	87.50	6.94	T3 - Thermal Fault, T >700 ˚C	T3 - Thermal Fault, T >700 ˚C
33	Sentul Raya TX1	30	T1	MTM	178	146	2037	7.54	6.18	86.28	D1 – Electrical Discharges of Low Energy	D1 – Electrical Discharges of Low Energy

34	Sungai Pusu TX2	30	T1	MTM	98	91	1052	7.90	7.33	84.77	D1 – Electrical Discharges of Low Energy	D1 – Electrical Discharges of Low Energy

4.5 Critical Points in Duval Triangle Software

There are 18 critical coordinates to identify in the Duval Triangle method. In the Java programming, the condition has been set manually referring to the Microsoft Excel Duval Calculator. This new software needs to decide the types of faults since that the fault is falling at the centre of three regions. Figure 4.7 shows the examples of critical coordinates in the Duval Triangle method. The green in colour point which is in the ratio of CH_4 = 76%, C_2H_4 = 20% and C_2H_2 = 4% could be falling either in the region of T1, T2 or DT. While red in colour point which is in the ratio of CH_4 = 64%, C_2H_4 = 23% and C_2H_2 = 13% could be falling either in the region of D1, D2 or DT. It is the same case goes to blue in colour point, which is in the ratio of CH_4 = 46%, C_2H_4 = 50% and C_2H_2 = 4% could be fall either in the region of DT, T3 or T2. All this condition has been set manually in the Java programming. Hence, the software will give the same result as in Microsoft Excel Duval Calculator.

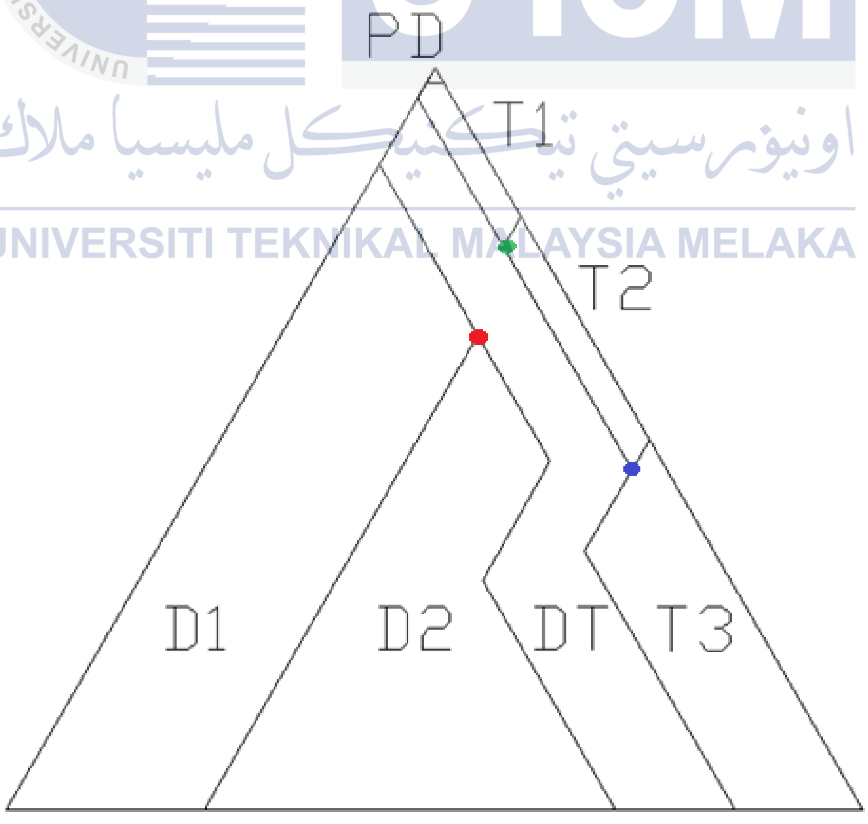


Figure 4.7: Location of critical coordinates in the Duval Triangle software

From the Table 4.4, the result obtained from new developed Duval Triangle software is the same as a result obtained from Microsoft Excel Duval Triangle Calculator. Hence, this software can be used by industries to analyze the fault occur in the power transformer.

Table 4.4: Critical coordinates in the Duval Triangle software

Critical Coordinates			New Developed Duval Triangle Software	Microsoft Excel Duval Triangle Calculator
CH_4 (%)	C_2H_4 (%)	C_2H_2 (%)		
0	0	100	D1	D1
0	23	77	D1	D1
64	23	13	D1	D1
87	0	13	D1	D1
0	71	29	D2	D2
0	85	15	T3	T3
35	50	15	T3	T3
46	50	4	T3	T3
96	0	4	T1	T1
47	40	13	D2	D2
31	40	29	D2	D2
76	20	4	T1	T1
80	20	0	T1	T1
98	2	0	PD	PD
98	0	2	PD	PD
50	50	0	T3	T3
0	100	0	T3	T3
100	0	0	PD	PD

4.6 Summary

In Chapter 4, there were six sections discussed included the summary in this chapter. Section 4.2, there are 34 samples used in this project. The simulation results been made with both software as mentioned in Section 4.3. Moreover, in Section 4.4 explained the validation result of new Duval Triangle software with the Microsoft Excel Duval Calculator. Both of this software gave the same simulation results. Lastly, in Section 4.5 described on the critical points exist in the Duval Triangle.

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

All the three objectives stated in Section 1.4 are achieved completely. Hence, the study of various DGA methods applied for power transformer specifically Duval Triangle method has been greatly achieved. From this project, the effect of insulation by oil filled in a power transformer has been studied and it was found that those methods using DGA are more accurate compared than another method. Furthermore, the development of a new software via Eclipse for simplification of Duval Triangle analysis has been completely done. The identification of faults that occurred inside of the oil-filled power transformer can do easily by implementation of the Duval Triangle method by using software. This software developed via the Eclipse software in identified the types of faults occur in the power transformer. Lastly, the verification on the new developed of Duval Triangle software with the existing hardware (Microsoft Excel Duval Calculator) by using the actual data from TNB has been greatly achieved. The comparisons between both of this software using real data from TNB have been made and it gives the same results. This new developed software can reduce cost, save the users time and make ease in the diagnosis job. Hence, the new developed Duval Triangle software can be used in industries worldwide. Lastly, this project concludes that all the objectives of this project already achieved and clear.

5.2 Recommendations/ Future Work

Based on result and conclusion of this project, the researcher can apply this new developed software by some modification so that it can apply for others Duval Triangle method. The Duval Triangle method for Load Tap Changer (LTC) of oil type, Low Temperature Fault in power transformer and Non-Mineral oils can develop by modification or additional codding in Java programming. In addition, another friendly programming software such as C, C++ or MATLAB can use for this project.

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APPENDIX A – JAVA PROGRAMMING OF DUVAL TRIANGLE SOFTWARE VIA ECLIPSE SOFTWARE

```
//Large triangle
canvas.drawLine( (int) 30, (int) 430, (int) 230, (int) 83.59, paint);
canvas.drawLine( (int) 430, (int) 83.59, (int) 430, (int) 430, paint);
canvas.drawLine( (int) 430, (int) 430, (int) 30, (int) 430, paint);

// D1 region
canvas.drawLine( (int) 122, (int) 430, (int) 250, (int) 208.2976, paint);
canvas.drawLine( (int) 250, (int) 208.3976, (int) 204, (int) 128.,
paint);

// D2 and DT region
canvas.drawLine( (int) 314, (int) 430, (int) 252, (int) 322.64,
paint);
canvas.drawLine( (int) 252, (int) 322.64, (int) 284, (int) 267.1872,
paint)
canvas.drawLine( (int) 284, (int) 267.1872, (int) 250, (int) 208.2976,
paint);

// T3 region
canvas.drawLine( (int) 370, (int) 430, (int) 300, (int) 308.7564,
paint);
canvas.drawLine( (int) 300, (int) 308.7564, (int) 330, (int) 256.7948,
paint);

// T1 and T2 region
canvas.drawLine( (int) 322, (int) 270.6512, (int) 222, (int) 97.4464,
paint);
canvas.drawLine( (int) 262, (int) 166.7284, (int) 270, (int) 152.872,
paint);

// PD region
canvas.drawLine( (int) 226, (int) 90.518,(int) 234, (int) 90.518,
paint);
//Large triangle
paint3.setStyle(Paint.Style.FILL);
paint3.setColor(Color.TRANSPARENT);
Path path8 = new Path();
path8.moveTo(30, 430); path8.lineTo(230, 84); path8.lineTo(430, 430);
path8.close();
canvas.drawPath(path8, paint3);

//D1 region
paint1.setStyle(Paint.Style.FILL); paint1.setColor(Color.CYAN);
Path path4 = new Path(); Path path41 = new Path(); path4.moveTo((int)x1,
(int)y1); path4.lineTo(122, 430); path4.lineTo(250, 209);
path4.lineTo(204, 128);
path41.moveTo((int)x1-1, (int)y1); path41.lineTo(122+1, 430);
path41.lineTo(250+1, 209); path41.lineTo(204+1, 128+1);
path4.close();path41.close();
canvas.drawPath(path4, paint1);

//D2 region
paint1.setStyle(Paint.Style.FILL);
paint1.setColor(Color.BLUE);
Path path1 = new Path();Path path11 = new Path();
```

```
path1.moveTo(122, 430); path1.lineTo(314,430); path1.lineTo(252, 323);
path1.lineTo(284, 267); path1.lineTo(250, 209);
path11.moveTo(122+1, 430); path11.lineTo(315,430); path11.lineTo(253+1,
324); path11.lineTo(285+1, 268); path11.lineTo(250+1, 209);
path1.close();path11.close();
canvas.drawPath(path1, paint1);

//DT region
paint3.setStyle(Paint.Style.FILL);
paint3.setStrokeWidth(2);
paint3.setColor(Color.MAGENTA);
Path path7 = new Path();
Path path71 = new Path();
path7.moveTo(314, 430); path7.lineTo(370, 430); path7.lineTo(300, 309);
path7.lineTo(322, 271); path7.lineTo(222, 97); path7.lineTo(204,
128);path7.lineTo(284, 267); path7.lineTo(252, 323);
path71.moveTo(314+1, 430); path71.lineTo(370-1, 430); path71.lineTo(300-
1, 308); path71.lineTo(322, 270); path71.lineTo(222, 97);
path71.lineTo(204+1, 128-1);path71.lineTo(284+1, 267);
path71.lineTo(252+1, 323);
path7.close();path71.close();
canvas.drawPath(path7, paint3);

//T1 region
paint3.setStyle(Paint.Style.FILL);
paint3.setColor(Color.GRAY);
Path path5 = new Path();Path path51 = new Path();
path5.moveTo(270, 152); path5.lineTo(262, 167); path5.lineTo(222, 97);
path5.lineTo(226, 91); path5.lineTo(234, 91);
path51.moveTo(270+1, 152+1); path51.lineTo(262, 167); path51.lineTo(222,
97); path51.lineTo(226-2, 91+1); path51.lineTo(234+2, 91+1);
path5.close();path51.close();
canvas.drawPath(path5, paint3);

//T2 region
paint3.setStyle(Paint.Style.FILL);
paint3.setColor(Color.GREEN);
Path path3 = new Path();Path path31 = new Path();
path3.moveTo(330, 257); path3.lineTo(322, 270); path3.lineTo(262-1, 167-
1); path3.lineTo(270, 152);
path31.moveTo(330, 257); path31.lineTo(322-1, 270); path31.lineTo(262-1,
167); path31.lineTo(270+1, 152+1);
path3.close();path31.close();
canvas.drawPath(path3, paint3);


//T3 region
paint2.setStyle(Paint.Style.FILL);
paint2.setColor(Color.RED);
Path path2 = new Path();Path path21 = new Path();
path2.moveTo((int)x3, (int)y3); path2.lineTo(370, 430); path2.lineTo(300,
309); path2.lineTo(330, 257);
path21.moveTo((int)x3+1, (int)y3); path21.lineTo(370-1, 430);
path21.lineTo(300-1, 309); path21.lineTo(330-1, 257-1);
path2.close();path21.close();
canvas.drawPath(path2, paint2);

//PD region
paint3.setStyle(Paint.Style.FILL);
paint3.setColor(Color.parseColor("#FFA500"));
Path path6 = new Path();Path path61 = new Path();
```

```
path6.moveTo(230, 84-1); path6.lineTo(226, 91); path6.lineTo(234, 91);
path61.moveTo(230,        84-2);        path61.lineTo(226-2,        91+1);
path61.lineTo(234+2, 91+1);
path6.close();path61.close();
canvas.drawPath(path6, paint3);

if (u1==0 && u2==0){
            l1.tfault.setText("D1 ELectrical Discharges of Low Energy");

        }
        else if(u2==0 && u3==0){
            l1.tfault.setText("PD Corona Partial Discharge");
            }
        else if(u1==0 && u3==0){
            l1.tfault.setText("T3 Thermal Faults, T>700°C");
            }
        else if ((Double.isNaN(u1))){
            l1.tfault.setText("Error Fault");
        }

        else if (l1.a1>=98 && l1.b1<=2 && l1.c1<=2){
            l1.tfault.setText("   PD Corona Partial Discharge  ");
        }

        else  if  (l1.a1<=98  &&  l1.a1>=96  &&  l1.b1<=20  &&  l1.b1>=2  &&
l1.c1<=4){
            l1.tfault.setText("      T1  Thermal  Faults  of  Temperature
T<300°C  ");
        }

        else  if  (l1.a1<=98  &&  l1.a1>=76  &&  l1.b1<=20  &&  l1.b1>=2  &&
l1.c1<=4){
            l1.tfault.setText("      T1  Thermal  Faults  of  Temperature
T<300°C  ");
        }
        else  if  (l1.a1<=98  &&  l1.a1>=76  &&  l1.b1<=20  &&  l1.b1>=0  &&
l1.c1<=4){
            l1.tfault.setText("      T1  Thermal  Faults  of  Temperature
T<300°C  ");
        }

        else if  (l1.a1<=50  && l1.b1>=50 && l1.c1<=15)      {
            l1.tfault.setText("  T3 Thermal Faults, T>700°C  ");
        }

        else  if  (l1.a1>=46  &&  l1.a1<=80  &&  l1.b1<=50  &&  l1.b1>=20  &&
l1.c1<=4){

            l1.tfault.setText("  T2 Thermal Faults, 300°C<T<700°C  ");
        }

        else if (l1.c1== 4 && l1.a1 >= 76 && l1.b1 <= 20){
            l1.tfault.setText("  D2 ELectrical Discharges of High Energy
");
        }

        else if (l1.c1== 29 && l1.a1 <= 35 && l1.b1 >= 50){
            l1.tfault.setText("  D2 ELectrical Discharges of High Energy
");
        }
```

```
        else if( l1.a1<=87 && l1.b1<=23 && l1.c1>=13){
            l1.tfault.setText("  D1 ELectrical Discharges of Low Energy
");
        }

        else if (l1.a1<=45 && l1.b1>=23 && l1.c1>=29 && l1.c1<=77){
            l1.tfault.setText("  D2 ELectrical Discharges of High Energy
");
        }

        else if (l1.a1<=64 && l1.a1 >=45 && l1.b1<=40 && l1.b1>=23 &&
l1.c1<=29 && l1.c1>=13){
            l1.tfault.setText("  D2 ELectrical Discharges of High Energy
");
        }

        else if (l1.a1<=47 && l1.a1 >=31 && l1.b1<=40 && l1.b1>=23 &&
l1.c1<=29 && l1.c1>=13){
            l1.tfault.setText("  D2 ELectrical Discharges of High Energy
");
        }

        else if ( l1.a1<=35 && l1.b1>=50 && l1.c1>=15 && l1.c1<=29){
            l1.tfault.setText("    DT Mixtures of Electical & Thermal
Faults  ");
        }

        else if (l1.a1>=20 && l1.a1<=55 && l1.b1>=40 &&  l1.b1<=50 &&
l1.c1>=4 && l1.c1<=29){
            l1.tfault.setText("    DT Mixtures of Electical & Thermal
Faults  ");
        }

        else if  (l1.a1>=47 && l1.a1<=96 && l1.b1<=40 && l1.c1<=13 &&
l1.c1>=4){
            l1.tfault.setText("   DT Mixtures of Electical & Thermal
Faults   ");
        }

//scale
        canvas.drawLine( (int) 83.3304, (int) 325.428,    (int) 97.4188,
(int) 325.428, paint);
        canvas.drawLine( (int) 142.292, (int) 223.3036,    (int)
156.3804, (int) 223.3036, paint);
        canvas.drawLine( (int) 203.3428, (int) 117.5604, (int) 217.4312,
(int) 117.5604, paint);
        canvas.drawLine( (int) 285.7172, (int) 190.3912, (int) 291.6484,
(int) 180.072, paint);
        canvas.drawLine( (int) 346.916, (int) 296.6072, (int) 352.8468,
(int) 286.288, paint);
        canvas.drawLine( (int) 406.9736, (int) 400.4132, (int) 412.9048,
(int) 390.094, paint);
        canvas.drawLine( (int) 305.76, (int) 422.7828, (int) 314.24,
(int) 437.2172, paint);
        canvas.drawLine( (int) 185.76, (int) 422.7828, (int) 194.24,
(int) 437.2172, paint);
        canvas.drawLine( (int) 65.76, (int) 422.7828, (int)  74.24, (int)
437.2172, paint);
```

APPENDIX B – VISUALIZING THE RESULT USING ECLIPSE AND MICROSOFT EXCEL DUVAL CALCULATOR

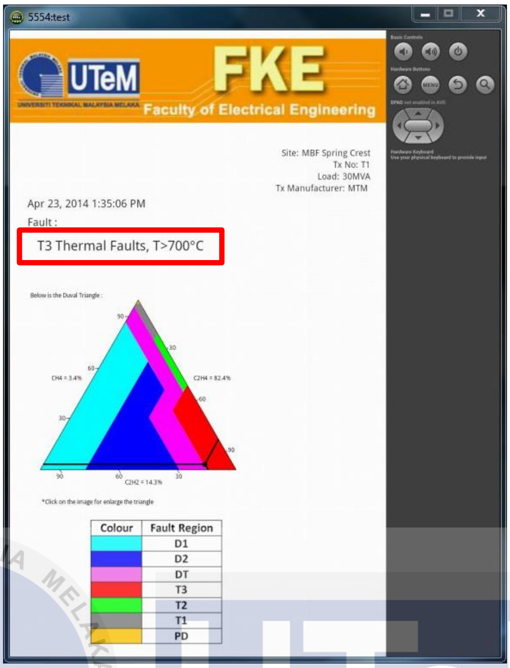

Figure B4 (a): Result simulation via new developed Duval Triangle software for MBF Spring Crest

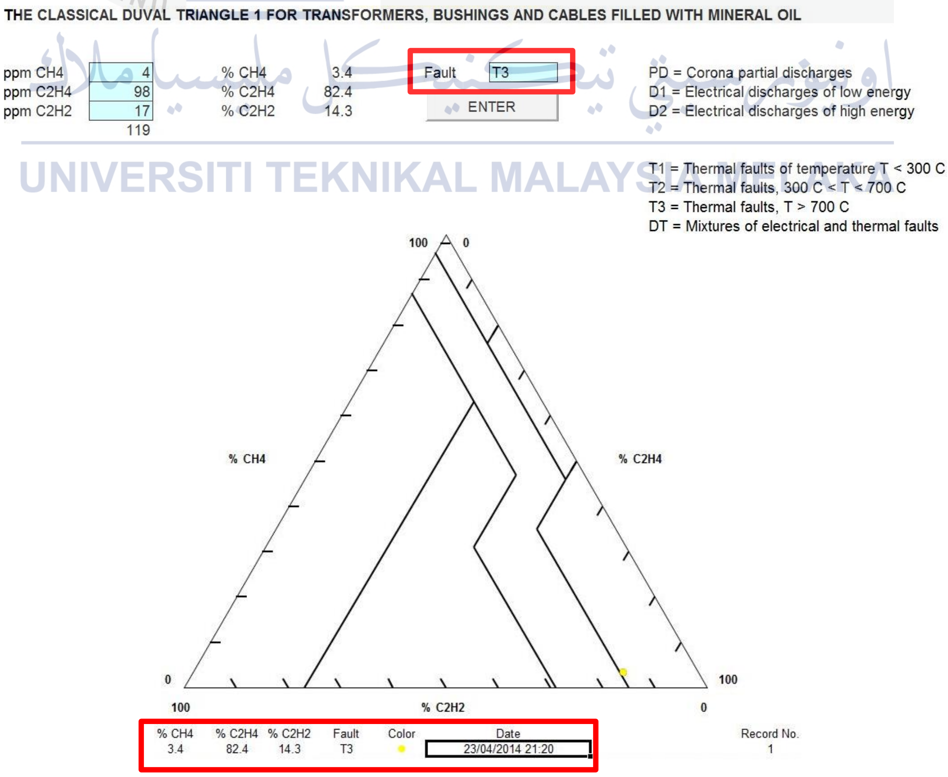

Figure B4 (b): Result simulation via Microsoft Excel Duval Triangle Calculator for MBF Spring Crest

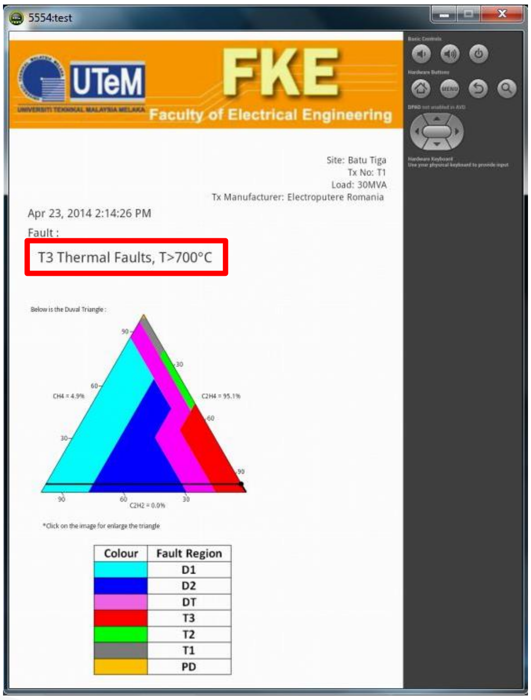

Figure B5 (a): Result simulation via new developed Duval Triangle software for Batu Tiga (Tx 1)

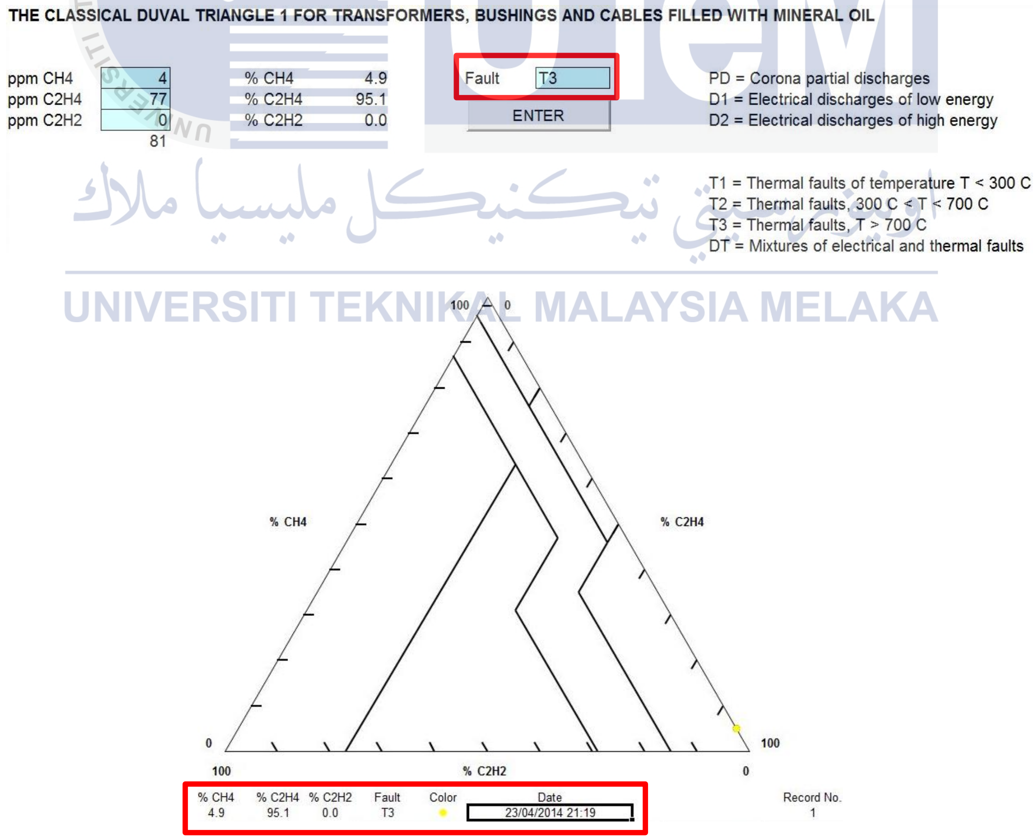

Figure B5 (b): Result simulation via Microsoft Excel Duval Triangle Calculator for Batu Tiga (Tx 1)

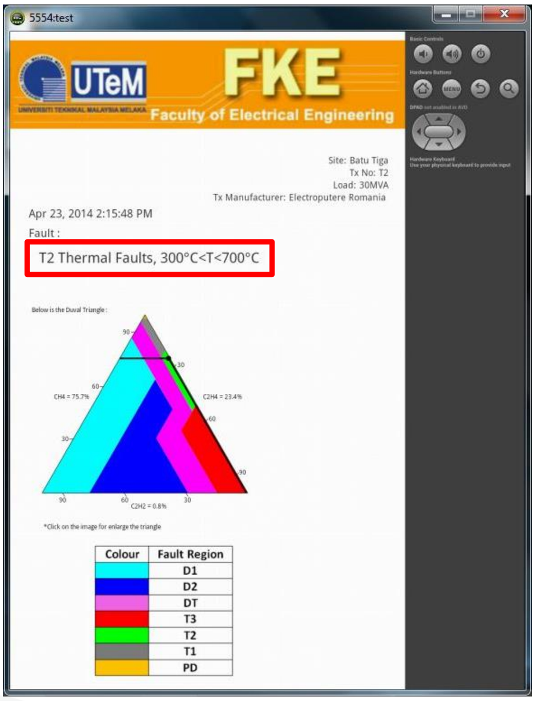

Figure B6 (a): Result simulation via new developed Duval Triangle software for Batu Tiga (Tx 2)

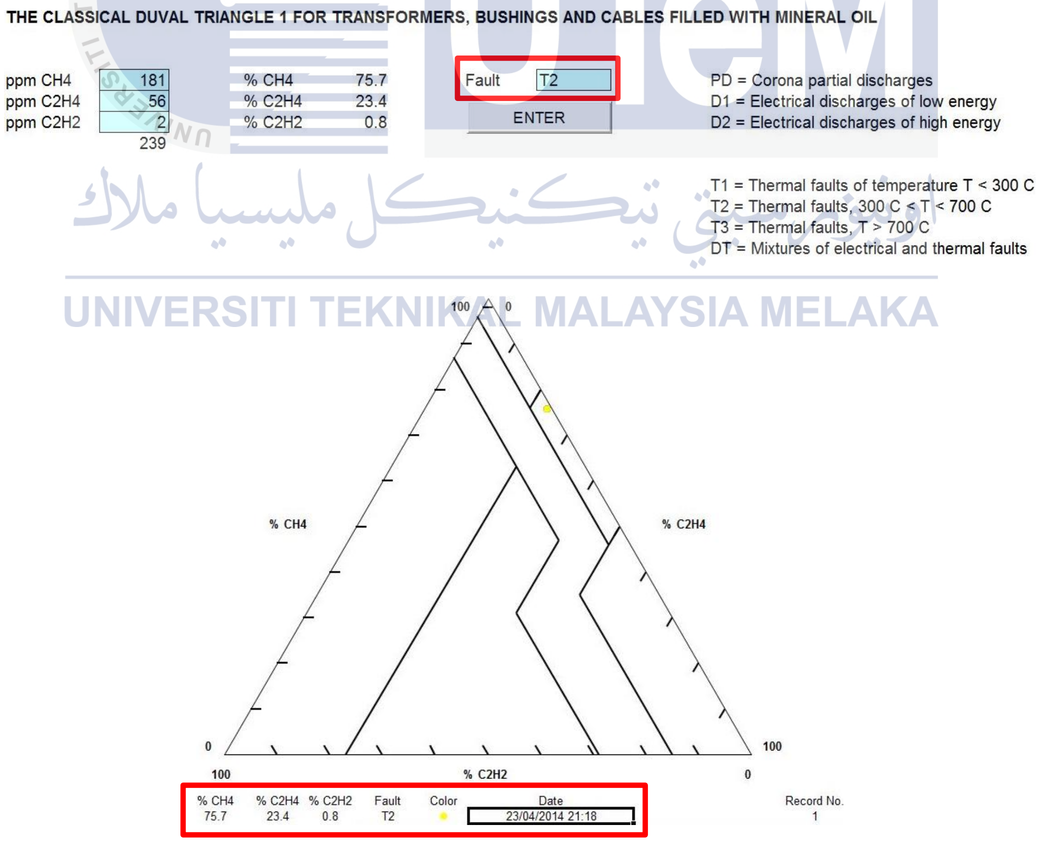

Figure B6 (b): Result simulation via Microsoft Excel Duval Triangle Calculator for Batu Tiga (Tx 2)

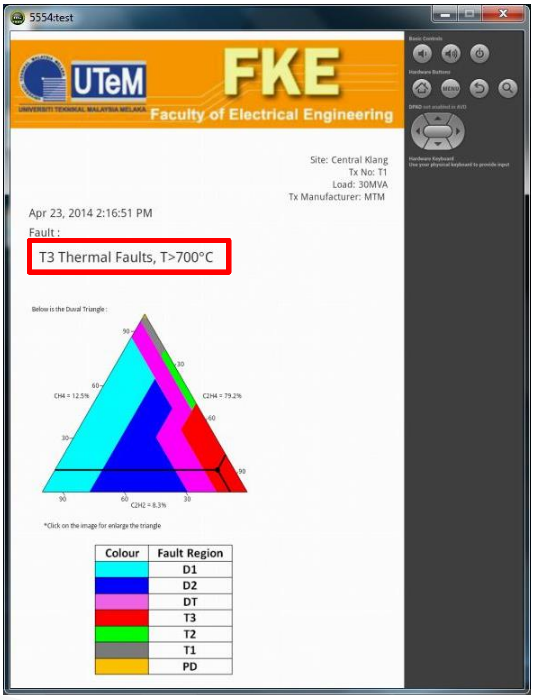

Figure B7 (a): Result simulation via new developed Duval Triangle software for Central Klang

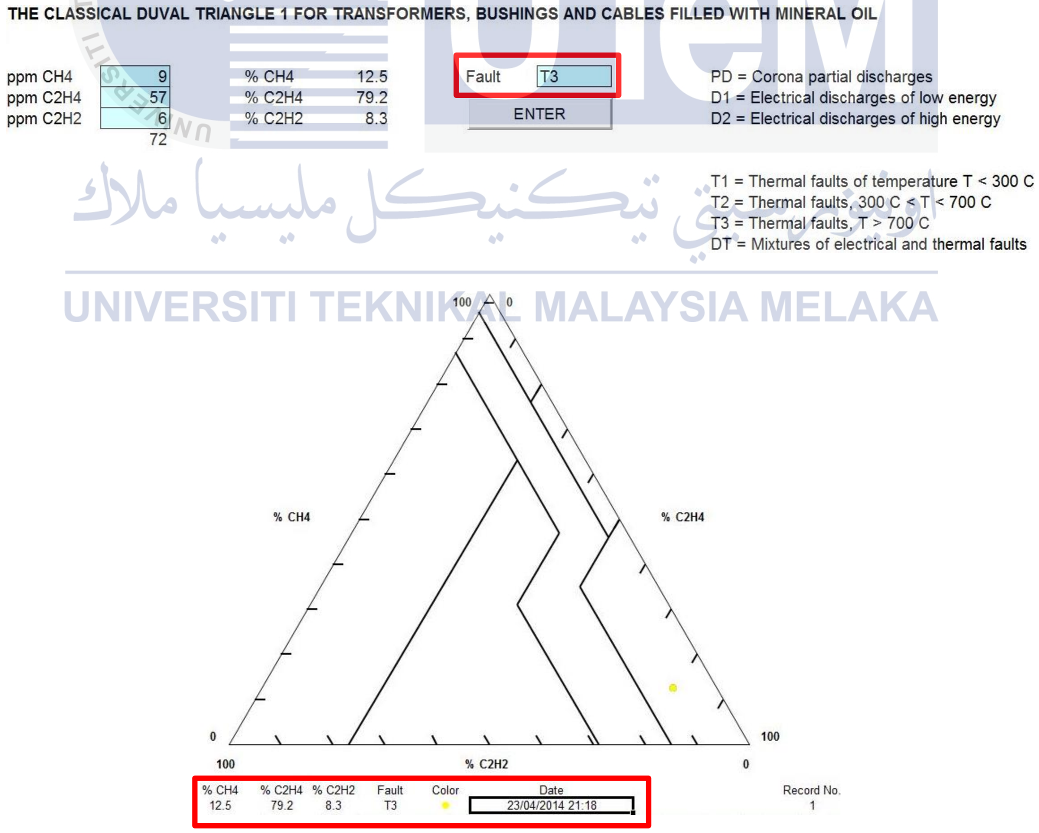

Figure B7 (b): Result simulation via Microsoft Excel Duval Triangle Calculator for Central Klang

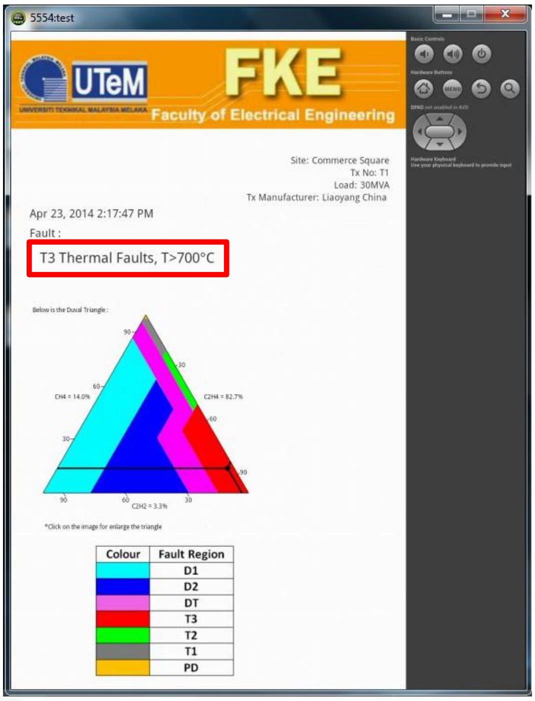

Figure B8 (a): Result simulation via new developed Duval Triangle software for Commerce Square

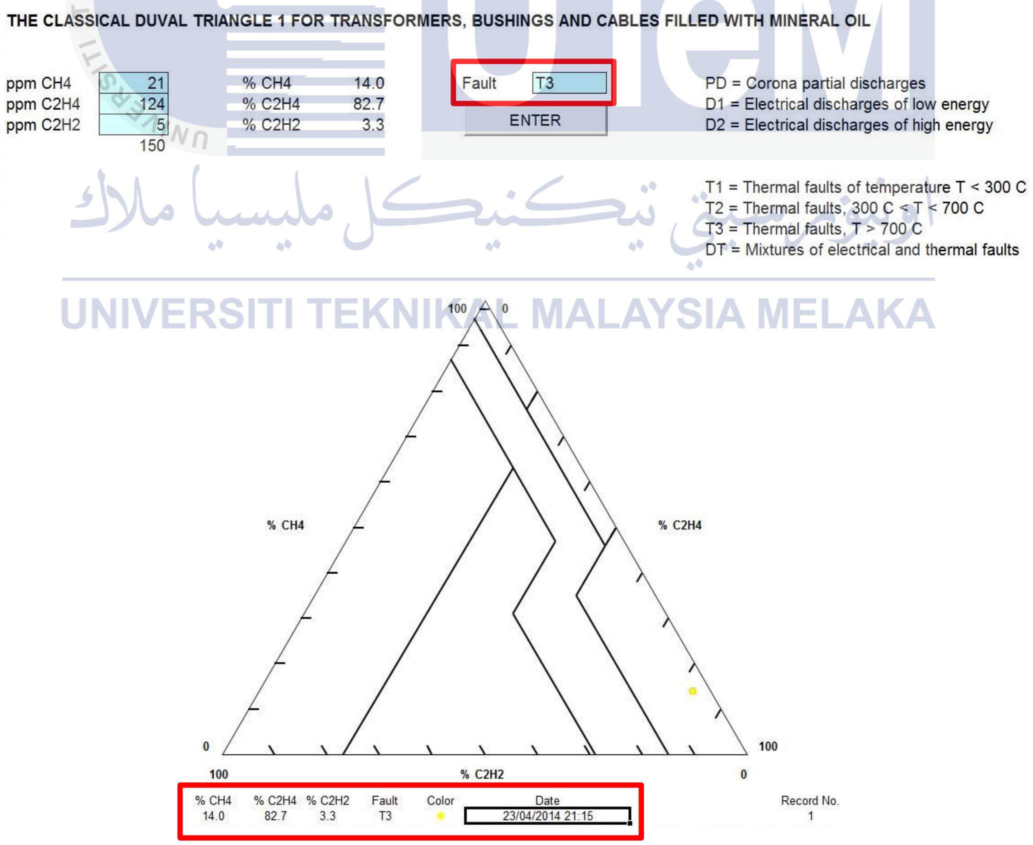

Figure B8 (b): Result simulation via Microsoft Excel Duval Triangle Calculator for Commerce Square

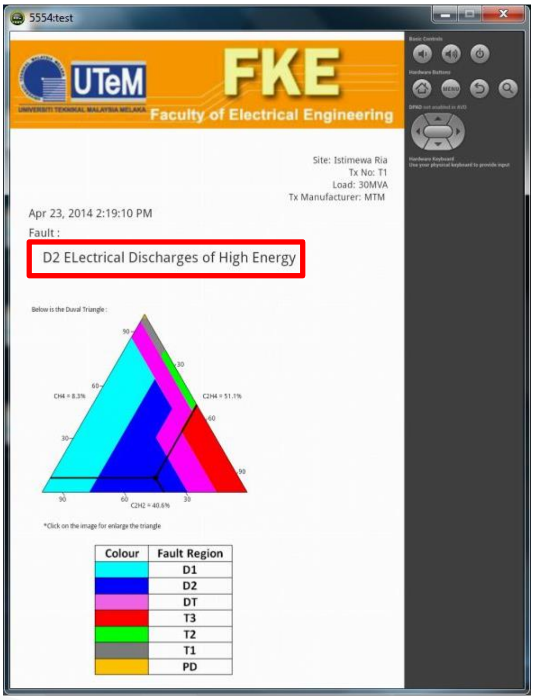

Figure B9 (a): Result simulation via new developed Duval Triangle software for Istimewa Ria (Tx 1)

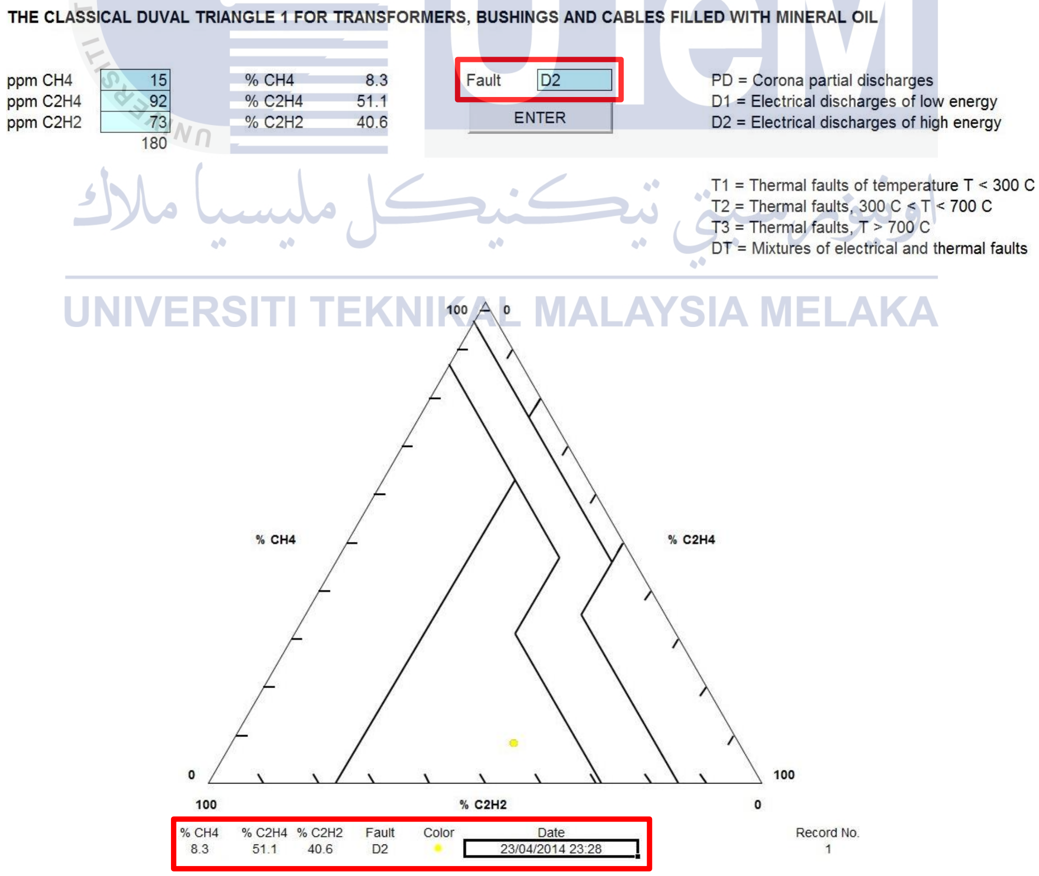

Figure B9 (b): Result simulation via Microsoft Excel Duval Triangle Calculator for Istimewa Ria (Tx 1)

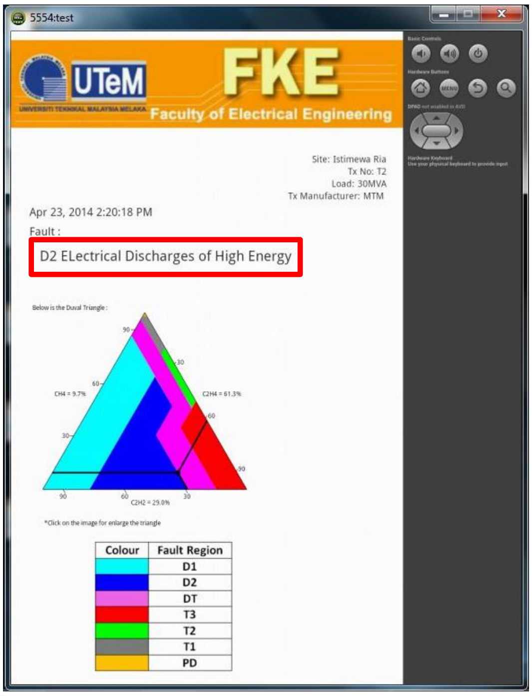

Figure B10 (a): Result simulation via new developed Duval Triangle software for Istimewa Ria (Tx 2)

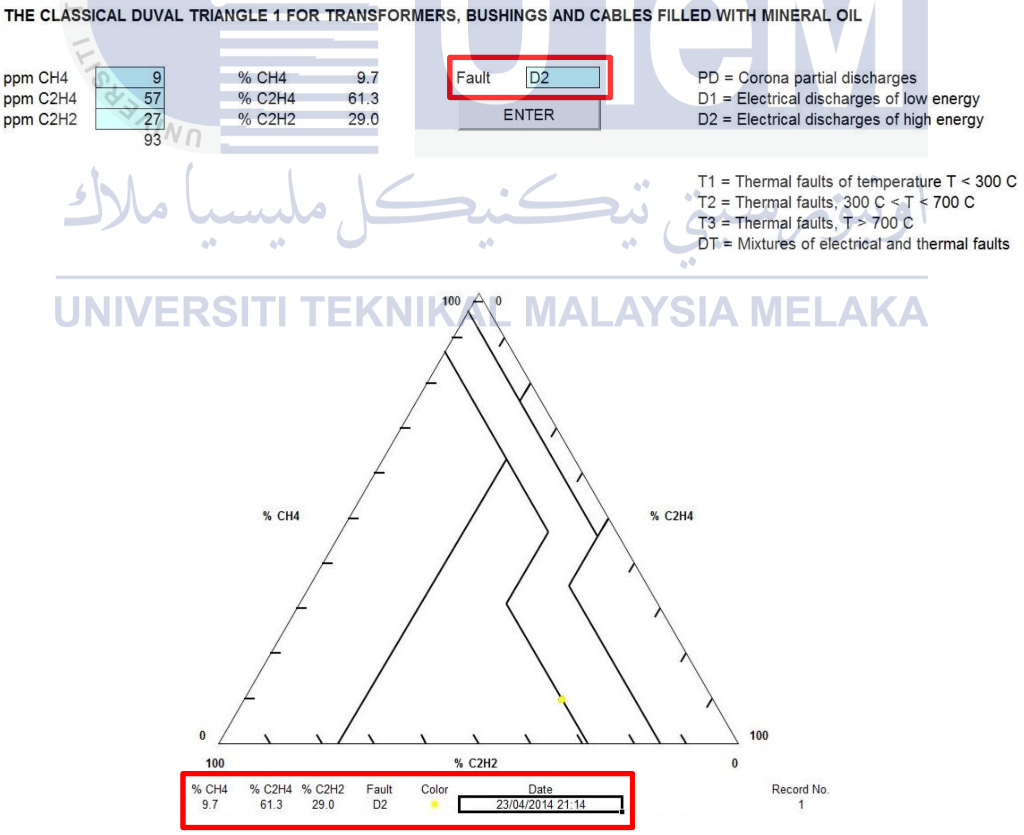

Figure B10 (b): Result simulation via Microsoft Excel Duval Triangle Calculator for Istimewa Ria (Tx 2)