"I hereby declare that I have read through this report entitle *"Transformer Faults Classification From Polarization Current Measurement Results by Using Statistical Technique"* and in my opinion this thesis is sufficient in terms of scope and quality for awarding the degree of *Bachelor of Electrical Engineering (Industrial Power)*"

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Supervisor's Name : MOHD SHAHRIL B AHMAD KHIAR

Date : 16 JUNE 2014

TRANSFORMERS FAULTS CLASSIFICATION FROM POLARIZATION CURRENTS MEASUREMENT RESULTS BY USING STATISTICAL TECHNIQUE

MOHAMMAD SYAHIR BIN MANSOR

A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

June 2014

I declare that this report entitle "*Transformer Faults Classification From Polarization Current Measurement Results by Using Statistical Technique*" is the result of my own research and work, 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 : ....

Name : MOHAMMAD SYAHIR BIN MANSOR

Date : 16 JUNE 2014

Specially dedicated, in thankful appreciation for the support, encouragement and understandings for my beloved mother, father, brother and my supervisor.

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ABSTRACT

In general, the presence of moisture and others impurities inside the insulator or oil can cause the breakdown of the power transformer. Polarization and Depolarization Current (PDC) is one of the technique to assess the condition of insulation oil in power transformer and can be applied in many electrical apparatus such as power cables and on load tap changer as well as to estimate conductive and moisture contents of the insulations. Basically, it is a technique that is based on time domain measurement and has been use since 1990's. This analysis work seeks to classify the pattern of faults by find the ranges in PDC data obtain from Tenaga Nasional Berhad Research (TNBR) by using Statistical Technique and Graphical Method. Actually, there will be some challenge to classify the faults into a proper range. These faults consists of partial discharge, arcing and overheating that will be focus on this analysis work. In analysis work result obtained, the range of partial discharge fault is $(5.0 - 8.0) \times 10^{-8}$ Ampere. Whereas, the range of arcing fault is $(8.0 - 11.0)\times 10^{-8}$ Ampere. Lastly, the overheating fault range is greater than 11.0×10^{-8} Ampere. At the end of the analysis work, the results obtained in analysis work will verify from the previous research by referring the ranking of the transformer faults. Furthermore, the results obtained in analysis work can be apply as a references to Tenaga Nasional Berhad Distribution (TNBD) when doing a maintenance process at the real power transformer using PDC measurement to find the transformer faults.

ABSTRAK

Secara umum, kehadiran kelembapan dan lain-lain kekotoran di dalam penebat atau minyak boleh menyebabkan kerosakan pada pengubah kuasa. *Polarization and Depolarization Current (PDC)* adalah salah satu teknik untuk menilai keadaan minyak penebat dalam kuasa pengubah dan boleh digunakan dalam pelbagai peralatan elektrik seperti kabel kuasa dan *on-load tap changer (OLTC)* untuk mengenalpasti konduktif dan kelembapan kandungan penebatan . Pada asasnya, ia adalah satu teknik yang berasaskan ukuran masa domain dan telah digunakan sejak tahun 1990-an. Analisis ini bertujuan untuk menentukan jenis kerosakan corak dengan mencari julat data PDC yang diperolehi daripada Tenaga Nasional Berhad Penyelidikan(TNBR) dengan menggunakan kaedah grafik dan teknik statistik. Sebenarnya, akan ada beberapa cabaran untuk mengklasifikasikan kerosakan semasa menentukan keputusan. Kerosakan ini terdiri daripada *partial discharge, arcing and overheating* yang akan memberi tumpuan dalam kerja-kerja penyelidikan ini. Dalam analisis hasil kerja yang diperolehi, julat *partial discharge fault* adalah 5.0 $-$ 8.0) $\times 10^{-8}$ Arus. Manakala, julat *arcing fault* ialah (8.0 $-$ 11.0)$\times$ 10^{-8} Arus. Akhir sekli, *overheating fault* ialah lebih besar 11.0$\times$ 10^{-8} Arus. Pada akhir kerja analisis, keputusan yang diperolehi dalam kerja-kerja analis akan disahkn melalui kajian sebelumnya dengan merujuk susunan pengubah rosak. Tambahan pula, keputusan dalam kerja analisis ini boleh digunakan sebagai rujukam kepada Tenaga Nasional Berhad Pengagihan (TNBD) apabila melakukan proses penyelenggaraan di pengubah kuasa sebenar menggunakan pengukuran PDC untuk mendapatkan pengubah yang rosak.

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LIST OF ABBREVIATION

RVM	-	Return Voltage Method (RVM)
FDS	-	Frequency Domain Spectroscopy
PDC	-	Polarization and Depolarisation Current
DC	-	Direct Current
TNB	-	Tenaga Nasional Berhad
TNBR	-	Tenaga Nasional Berhad Research
TNBD	-	Tenaga Nasional Berhad Distribution
OLTC	-	On-load tap changer
SOM	-	Self-Organizing Map

LIST OF SYMBOL

Co	-	The geometrical capacitance of the test object
σ_o	-	DC conductivity of the dielectric material
ε_o	-	The vacuum permittivity
δ(t)	-	The delta function
f (t)	-	Fundamental memory property of the dielectric system
I_{pol}	-	Polarization current
I_{dpol}	-	Depolarization current
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
μ	-	Mean of a sample
X_n	-	Sample values
n	-	The total number of samples
σ^2	-	Variance
σ	-	Standard Deviation
r_{xy}	-	Sample correlation
s_{xy}	-	Sample covariance.
s_x s_y	-	Sample standard deviations
p_{xy}	-	Population correlation coefficient
σ_{xy}	-	Population covariance
σ_x σ_y	-	Population standard deviations
A	-	Current

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 General Background

Power transformers play a vital role in the whole electrical power system. The main insulation system or power transformer consists of insulation oil which degrades under a combined a action of thermal, electrical, mechanical and other impurities during transformer routine operation [1,2]. The degradation of the main insulation system in transformer is recognized to be one of the major causes of transformer breakdown [3,4]. Therefore, accurately assessing the status of the transformer insulation is important. In recent years, exploring the new characteristic quantities and new technologies those reflected the state of transformer insulation has been taken seriously.

Return Voltage Method (RVM), Frequency Domain Spectroscopy (FDS) and Polarization and Depolarisation Current (PDC) are new non-destructive diagnostic techniques for determining the moisture content and faults of a power transformer [5]. However, this research work will be focused on PDC as one of the non-destructive method for determining the faults of a power transformer. The advantages of PDC is they are easy to handle due to its ability to assess the condition of oil and paper separately without opening the transformer tank [6]. There are many research about the influence of moisture, ageing and temperature on the PDC characteristics of mineral oil paper insulation [7,8]. Basically, PDC gives information about about the oil conductivity within seconds after a DC voltage step application and about the barrier conductivity over a long period of time. PDC measurement is done by application of a direct current (DC) voltage across the test object for a long duration (up to 10,000 seconds) [9].

In general, this analysis work will be focussed on PDC data collected from TNBR. Basically, PDC data consists of normal condition samples and faults condition samples of transformer. For the transformer faults condition, it can be divided by three faults which is partial discharge fault, arcing fault and overheating fault. In addition, PDC data collected from different sites location of transformer at Pencawang Pembahagian Utama (PPU). Each PDC data consists of three samples. From each samples PDC data, consists of five repetitions of polarization and depolarization current data. All the samples consists of thousonds PDC data in ampere. Therefore, PDC data will be analyse using graphical method and statistical technique to classify the transformer faults into a proper range.

1.2 Motivation

Previously, this analysis work is linked from TNBR where the real PDC data collected from the real transformers due to a transformer faults problem. Basically, there is no reference about the PDC analysis ranges due to faults transformer problem. Therefore, the project gives motivation to produce a new method to analyse PDC data by using statistical technique and graphical method to pattern classification transformer fault. Futhermore, the results obtain in analysis work will be validate with the previous research that will be explain in Chapter 2. At the end of analysis work, new reference will be coming out which can assist Tenaga Nasional Berhad Distribution (TNBD) and TNBR to determine the transformer faults based on the proper range results.

1.2 Problem Statement

PDC is one of the non-destructive method that being widely used to assess the moisture contents, ageing condition and faults of electrical equipments. In this analysis work, the PDC data collect from TNBR. Previously, PDC measurement was used to access the condition of oil transformer, whether in normal condition or faults condition. These faults consist of arcing, overheating and partial discharge. The problem with this research is to analyse the PDC data collected from TNBR and classify the faults into a proper range. Basically, there is no reference about the PDC analysis range due to transformer faults problem. Therefore, the statistical technique and graphical method will introduce in analysis work to analyse PDC data to produce a proper range results. At the end of the analysis work, the results obtains in statistical technique and graphical technique will be validate with the previous research.

1.3 Objective of Study

In order to achieve this study, the following points are highlighted:

(i) To collect the PDC data from different conditions of transformer which consists of normal, arcing, overheating and partial discharge from TNBR.

(ii) To analyse and classify the transformer faults into a proper range by using graphical method and statistical technique.

(iii) To verify the result obtain by referring the previous research.

1.3 Scope of Study

(i) From PDC data collected from TNBR, only polarization current data will be used to analyse the transformer faults.

(ii) Transformer faults consists of overheating, arcing and partial discharge as a data set.

(iii) Using standard deviation method to obtain the transformer faults result into a proper range.

(iv) Verify the results with previous research which is related faults in mineral transformer oil.

1.5 Report Outline

This report basically is divided into five chapters. In Chapter 1, provides readers a first glimpse at the basic aspects of the research undertaken, such as general background, motivation, problem statement, objectives of study and scopes.

In Chapter 2, discuss about the reviews of past studies which is related in analysis work. The literature review is conducted to understand the concept and also to get some ideas about the PDC and types of Statistical Technique that had been trying to give some explanation.

In Chapter 3, presents the flow of the study and methodology being used in this study. This is shown the steps that to clear a view of the flow of this project and try to manage the project according time given. The flow is to analysed the PDC data and apply the standard deviation method in statistical technique to produce the results.

In Chapter 4, shows project achievement by highlighting the results achieved by using standard deviation method. In this analysis work, power transformers at different places consists of three sample data collected during testing will be analysed. The results then will be compared from the previous research which is related in this analysis.

In Chapter 5, consists of conclusions based on the overall works and results. This is followed by project contribution and recommendations for future study work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Literature Review

In this chapter, a review of past studies that is related to this research work will be discussed. The literature review is conducted to understand the concept and also to get some ideas about the Polarization and Depolarization Current (PDC) and types of statistical technique. For previous years, many of the studies that have been done to diagnose of the power transformer by different methods in order to find defects of the transformer. In recent years, exploring the new characteristic quantities and new technologies those reflected the state of transformer insulation has been taken seriously. In [5], Return Voltage Method (RVM), Frequency Domain Spectroscopy (FDS) and PDC are new non-destructive diagnostic techniques for determining the moisture content and faults of a power transformer. The reason is, they are easy to handle and portable information which have been widely studied. However, in this research only PDC techniques will be discussed in this chapter.

This chapter, will review previous research related in PDC technique and statistical techniques to get some ideas to analyse PDC data collected from TNBR and classify the transformer faults into a proper range. Section 2.2, will be discussed about the theoretical of PDC. This section is important because it will be explained clearly the basic concept about PDC principle and theory. In Section 2.3, will be discussed the details about the application of PDC for electrical equipments. These electrical equipments applied in PDC consist of solid insulation, cable insulation and oil insulation will be explained in Section 2.3.1 to Section 2.3.3. Furthermore, Section 2.4 will be discussed the application PDC analysis on Power Transformer. In Section 2.4.1, discuss about the moisture and surface humidity in two identical transformers. While, Section 2.4.2 will be discussed about PDC analysis applied in free water in a refurbished transformer. For the Section 2.4.3, will be discussed PDC analysis applied in water and contaminants in a new On-Load Tap Changer (OLTC). In addition, Section 2.5 will be discussed in details about PDC applied in mineral transformer oil. Basically, this research results will be used as a reference in this analysis work. Whereas, in Section 2.6 will review about the types of the statistical techniques. Mean, variance, standard deviation, and correlation coefficients function (CCF) will be explained in Section 2.6.1 to Section 2.6.4.

2.2 Theoretical of Polarization and Depolarization Current

According to [10-15], researcher had been investigate the principles of PDC measurement technique. PDC measurement is a useful technique for assessing the condition of the insulation materials in power transformers. The PDC measurement procedure consists in applying a DC high voltage across a test sample for a long time (up to 10,000 seconds). Figure 2.1 shows the schematic diagram of the PDC measuring technique.

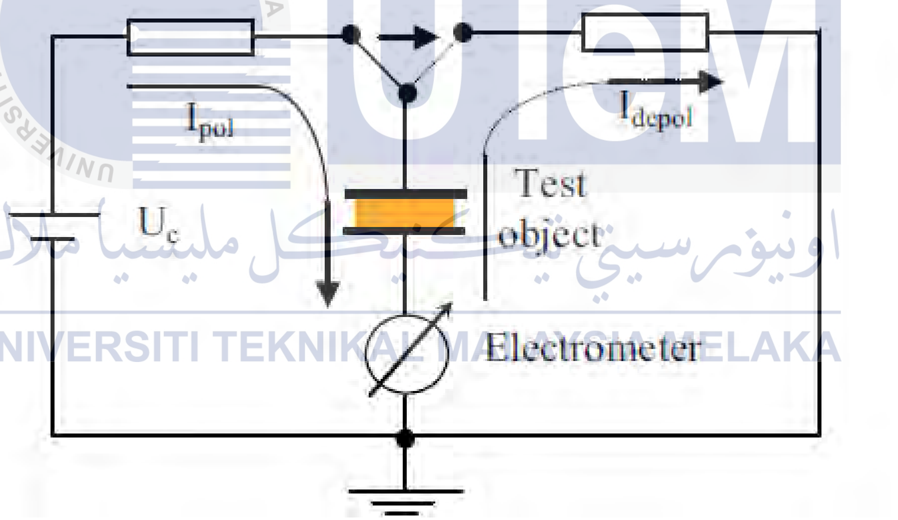

Figure 2.1: Principle of test arrangement for the PDC measuring technique [15]

From the Equation 2.1 and Equation 2.2, *Co* is the geometrical capacitance of the test object, σ_o is the DC conductivity of the dielectric material, ε_o= 8.8852 $\times 10^{-12}$ As/Vm is the vacuum permitivity and *δ(t)* the delta function arising from the suddenly applied step voltage at t=t_o. The response function *f (t)* describes the fundamental memory property of the dielectric system and can provide significant information about the insulating material. The formula from Equation 2.1 represent the charging period, I_{pol} *(t)* (polarization current or absorption or charging) :

$$I_{pol}\,(t) = C_o U_C[\frac{\sigma_0}{\varepsilon_0} + \varepsilon_\infty \delta(t) + f(t)] \quad (2.1)$$

where

I pol = Polarization of currents

Co = Geometrical capacitance of the test object

σ_o = DC conductivity of the dielectric material

ε_o = 8.8852 $\times 10^{-12}$ As/Vm

δ(t) = Delta function

f (t) = The response function

The test sample is then short-circuited by removing the applied voltage *at t* = t_c, enabling the measurement of the depolarization current (or discharging) I_{dpol}*(t)* in the opposite direction, without contribution of the conductivity. Once the step voltage is removed and the insulation system is short to ground, the depolarization can be written as in Equation 2.2:

$$I_{depol}(t) = -C_o U_C[f(t) - f(t) - f(t + T_C] \quad (2.2)$$

where

I depol = Depolarization of currents

Co = Geometrical capacitance of the test object

σ_o = DC conductivity of the dielectric material

ε_o = 8.8852 $\times 10^{-12}$ As/Vm

δ(t) = Delta function

f (t) = The response function

Figure 2.2 shows the nature of the polarization current after applying a DC voltage Uc and depolarization current during a short circuit. The test object is charged from $t_o \leq t \leq t_c$ (polarization current or charging) and short circuited is from $t \geq t_c$ (depolarization current or discharging)

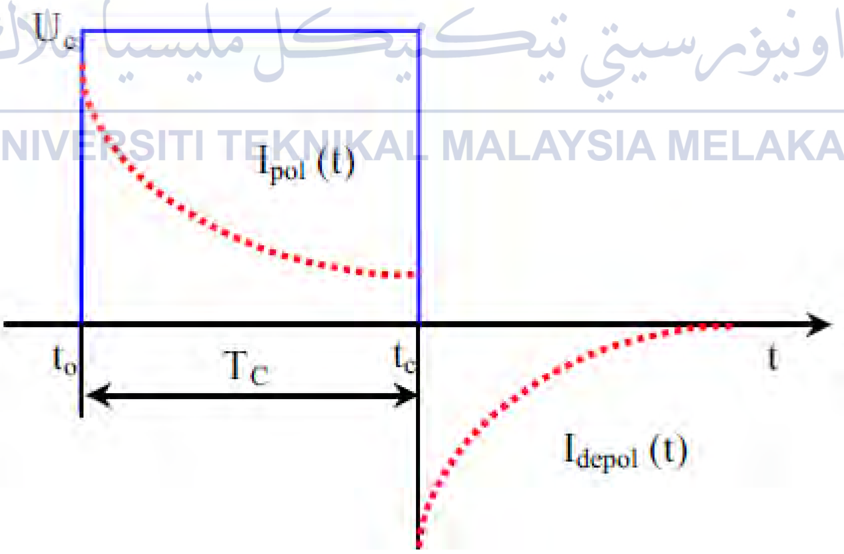

Figure 2.2: Principle of polarization and depolarization current [14,16]

2.3 Application of Polarization and Depolarization Current for Electrical Equipments

According to [10], a researcher had been investigating that PDC is new non-destructive diagnostic techniques to determine the moisture content and faults of a power transformer. They are easy to handle and portable information which have been widely studied. The other advantage about PDC is a high voltage (HV) equipment can be applied in many electrical apparatus such as solid insulation, cables, transformer and OLTC as well as to estimate conductive and moisture contents of the insulations. As we know that the presence of moisture and other impurities inside the insulator can cause the breakdown and conduction of a dielectric inside the insulator. Therefore, this technique is very useful to estimate conductivity, moisture and faults contents of the insulation. This chapter has reviewed about the application of PDC technique in determining the conductivity of the insulation of the electrical equipments.

2.3.1 Polarization and Depolarization Current applied to Solid Insulation

In [10], the polarization current measurement is performed by applying a DC voltage step on the dielectric materials and depolarization current is measured by removing the DC voltage source with a switch which turn on to short circuit at the under test objects. The DC voltage applied was 1000V for about 10,000 seconds for polarization and depolarization time. Figure 2.3 shows an example of the PDC measurement setup that have been developed. The control software was developed in the LabVIEW environment which enables the operator to record voltage and currents, automatically during PDC measurements [10,11].

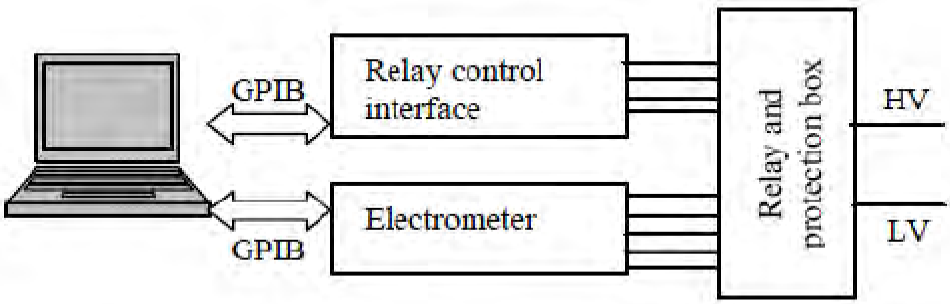

Figure 2.3: Schematic diagram of the PDC measurement setup [10,11]

The principles of PDC measurement arrangement on insulation windings and power cable with isolated shield is shown in Figure 2.4.

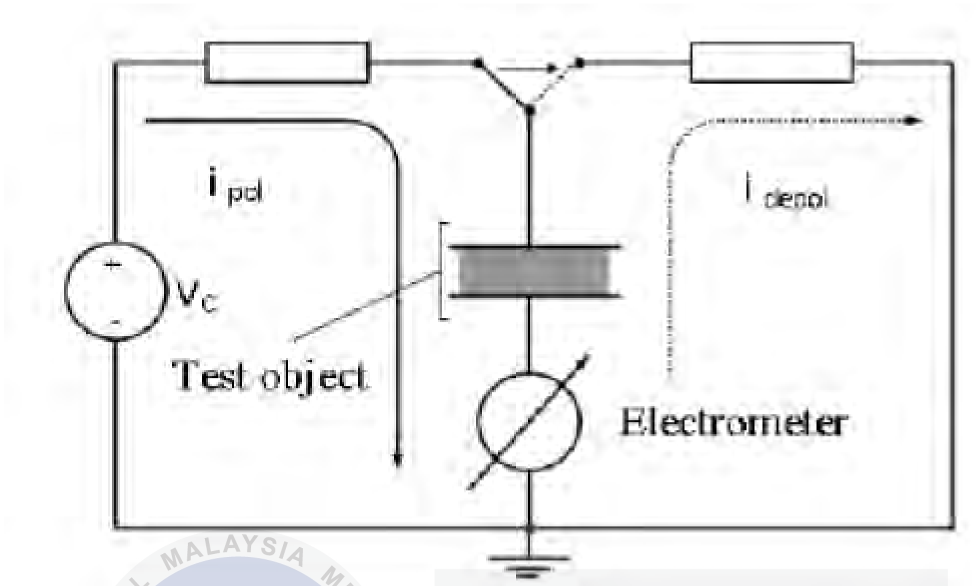

Figure 2.4: Principle of test arrangement for PDC measurement with isolated shield [10]

Researchers [12,13] set measurement arrangement as shown in Figure 2.5 for measurement of ground insulation of each winding and power cable with a grounded shield in case of sheath damage which can cause high conduction to ground of insulation shield.

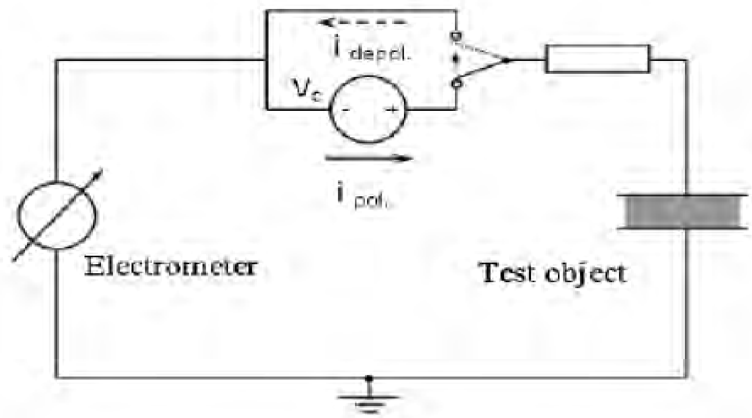

Figure 2.5: Principle of test arrangement for PDC measurement with grounded shield [12,13]

The analysis PDC measurement for machine insulation was done based on result in paper research [14]. Figure 2.6 and Figure 2.7 show that polarization and depolarization current for polyester-mica coil is higher than ep-Oxy-mica bar in both conditions. Its conductivity increases sharply after moisture absorption, which caused a significant change in the dielectric response of the insulation system, resulting into the occurrence if an interracial polarization peak within the time frame of observation. Higher solid insulation, moisture or conductivity tends to increase the magnitude of the polarization and depolarization currents at longer times.

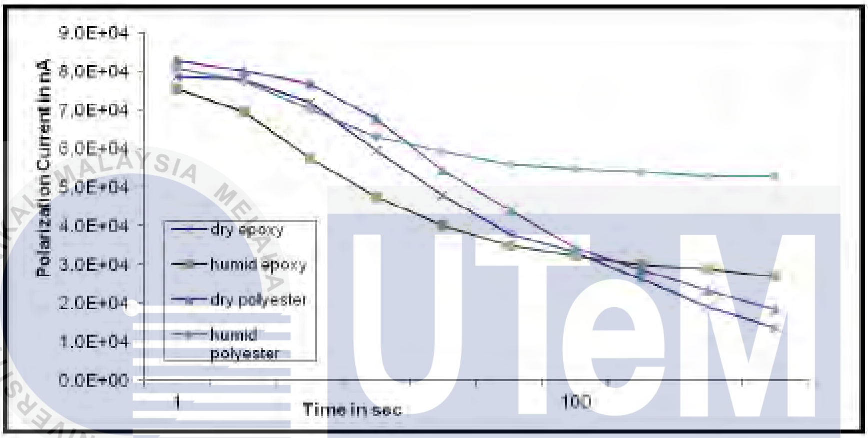

Figure 2.6: Charge currents for epoxy-mica bars and a polyester-mica oil before (dry) and after (humid) one week under a humid atmosphere [14]

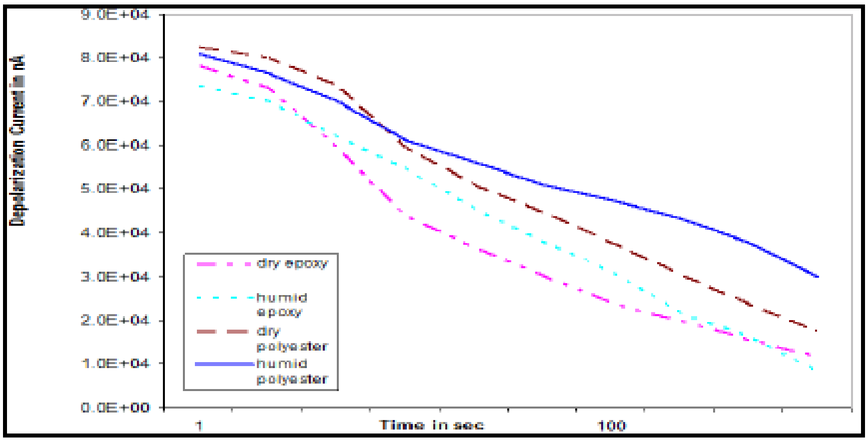

Figure 2.7: Discharge currents for epoxy-mica bars and a polyester-mica coil before (dry) and after (humid) one week under a humid atmosphere [14]

2.3.2 Polarization and Depolarisation Current applied to Cable Insulation

PDC application of cable insulation was done on the previous research. Based on research [14,15], the test was classified into several cable classifications as listed in Table 2.1. Cluster A contains the newest cables with no joints and some intermediate aged couples. Cables in Cluster B have failed and had been repaired many times, but there is degradation of the cable insulation. Cables in Cluster C contain one of the newest cables with poor joints insulation quality. Cables in Cluster D appear to share characteristics of cable in cluster B and C.

Table 2.1: Cable conductivity for different concdition [14,15]

Cluster	Cable Joint	Fault	New Cable	σ_{app}	DONL
A	×	×	/	$<10 \times 10^{-16}$	=1.0
B	×	/	×	$100 \times 10^{-16} < \sigma < 1000 \times 10^{-16}$	=1.0
C	/	×	/	$< 10 \times 10^{-16}$	1.2<DONL<6
D	/	/	/	$100 \times 10^{-16} < \sigma < 1000 \times 10^{-16}$	1.2<DONL<10

Observation of the above table shows the cables with $\sigma_{app} > 10 \times 10^{-16}$ S/m and degree of non-linearity, DONL > 1.2 but < 2 they could have joint or water tree problems. If cables with $\sigma_{app} < 10 \times 10^{-16}$ S/m and DONL > 1.2 but < 2, the cables have higher water tree density where no tree is bridge the insulation and if the cables with $\sigma_{app} < 10 \times 10^{-16}$ S/m and DONL < 1.2, cables are in good condition. As temperature increase, apparent conductivity increases. This is due to insulation degradation with temperature with refer to ageing process.

2.3.3 Polarisation and Depolarisation Current applied on Oil-Paper Insulation

Based on [16], PDC measurement which is based on the dielectric response is currently widely used for condition assessment of transformer insulation as non-destructive testing method. This research based on the equivalent model of oil-paper insulation structure-X model. Polarization and depolarization current were measured under different aging degrees. Experimental results show that, PDC values and the corresponding values characteristic parameters would change regularly with aging degree. In guarantee under the condition of water content is consistent, the PDC can be used to assess the aging state of transformer oil-paper insulation. The polarization current curve under different aging degree were shown in Figure 2.8 and depolarisation current curves in Figure 2.9.

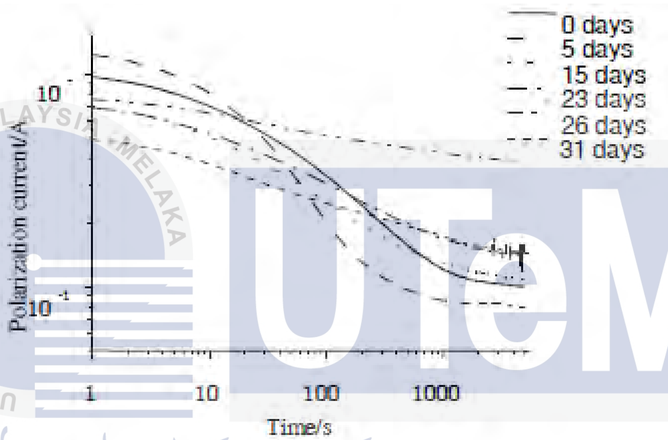

Figure 2.8: The polarization currents of samples in different aging degree [16]

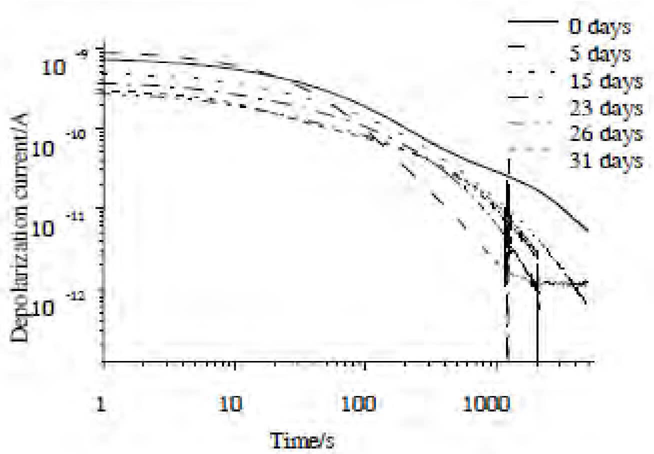

Figure 2.9: The depolarization currents of samples in different aging degree [16]

From Figure 2.8 and Figure 2.9 shows that the polarization current and depolarization current of samples in different aging degree. This paper [16] discussed the tail of polarization and depolarization currents curves. With the increase of aging degree, the amplitude of tail of measured polarization and depolarization current significantly increased. Thus, the higher the aging degree was the greater the amplitude of current. The reason are that oil-paper insulation system aged gradually under high temperature. With the accelerated thermal aging time increased the glycosidic bond of cellulose in insulating papers fractured and glucose key broken. Then the polymerization degree and tensile strength of paperboards decreased and a single glucose, carbon monoxide (CO), carbon dioxide (CO_2) and moisture were produced. These kind all moisture can reducing the dieletric strength and properties of insulating paperboards.

2.4 Application of Polarization and Depolarization Current Analysis on Power Transformer

Researcher [17] had been investigate analysis on how to identify wet insulation system in an power transformer and on-load tap changer (OLTC) by PDC analysis. The first two case studies on transformers without oil (before oil refiling) demonstrate how aging type of solid insulation can be identified by the PDC technique. For another case studies related on OLTC, it emphasizes the importance of filling a new transformer with good oil having very low conductivity.

2.4.1 Moisture and Surface Humidity in Two Identical Transformers

PDC measurement of insulation between winding was carried out on two identical 20MVA, 33/11kV transformers, Tx A and Tx B, after workshop refurbishment but before oil refilling. The results are shown in Figure 2.10. Moisture in pressboard of a transformer without oil increases both polarization current (I pol) and depolarization current (I depol.) in related shapes. Surface humidity by deposits on pressboard surfaces increases only I pol. but not I depol. This means Tx-A has higher surface humidity of pressboard than Tx-B because of higher I pol. In a conclusion, surface humidity increases the amplitude of polarization current at longer time, but not the depolarization current.

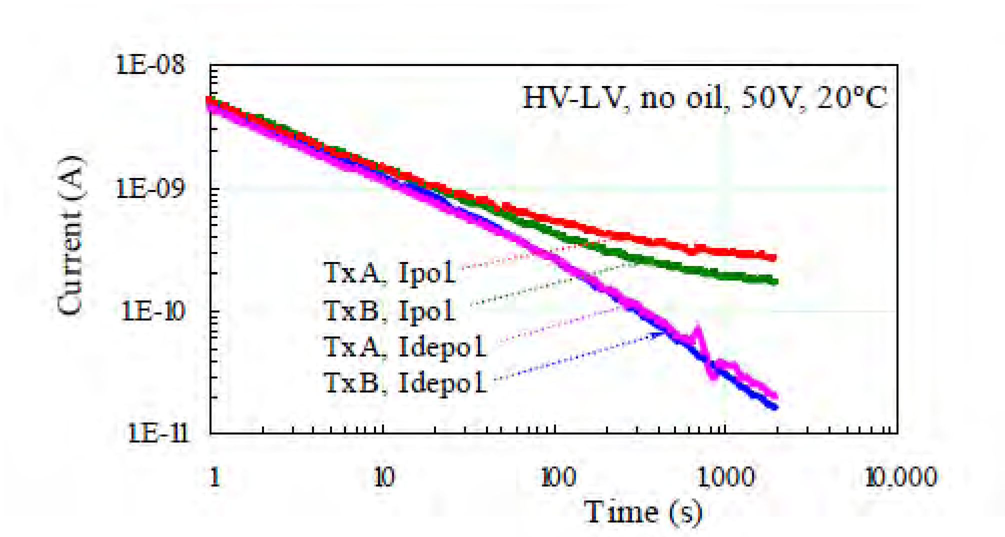

Figure 2.10: PDC measurement and evaluation results of two identical transformers after refurbishment, but before oil refilling (without oil) [17]

2.4.2 Free Water In A Refurbished Transformer

Author in [17] analysed of a transformer without oil allows aging condition. This aging condition can be identified as thermal aging. Water entered the main tank of this 25 MVA, 66/11 kV transformer after refurbishment as the hose used for oil refilling contained water. Figure 2.11 shows PDC measurement and evaluation results of high voltage to the ground insulation (HV-E) and low voltage to the ground insulation (LV-E) without oil of the transformer. This transformer without oil revealed the insulation between winding, HV-LV, had not yet been influenced by water. But the result of LV-E indicated surface humidity or free water, moisture in solid and thermal aging. It can be identified by an increase in PDC amplitudes (I polarization and I depolarization). In addition, the bending of I polarization is the pattern of thermal aging in solid insulation.

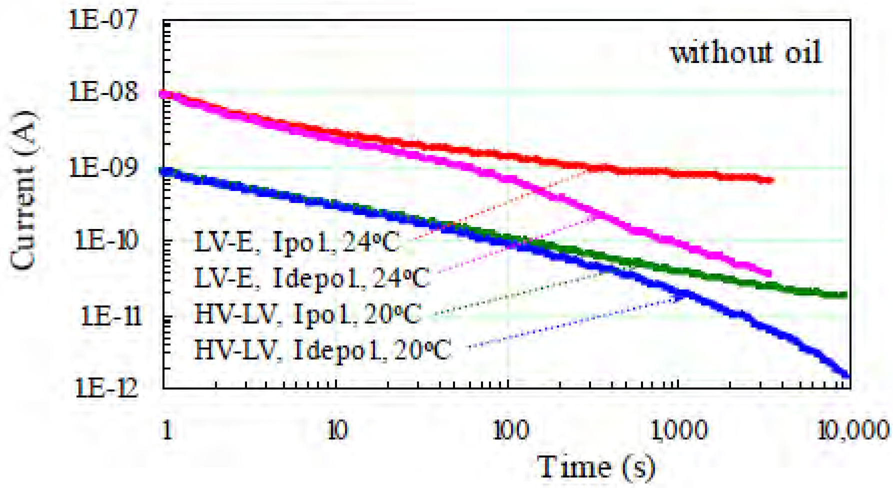

Figure 2.11: PDC measurement and evaluation results of HV-LV and LV-E insulation without oil of the transformer [17]

2.4.3 Water and Contaminants in a new OLTC

PDC analysis was applied as a commisioning of a new 25 MVA, 66/11KV transformer. The transformer which has an OLTC on the high voltage side. Figure 2.12 presents the PDC time domain measurement results between high voltage and low voltage windings (HV-LV) as well as the ground insulation of high voltage winding (HV-E). For HV-LV, PDC advanced evaluation software showed moisture in pressboard was 1.4% and conductivity at 20°C of oil in the main duct was 0.79 pS/m. Though the results was not considered good for a new transformer. For HV-E, an indication for the high moisture in solid insulation are high amplitude of polarisation currents. At longer time, big difference between polarization current and depolarization currents. Since the insulation system of HV-LV was not consider good, OLTC was suspected.

After confirmation of moisture in OLTC, internal inspection was carried out. Finally, free water were found as shown in Figure 2.13. The PDC advanced evaluation showed conductivity oil in the main duct between windings was 0.79 Ps/m at 20°C, which was possible for a new transformer which has not yet in service. This means it was not too late to give good life to this new transformer. After OLTC was clean and dry, both oil in main tank OLTC was replaced with new oil having conductivity of 0.08 Ps/m at 20°C. PDC test after oil replacement showed conductivity of oil duct between windings was 0.11 ps/m at 20°C. Finally, good oil can improved the life of this new transformer.

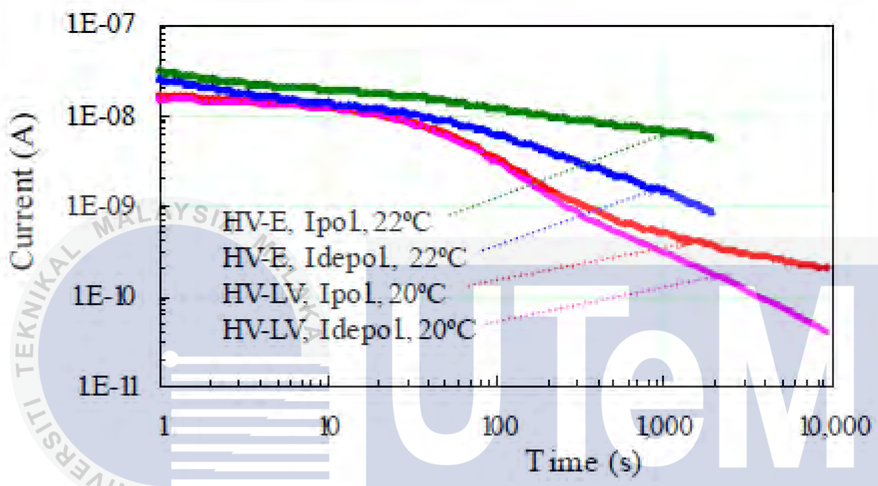

Figure 2.12: PDC measurement and evaluation results of HV-LV and HV-E insulation before oil replacement [7]

Figure 2.13: Free water found inside the new on-load tap changer [7]

2.5 Polarization and Depolarization Current Applied on Mineral Transformer Oil

Author in [18] had been to analysed to find the PDC pattern of the mineral transformer oil after being subject to a faults. This experiment was carried out in the laboratory to obtain PDC patterns generated by both oils after being subjected to different types of faults. These faults consist of partial discharge, arcing and overheating. At the of this researched, can be concluded that using PDC analysis, it can be traced these such faults. Partial discharge, arcing and overheating faults were applied to oils taken directly from the drum which is no further drying was done to the oil to remove the moisture. This research is similar in analysis work but different country. My analysis work will be focused on PDC data collected from TNBR in Malaysia, but the previous research is made from Australia at University of New South Wales, Sydney. Therefore, the results will be difference in ranges due to differents in temperature, places and condition of oil which is will cause the transformer faulty.

2.5.1 Test Mineral Oil Preparation

The purpose is to investigare the PDC of mineral and biodegradable oils after being subjected to a fault. Partial discharge, arcing and overheating faults were applied to oils taken directly from the drum. Then an oil sample from each fault simulation test was extracted for use in the PDC test. The fault simulation was done according to the procedures below [18].

For partial discharge transformer fault, the test cell used for the partial discharge experiment was constructed according to IEC 60897 [19]. The test circuit and procedure to measure partial discharge followed IEC 60270 standard. Partial discharge in the bulk oil was achieved by application of AC voltage across a point-plane electrode to well above its partial discharge inception level. Partial discharge activities in the oil were monitered and recorded using partial discharge detection system. The partial discharge fault was allowed to continue for at least 50 minutes before an oil sample was taken to perform PDC test [18].

Futhermore, the same test cell configuration was used for the arcing transformer fault. In this test, the applied voltage was increased until arcing or breakdown occured. For tests without pressboard, the breakdown was repeated for 200 times before the oil sample was taken [18].

Lastly, for the overheating transformer fault, test was performed by heating the oils in the oven temperature maintained between 130°C for 150 hours. This is below the flash point limit for both oils. These were made with a temperature resistant screw-cap fitted with a PTFE-coated silicone seal and matching pouring ring. They can be used in temperature up to 260°C and are also capable of being sealed gas tight [18].

2.5.2 Results of Mineral Transformer Oil

Basically, experimental results indicate that oil which experienced a fault can be traced by using PDC analysis. Event no unique pattern was traced in mineral oil after faults, the conductivity and current pattern after fault is different compared to fresh oil. Thus could give some indication to what had happened inside the transfomer. For this mineral oil , the difference in the patterns is much clearer. Thus faults happened in transformers insulated with this oil can be detected and recognized [18].

Figure 2.14 shows the polarization and depolarization current pattern for mineral oil after partial discharge fault. From Figure 2.14, it can be seen current start stabilize at the point below 1.00×10^{-10} for the polarization current. Whereas, depolarization current line approach to zero.

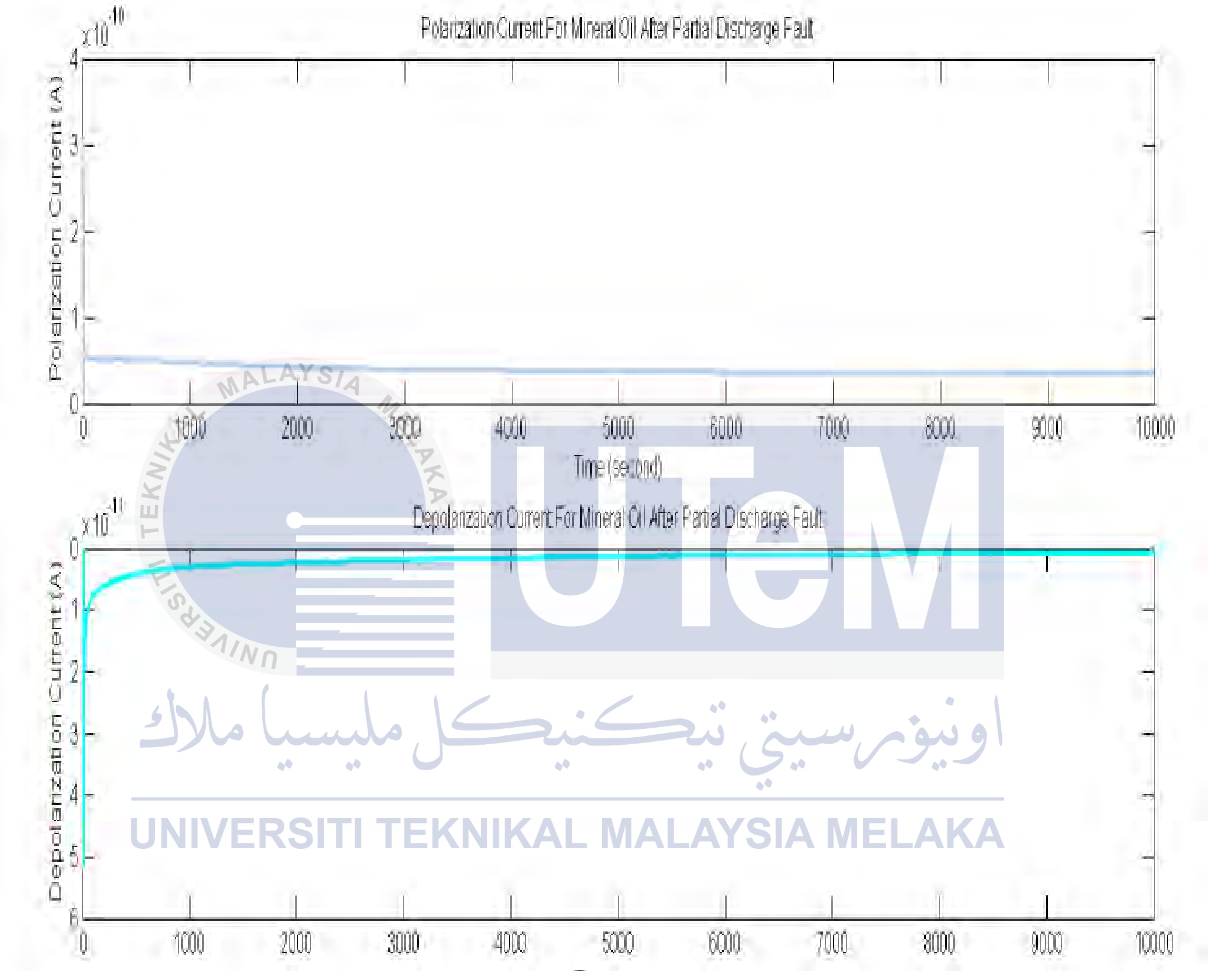

Figure 2.14: PDC result for mineral oil after partial discharge [18]

Figure 2.15 shows the polarization and depolarization current pattern for mineral oil after breakdown fault or arcing fault. From Figure 2.15, it can be seen the current start stabilize at the point 2.00×10^{-10} For the polarization current which is after partial discharge occurred. Whereas, depolarization current line approach to zero.

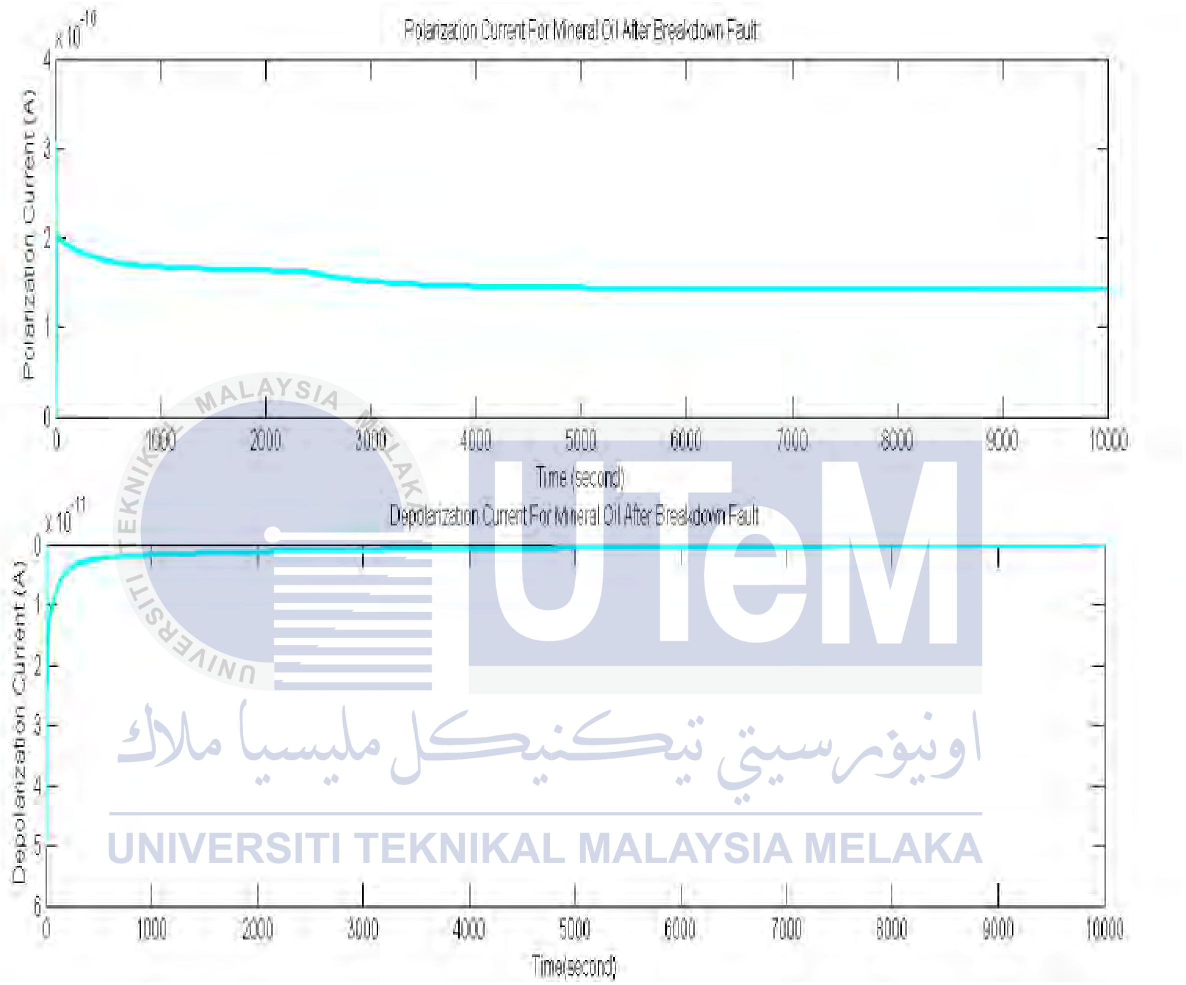

Figure 2.15: PDC result for mineral oil after breakdown fault [18]

Figure 2.16 shows the polarization and depolarization current pattern for mineral oil after overheating fault. From Figure 2.16, it can be seen the current start stabilize at the point 4.00×10^{-10} for the polarization current which is after a partial discharge fault and arcing fault occured. Whereas, depolarization current line approach to zero.

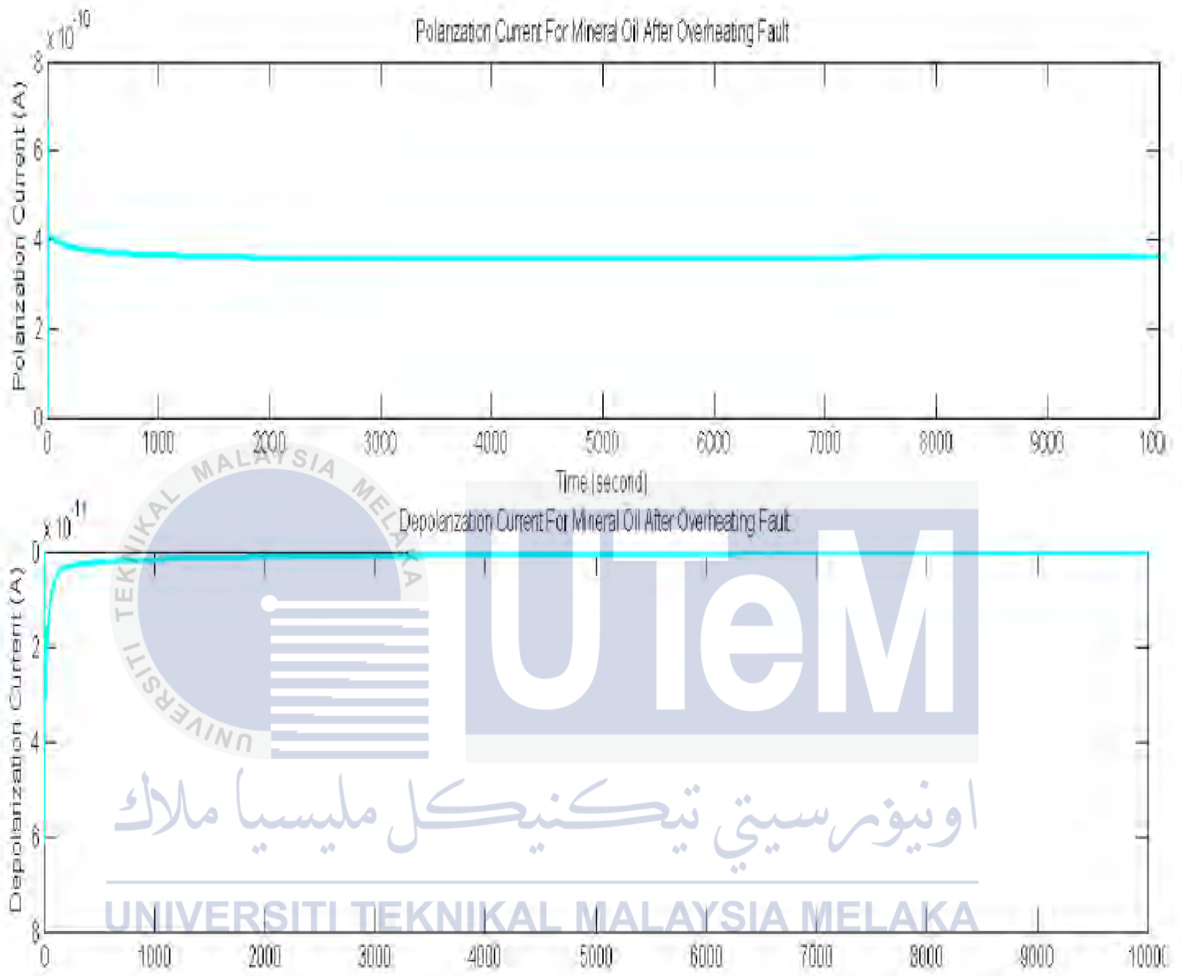

Figure 2.16: PDC result for mineral oil after overheating fault [18]

At the end of the researched, the results for PDC tests on mineral transformer oil after faults will be summary as shown in Table 2.2. The test conducted will be covered in moisture level before test, measured capacity value, maximum PDC and maximum conductivity. According the results, only maximum PDC will be used as a reference during analysis work.

Table 2.2: Summary of analysis results for PDC tests on oil after faults [18]

Oil Types	Oil Conditions	Moisture Level Before Test (ppm)	Measured Capacity Value (Pf)	Maximum PDC (A)	Maximum Conductivity (σ_r) (S/m)
Mineral Oil	Partial Discharge Fault	29	19.9	0.5×10^{-10}	2.653×10^{-13}
	Breakdown / Arcing Fault	30	19.4	2.0×10^{-10}	2.713×10^{-13}
	Overheating Fault	48	16.2	4.0×10^{-10}	7.514×10^{-13}

2.7 Statistical Technique

The PDC data will be apply in statistical technique where this technique can classify the faults into a proper range during analysis. Statistics is the study of the collection, analysis, interpretion and presentation of data [20]. It deals with all aspects of data including the planning of data collection in terms of the design of analysis. There are four of types of statistical technique that have been discuss in this chapter to chosen the best and suitable technique to applied in this PDC analysis. This technique which consists of mean, variance, standard deviation and cross-correlation coefficients function.

2.7.1 Mean

In statistic, mean or average is the sum of number divided by the number of numbers in the collection [21]. This collection is a set of results of PDC data. The average value of finitely many number X_1, X_2, X_3,..., X_n is defined in Equation 2.3.

$$\mu = \frac{X_1 + X_2 + X_3 + \cdots + X_n}{n} \tag{2.3}$$

Where μ = Mean of a sample

X_n = Sample values

n = The total number of samples

2.7.2 Variance

According [22], variance is a measurement of the spread between numbers in a data set. The variance measures how far each number in the set is from the mean. Variance is calculated by taking the difference between each number in the set and the mean, squaring the differences to make them positive and dividing number of values in the set. A large variance indicates that numbers in the set are far from the mean and each other, while a small variance indicates the opposite. Statisticians use variance to see how individual numbers related to each other within a data set. The basic formula of variance is defined in Equation 2.4.

$$\sigma^2 = \frac{\sum_{i=1}^{N}(X_i - \mu)^2}{N} \tag{2.4}$$

where

σ^2 = Variance

$\sum X - \mu$ = The difference between each number in the set and the mean

N = Number of values in the set

2.7.3 Standard Deviation

In statistics [23], the standard deviation represents as sigma, σ shows how much variation from the average exists. The standard deviation of a data set is the square root of its variance. Same as variance, a low standard deviation indicates that the data points tend to be very close to the mean. While a high standard deviation indicates that the data are large range of values. This standard deviation gives a value that is in the same units as the original values, which makes it much easier in analysis compared as variance which is not. The basic formula of standard deviation is defined in Equation 2.5.

$$\sigma = \sqrt{\sigma^2} \tag{2.5}$$

where

σ = Standard Deviation

σ^2 = Variance

2.7.4 Correlation Coefficients Function (CCF)

According to [24], the correlation coefficient of two variables in a data sample is their covariance divided by the product of their individual standard deviations. It is a normalized measurement of how the two are linearly rated. Formally, the sample correlation is defined by the following formula, where s_x and s_y are the sample standard deviations and s_{xy} is the sample covariance as shown in Equation 2.6.

$$r_{xy} = \frac{s_{xy}}{s_x\, s_y} \tag{2.6}$$

Similarly, the population correlation coefficient is defined as follows, where σ_x and σ_y are the population standard deviations and σ_{xy} is the population covariance as shown in Equation 2.7.

$$p_{xy} = \frac{\sigma_{xy}}{\sigma_x\, \sigma_y} \tag{2.7}$$

If the correlation coefficient is close to 1, it would indicates that variables are positively linearly related and the scater plot falls almost along a straight line with positive slope. For -1, it indicates that the variables are negatively linearly related and the scatter plot almost falls along a straight line with negative slope. And for zero, it would indicates no linear relationship between the variables.

2.8 Summary of Literature Review

In this chapter give the concept of the PDC applied at transformer oil. Review the previous research to get some ideas is important step before move to another step. After review the previous research, it is clear prove the PDC is one of the technique can be applied in many electrical equipment include transformer due to find faults. From the previous Section 2.5, the results for PDC tests on mineral transformer oil after faults will be used as a reference during analysis work.

Furthermore, statistical technique was introduce in analysis work to analyse PDC data to produce the results by classify the faults into a proper range. After review several statistical technique to be applied in PDC analysis, the standard deviation method has their own advantages to classify the pattern of faults into a proper range. Basically, the standard deviation is calculated by taking the difference between each number in the set and the mean. A larger standard deviation indicates that numbers in the set are far from the data set, while a small standard deviation indicates the opposite. Therefore, the standard deviation is suitable and accurate to pattern the classification of faults due to provide the results.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, will started with the flow chart of methodology illustrated in Figure 3.1. The flow chart shows the activities or tasks to be done at each stage of the project's planning. In Section 3.2, will be explain about the PDC data collection from TNBR. In this section, will be explain in details about the samples of the contents in PDC data, the location site of power transformer and the type of oil used during testing. While, Section 3.3 will be discuss the steps to analyse PDC data using graphical method. Furthermore, Section 3.4 will be discuss the classification the transformer faults pattern using statistical technique. In this section, the steps of the statistical technique will be explain during to get a proper range faults. Whereas, validation of PDC data will be explain in Section 3.5.

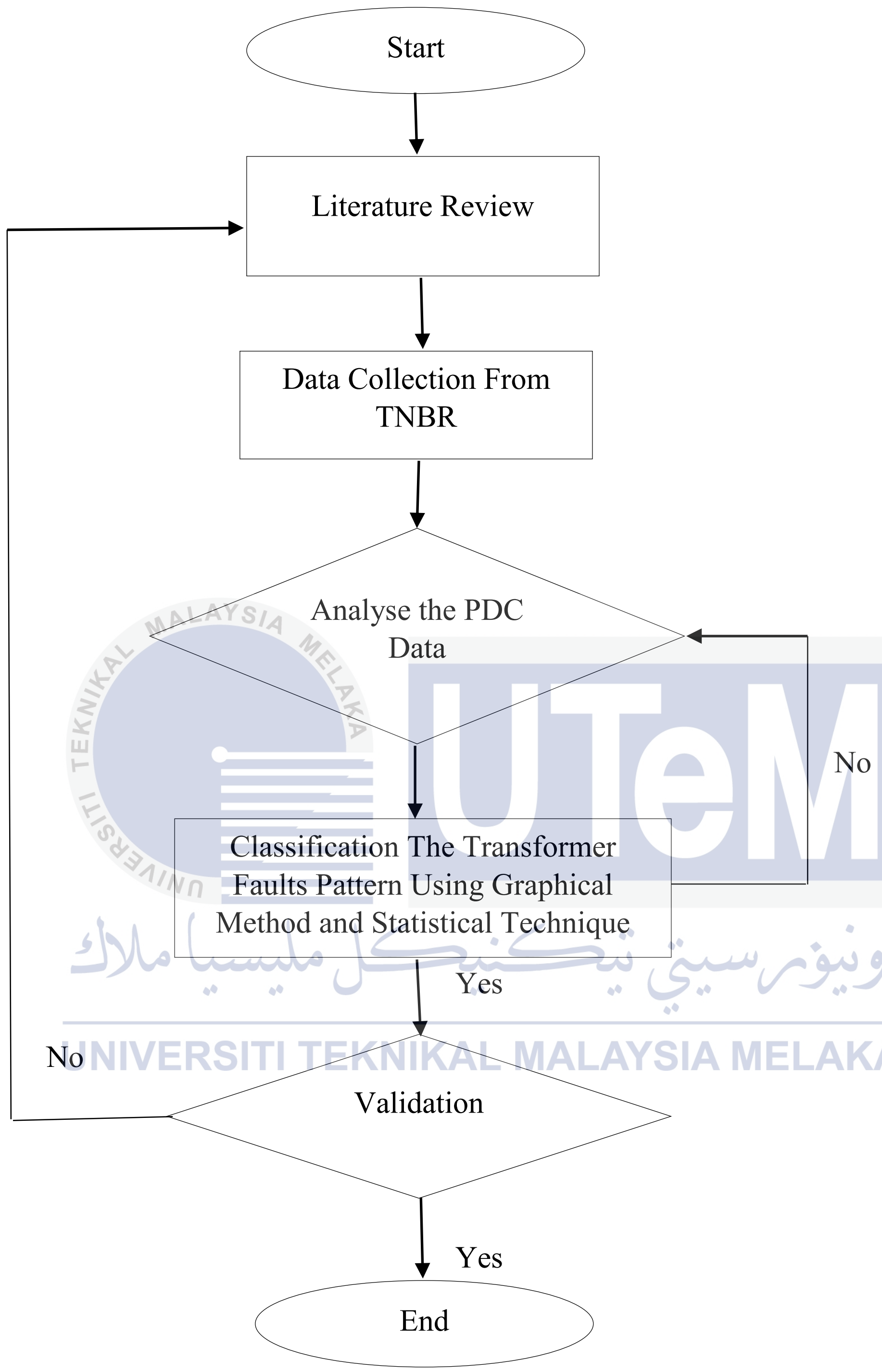

Figure 3.1: Flow chart of methodology

3.2 PDC Data Collection From TNBR

This analysis work focus on PDC data collected from TNBR. These data consists of transformer normal sampes and transformer faults samples. These faults consists of arcing, overheating and partial discharge. Basically, PDC data consists different location of power transformers during testing. Previously, mineral oil was used as the test object in the oil insulation during PDC measurement conducted by TNBD.

In addition, each power transformer consists of three sample PDC data collected during measurement. Each sample consists of polarization and depolarization currents data with time taken during testing. Futhermore, polarization and depolarization currents consists of five repetitions. From the previous research [9], the basic concept of PDC measurement is done by application of a DC voltage across the test object for a long duration which is up to 10,000 seconds. Whereas, time taken during PDC measurement conduct by TNBD is starting from 1 seconds to 9120 seconds. The details samples of PDC data are as attached in Appendix A and Appendix B.

Table 3.1 shows the details about the location of transformers based on the condition of transformers. From Table 3.1, only one normal transformer sample will be select in analysis work. Whereas ten transformers will be select as samples from each faults. Previously, all the location sites is taken at PPU during PDC measurement conducted by TNBD.

Table 3.1: Location Site of Power Transformers

Location of Transformers	Types of Faults
Bukit Merah	Normal
Bandar Sunway	Arcing
Lion Industrial Park	Arcing
Labur Bina	Arcing
Danau Kota	Arcing
Salinas	Arcing
Sg. Lang	Arcing
Sime UEP	Arcing
Wonderful	Arcing
New Town Port	Arcing
Bintang Buana	Arcing
Sri Edaran	Overheating
Farizar	Overheating
Bukit Maluri	Overheating
Sri Hartamas	Overheating
Star Hills	Overheating
TNB Kepong	Overheating
Paya Terubung Tx1	Overheating
Paya Terubung Tx2	Overheating
Seberang Jaya	Overheating
Hicom	Overheating
Jalan Gopeng	Partial Discharge
Hutan Melintang	Partial Discharge
Sunway City	Partial Discharge
Damansara Damai	Partial Discharge
Balik Pulau	Partial Discharge
Jalan Pahang	Partial Discharge
City Hall	Partial Discharge
MPAJ	Partial Discharge
City Hall	Partial Discharge

3.3 Analyse the PDC Data

There are hundreds of numbers consists in PDC data samples. The problem in this research is how to interpret and analyse the PDC data to classify the transformer faults into a proper range in determining arcing fault, overheating fault and partial discharge fault. For PDC data, there are three samples from each transformers. Each samples, consists of five repetitions of polarization and depolarization current. The details samples of PDC data are as attached in Appendix A and Appendix B. Basically, there are two techniques to analyse PDC data in order to classify the transformer fault into a proper range. One of the techniques to analyse the PDC data is the scatter with smooth lines in order to presents results in graphical technique. Besides that, the statististical technique will be use in order to analyse PDC data to classify the transformer faults. Futhermore, the results obtain in graphical technique will be compare with the statistical technique. The ranges of the results may conclude as valid and acceptable as if the statistical technique results same with the PDC data present in graph. If the graph results is not in the ranges of the statistical technique result, this situation may conclude as wrong result.

3.3.1 Classification The Transformer Faults Pattern Using Graphical Method

In general, the transformer faults will be presents in graphical method during analyse PDC data. The type of scatter with smooth lines graph will be select in order to present the transformer faults. The advantages using scatter with smooth lines graph is it can show patterns in large sets of data. In addition, scatter lines are useful for illustrating the patterns in the data, for example by showing linear data and clusters the data. Basically, PDC data can directly copy to worksheet as shown in Figure 3.2. Figure 3.2 shows the basic technique in graphical method to copy from PDC data to worksheet in Microoft Word.

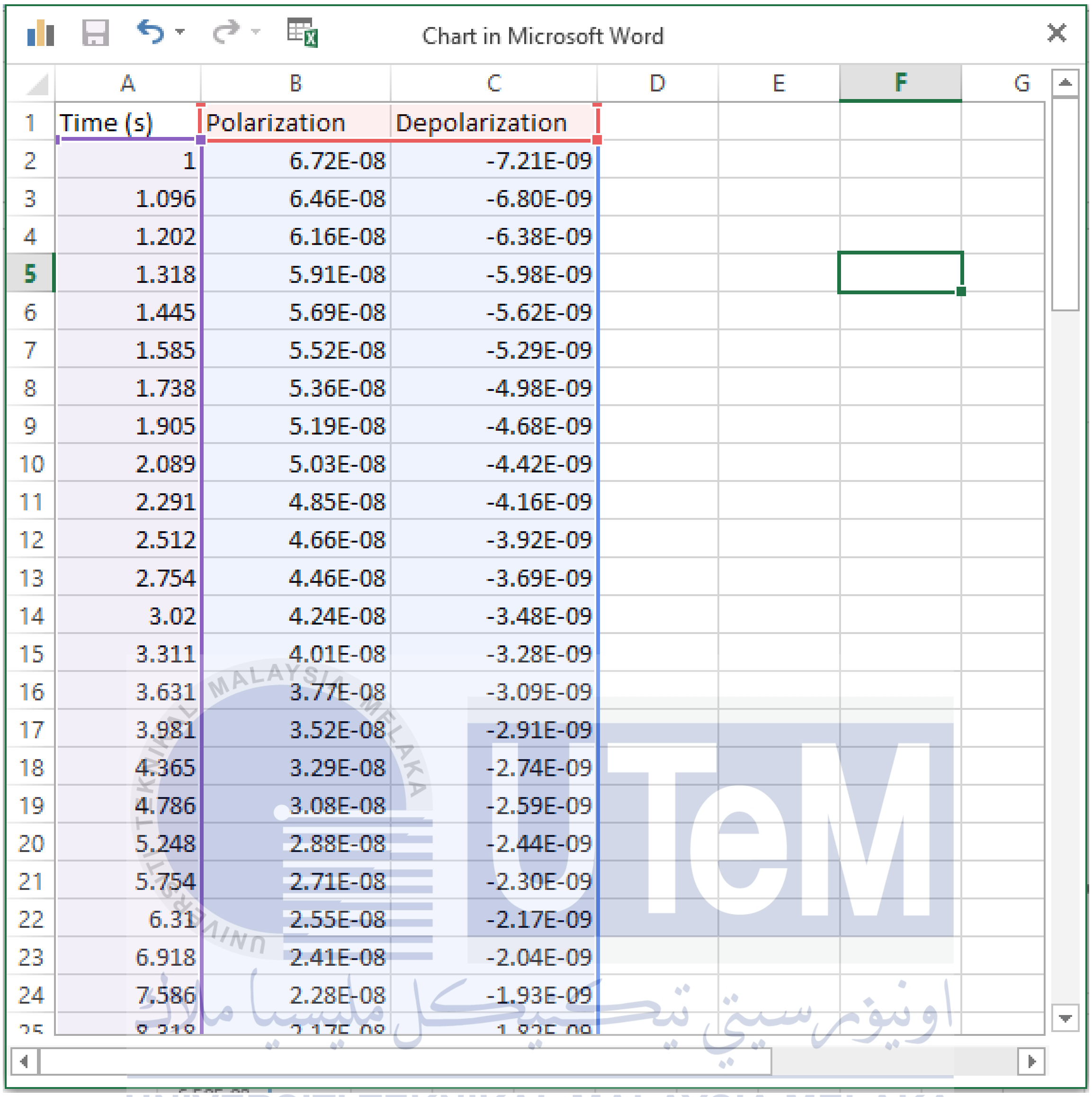

Chart in Microsoft Word

	A	B	C
1	Time (s)	Polarization	Depolarization
2	1	6.72E-08	-7.21E-09
3	1.096	6.46E-08	-6.80E-09
4	1.202	6.16E-08	-6.38E-09
5	1.318	5.91E-08	-5.98E-09
6	1.445	5.69E-08	-5.62E-09
7	1.585	5.52E-08	-5.29E-09
8	1.738	5.36E-08	-4.98E-09
9	1.905	5.19E-08	-4.68E-09
10	2.089	5.03E-08	-4.42E-09
11	2.291	4.85E-08	-4.16E-09
12	2.512	4.66E-08	-3.92E-09
13	2.754	4.46E-08	-3.69E-09
14	3.02	4.24E-08	-3.48E-09
15	3.311	4.01E-08	-3.28E-09
16	3.631	3.77E-08	-3.09E-09
17	3.981	3.52E-08	-2.91E-09
18	4.365	3.29E-08	-2.74E-09
19	4.786	3.08E-08	-2.59E-09
20	5.248	2.88E-08	-2.44E-09
21	5.754	2.71E-08	-2.30E-09
22	6.31	2.55E-08	-2.17E-09
23	6.918	2.41E-08	-2.04E-09
24	7.586	2.28E-08	-1.93E-09
25	[illegible]	[illegible]	[illegible]

Figure 3.2: PDC data inserted in worksheet

After done copy PDC data to worksheet, PDC data will be select in order to plot in the scatter line. Figure 3.3 shows the scatter with smooth lines graph will be select in analysis work to analyse PDC data. In general, this grapical method will be focus on the transformer faults consists of partial discharge, arcing and overheating during analysis work. Basically, y-axis represents polarization and depolarization currents. Whereas, x-axis represents the time taken during measurement in seconds. The results of the graph is refer in the range of polarization and depolarization currents on the y-axis. Futhermore, different transformer faults will be different range of polarization and depolarization currents on the y-axis.

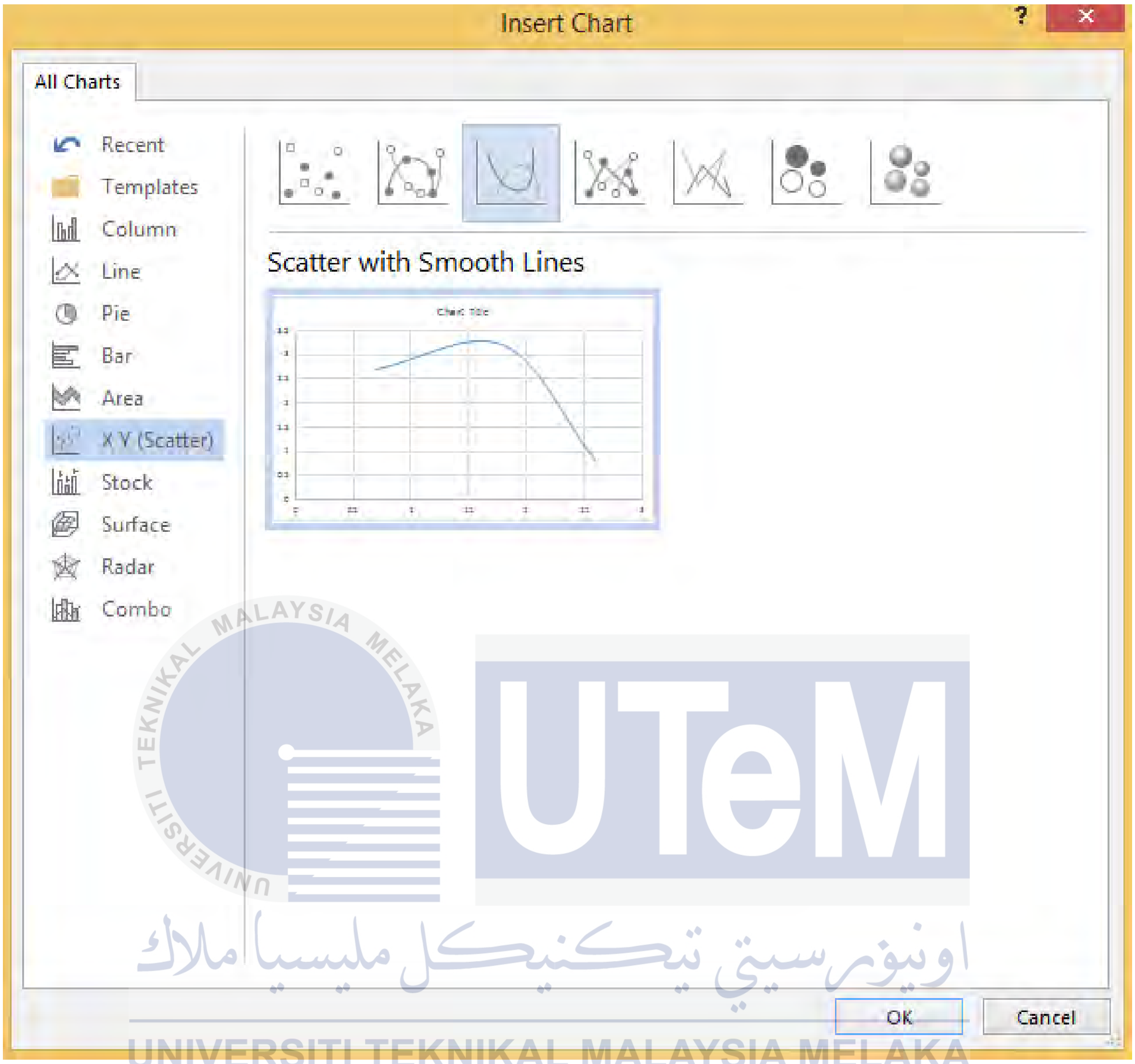

Figure 3.3: Selection scatter line type of graph

3.3.2 Classification The Transformer Faults Pattern Using Statistical Technique

Basically, to pattern the classification of faults is not an easy work due to thousands of currents in polarization and depolarization current data. Although to pattern classify the transformer faults into a proper range is a complex work, there is one statistical technique that may help and make the classification process of transformer faults become more easier. The technique is the standard deviation method due to obtain transformer faults results into a proper range. By using the standard deviation method, the difference between each number in normal data and faults data is calculated. A low standard deviation indicates that the faults data set tend to be very close to the normal data set. While a high standard deviation indicates the faults data are large range of values from the normal data. The basic formula of standard deviation is defined in Equation 3.1.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(X_i - \mu)^2}{N}} \tag{3.1}$$

where

σ = Standard Deviation

$\sum X - \mu$ = The difference between each number in the set and the mean

N = Number of values in the set

According Equation 3.1, standard deviation is a measurement of the spread between numbers in a data set. The standard deviation is measures how far each number in the set is from the mean. Basically, the average of data or mean (μ) is the samples of PDC in transformer normal condition. Whereas, X value represents the samples of PDC in transformer faults condition. These transformer faults consists of partial discharge, arcing and overheating. Futhermore, samples of transformer faults data will be spread between samples of transformer normal data. Standard deviation is calculated by taking the square root difference between each number in the transformer normal data and transformer faults data and dividing number of values in the set. The reason squaring the differences between the transformer normal data and transformer faults data is to make data positive.

A large standard deviation indicates that transformer faults in the set are far from the transformer normal, while a small standard deviation indicates the opposite. In order to get a proper ranges of transformer faults, 10 samples of transformers from each fault will be analyse by using the standard deviation method. However, this analysis work is concerned in polarization current data which have been analyse by using statistical technique to classify the transformer faults into a proper range.

In general, the PDC data samples represent currents in nano ampere. Therefore, it is hard to analyse the data in a small number when applied in statistical technique. Thus, by using Microsoft Excel it is easy to simplify these PDC data by converted currents from nano ampere to a single numbers. Figure 3.4 and Figure 3.5 shows the example of PDC data sample transformer before and after converted by using Microsoft Excel.

C	D	E	F	G	H	I	J	K	L	M	N	O
		Sample 1										
	Time	Pol.	Depol.	Pol.	Depol.	Pol.	Depol.	Pol.	Depol.	Pol.	Depol.	
	1	7.96E-08	-7.18E-09	9.00E-08	-7.11E-09	7.09E-08	-7.12E-09	6.72E-08	-7.21E-09	6.92E-08	-7.12E-09	
	1.096	7.22E-08	-6.76E-09	8.48E-08	-6.70E-09	6.77E-08	-6.71E-09	6.46E-08	-6.80E-09	6.67E-08	-6.72E-09	
	1.202	6.75E-08	-6.32E-09	7.93E-08	-6.28E-09	6.41E-08	-6.29E-09	6.16E-08	-6.38E-09	6.43E-08	-6.30E-09	
	1.318	6.45E-08	-5.92E-09	7.53E-08	-5.89E-09	6.11E-08	-5.90E-09	5.91E-08	-5.98E-09	6.21E-08	-5.92E-09	
	1.445	6.21E-08	-5.55E-09	7.25E-08	-5.54E-09	5.89E-08	-5.55E-09	5.69E-08	-5.62E-09	6.01E-08	-5.57E-09	
	1.585	5.99E-08	-5.21E-09	7.02E-08	-5.21E-09	5.70E-08	-5.23E-09	5.52E-08	-5.29E-09	5.82E-08	-5.24E-09	
	1.738	5.78E-08	-4.91E-09	6.80E-08	-4.91E-09	5.53E-08	-4.92E-09	5.36E-08	-4.98E-09	5.64E-08	-4.95E-09	
	1.905	5.56E-08	-4.61E-09	6.58E-08	-4.62E-09	5.36E-08	-4.63E-09	5.19E-08	-4.68E-09	5.45E-08	-4.65E-09	
	2.089	5.38E-08	-4.34E-09	6.35E-08	-4.35E-09	5.19E-08	-4.36E-09	5.03E-08	-4.42E-09	5.27E-08	-4.39E-09	
	2.291	5.20E-08	-4.08E-09	6.12E-08	-4.10E-09	5.01E-08	-4.11E-09	4.85E-08	-4.16E-09	5.08E-08	-4.14E-09	
	2.512	5.05E-08	-3.84E-09	5.88E-08	-3.86E-09	4.81E-08	-3.87E-09	4.66E-08	-3.92E-09	4.88E-08	-3.90E-09	
	2.754	4.90E-08	-3.62E-09	5.63E-08	-3.64E-09	4.60E-08	-3.65E-09	4.46E-08	-3.69E-09	4.68E-08	-3.68E-09	
	3.02	4.74E-08	-3.40E-09	5.36E-08	-3.43E-09	4.38E-08	-3.43E-09	4.24E-08	-3.48E-09	4.46E-08	-3.46E-09	
	3.311	4.60E-08	-3.20E-09	5.08E-08	-3.23E-09	4.14E-08	-3.24E-09	4.01E-08	-3.28E-09	4.24E-08	-3.27E-09	
	3.631	4.46E-08	-3.02E-09	4.81E-08	-3.04E-09	3.90E-08	-3.05E-09	3.77E-08	-3.09E-09	4.00E-08	-3.08E-09	
	3.981	4.34E-08	-2.84E-09	4.53E-08	-2.87E-09	3.65E-08	-2.88E-09	3.52E-08	-2.91E-09	3.77E-08	-2.90E-09	
	4.365	4.22E-08	-2.68E-09	4.26E-08	-2.71E-09	3.41E-08	-2.71E-09	3.29E-08	-2.74E-09	3.54E-08	-2.74E-09	
	4.786	4.11E-08	-2.53E-09	3.99E-08	-2.55E-09	3.19E-08	-2.56E-09	3.08E-08	-2.59E-09	3.31E-08	-2.59E-09	

Figure 3.4: PDC data before converted in Microsoft Excel

	Sample 1									
Time	Pol.	Depol.	Pol.	Depol.	Pol.	Depol.	Pol.	Depol.	Pol.	Depol.
1	7.96E+00	-7.18E-01	9.00E+00	-7.11E-01	7.09E+00	-7.12E-01	6.72E+00	-7.21E-01	6.92E+00	-7.12E-01
1.096	7.22E+00	-6.76E-01	8.48E+00	-6.70E-01	6.77E+00	-6.71E-01	6.46E+00	-6.80E-01	6.67E+00	-6.72E-01
1.202	6.75E+00	-6.32E-01	7.93E+00	-6.28E-01	6.41E+00	-6.29E-01	6.16E+00	-6.38E-01	6.43E+00	-6.30E-01
1.318	6.45E+00	-5.92E-01	7.53E+00	-5.89E-01	6.11E+00	-5.90E-01	5.91E+00	-5.98E-01	6.21E+00	-5.92E-01
1.445	6.21E+00	-5.55E-01	7.25E+00	-5.54E-01	5.89E+00	-5.55E-01	5.69E+00	-5.62E-01	6.01E+00	-5.57E-01
1.585	5.99E+00	-5.21E-01	7.02E+00	-5.21E-01	5.70E+00	-5.23E-01	5.52E+00	-5.29E-01	5.82E+00	-5.24E-01
1.738	5.78E+00	-4.91E-01	6.80E+00	-4.91E-01	5.53E+00	-4.92E-01	5.36E+00	-4.98E-01	5.64E+00	-4.95E-01
1.905	5.56E+00	-4.61E-01	6.58E+00	-4.62E-01	5.36E+00	-4.63E-01	5.19E+00	-4.68E-01	5.45E+00	-4.65E-01
2.089	5.38E+00	-4.34E-01	6.35E+00	-4.35E-01	5.19E+00	-4.36E-01	5.03E+00	-4.42E-01	5.27E+00	-4.39E-01
2.291	5.20E+00	-4.08E-01	6.12E+00	-4.10E-01	5.01E+00	-4.11E-01	4.85E+00	-4.16E-01	5.08E+00	-4.14E-01
2.512	5.05E+00	-3.84E-01	5.88E+00	-3.86E-01	4.81E+00	-3.87E-01	4.66E+00	-3.92E-01	4.88E+00	-3.90E-01
2.754	4.90E+00	-3.62E-01	5.63E+00	-3.64E-01	4.60E+00	-3.65E-01	4.46E+00	-3.69E-01	4.68E+00	-3.68E-01
3.02	4.74E+00	-3.40E-01	5.36E+00	-3.43E-01	4.38E+00	-3.43E-01	4.24E+00	-3.48E-01	4.46E+00	-3.46E-01
3.311	4.60E+00	-3.20E-01	5.08E+00	-3.23E-01	4.14E+00	-3.24E-01	4.01E+00	-3.28E-01	4.24E+00	-3.27E-01
3.631	4.46E+00	-3.02E-01	4.81E+00	-3.04E-01	3.90E+00	-3.05E-01	3.77E+00	-3.09E-01	4.00E+00	-3.08E-01
3.981	4.34E+00	-2.84E-01	4.53E+00	-2.87E-01	3.65E+00	-2.88E-01	3.52E+00	-2.91E-01	3.77E+00	-2.90E-01
4.365	4.22E+00	-2.68E-01	4.26E+00	-2.71E-01	3.41E+00	-2.71E-01	3.29E+00	-2.74E-01	3.54E+00	-2.74E-01
4.786	4.11E+00	-2.53E-01	3.99E+00	-2.55E-01	3.19E+00	-2.56E-01	3.08E+00	-2.59E-01	3.31E+00	-2.59E-01

Figure 3.5: PDC data after converted in Microsoft Excel

3.4 Validation of PDC

By referring the polarization currents obtained from the standard deviation results, these results will be compare with the PDC results presents in graphical technique. The ranges of the results may conclude as valid and acceptable as if the standard deviation results same with the graphical technique. However, if the standard deviation results is not in range of the graphical technique, this situation may conclude as wrong result. At the end of analysis work, the ranking of transformer faults obtain from analysis work will be referred to with previous research in Australia, which is related about PDC analysis that already discuss in the literature review.

3.6 Summary of the Methodology

In this methodology part, the process are followed referring to the flowchart which is illustrate in Figure 3.1. From the previous Section 3.2, explain the details about the types of condition transformer faults data collected from TNBR and explain the location site of power transformer at PPU during conduct PDC measurement. Basically, there are consists of transformer normal samples and transformer faults samples. For the transformer faults samples consists of three types of faults which are partial discharge fault, arcing fault and overheating fault. From the Section 3.3, explain about analyse PDC data by using two technique which are graphical technique and statistical technique. In statistical technique, the standard deviatiom method will be apply in order to classify the transformer faults into a proper range. The results obtain the standard deviation method will be compare with the graphical method. At the of the analysis work, the results obtain by both techniques will be compare with the previous research which is related in the analysis work by referring the ranking of transformer faults as explain in Section 3.4.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, it is shown all the results gather from this analysis work. In Section 4.2, the PDC data is presented in graphs using Microsoft Excel. In Section 4.3, will be discussed about analysis polarization current data to classify the transformer faults by using statistical technique. For the Section 4.4, the results obtained in analysis work will be refer from previous research to validate the results.

4.2 PDC Results Pattern Present in Graph Method

In general, this analysis work concerns about the PDC graphs of transformer faults. Figure 4.1 to Figure 4.3 shows the graphs of PDC results obtained when using scatter chart to plotted the graphs. From these graphs, the y-axis represents the polarization current data and depolarization currents data in ampere, while x-axis represents the time taken in seconds during measurements.

Referring to the graphs, the blue line represent the averages of the polarization current data in three samples fault, while the orange line represent the averages of the depolarization current data in three samples fault. By referring to these graphs, polarization current refers on the top axis due to the positive value of current in polarization data. Therefore, all the polarization currents become upward on the x-axis for these graphs. Otherwise, depolarization currents refers to the below axis due to the negative value of currents in depolarization data. Therefore, all the depolarization currents become downward on the x-axis.

From the Figure 4.1 to Figure 4.3 it can be seen that depolarization currents are much smaller compared to the polarization currents. The orange line depolarization currents indicates it is more approach to zero. Therefore, it is hard to analysed the depolarization current data when using the graphical technique due to smaller difference at each faults. One of the possible explanation is the depolarization currents are too stable during PDC analysis compared to polarization currents [18]. Therefore, for this analysis work will be focused on the polarization current data only to pattern the classification of faults by using the graphical technique.

From these graphs, it can be shown that all the faults indicates the different polarization current ranges on the y-axis. Basically, partial discharge fault result shows the lower current when it comes stabilize compared to other faults which is 5.50×10^{-8} Ampere as shown in Figure 4.1. Figure 4.1 shows the partial discharge fault graph in power transformer at Pencawang Pembahagian Utama (PPU) Jalan Gopeng site.

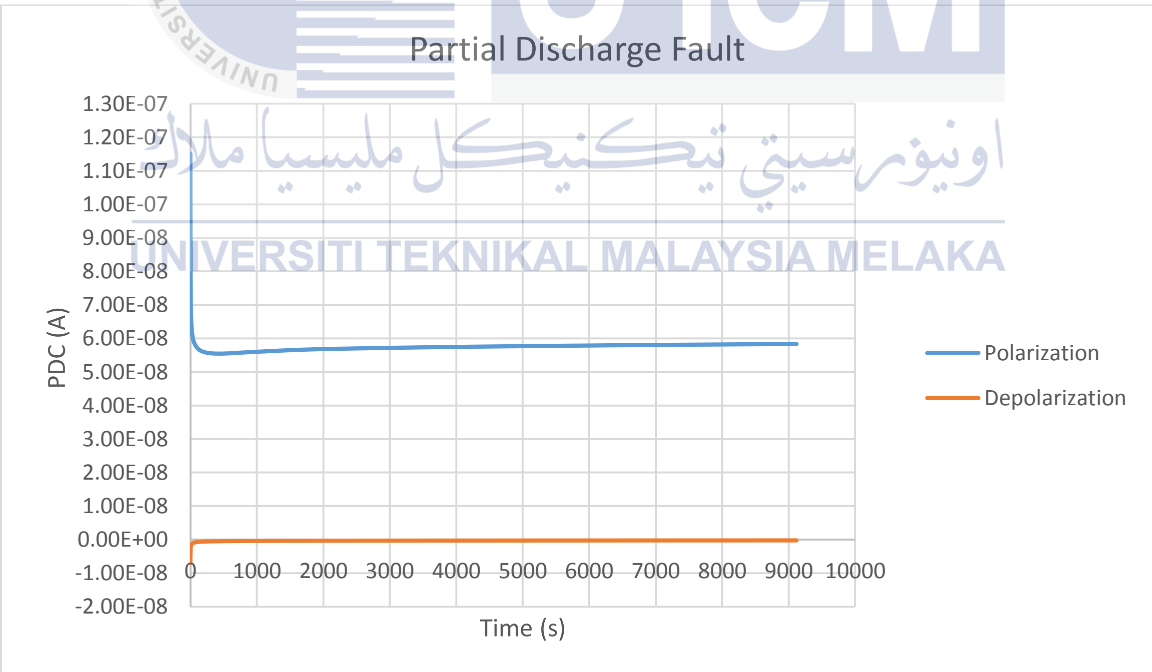

Figure 4.1: Partial Discharge Fault in Power Transformer

From Figure 4.2 show the arcing fault in power transformer at PPU Bandar Sunway site. Basically, the blue line is represent average of the polarization current in three samples of arcing faults. Whereas, the orange line indicate the average of depolarization current in samples fault. From this graph, it can be seen that current start stabilize at the point 9.00×10^{-8} Ampere which is after partial discharge occured. On the other side, the depolarization current still approaches to zero in PDC data which is the same result in the partial discharge fault graph.

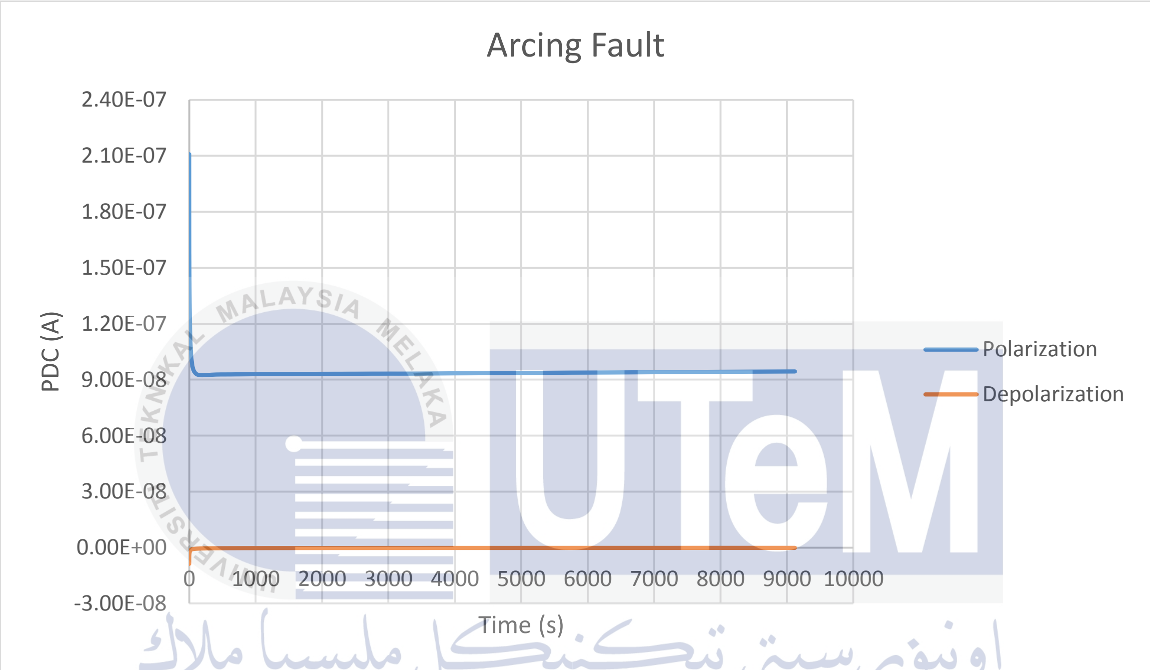

Figure 4.2: Arcing Fault in Power Transformer

From Figure 4.3 show the overheating fault graph in power transformer at PPU Bukit Maluri site. Basically same as the previous graphs, the blue line is represent average of the polarization current in three samples of overheating faults. Whereas, the orange line indicate the average of depolarization current in three samples of overheating fault. From this graph, it show that current start stabilize at the point 17.0×10^{-8} Ampere which is after partial discharge and arcing occured. Therefore, from this graph it can be concluded the overheating faults is the highest fault in power transformer compared to others faults in this PDC technique. On the other side, the depolarization current still approaches to zero in PDC data which is the same result in a partial discharge fault and arcing fault.

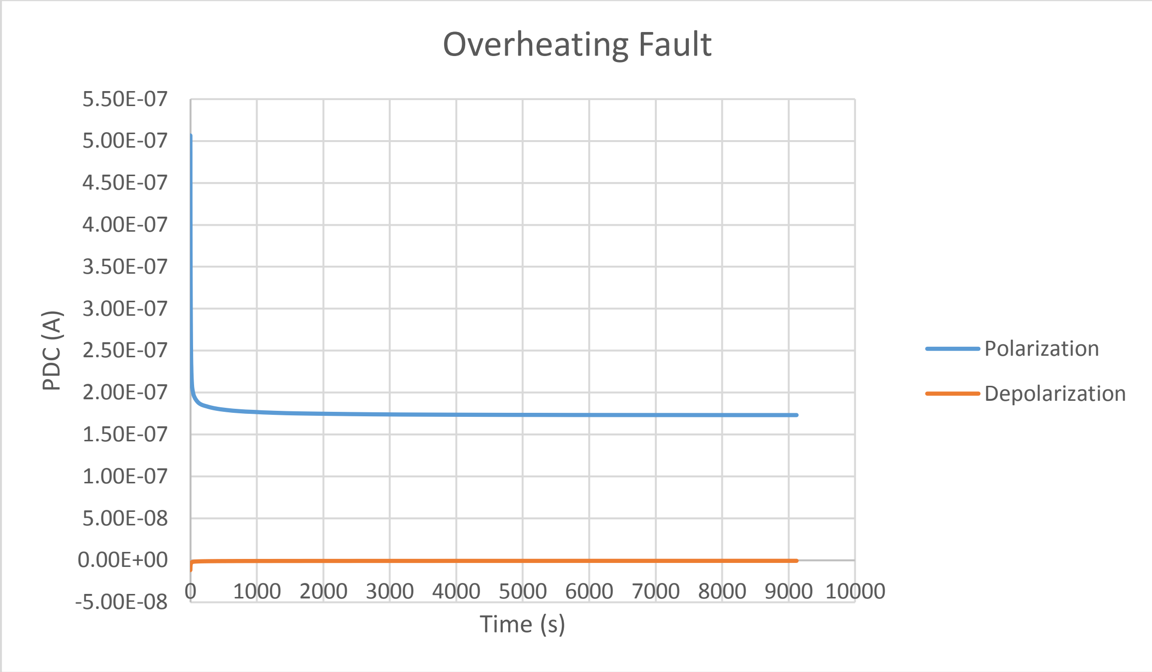

Figure 4.3: Overheating Fault in Power Transformer

4.3 Classify The Transformer Faults Using Statistical Technique

This analysis work is concerned in polarization current data which have been analyse using statistical technique to classify the transformer faults into a proper range. From analysis work, the average of the three normal samples in Bukit Merah PDC data will be set as a benchmark data. Whereas, transformer faults PDC data will be spread between the normal samples. By using the standard deviation method, the difference between each number in normal data and faults data is calculated. A low standard deviation indicates that the faults data set tend to be very close to the normal data set. While a high standard deviation indicates the faults data are large range of values from the normal data. Futhermore, Table 3.2 shows the sample of standard deviation result in overheating fault of power transformer by using Microsoft Excel. In order to get a proper ranges of transformer faults, 10 samples of transformers from each fault will be analyse using the standard deviation method. The details of example analyse PDC data using standard deviation method samples of PDC data are as attached in Appendix D.

In this analysis work, each from 10 transformer faults will be considered as the samples to analyse by applied the standard deviation method. This faults consists of partial discharge, arcing and overheating. Table 4.1 to Table 4.3 shows the range of the results by using the standard deviation method. As mentioned before this, this PDC data consists of five repetitions in polarization and depolarization current data. However, on this research work will be only focused on polarization currents. Therefore, five repetitions polarization at each samples will be analyse by using the standard deviation method.

In Table 4.1 shows the partial discharge fault by applying the standard deviation method. This partial discharge fault which consists of 10 samples location site transformer. All the PDC samples were taken in the PPU. Table 4.1 indicate the current ranges of partial discharge experience a fault and all the ranges in polarization current data get in these results could give indication currents pattern after partial discharge faults occurs in $(5.0 - 8.0) \times 10^{-8}$ Ampere.

Table 4.1: Partial Discharge Fault by using the Standard Deviation Method

Location of Transformers	**Pol. 1** (1×10^{-8})	**Pol. 2** (1×10^{-8})	**Pol. 3** (1×10^{-8})	**Pol. 4** (1×10^{-8})	**Pol. 5** (1×10^{-8})
Sunway City (Sample 3)	5.374390447	6.300434884	6.85244166	7.331183672	7.182233374
Jalan Gopeng (Sample 1)	5.238027063	6.725475104	7.027429612	7.20609096	7.057508341
Hutan Melintang (Sample 1)	4.60253219	6.132478901	6.44037532	6.474996347	6.620770584
Hutan Melintang (Sample 2)	5.374390447	7.032953316	6.85244166	7.1530106	7.171975055
Balik Pulau (Sample 3)	5.170743196	6.661218668	6.963602207	7.142335589	6.99415118
City Hall (Sample 1)	5.387226205	6.864575529	7.165041189	7.194181395	7.343184966
Jalan Pahang (Sample 2)	5.170743196	6.99415118	6.661218668	6.963602207	7.142335589
Jalan Pahang (Sample 3)	5.374390447	6.85244166	7.1530106	7.331382065	7.331183672
MPAJ (Sample 3)	5.260495728	6.554775164	6.745777773	7.077358819	7.225932473
Damansara Damai (Sample 2)	5.966364856	6.132478	6.620770584	6.44037532	6.474996347

In Table 4.2 show the arcing fault by applied the standard deviation method. This arcing fault consists of 10 samples site location power transformer. All the PDC samples were taken in the PPU. Based on Table 4.2, indicates the current range of arcing experience a fault and all the range of the power transformer gets in these results could give indication currents pattern after arcing faults in $(8.0 - 11.0) \times 10^{-8}$ Ampere.

Table 4.2: Arcing Faults by using the Standard Deviation Method

Location of Transformers	**Pol. 1** (1×10^{-8})	**Pol. 2** (1×10^{-8})	**Pol. 3** (1×10^{-8})	**Pol. 4** (1×10^{-8})	**Pol. 5** (1×10^{-8})
Bintang Buana (Sample 2)	9.058008423	8.516596344	8.323525538	8.033354201	8.17401846
Bandar Sunway (Sample 1)	9.058008423	8.971187499	8.427330695	8.233382715	8.233382715
Lion Industrial Park (Sample 3)	8.132212869	8.427330695	8.233382715	8.971187499	8.085460092
Labur Bina (Sample 1)	9.397547547	9.262169896	8.880739121	9.674087934	10.27886945
New Town Port (Sample 3)	10.75696801	10.20249964	10.81554087	10.88587759	10.67612086
Danau Kota (Sample 2)	8.529761249	9.070824556	8.529761249	8.336815008	8.115551338
Sime UEP	8.207691199	8.207691199	8.319764206	8.401912077	8.722776393
Wonderful (Sample 1)	8.137799741	8.133031959	8.41085607	8.648928133	8.659051555
Sungai Lang (Sample 2)	8.33949002	8.532419536	8.352173798	8.589361979	8.70419726
Salinas (Sample 3)	8.53832002	8.362383778	8.43424679	8.679351867	8.61328745

Finally, Table 4.3 shows the overheating fault by applied the standard deviation method. This overheating fault which consists of 10 samples sites location power transformer. All the PDC samples were taken in the PPU. Based on Table 4.3, indicates the current range of overheating experience a fault and all the range of the transformer gets in these results could give indication currents pattern after faults which is greater than equal 11.0×10^{-8} Ampere will be considered as overheating fault in this PDC analysis.

Table 4.3: Overheating Faults by using the Standard Deviation Method

Location of Transformers	**Pol. 1** (1×10^{-8})	**Pol. 2** (1×10^{-8})	**Pol. 3** (1×10^{-8})	**Pol. 4** (1×10^{-8})	**Pol. 5** (1×10^{-8})
Sri Edaran (Sample 2)	13.99965289	11.08378296	13.63124643	13.20193467	13.08678054
Farizar (Sample 3)	13.2853924	12.91462087	12.36698867	12.48431021	13.2853924
Bukit Maluri (Sample 1)	13.63124643	13.2853924	13.08678054	13.06818414	13.49776934
Sri Hartamas (Sample 1)	11.07089548	13.98768785	13.33673785	13.18992172	13.49776934
Star Hills (Sample 1)	12.93824348	13.47477451	13.32800252	13.29062497	13.0747339
TNB Kepong (Sample 1)	10.19504651	15.92702255	16.84764019	16.65614072	12.7186857
Paya Terubung Tx1	11.08378296	13.99965289	13.99965289	13.63124643	14.51976542
Paya Terubung Tx2	10.95938578	13.88458925	12.97079902	13.08629292	13.20193467
Seberang Jaya (Sample 2)	10.30941257	13.2853924	12.91462087	12.48431021	13.51579265
Hicom (Sample 2)	10.93967107	13.86666888	13.49776934	13.06818414	12.95262549

4.4 Validation

In this section, the results obtain using standard deviation method will be compare with the PDC result present in graphs. The ranges of the standard deviation results may conclude as valid and acceptable as if the results same with the PDC data present in graph. If the results obtain from the graphs is not in the ranges of the standard deviation method, this situation may conclude as wrong result. However, by using standard deviation in analysis work, the polarization ranges gets from these results is almost same as compared with the PDC results present in graphs.

In addition, by referring the previous research that has already reviewed in the Chapter 2, which is using mineral oil in PDC measurement conduct at Australia, it shows the ranking of transformer faults occurred in power transformer starting from the partial discharge faults followed by the arcing fault and lastly is overheating fault [18]. Futhermore, in term of the ranking from the previous, the results obtain in the graphical technique and the statistical technique is identical. However, the range of the results obtain from previous research and analysis work are different. The reason results are different in range of currents are due to differents in temperature, location of transformer and condition of oil which will causes the transformer breakdown. Therefore, these results can be as a reference for this analysis work by referring the ranking of transformer faults occur using PDC analysis. Table 4.4 shows the summary of the results obtain from graphical method, statistical technique and results obtain from previous research that was conducted in Australia.

Table 4.4: Summary of results

Faults	PDC Results Present In Graph Method	Results Obtained From Statistical Technique	Results Obtained From Previous Research
Partial Discharge	5.50×10^{-8} A	$(5.0 - 8.0) \times 10^{-8}$ A	0.5×10^{-10} A
Breakdown / Arcing	9.00×10^{-8} A	$(8.0 - 11.0)\times 10^{-8}$ A	2.0×10^{-10} A
Overheating	17.0×10^{-8} A	Greater than 11.0×10^{-8} A	4.0×10^{-10} A

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

According to the first objective, the PDC data from different conditions of transformer which consists of normal, arcing, overheating and partial discharge collected from TNBR is achieved.

Futhermore, the statistical technique and graphical method to give classification of faults by referring the ranges are the same results in both techniques. The ranges of the results may conclude as valid and acceptable as if the statistical technique results same with the PDC data present in graph. If the graph results is not in the ranges of the statistical technique result, this situation may conclude as wrong result. Therefore, the second objective is sucessful because the graph results obtain is same with the statistical technique results. Basically, the standard deviation is calculated by taking the difference between each number in the normal data set and the faults data set. The faults PDC data will be spread between number in normal data set. A larger standard deviation indicates that numbers in the set are far from the normal data set, while a small standard deviation indicates the opposite. Therefore, the standard deviation method can be applied in PDC analysis to give an accurate result to classify the faults into a proper range.

Lastly, the third objective is achieved when verify the results obtain in analysis work by referring the previous research. From the results obtained in graphical method and standard deviation, the faults transformer occurred starting from partial discharge, followed by arcing fault and lastly is overheating fault. These results is same with the previous research. In a conclusion, all the three objective of this analysis work is carry out successfully.

5.2 Project Contribution

The project contribution is to analyse the PDC data where it is performs the standard deviation method to give the pattern classification of faults by referring the ranges get from the results. Basically, this analysis work is links from TNBR where the real PDC data collected from the real power transformers due to faults problem by using PDC measurement. Therefore, this classify the faults into a proper range using standard deviation can be use as a reference from TNBD and TNBR to determine and detect the transformer faults.

5.3 Recommendation for Future Work

For the future work, it can be suggested that TNBR and TNBD especially in Transformer Performance and Diagnostic division to use Self Organizing Map (SOM) to perform their diagnosis of power transformers in PDC analysis. SOM is the tools in Matlab software that can explore the data and give the conclusion all the data. SOM toolbox can be used to pattern the classification of faults due to provide the detail and can labeling each part of the data. By applying SOM toolbox, the majority clustering number color of neurons will determine the ranges of transformer faults as illustrated in Figure 5.1.

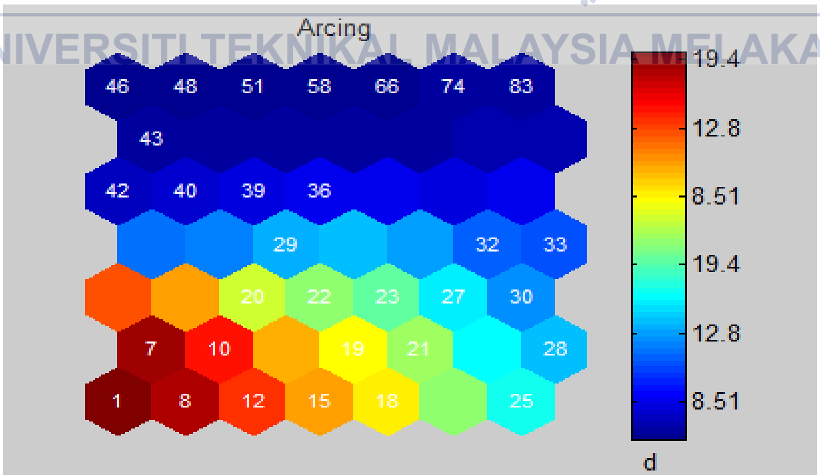

Figure 5.1: Clustering in SOM

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APPENDIX A

PDC RESULT OBTAINED FROM TNBR FOR TRANSFORMER NORMAL CASE

Sample 1					
Time	Pol.	Pol.	Pol.	Pol.	Pol.
1	3.58E-08	3.13E-08	3.18E-08	2.83E-08	2.78E-08
1.096	3.52E-08	3.08E-08	3.12E-08	2.79E-08	2.73E-08
1.202	3.45E-08	3.01E-08	3.06E-08	2.73E-08	2.69E-08
1.318	3.38E-08	2.96E-08	3.00E-08	2.69E-08	2.63E-08
1.445	3.31E-08	2.90E-08	2.94E-08	2.63E-08	2.58E-08
1.585	3.24E-08	2.84E-08	2.88E-08	2.58E-08	2.52E-08
1.738	3.16E-08	2.78E-08	2.82E-08	2.53E-08	2.47E-08
1.905	3.09E-08	2.72E-08	2.75E-08	2.47E-08	2.41E-08
2.089	3.01E-08	2.66E-08	2.69E-08	2.42E-08	2.35E-08
2.291	2.93E-08	2.60E-08	2.62E-08	2.37E-08	2.30E-08
2.512	2.85E-08	2.54E-08	2.57E-08	2.31E-08	2.24E-08
2.754	2.78E-08	2.49E-08	2.50E-08	2.25E-08	2.18E-08
3.02	2.69E-08	2.42E-08	2.43E-08	2.19E-08	2.12E-08
3.311	2.61E-08	2.35E-08	2.36E-08	2.13E-08	2.06E-08
3.631	2.54E-08	2.28E-08	2.28E-08	2.06E-08	2.00E-08
3.981	2.46E-08	2.21E-08	2.21E-08	1.99E-08	1.93E-08
4.365	2.39E-08	2.14E-08	2.13E-08	1.92E-08	1.86E-08
4.786	2.31E-08	2.08E-08	2.06E-08	1.85E-08	1.80E-08
5.248	2.25E-08	2.01E-08	1.98E-08	1.78E-08	1.74E-08
5.754	2.17E-08	1.95E-08	1.91E-08	1.71E-08	1.67E-08
6.31	2.12E-08	1.88E-08	1.85E-08	1.65E-08	1.61E-08
6.918	2.06E-08	1.83E-08	1.78E-08	1.59E-08	1.56E-08
7.586	2.00E-08	1.78E-08	1.73E-08	1.54E-08	1.51E-08
8.318	1.95E-08	1.74E-08	1.69E-08	1.50E-08	1.47E-08
9.12	1.92E-08	1.71E-08	1.66E-08	1.46E-08	1.44E-08

10	1.90E-08	1.68E-08	1.63E-08	1.44E-08	1.41E-08
10.96	1.88E-08	1.65E-08	1.60E-08	1.42E-08	1.38E-08
12.02	1.85E-08	1.63E-08	1.57E-08	1.39E-08	1.36E-08
13.18	1.82E-08	1.61E-08	1.55E-08	1.37E-08	1.34E-08
14.45	1.78E-08	1.59E-08	1.54E-08	1.35E-08	1.32E-08
15.85	1.77E-08	1.57E-08	1.52E-08	1.34E-08	1.30E-08
17.38	1.75E-08	1.57E-08	1.50E-08	1.33E-08	1.29E-08
19.05	1.74E-08	1.56E-08	1.49E-08	1.31E-08	1.28E-08
20.89	1.72E-08	1.54E-08	1.47E-08	1.29E-08	1.26E-08
22.91	1.71E-08	1.52E-08	1.45E-08	1.28E-08	1.25E-08
25.12	1.69E-08	1.51E-08	1.44E-08	1.27E-08	1.24E-08
27.54	1.69E-08	1.50E-08	1.43E-08	1.26E-08	1.23E-08
30.2	1.68E-08	1.49E-08	1.42E-08	1.25E-08	1.22E-08
33.11	1.67E-08	1.48E-08	1.40E-08	1.24E-08	1.21E-08
36.31	1.67E-08	1.48E-08	1.39E-08	1.22E-08	1.20E-08
39.81	1.67E-08	1.46E-08	1.38E-08	1.22E-08	1.19E-08
43.65	1.67E-08	1.45E-08	1.37E-08	1.21E-08	1.18E-08
47.86	1.66E-08	1.44E-08	1.36E-08	1.20E-08	1.17E-08
52.48	1.64E-08	1.43E-08	1.35E-08	1.19E-08	1.16E-08
57.54	1.63E-08	1.43E-08	1.34E-08	1.18E-08	1.15E-08
63.1	1.62E-08	1.42E-08	1.33E-08	1.17E-08	1.14E-08
69.18	1.61E-08	1.41E-08	1.33E-08	1.17E-08	1.13E-08
75.86	1.60E-08	1.41E-08	1.32E-08	1.16E-08	1.12E-08
83.18	1.60E-08	1.40E-08	1.31E-08	1.15E-08	1.12E-08
91.2	1.59E-08	1.39E-08	1.30E-08	1.14E-08	1.11E-08
100	1.55E-08	1.39E-08	1.30E-08	1.13E-08	1.10E-08
109.6	1.53E-08	1.38E-08	1.29E-08	1.13E-08	1.10E-08
120.2	1.52E-08	1.37E-08	1.28E-08	1.13E-08	1.09E-08
131.8	1.55E-08	1.36E-08	1.28E-08	1.12E-08	1.09E-08
144.5	1.58E-08	1.36E-08	1.27E-08	1.11E-08	1.08E-08
158.5	1.56E-08	1.35E-08	1.27E-08	1.11E-08	1.08E-08
173.8	1.59E-08	1.34E-08	1.26E-08	1.10E-08	1.07E-08
190.5	1.58E-08	1.34E-08	1.26E-08	1.10E-08	1.07E-08

208.9	1.56E-08	1.34E-08	1.25E-08	1.09E-08	1.06E-08
229.1	1.57E-08	1.34E-08	1.25E-08	1.08E-08	1.06E-08
251.2	1.57E-08	1.33E-08	1.24E-08	1.08E-08	1.05E-08
275.4	1.55E-08	1.33E-08	1.24E-08	1.07E-08	1.05E-08
302	1.54E-08	1.32E-08	1.24E-08	1.07E-08	1.05E-08
331.1	1.53E-08	1.32E-08	1.23E-08	1.07E-08	1.04E-08
363.1	1.52E-08	1.32E-08	1.23E-08	1.06E-08	1.04E-08
398.1	1.52E-08	1.32E-08	1.23E-08	1.06E-08	1.04E-08
436.5	1.51E-08	1.31E-08	1.22E-08	1.05E-08	1.03E-08
478.6	1.50E-08	1.31E-08	1.22E-08	1.05E-08	1.03E-08
524.8	1.49E-08	1.31E-08	1.22E-08	1.05E-08	1.03E-08
575.4	1.48E-08	1.30E-08	1.22E-08	1.05E-08	1.03E-08
631	1.48E-08	1.30E-08	1.22E-08	1.05E-08	1.02E-08
691.8	1.47E-08	1.30E-08	1.22E-08	1.04E-08	1.02E-08
758.6	1.46E-08	1.30E-08	1.22E-08	1.04E-08	1.02E-08
831.8	1.46E-08	1.29E-08	1.22E-08	1.04E-08	1.02E-08
912	1.45E-08	1.29E-08	1.22E-08	1.04E-08	1.02E-08
1000	1.45E-08	1.28E-08	1.22E-08	1.04E-08	1.02E-08
1096	1.44E-08	1.27E-08	1.21E-08	1.04E-08	1.01E-08
1202	1.43E-08	1.27E-08	1.21E-08	1.03E-08	1.01E-08
1318	1.43E-08	1.27E-08	1.21E-08	1.03E-08	1.01E-08
1445	1.42E-08	1.26E-08	1.21E-08	1.03E-08	1.01E-08
1585	1.42E-08	1.26E-08	1.21E-08	1.03E-08	1.01E-08
1738	1.41E-08	1.26E-08	1.20E-08	1.03E-08	1.01E-08
1905	1.38E-08	1.26E-08	1.20E-08	1.02E-08	1.01E-08
2089	1.37E-08	1.26E-08	1.20E-08	1.02E-08	1.01E-08
2291	1.36E-08	1.26E-08	1.20E-08	1.02E-08	1.01E-08
2512	1.35E-08	1.26E-08	1.19E-08	1.02E-08	1.01E-08
2754	1.34E-08	1.25E-08	1.19E-08	1.01E-08	1.01E-08
3020	1.33E-08	1.25E-08	1.19E-08	1.01E-08	1.01E-08
3311	1.32E-08	1.25E-08	1.19E-08	1.01E-08	1.01E-08
3631	1.32E-08	1.24E-08	1.19E-08	1.01E-08	1.01E-08
3981	1.31E-08	1.24E-08	1.19E-08	1.00E-08	1.00E-08

4365	1.31E-08	1.23E-08	1.18E-08	1.00E-08	1.00E-08
4786	1.30E-08	1.23E-08	1.18E-08	1.00E-08	1.00E-08
5248	1.30E-08	1.23E-08	1.18E-08	9.99E-09	1.00E-08
5754	1.29E-08	1.23E-08	1.18E-08	9.97E-09	1.00E-08
6310	1.29E-08	1.22E-08	1.18E-08	9.95E-09	1.01E-08
6918	1.28E-08	1.22E-08	1.18E-08	1.01E-08	1.01E-08
7586	1.28E-08	1.22E-08	1.17E-08	1.01E-08	1.01E-08
8318	1.27E-08	1.22E-08	1.17E-08	1.01E-08	1.01E-08
9120	1.27E-08	1.21E-08	1.17E-08	1.00E-08	1.01E-08

APPENDIX B

PDC RESULT OBTAINED FROM TNBR FOR TRANSFORMER FAULTS CASE

Sample 2					
Time	Pol.	Pol.	Pol.	Pol.	Pol.
1	3.97E-07	5.54E-07	5.36E-07	5.27E-07	5.19E-07
1.096	3.91E-07	5.44E-07	5.26E-07	5.18E-07	5.10E-07
1.202	3.83E-07	5.32E-07	5.15E-07	5.06E-07	4.99E-07
1.318	3.77E-07	5.19E-07	5.03E-07	4.92E-07	4.87E-07
1.445	3.69E-07	5.06E-07	4.91E-07	4.78E-07	4.73E-07
1.585	3.64E-07	4.93E-07	4.79E-07	4.65E-07	4.60E-07
1.738	3.56E-07	4.80E-07	4.66E-07	4.53E-07	4.48E-07
1.905	3.46E-07	4.66E-07	4.53E-07	4.40E-07	4.36E-07
2.089	3.32E-07	4.54E-07	4.41E-07	4.28E-07	4.24E-07
2.291	3.32E-07	4.42E-07	4.29E-07	4.16E-07	4.12E-07
2.512	3.28E-07	4.30E-07	4.18E-07	4.05E-07	4.01E-07
2.754	3.18E-07	4.20E-07	4.08E-07	3.94E-07	3.90E-07
3.02	3.09E-07	4.09E-07	3.98E-07	3.83E-07	3.80E-07
3.311	2.98E-07	3.98E-07	3.88E-07	3.73E-07	3.70E-07
3.631	2.91E-07	3.88E-07	3.78E-07	3.63E-07	3.60E-07
3.981	2.89E-07	3.77E-07	3.68E-07	3.53E-07	3.50E-07
4.365	2.87E-07	3.67E-07	3.58E-07	3.43E-07	3.41E-07
4.786	2.83E-07	3.56E-07	3.48E-07	3.33E-07	3.31E-07
5.248	2.77E-07	3.46E-07	3.38E-07	3.23E-07	3.21E-07
5.754	2.70E-07	3.35E-07	3.28E-07	3.14E-07	3.11E-07
6.31	2.62E-07	3.25E-07	3.18E-07	3.04E-07	3.02E-07
6.918	2.56E-07	3.15E-07	3.08E-07	2.94E-07	2.92E-07
7.586	2.50E-07	3.05E-07	2.98E-07	2.84E-07	2.82E-07
8.318	2.42E-07	2.94E-07	2.88E-07	2.74E-07	2.72E-07
9.12	2.35E-07	2.84E-07	2.78E-07	2.65E-07	2.63E-07

10	2.31E-07	2.74E-07	2.69E-07	2.55E-07	2.54E-07
10.96	2.27E-07	2.65E-07	2.60E-07	2.47E-07	2.46E-07
12.02	2.22E-07	2.58E-07	2.52E-07	2.40E-07	2.39E-07
13.18	2.17E-07	2.51E-07	2.46E-07	2.34E-07	2.33E-07
14.45	2.13E-07	2.45E-07	2.40E-07	2.29E-07	2.28E-07
15.85	2.10E-07	2.40E-07	2.35E-07	2.24E-07	2.24E-07
17.38	2.06E-07	2.35E-07	2.30E-07	2.20E-07	2.19E-07
19.05	2.02E-07	2.31E-07	2.26E-07	2.16E-07	2.16E-07
20.89	2.00E-07	2.27E-07	2.22E-07	2.13E-07	2.12E-07
22.91	1.98E-07	2.23E-07	2.18E-07	2.10E-07	2.10E-07
25.12	1.95E-07	2.20E-07	2.15E-07	2.07E-07	2.07E-07
27.54	1.93E-07	2.18E-07	2.13E-07	2.05E-07	2.05E-07
30.2	1.91E-07	2.15E-07	2.11E-07	2.04E-07	2.03E-07
33.11	1.90E-07	2.13E-07	2.09E-07	2.02E-07	2.01E-07
36.31	1.90E-07	2.12E-07	2.07E-07	2.01E-07	2.00E-07
39.81	1.89E-07	2.10E-07	2.06E-07	1.99E-07	1.98E-07
43.65	1.88E-07	2.08E-07	2.04E-07	1.97E-07	1.97E-07
47.86	1.87E-07	2.06E-07	2.03E-07	1.96E-07	1.96E-07
52.48	1.87E-07	2.05E-07	2.01E-07	1.95E-07	1.94E-07
57.54	1.86E-07	2.03E-07	2.00E-07	1.94E-07	1.93E-07
63.1	1.86E-07	2.02E-07	1.99E-07	1.93E-07	1.92E-07
69.18	1.85E-07	2.01E-07	1.98E-07	1.92E-07	1.91E-07
75.86	1.84E-07	2.00E-07	1.97E-07	1.91E-07	1.90E-07
83.18	1.84E-07	1.99E-07	1.96E-07	1.90E-07	1.90E-07
91.2	1.83E-07	1.98E-07	1.95E-07	1.89E-07	1.89E-07
100	1.82E-07	1.97E-07	1.93E-07	1.88E-07	1.88E-07
109.6	1.82E-07	1.96E-07	1.92E-07	1.87E-07	1.87E-07
120.2	1.81E-07	1.95E-07	1.91E-07	1.86E-07	1.86E-07
131.8	1.81E-07	1.94E-07	1.91E-07	1.85E-07	1.85E-07
144.5	1.81E-07	1.93E-07	1.90E-07	1.85E-07	1.84E-07
158.5	1.81E-07	1.92E-07	1.89E-07	1.84E-07	1.84E-07
173.8	1.80E-07	1.91E-07	1.88E-07	1.83E-07	1.83E-07
190.5	1.80E-07	1.91E-07	1.88E-07	1.83E-07	1.83E-07

208.9	1.80E-07	1.90E-07	1.87E-07	1.82E-07	1.82E-07
229.1	1.80E-07	1.89E-07	1.86E-07	1.82E-07	1.82E-07
251.2	1.80E-07	1.89E-07	1.86E-07	1.81E-07	1.81E-07
275.4	1.79E-07	1.88E-07	1.85E-07	1.81E-07	1.81E-07
302	1.79E-07	1.87E-07	1.84E-07	1.80E-07	1.80E-07
331.1	1.79E-07	1.87E-07	1.84E-07	1.80E-07	1.79E-07
363.1	1.78E-07	1.86E-07	1.83E-07	1.79E-07	1.79E-07
398.1	1.78E-07	1.86E-07	1.83E-07	1.79E-07	1.78E-07
436.5	1.77E-07	1.85E-07	1.82E-07	1.78E-07	1.78E-07
478.6	1.77E-07	1.85E-07	1.81E-07	1.78E-07	1.77E-07
524.8	1.77E-07	1.84E-07	1.81E-07	1.77E-07	1.77E-07
575.4	1.76E-07	1.84E-07	1.80E-07	1.77E-07	1.77E-07
631	1.76E-07	1.83E-07	1.80E-07	1.76E-07	1.76E-07
691.8	1.76E-07	1.83E-07	1.79E-07	1.76E-07	1.76E-07
758.6	1.76E-07	1.82E-07	1.79E-07	1.76E-07	1.75E-07
831.8	1.76E-07	1.82E-07	1.78E-07	1.75E-07	1.75E-07
912	1.76E-07	1.81E-07	1.78E-07	1.75E-07	1.75E-07
1000	1.76E-07	1.81E-07	1.77E-07	1.75E-07	1.74E-07
1096	1.76E-07	1.80E-07	1.77E-07	1.74E-07	1.74E-07
1202	1.76E-07	1.80E-07	1.77E-07	1.74E-07	1.73E-07
1318	1.76E-07	1.79E-07	1.76E-07	1.74E-07	1.73E-07
1445	1.75E-07	1.79E-07	1.76E-07	1.73E-07	1.73E-07
1585	1.75E-07	1.79E-07	1.75E-07	1.73E-07	1.73E-07
1738	1.75E-07	1.79E-07	1.75E-07	1.73E-07	1.73E-07
1905	1.75E-07	1.78E-07	1.75E-07	1.73E-07	1.72E-07
2089	1.75E-07	1.78E-07	1.75E-07	1.73E-07	1.72E-07
2291	1.75E-07	1.78E-07	1.74E-07	1.73E-07	1.72E-07
2512	1.74E-07	1.77E-07	1.74E-07	1.72E-07	1.72E-07
2754	1.74E-07	1.77E-07	1.74E-07	1.72E-07	1.72E-07
3020	1.74E-07	1.77E-07	1.73E-07	1.72E-07	1.72E-07
3311	1.74E-07	1.77E-07	1.73E-07	1.72E-07	1.71E-07
3631	1.74E-07	1.77E-07	1.73E-07	1.72E-07	1.71E-07
3981	1.74E-07	1.77E-07	1.73E-07	1.72E-07	1.71E-07

4365	1.74E-07	1.76E-07	1.73E-07	1.72E-07	1.71E-07
4786	1.74E-07	1.76E-07	1.73E-07	1.72E-07	1.71E-07
5248	1.74E-07	1.76E-07	1.73E-07	1.72E-07	1.71E-07
5754	1.74E-07	1.76E-07	1.73E-07	1.72E-07	1.71E-07
6310	1.74E-07	1.76E-07	1.72E-07	1.72E-07	1.71E-07
6918	1.74E-07	1.76E-07	1.72E-07	1.72E-07	1.71E-07
7586	1.74E-07	1.76E-07	1.72E-07	1.72E-07	1.71E-07
8318	1.74E-07	1.76E-07	1.72E-07	1.72E-07	1.71E-07
9120	1.74E-07	1.76E-07	1.72E-07	1.72E-07	1.71E-07

APPENDIX C

PROJECT GANNT CHART

WORKS	MONTH	SEP	OKT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE
Choosing suitable topic for PSM											
Review the previous researh											
PSM 1 seminar											
Collected the PDC data from TNBR											
Analyse and pattern classification of Faults by using Graphical and Standard Deviation Technique											
Writing final report											
PSM 2 seminar											

APPENDIX D

ANALYSE PDC DATA USING STANDARD DEVIATION METHOD

Normal	Overheating Fault	Standard Deviation
3.58125	51.93026	12.88684
3.52085	51.04475	
3.44934	49.93635	
3.3755	48.66232	
3.30586	47.34558	
3.23633	46.04964	
3.16351	44.80969	
3.08731	43.55191	
3.00816	42.35199	
2.93147	41.19307	
2.85088	40.08084	
2.78117	39.04222	
2.68843	38.00822	
2.60964	37.01459	
2.53899	36.0064	
2.46139	35.01636	
2.38837	34.05248	
2.3105	33.0692	
2.24719	32.09574	
2.1698	31.12163	
2.11708	30.15593	
2.05544	29.2007	
1.99984	28.22336	
1.95386	27.23787	
1.91814	26.27018	
1.89735	25.36761	

1.87715	24.59267
1.84741	23.90824
1.8156	23.32101
1.78385	22.81453
1.76746	22.35779
1.7484	21.93873
1.73686	21.56652
1.71897	21.24051
1.70832	20.95461
1.69493	20.69971
1.68644	20.48447
1.67865	20.32075
1.66978	20.14769
1.66752	19.99719
1.67354	19.83429
1.66554	19.69064
1.65614	19.55484
1.63836	19.42626
1.62885	19.31792
1.62002	19.22314
1.60884	19.13722
1.59689	19.04852
1.59951	18.95024
1.58606	18.85806
1.54719	18.77097
1.53398	18.68484
1.52217	18.59433
1.55129	18.51261
1.57654	18.43328
1.56349	18.35917
1.59064	18.29755
1.57541	18.25517
1.55861	18.19907

1.57486	18.15157
1.56606	18.11148
1.55345	18.05083
1.54218	17.98648
1.53019	17.9358
1.52424	17.88571
1.51617	17.83671
1.50898	17.79962
1.50038	17.7459
1.49068	17.70475
1.48477	17.65702
1.47687	17.61317
1.47117	17.57002
1.46495	17.526
1.4577	17.49448
1.449	17.46954
1.45034	17.42147
1.44352	17.37485
1.43478	17.34488
1.4258	17.31959
1.42376	17.28966
1.42354	17.27136
1.40748	17.25795
1.37675	17.24276
1.37024	17.21808
1.36097	17.19563
1.35107	17.18247
1.33823	17.1726
1.33055	17.15595
1.32447	17.14187
1.31901	17.13504
1.31277	17.12185
1.30899	17.1136

1.30234	17.11425
1.29567	17.10895
1.29271	17.10608
1.28718	17.10374
1.28298	17.10264
1.27514	17.10005
1.2741	17.09862
1.27027	17.09867