"I hereby declare that I have read this fully report entitled
"*Life Assessment for Power Transformer in Distribution Electrical Network* "
and found that it has achieve the requirement for awarding the
Bachelor of Electrical Engineering (Industrial Power)"

Signature : ....

Supervisor's Name : Mr. Imran Bin Sutan Chairul

Date : ....

LIFE ASSESSMENT FOR POWER TRANSFORMER IN DISTRIBUTION ELECTRICAL NETWORK

MUHAMMAD NAIM BIN ABDUL MUTHALIB

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

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

I declare that this report entitle

"*Life Assessment for Power Transformer in Distribution Electrical Network* "

is the result of my own research except as cited in the references.

The report has not been accepted for any degree and not concurrently submitted in candidature of any other degree.

Signature : ....

Name : MUHAMMAD NAIM BIN ABDUL MUTHALIB

Date : ....

Dedicated with deepest love to:

My beloved family and fiancee for their support, guidance and love.

My dearest friends for being there whenever I need them.

My supervisor for his support and aid.

ACKNOWLEDGEMENT

First of all, I would like to thank Allah for His firm hands in guiding me in the course of completing this thesis writing. Alhamdulillah.

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Lastly, I really appreciate to have this responsibility to finish this project. This task has taught a lot of lesson and knowledge which is much valuable for me in the future.

ABSTRACT

Power transformers are one of the most essential and important equipment of the electrical power system, which ensure stable and reliable energy delivery. Transformer operational life depends on its insulation system, which are insulating oil and solid insulating material. The degradation of the insulation occurs as the operating time of the transformer increases. Paper insulation is the most critical component of the transformer insulation system. Experimental and simulation studies on paper insulation showed that temperature, oxygen and moisture contents contributed to its degradation. In this study, level of parameters such as dissolved gases, coil temperature and oil temperature were obtained from transformers in Malakoff Prai Power Plant (PPSB). Then each parameter were differentiate and categorize for end-of-life analysis. The data will be analyse by using Unreliability for a Given Operating Time method in Weibull++ 7 software and Microsoft Excel.

ABSTRAK

Transformer kuasa adalah salah satu peralatan yang paling penting dalam sistem kuasa elektrik, yang memastikan penghantaran tenaga yang stabil dan boleh dipercayai. Jangka hayat transformer bergantung kepada sistem penebat, iaitu penebat minyak dan bahan penebat pepejal. Kemerosotan penebat berlaku sebagai masa operasi transformer meningkat. Penebat kertas adalah komponen yang paling penting dalam sistem penebat transformer. Kajian eksperimen dan simulasi mengenai penebat kertas menunjukkan suhu, oksigen dan kelembapan kandungan menyumbang kepada kemerosotan itu. Dalam kajian ini, tahap parameter seperti gas terlarut, suhu gegelung dan suhu minyak diperolehi daripada transformer di Malakoff Prai Power Plant (PPSB). Maka setiap parameter akan dibezakan dan dikategorikan untuk analisa jangka hayat. Data ini akan dianalisa dengan menggunakan kaedah "Unreliability for a Given Operating Time" dalam perisisan Weibull++ 7 dan juga perisian Microsoft Excel.

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NOMENCLATURE

DGA	Dissolved Gas Analysis
DP	Degree of Polymerization
kV	Kilo Volt
MVA	Mega Volt Ampere
CO	Carbon Monoxide
CO2	Carbon Dioxide
HPLC	High Performance Liquid Chromatography
GC	Gas Chromatography
GSUT	Generator Step-Up Transformer
UAT	Unit Auxiliary Transformer
PPB	Part Per Billion
PPM	Part Per Million
^{O}C	Degree Celcius
PPSB	Prai Power Sdn. Bhd.

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.0 Research Background

Power transformers are one of the most essential and important equipment of the electrical power system, which ensure stable and reliable energy delivery. The operational life of a common power transformer is usually depends on its insulation system, which consist of insulating oil and solid insulating material.

The insulation oil is a highly refined mineral oil that is stable at high temperature and has excellent electrical insulating properties. Its usefulness is to insulate, suppress corona and arcing, and to serve as a coolant. Meanwhile, the solid insulation material that being used are types of paper that are used as electrical insulation due to pure cellulose having exceptional electrical properties.

Under normal operational conditions, gradual aging of insulation oil and solid insulating material will occur due to the joint effect of the electrical, thermal, chemical, humidity, and oxidation. The condition of oil-paper insulation system is the main diagnostic indicator that influences the operational of transformers.

This project focused on paper insulation condition and its life assessment based on the parameters levels of dissolved gases, coil temperature and oil temperature.

1.1 Project Motivation

As a student which is studying electrical engineering, I have been interested in this field since my interest in engineering began. My own experience of doing power transformer routine check during my time at Malakoff Prai Power Plant (PPSB) for industrial training has led me to ponder many questions as to why there are so many type of transformer with different functions and why is the transformer is very important to the power plant . This project has given me the opportunity to explore the world of electrical to find out the answer to my questions.

My knowledge of this field at the start of the project was casual. I knew generally about the main function of the transformer and its working principle without knowing anything specific about the insulation system, effect of temperature to the insulation and overall structure of the transformer lifetime. As this is a subject I am interested in making my career in, studying the insulation system and lifetime analysis of the transformer seemed a natural choice of study which I knew would be both challenging and interesting.

Form the theory aspect, I have done much research into the transformer insulation system and its related to the degradation o the transformer lifetime. The challenging part and most interesting is collecting real data from the transformer in Malakoff Prai Power Plant (PPSB) and perform the life assessment of the power transformer.

1.2 Problem Statements

Power transformer in every power plant is custom-made based on the plant power output capacity which means that it is only made upon request. Power transformer failure will force a power plant to shut down for a long period of time because it is one of the most important equipment of the electrical power system, which ensure stable and reliable energy delivery. Due to that, the power transformer needs to be monitored and well maintained. In this study, the parameters of dissolved gases, coil temperature and oil temperature from the power transformers in Malakoff Prai Power Plant (PPSB) were collected. The effect of each parameter on the condition of paper insulation were investigated and the transformers life assessment was conducted.

1.3 Objectives of Study

The objectives of this study are:

1. To obtain the level of dissolved gases, coil temperature and oil temperature from transformers in Malakoff Prai Power Plant (PPSB).
2. To differentiate and categorize the condition of each parameter either acceptable (S) or not acceptable (F).
3. To assess the life of power transformer using Weibull plot.

1.4 Scope of Works

The scopes of this thesis are:

1. Parameters levels were obtained from 2 different units of in-service Malakoff's power transformer in Malakoff Prai Power Plant (PPSB). The specifications of these transformers are 463600KVA, 132/19kV for the Generator Transformer and 23000KVA, 19/6.6kV for the Auxiliary Transformer with both liquid and solid insulation.
2. The parameters obtained are dissolved gases, coil temperature and oil temperature.
3. Statistical techniques conducted are in term of unreliability for a given operating time and parameter estimation technique.

1.5 Thesis Outline

This thesis is divided into five chapters, which consists of:

Chapter 1 : Introduction

Chapter 2 : Literature Review

Chapter 3 : Research Methodology

Chapter 4 : Result and Discussion

Chapter 5 : Conclussion and Recommendation

Chapter 1 describe background, problem statement, objective, and scope of the project.

Chapter 2 presents the literature review of the project. This chapter explain what type of analysis that available and which is the best type that can be use to conduct the projet.

Chapter 3 discuss the methodology adopted for this research work. It involves dissolved gas analysis and Weibull analysis using Reliasoft and Microsoft Excel.

Chapter 4 show the result obtain from the data collected with the discussion of the project.

Chapter 5 explain the conclusion achieved in this project and suggest recommendation for future work.

CHAPTER 2

LITERATURE REVIEWS

Introduction

The basic insulation materials used in the oil filled transformers are paper and pressboard. The advantages of these materials are they have good electrical and thermal properties. The winding of the transformers is wrap using the paper. Under large oil gap, breakdown may happen at a lower voltage. This is known as volume effect. In order to enhance the dielectric strength of oil gaps, pressboard is used as spacer and barrier to divide the oil volumes into smaller oil gaps. If flashover occurs in an oil gap, the total breakdown can be avoided since the voltage is taken by the rest of oil gaps [1].

Pressborad and paper are made from cellulose. One of the weakness of cellulose insulation is that the ageing is restored. The transformer performance could be affected as the paper undergo ageing process. Conductor fault can occur and brittle paper can break away from the winding and block the ducts due to the overheating, The overheating occurs because of the increasing of the local carbonising of the paper. On top of it, moisture and acidity which are the by-products of paper ageing could accelerate the degradation of the paper.

The catastrophic failure of a transformer can be avoid by monitoring the condition of the paper. The property that is affected by the ageing state of the paper is mechanical strength while others property such as electrical is not affected. Due to that, the best technique to determine ageing state of paper is the mechanical strength measurement. However, paper samples from in-service transformers is impossible to obtain. Due to that, non-intrusive methods are used to determine the condition of the paper by measuring by-products of paper ageing from Furanic Compound Analysis (FCA), Degree of Polymerization (DP), and Dissolved Gas Analysis (DGA).

2.1 Paper Degradation Monitoring Techniques

2.1.1 Furan Compound Analysis

The molecular formula of grain is C_4H_4O. Based on the molecular formula, it represents four carbons and one oxygen in a five membered ring with each of the carbons having a hydrogen attached. Franc compounds are normally arise due to paper oxidation and hydrolysis processes can be directly extracted from the oil to classify the thermal decomposition of insulation paper. Furan concentration in transformer oil depends on the mass ratio between oil and cellulose. The five most common derivatives of green that produced by the degradation of the cellulose and that are soluble in oil are 2-Fulfural (2FAL), 2-Fulfurol (2FOL), 5-Hydroxy methyl-2-furfural (5HMF), 5-Methyl-2-furfural (5MEF), and 2-Acetyl furan (2ACF) as shown in figure 2.1 [2].

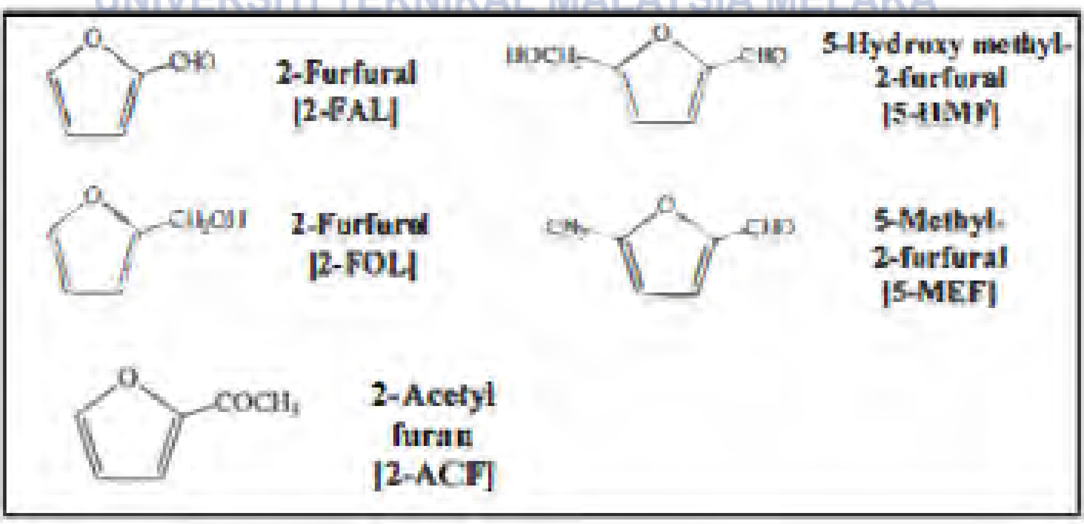

Figure 2.1: Derivatives of Furan From Degradation of Cellulose [2

Furan concentration in transformer oil depends on the mass ratio between oil and cellulose. Franc concentration in oil can be quantified by using High Performance Liquid Chromatography (HPLC) or Gas Chromatography-Mass Spectrometry (GC/MS) based on American Society for Testing and Material (ASTM D5837-Standard Test Method for Furanic Compounds in Electrical Insulating Oil by Gas Chromatography). Both techniques qualified to provide accurate and reliable measurement of grain derivative concentration in transformer oil [2].

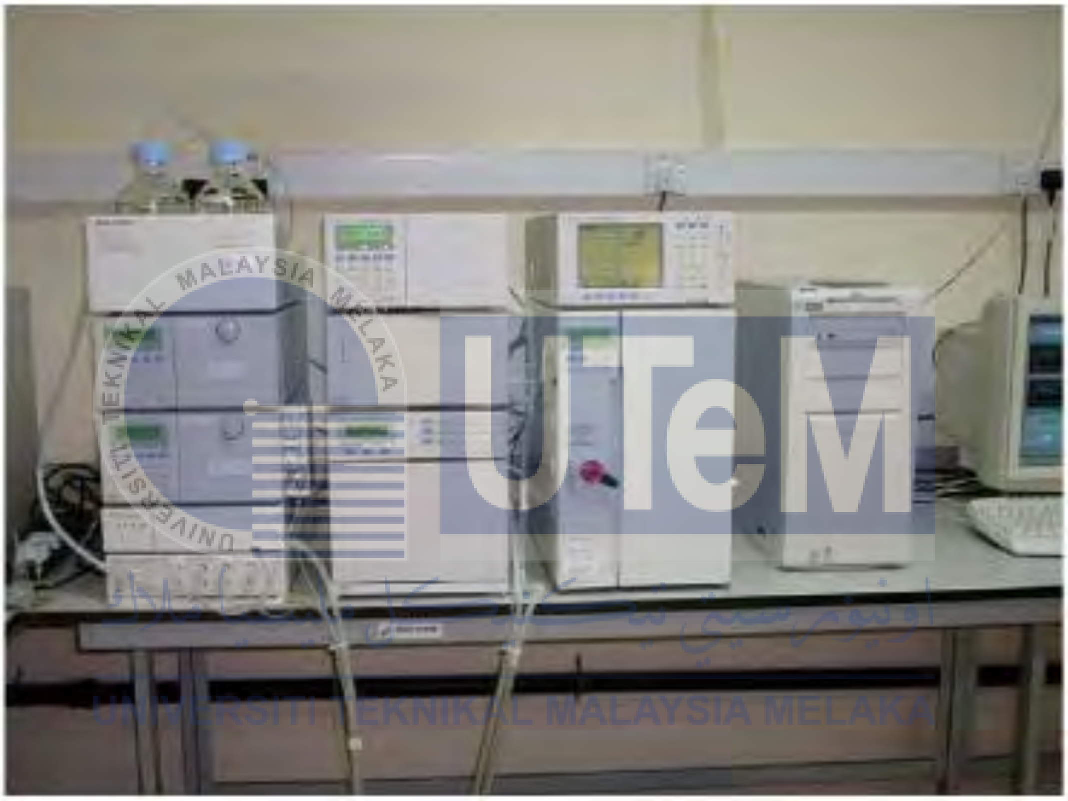

Figure 2.2: High Performance Liquid Chromatography (HPLC) [3]

There are several methods being used to extract the five most common derivatives of grain that produce by the degradation of the cellulose from the insulating oil. The reason this deravatives was extracted from the insulating oil instead of the insualting paper is because sample of paper could not be obtained from in-service power transformer. Due to that, the deravatives is extracted from the transformer insulating oil. This method is valid because the deravatives of furan that produce by the degradation of the cellulose is soluble in oil.

Based on study that had been done by P Verma [4], the furanic compounds that exist in the aged oil smaples have been analysed by HPLC, after extraction with solvent mixture as per IEC 61198. The samples are tested at 120^{o}C, 140^{o}C and 160^{o}C and at electric stress 2.5 kV for 360, 720, 1080 and 1440 hours. A special test cell has been design for accelearated thermal and electrical ageing treatment on paper. Figure 2.3 shows the schematic diagram of the test cell.

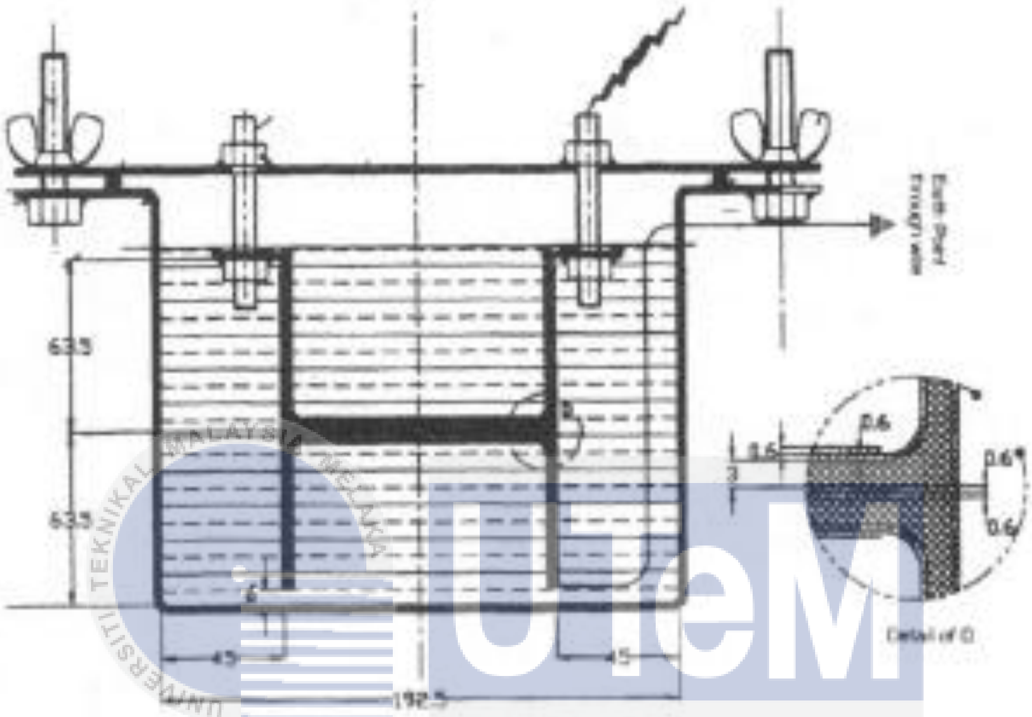

Figure 2.3: Test Cell[4]

The test cell had be made by using a mild steel of 3.5 mm thickness with a capacity of three litres. A high temperature resistant enamelled paint was used to polished the inner surface of the test cell. In order to prevent the leakage of gases at high temperature, the silicon sealing has been provided in between the top cover. Two copper strips covered with paper joined together were placed in the cell when the paper was tested in the presence of oil. The paper and oil were put in the ratio of 20:1 by weight. The temperature control of the oven was within $\pm$2^{o}C. The paper and oil samples were taken periodically from the test cell at 120^{o}C/2.5 kV, 140^{o}C/2.5 kV and 160^{o}C/2.5 kV after 360, 720, 1080 and 1440 hours.

Standard solution was prepare by using high purity furan compounds. UV detector is used to identify the furan derivatives after separation at two different wave lengths, 220 nm and 276. Samples peaks are identified by comparing the elution times with respect to standard samples of furans and concentration calculations are made in parts per billion taking into account the concentration of standard furan compounds injected. These are calculated from standard and sample peaks. Table 2.1 shows the results.

Table 2.1: Furfural Compound Formation[4]

Aging condition		2-Furfuraldehyde (ppb)	2-Acetyl Furan (ppb)	5-Methyl Furfuraldehyde (ppb)	5-hydroxy Methyl Furfural Dehyde (ppb)
1.	120^{o}C 2.5 kV 360hrs	41	12	16	22
2.	120^{o}C 2.5 kV 720hrs	54	19	23	29
3.	120^{o}C 2.5 kV 1440hrs	76	27	38	51
4.	140^{o}C 2.5 kV 360hrs	106	41	54	82
5.	140^{o}C 2.5 kV 720hrs	116	42	57	90
6.	140^{o}C 2.5 kV 1440hrs	150	48	59	97
7.	160^{o}C 2.5 kV 360hrs	480	154	135	265
8.	160^{o}C 2.5 kV 720hrs	4920	155	140	267
9.	160^{o}C 2.5 kV 1440hrs	5600	162	151	290

As per Mr. S.D Mayers Co.[5], For evaluation of remnant life using 2-FAL and DP as given in Table 2.2. This gives general guidelines to analyse the power transformers life aging based on the fural compounds.

Table 2.2: Guidelines for life aging based on 2-FAL[5]

55 °C Rise Transforme r 2FAL (ppb)	Evaluated Degree of Polymerization (DP)	Evaluated Percentage of Remaining Life	Suggested Interpretation
58	800	100	Normal Ageing Rate
130	700	90	
292	600	79	
654	500	66	Accelerated Ageing Rating
1,464	400	50	
1,720	380	46	
2,021	360	42	
2,374	340	38	Excessive Ageing Danger
2,789	320	33	
3,277	300	29	Zone
3,851	280	24	High Risk of Failure
4,524	260	19	
5,315	240	13	End of Expected Life of Paper Insulation and of the transformer
6,245	220	7	
7,337	200	0	

The table above shows that for a range of 2-FAL from 0-292 ppb, the power transformer has normal ageing rate. For range between 654-2012 ppb, the transformer has accelerated ageing rate. For range between 3851-4524 ppb, the transformer has high risk of failure. Tha tarnsfomer was expected to totally damage at the range of 2-FAL above 5315 ppb.

The reason furan analysis is used to analyse the insulation paper degradation in power transformer is because the aging process of the power transformer oil does not produce furfurol. In contrast, molecule of furfurol in liquid form, with the formula (C4H3OCHO) and dissolved in oil, is the principal resultant from the paper insulation decomposition. Bases on previous researched, the state and condition of paper insulation aging can be quickly and accurately diagnosed by measuring the content of furfurol with HPLC (High Performance Liquid Chromatography) method. Nevertheless, other evidences should be used to accurately determine the condition of solid insulating aging because other factors may affected the resulting furfurol [6].

One of the best method for assessing the condition of paper insulation was Furan analysis. This is because this method only required the transformer oil to be sampled out and not the paper from the transformer during on-line operation of the transformer. The advantage of this technique as a diagnostic tool is that these compounds are formed from the degradation of paper insulation, and it cannot be produced by oil. 2-furfural is the most predominant [4].

According to all the products, the concentration of 2-furadehyde (furfural) was found to be the highest. The furfural analysis could provide a sensitive trouble-shooting tool for rapid ageing because the concentration of most products increased rapidly as the paper approached the end of its useful life [7].

2.1.2 Degree of Polymerization

Degree of polymerization , which is defined as the average length of the cellulosic chain, measured by the average viscometric method is the most convinent method for analysing the Kraft paper aging. DP value reveals a strong correlation between the insulation paper deterioration and formation of aging products. The number of anhydro-β-glucose monomers, $C_6H_{10}O_5$ units (also known as DP) in cellulose chain is a direct indicator of the cellulose decomposition. Based on DP technique, the length of the cellulose chain is measured by the average DP based in viscocity (DP_v) method to determine the qualify of cellulose.

In early 1930's, Staudinger had introduced the Viscometer method to determine DP values. Then in early 1940, the correlation of intrinsic viscosity with molecular weight, known as Mark-Houwink equation was formulated. The intrinsic viscosity of a polymer in a dilute solution is correlated to the volume of hydrodynamic sphere of the molecule in solution, which depends on the shape and type of polymer. However, Mark-Houwink equation was only valid for dilute solutions approximately between 0.1 to 1.0%,since the relationship od DP and intrinsic viscosity is linear within this range only. According to standard ASTM D4243-99, it clearly state that the value of intrinsic viscosity (η) must remain below 1. Apart from that, Huggins-Kraemer had prposed a technique to measure η based on the concentration of cellulose (g/100ml of solution). In ASTM D4243 standard procedure, Martin's formula is used to calculate the intrinsic viscosity which is quite similar with Huggins-Kraemer's equation. The first standard procedure to measure the average viscometric of degree of polymerization was published in 1974 known as IEC 450 (known later as IEC60450) [2].

Furthermore, DP of paper can be measured by using Ubbelohde viscometer tube as shown in figure 4. This tube is used to obtained the value of specific viscosity.Intrinsic viscosity, v can be obtained based on the specific viscosity and concentration of the solution based on Equation 2.1.

$$v = \lim_{c \to 0} \left[\frac{v_s}{c} \right] \tag{2.1}$$

Where c = Concentration of paper and Cuen

Next, the value of DP can be calculate by using equation 2.2 based on intrinsic viscosity.

$$[v] = K\overline{DP}_v^{\alpha} \tag{2.2}$$

Where K and α = Mark Houwink constant (K=0.0075 and α = 1)

DP^v = Average degree of polymerization

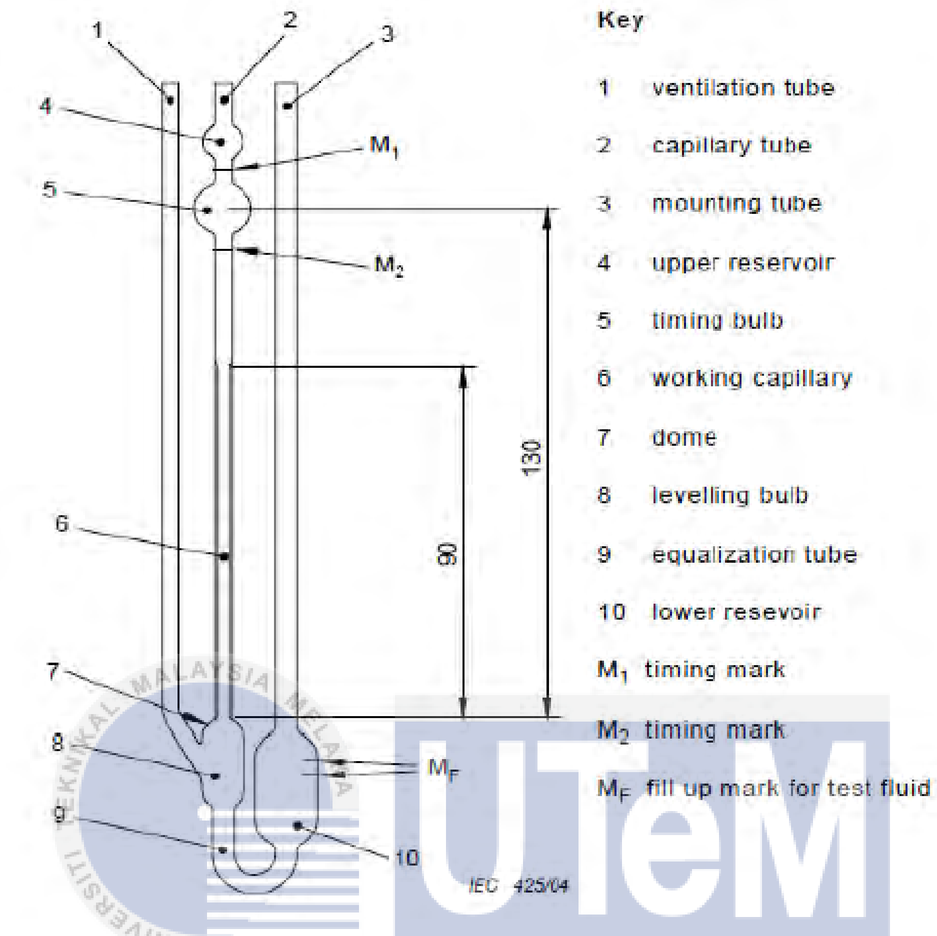

Figure 2.4: Viscometer tube

Factors that might affect the measurement of DP are [8]:

1. Important factors in the preparation of the sample are the removal of oil from the paper and correct measurement of the dry weight of sample, theconcentration of the polymer in solution and oxidative and mechanical degradation during mixing.
2. Important factors in the measurement of viscosity are shear degradation effects in the viscometer tube, degradation of the solution and/or polymer in solution by oxygen, and the temperature of analysis.
3. A number of different values for the MHS equation parameters exist in the literature for the calculaying the DP from the viscosity measurements and it is important to ensure that the correct, or at least consistent, values are used.

`

After the result of the DP being obtained, the result were compared with a standard or reading. New Kraft paper has an average length of DP around 1000 to 1500. When the DP value decreases from 1000 to 450, it is considered as moderate deterioration. However, when the value is falling down below 450, it is an indicator that the mechanical strength in paper is critical. The transformer life is considered over if the DP value reaches between 150 to 200. This condition is simplified as in table 2.3. This reading or standard is used in order to see what is the relationship of the DP value with the mechanical strength. We also can observed the significant of the transformer condition [2,9].

Table 2.3: Relationship between DP value and mechanical strength[2]

DP Value	Mechanical Strength	Significant of Transformer
1000-1500	Greater (New paper)	Healthy Insulation
450-1000	Constant (Normal operation)	Moderate Deterioration
250-450	Critical (Lower requirement)	Extensively Deterioration
200-250	Nearly Losses Strength	Crucial Deterioration
<200	Zero Strength (Endless)	End of Life Criteria

This analyzing technique has its own advantages and disadvantage. Although it was recognized as the best method to study the condition of the paper insulation, it has its own restraint in order for this method to be implemented. The condition of paper insulation aging is best indicated by its degree of polymerization, which can be used as a direct and efficient index. On top of it, the degree of polymerization has a good correlation with the tensile strength of insulating paper. Based on this, the mechanical strength of the insulating oil paper is best reflect by the degree of polymerization. Furthermore, the detection of the degree of polymerization of insulation paper samples can judge the ageing extent of the transformer overall insulation or the insulation ageing condition of the smaple parts.[6,9]

The restraint of this tehnique or method is that, it is difficult to make measurements by taking paper samples on a regular basis, not without routinely shutting down and taking apart the transformer. Furthermore, the solid isnulation of a transformer has complex structures. Due to this circumstances, the degree of polymerization measured from the samples of paper or filling pieces taking from limited locations may not represent the overall condition of insulation aging inside the transformer. According on IEC 60450, a sample of insulation paper from servicing transformer is required for direct measurement of DP. This paper must be taken from locations that have the most rapidly aging paper (hot spot locations). [2,6]

2.1.3 Dissolved Gas Analysis

Dissolved Gas Analysis (DGA) is the study or analysis by using samples of transformer oil extracted from in-servive power transformer. Liquid insulating oils are mixtures of many different hydrocarbon molecules, which are composed essentially of saturated hydrocarbon. On the other hand, solid cellulose insulation (paper,pressboard,wood blocks) contain a large number of anhydroglucose rings, weak C-O molecular bonds and glycoside bonds which are thermally less stable than the hydrocarbon bonds in oil, and which decompose at lower temperatures. When fault occurs inside oil-filled equipment such as a trasnformer, both liquid and solid insulation materials are affected and decomposed by the energy and then produce various gases, such gases are dissolved into insulating oil.

The type of the internal fault can be determine by the distribution and concentration of these gases. In addition, the severity of the fault can be indicate by the rate of gas generation. The common collected and analyzed gases are H2, CH4, C2H2, C2H4, C2H6, CO and CO2. The DGA results during the operation of the transformer can be interpret based on guidelines provide by IEC 60599 and IEEE C57.104 standards. There are several method described in the IEEE C57.104 which are the key gases, Doernenburg ratios, and Rogers Ratio. Furthemore, the three basic gas ratio methods and the Duval triangle method are described in the IEC 60599 [10].

Method	F1	F2	F3	F4
Roger	Thermal Fault <150°C Thermal Fault between 150-300°C Thermal Fault between 300-700°C Thermal Fault >700°C	Partial Discharge of low energy Partial Discharge of High energy Continues Sparking Discharge of high energy	Normal	Out of code
IEC	Thermal Fault <150°C. Thermal Fault between 150-300°C. Thermal Fault between 300-700°C Thermal Fault >700°C	Partial Discharge of low energy Partial Discharge of High energy Continues Sparking Discharge of high energy	Normal	Out of code
Doernenburg	Thermal Decomposition	Arcing/Corona	Normal	Out of code
Duval	Hot spot Hot spot <200°C Hot spot between 200-700°C Hot spot >400°C	Corona discharge High Energy Arcing Low Energy Arcing	Normal	Out of code
Key gas	Over heated oil Over heated cellulosic	Arcing in oil Corona in oil	Normal	Out of code

Figure 2.5: Fault types[11]

One of the main important parts of DGA is gas extraction. Toepler methods or Headspace methods are used in most for the laboratory in order to extract gas from oil. Both methods have their own advantages and disadvantages. There is a possibility that the gas is not completely removed from the oil although there are no partition coefficients involve with Toepler pump. Furthermore, the mercury in the Toepler pump may cause harm to the laboratory staff. Discussing Headspace method, it can produce a good repetability of measurements. It also has the capability to analyze large samples in a short period. However, to archieve equilibrium between gas and oil phase, the technique requires a good controlled condition such as temeprature, pressure, and agitation.

The mode use to operate the Toepler pump is the multi-cycle mode. This mode is operated under vacuum condition.The gas must be extract from the oil. This is perform by repeating the vacuum process several times. Besides, the partition coefficient for different type of liquids is not required by the method. The maount of gas which can be extract after performing between four to twenty cycles is 97%. Discussing the Headspace technique, the gas equilibrium principle between oil and headspace is use to operate it. In a closed vessel purged with argon, oil samples are brought into contact with the Headspace. Then, under controlled condition, the oil containing dissolved gases are then equilibrated between oil and Headspace. After that, the headspace is over pressurized with argon. This is done under equilibrium condition. Last step is where the extracted gas is introduce into the GC machine. Henry's law is used to calculate the partition coefficient between oil and headspace. The type of oil play an important role [12].

Gases dissolved in transformer can extracted using ASTM D3612 – Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography as in Figure 2.6 [2].

Figure 2.6: Gas Chromatography

Carbon monoxide and carbon dioxide gases are generated with the fault of cellulose aging ang thermal fault-cellulose. In particular , hydrogen gas is generated with all types of faults excide cellulose aging.[10] Dep Pablo reported that water and carbon dioxide are the main by-products of the thermal degradation of cellulose. Hence, the ratio of CO/CO_2 is normally used as an indicator of thermal decomposition of cellulose.[4] Furthermore, as in [11], it is stated that except for CO and CO_2, all other gases are formed due to the decomposition of oil. CO and CO_2 represent a good source of paper monitoring and the ratio CO/CO_2 is considered as the major factor in cellulose degradation.[11] However, there are also researcher that believe that the CO2 and CO may produced by the decomposition of transformer oil, and it is technically impossible to identify the original source of CO2 and CO products.[6]

2.2 Weibull Analysis vis Reliasoft Software

In life data analysis [13], the life of a product is predicted based on a set of data obtained from the product itself. The collected parameters can be used to estimate of predict the reliability or probability of failure at a specific time of the product. A researcher which performing the life data analysis need to do the following steps:

1. Gather life data from the product
2. Select a lifetime distribution that will fit the data and model the life of the product.
3. Estimate the parameters that will fit the distribution to the data.
4. Generate plots and results that estimate the life characteristics of the product, such as the reliability or mean life.

2.2.1 Unreliability for a Given Operating Time

Ten identical units were reliability tested at the same application and operation stress levels. Six of these units failed during the test after operating for the following times, T_j : 16,34,53,75,93, and 120 hr. Four units was susupended after 120 hr. Determine the parameters that represent this set of data set and create the Probability plots [12].
Click 'Create a New Project' in the intial window. Then select 'Times-to-failure data' for the Folio Data Type and select 'My Data set contains suspensions (right censored data)' as shown in figure 2.7 .

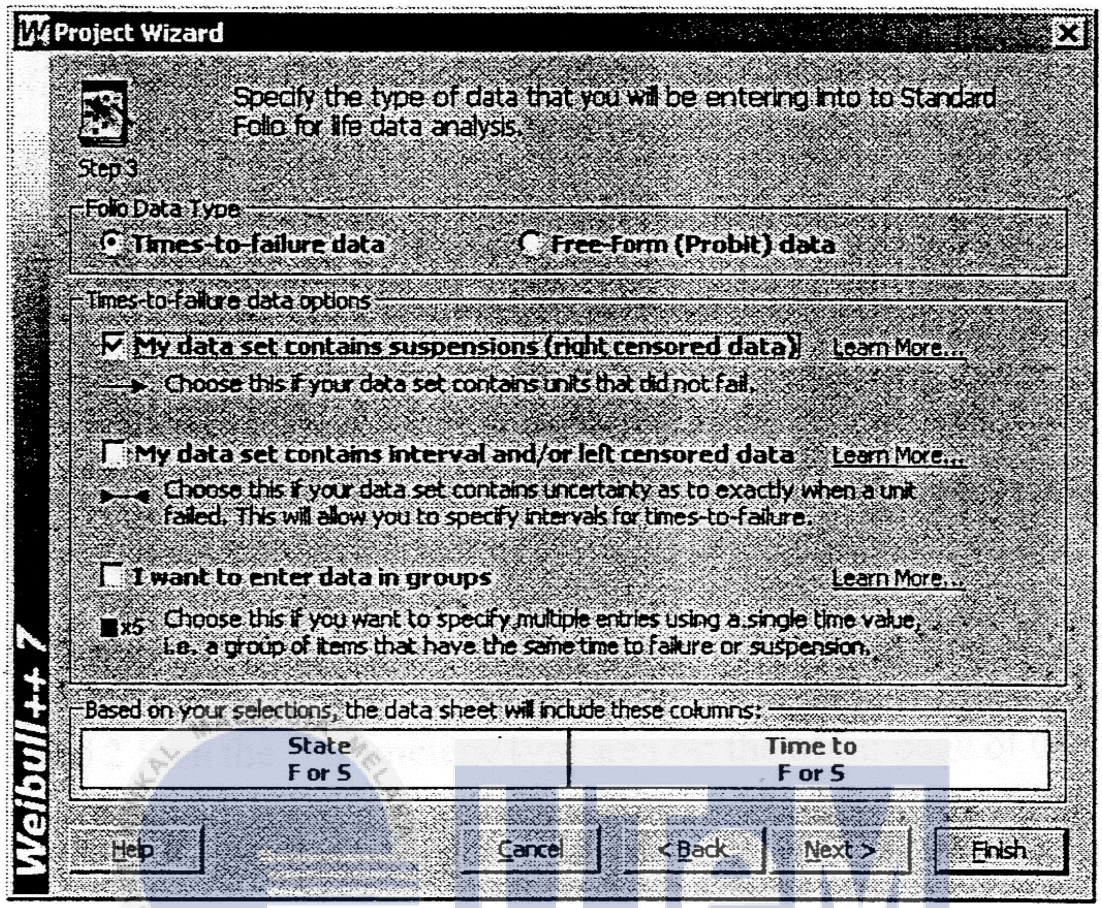

Figure 2.7: Project Wizard

Then click 'Finish' to create the new project with the appropriate Standard Folio. 'F' indicate failure where 'S' indicate suspension. Data for this example was enter as in figure 2.8.

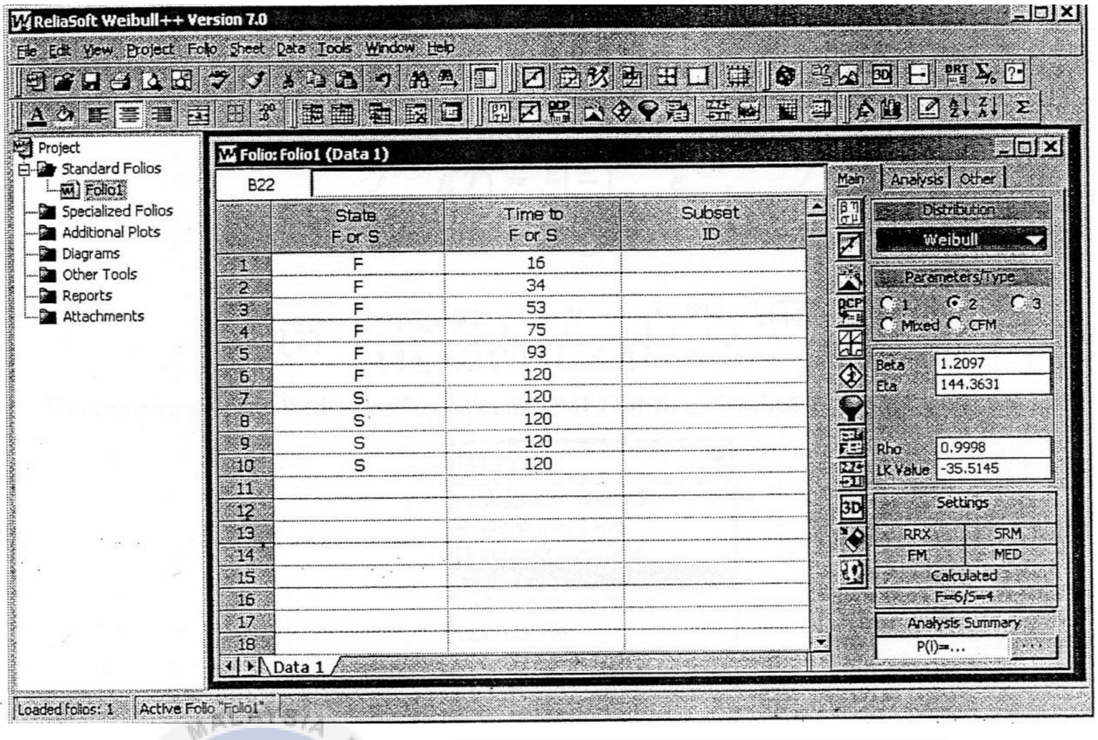

Figure 2.8: Data Entered

The 2-parameter Weibull distribution and Rank Regression on X (RRX) will be used to calculate the parameters. The Weibull Probability plot for this data set is shown in figure 2.9.

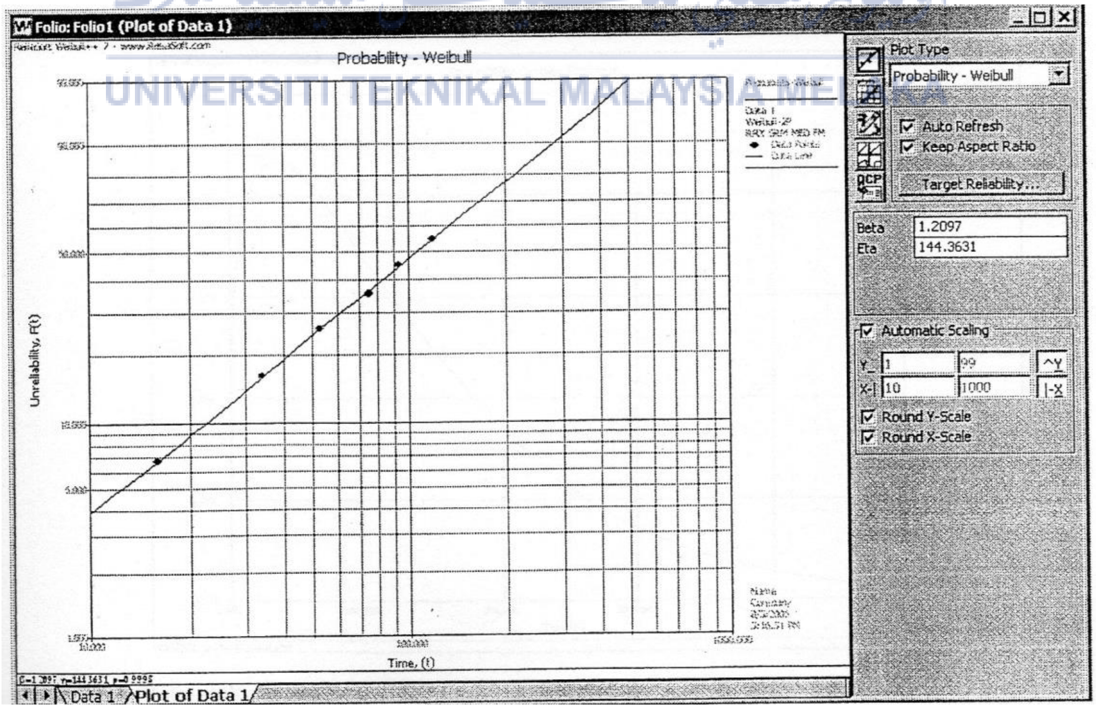

Figure 2.9: Weibull Probability Plot

2.2.2 Degradation Data Analysis

Once the degradation information has been recorded, the next task is to extrapolate the measurements to the defined failure level in order to estimate the failure time. Weibull++ allows the user to perform such extrapolation using a linear, exponential, power of logarithmic model[14]. These models have the following forms as in figure 2.10:

$$\begin{array}{cc} Linear & y = a \cdot x + b \\ Exponential & y = b \cdot e^{a \cdot x} \\ Power & y = b \cdot x^{a} \\ Logarithmic & y = a \cdot ln(x) + b \\ Gompertz & y = a \cdot b^{c^{x}} \\ Lloyd - Lipow & y = a - \frac{b}{x} \end{array}$$

Figure 2.10: Models forms equations[14]

Where y represents the performance, x represents time, and a, b and c are model parameters to be solved for. Once the model parameters ai, bi, and ci are estimated for each sample I, a time. Xi can be extrapolated, which cirresponds to the defined level of failure y. The computed xi values can now be used as our time-to-failure for subsequent life data analyis. As with any sort of extrapolation, one must be careful not to extrapolate too far beyonf the actual range of data to avoid large inaccuracies (modeling errors) [13].

As an example 14], five turbine blade were tested for crack propagation under normal use condition. The test units were cyclically stressed and inspected every 100000 cycles for crack length. Failure is define as a crack of length 30mm or greater. The test are as in Table 2.4:

Table 2.4: Crack propagation data

Cycles (x100)	Unit A	Unit B	Unit C	Unit D	Unit E
100	15 mm	10 mm	17 mm	12 mm	10 mm
200	20 mm	15 mm	25 mm	16 mm	15 mm
300	22 mm	20 mm	26 mm	17 mm	20 mm
400	26 mm	25 mm	27 mm	20 mm	26 mm
500	29 mm	30 mm	33 mm	26 mm	33 mm

The data was entered as in Figure 2.11 and 'Exponential' was selected for the model and '30' was entered for the Critical Degradation.

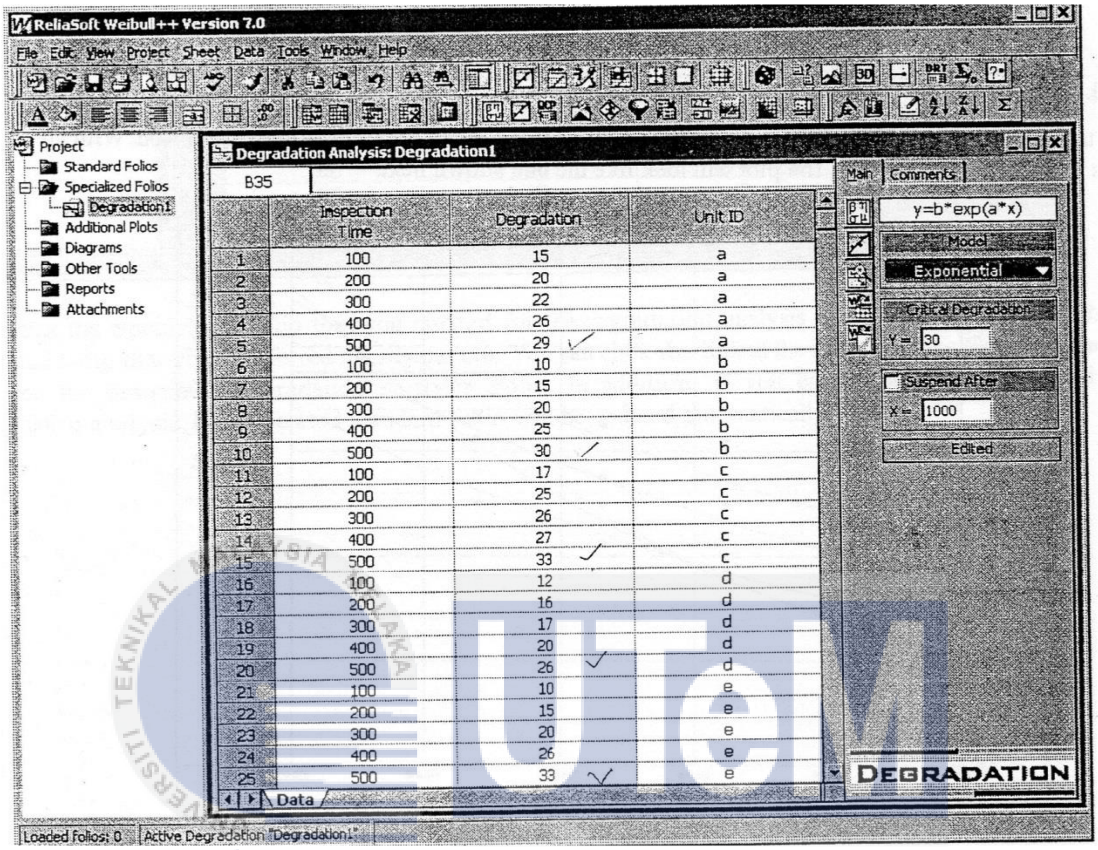

Figure 2.11: Data entered

A plot of analysis is presented in Figure 2.12.

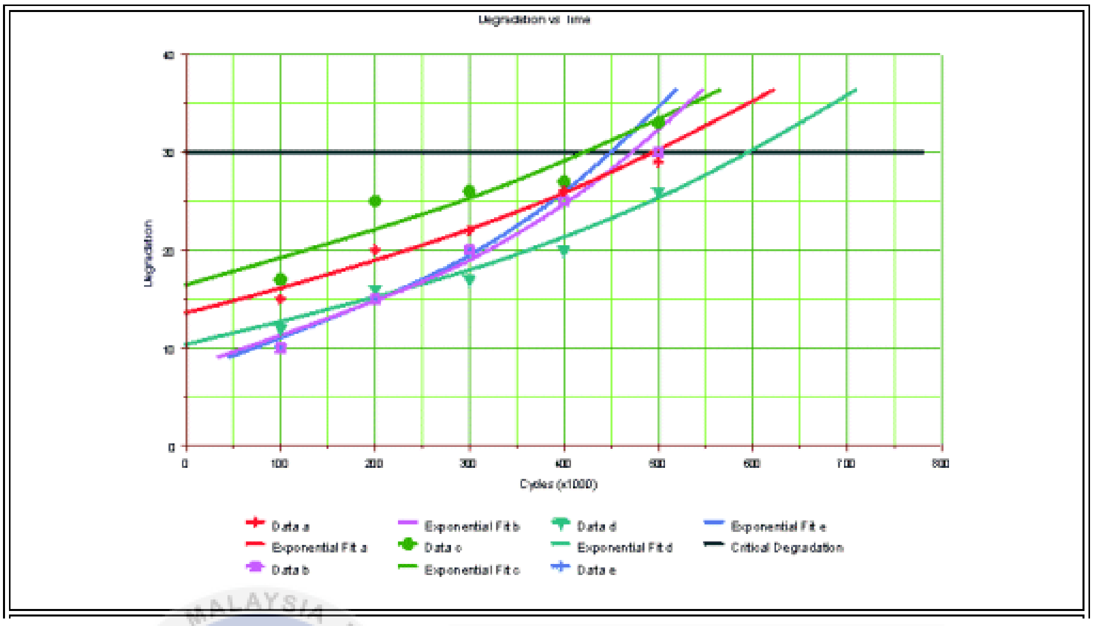

Figure 2.12: Plot of degradation results from Weibull++

2.3 Weibull Analysis By Using Parameter Estimation Techniques in Excel

Parameter estimation refers to the process of using sample data (in reliability engineering, usually times-to-failure or success data) to estimate the parameters of the selected distribution [16].

The method used to obtain the unreliability for each failure is the Median Ranks method. The median rank is the value that the true probability fo failure should have at the j^{th} failure out of a sample of *N* units as the 50% confidence level. Instead of other ranking methods, median rank position are used because median ranks are at specific confidence level (50%). Figure 2.13 illustrate the graph constructed by using the median rank in percentage for the Y-axis and time,(t) for the X-axis.

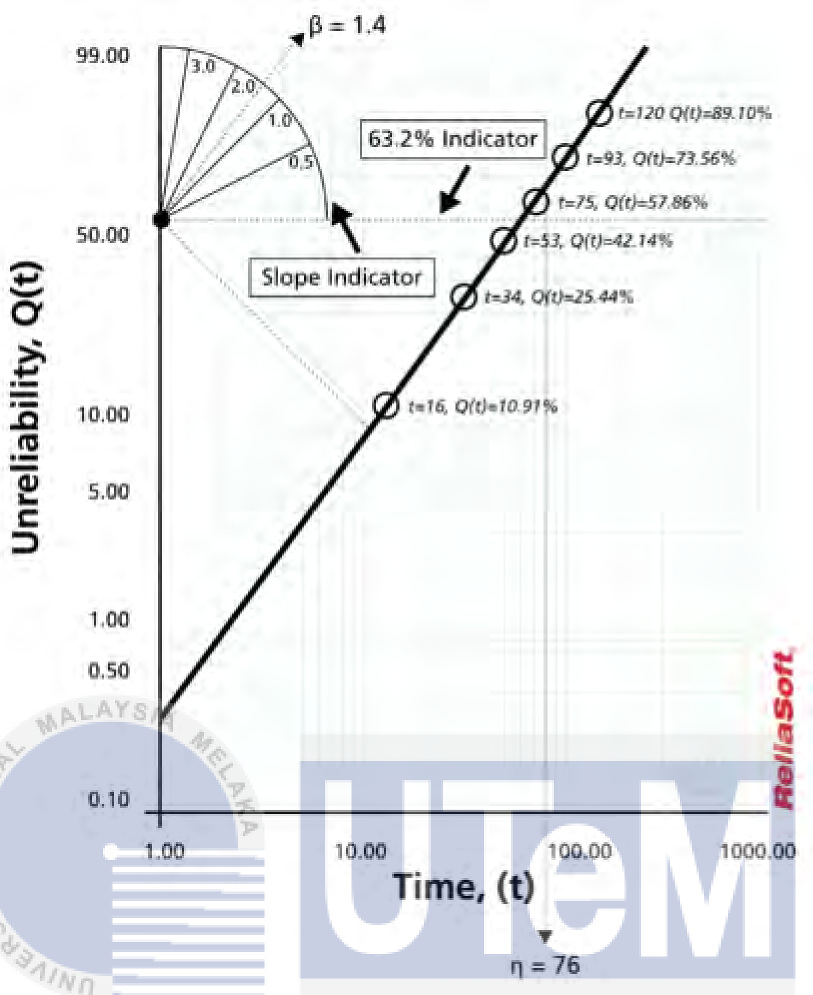

Figure 2.13 : Graph of Unrelibility, Q(t) versus Time, (t)

The slope of the line can be obtained once the line has been drawn. This is the parameter β, which is the value of the slope. To determine the scale parameter, η (also called characteristic life), one reads the time from the x-axis corresponding to Q(t) = 63.2%. By using this, the paramters of the Weibull distribution can be estimated

2.3.1 Weibull Shape Parameter, β

The weibull shape parameter, β, is also known as the Weibull slope. The slope of the line in a probability plot is equal to the value of β. The effects behavior of the distribution can be marked by the different values of the shape parameter. Figure 2.14 shows how the slope of the Weibull probability plot changes with β. All three lines have the same value of η.[17]

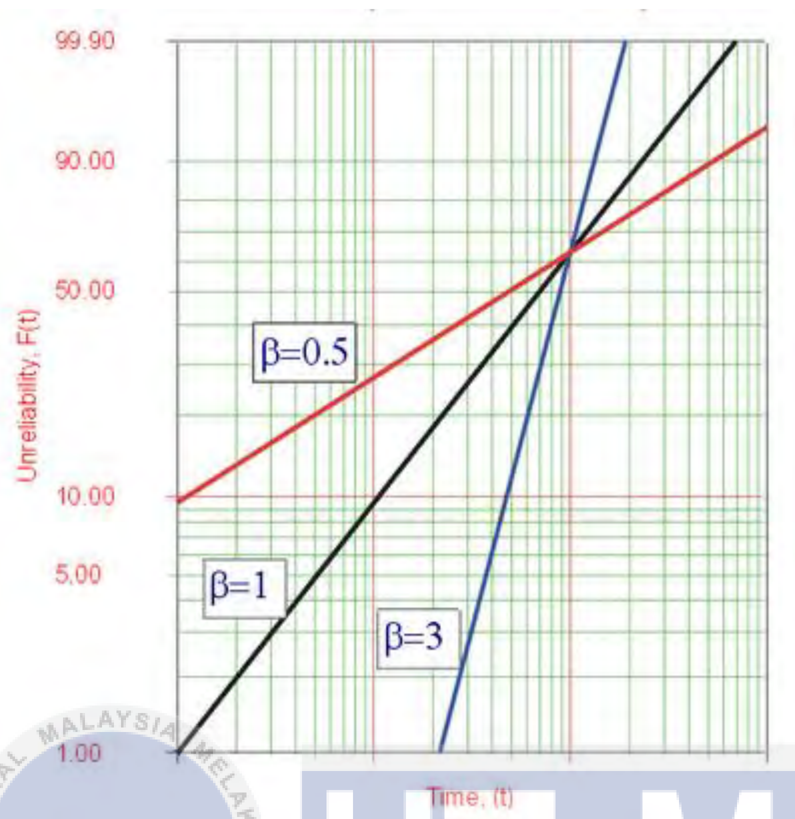

Figure 2.14 : Plot of Weibull Probability with different β value but same η value

This is one of the most important aspects of the effect of β on the Weibull distribution. As is indicated by the plot, Weibull distributions with $\beta < 1$ have a failure rate that decreases with time known as early-life failures. Weibull distributions with β equal to 1, $\beta = 1$ have a constant failure rate. Lastly, Weibull distributions with $\beta > 1$ have a failure rate that increases with time, known as wear-out failures[18,19]. The comprise of all three condition form the classic “bathtub curve”. An example of a bathtub curve is shown in figure 2.15.

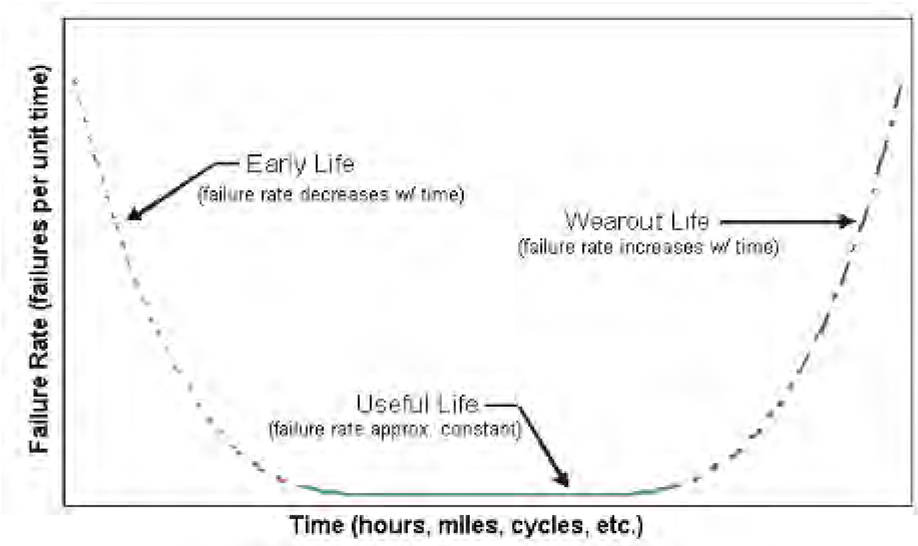

Figure 2.15 : Comprise of all three β conditions

2.4 Summary

Based on all three techniques of analyzing the paper insulation degradation, DP is the best and most accurate method followed by the furanic compound analysis which come second best tehcniques for analyzing the degradation of paper insulation. The last technique which are DGA analysis is considered as applicable but secondary gases has to be count.

Weibull++7 provide many type of analysis for the life assessment of the power transformer. This analysis will be execute by using the collected parameters from among three techniques that had been mentioned before. The analysis method by using Weibull++ 7 that are suitable to be perform are the “Unreliability for a Given Operating Time” and “Degradation Data Analysis”.

In this study, the method that will be used are the DGA technique by taking the ration of CO2/CO as the analyse data, “Unreliability for a Given Operating Time” technique, and “Parameter Estimation Technique in Excel”. This technique was choosed because the parameters levels collected only contained the DGA results which are suitable for the study to be carry out.

CHAPTER 3

METHODOLOGY

3.0 Introduction

This chapter describes methods used to execute this study. The methodology of study flow chart is shown in figure 8 which clearly state the individual tasks for the study.

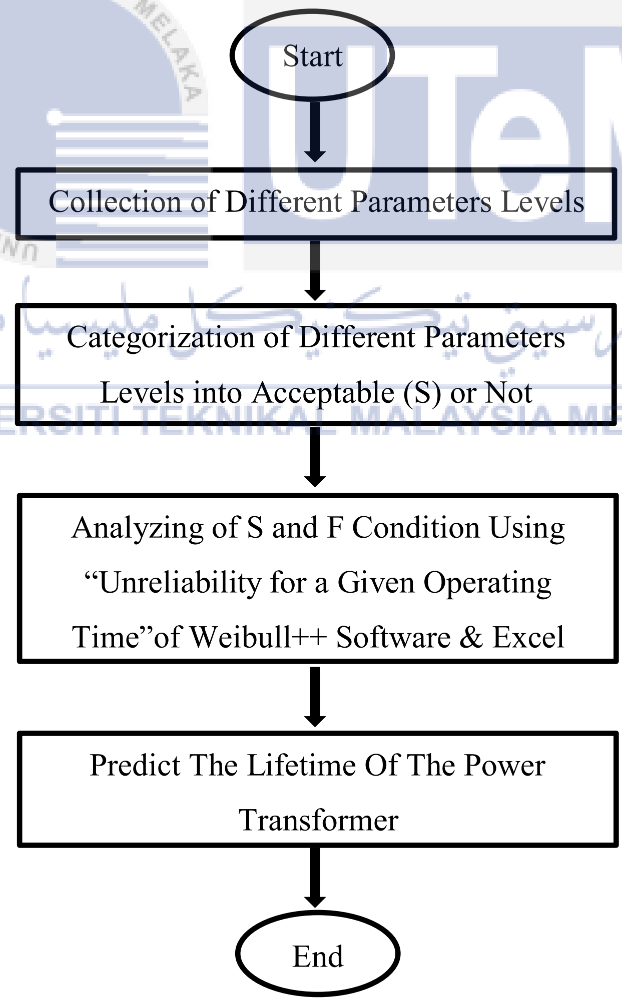

Figure 3.1 : Flow Chart of Study Methodology

3.1 Collection of Different Parameters Levels

Different parameter levels were collected from in-service power transformer which are dissolved gas analysis,oil temperature, and coil temperature. The transformers that were selected for this study are the generator transformer 463600KVA, 132/19kV and Auxiliary Transformer 23000KVA, 19/6.6kV for the Auxiliary Transformer.

The Dissolved Gas levels are recorded in parts per million and are determined by using the Gas Chromatography equipment based on the samples of the transformers oil. The Gas Chromatography was executed according to ASTM D3612 standard as in [4]. The oil temperature and coil temperature levels are obtained as per display on the temperature panel of each transformers.

3.1.1 Oil Sampling

An outside contractor was appointed to do the oil sampling from the transformer in the plant. The contractor that was appointed was TXM Services Sdn. Bhd, a company that provides Tranformer Life Extension Service (TLES) in Malaysia. They provide services such as laboratory testing and analysis for transformer oil, Condition Monitoring Services (CMS), and operation.

The oil sample was taken and was sent to their lab for analysis. As mention before, oil sampling was done annually or once in every six months depending on the transformer condition.

Figure 3.2: Oil sampling of Trasnformers by TXM Services Sdn. Bhd

Type of oil testing that clients want to do will determine the amount of oil taken. There are about 13 types of test that needed to be conducted for this plant. The oil needed varies with the type of test done. Due to that the oil sample taken vary according to the test conducted.

Figure 3.3: Specially Designed Beaker Used to Store the Collected Oil Sample

There oil was collected from several points which is from the Generator Transformer (GSUT), Unit Auxiliary Transformer (UAT), Load Commutative Inverter (LCI), and EX2000 Trasformer. There are 4 transformers in this plant which are located side by side.

Figure 3.4: A Small Hose is Used to Collect the Oil Sample from The Drain Pipe Outlet

The sampling beaker need to be flushed using the oil before storing the oil in order to minimise degassing and to remove any particles or water molecules. Then the beaker was sealed securely. The contractor appointed to do the sampling need to be well-trained and follow all the procedure. They need to be aware at all time because small mistake may influence the result of the analysis afterward.

3.1.2 Oil Temperature and Coil Temperature Reading

The oil and coil temperature was taken during the oil sampling through the temperature gauge meter located at the transformer.

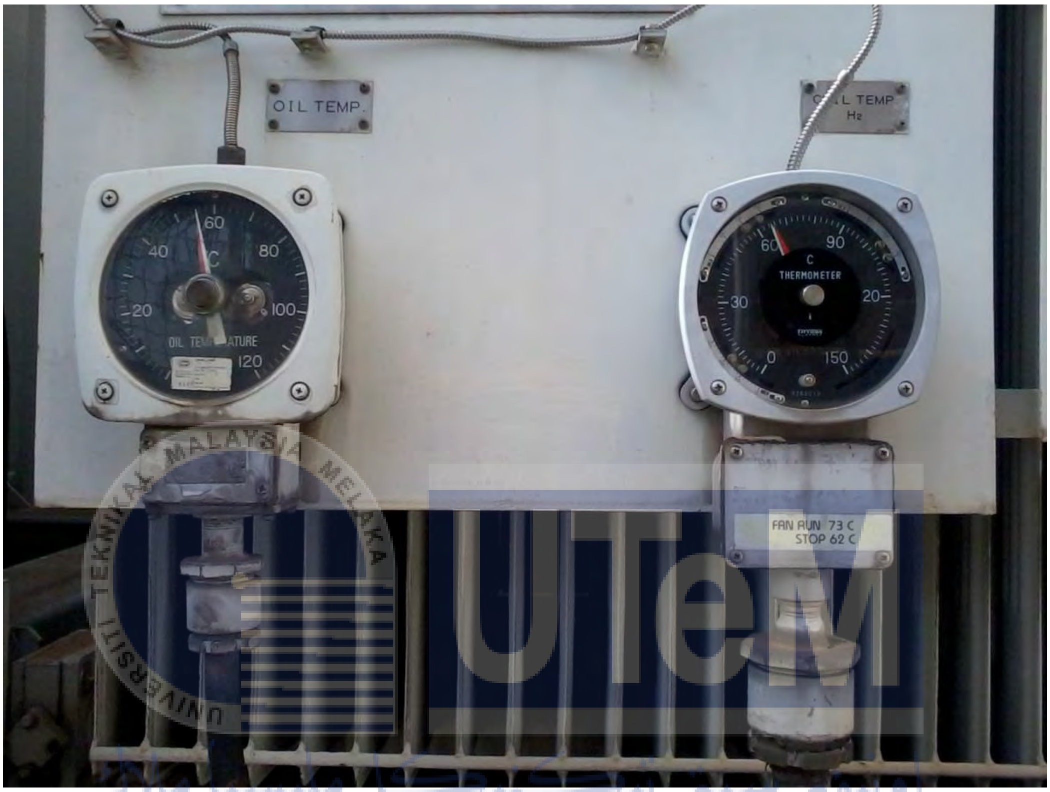

Figure 3.5: Generator Transformer Temperature Gauge Meter

Figure 3.6: Auxiliary Transformer Temperature Gauge Meter

3.2 Categorization of Different Parameters Levels

The categorization using dissolved key gas concentration are as in table 3.1 which used as the guidelines for the condition of the insulation. Condition 1 indicates that the transformer is operating satisfactorily. Condition 2 indicates greater than normal combustible gas level. Condition 3 indicates a high level of decomposition. Lastly, condition 4 indicates excessive decomposition which state that continued operation could result in failure of the transformer. [c57.104]

Table 3.1: Dissolved Gas Concentrations Status[15]

Status	Dissolved key gas concentration limits [μL/L (ppm)[a]]							
	Hydrogen (H_2)	Methane (CH_4)	Acetylene (C_2H_2)	Ethylene (C_2H_4)	Ethane (C_2H_6)	Carbon monoxide (CO)	Carbon dioxide (CO_2)	TDCG[b]
Condition 1	100	120	1	50	65	350	2 500	720
Condition 2	101–700	121–400	2–9	51–100	66–100	351–570	2 500–4 000	721–1920
Condition 3	701–1800	401–1000	10–35	101–200	101–150	571–1400	4 001–10 000	1921–4630
Condition 4	>1800	>1000	>35	>200	>150	>1400	>10 000	>4630

The aging assessment will be conduct by using the DGA results. In specific, key gases method will be use and the ratio of CO2/CO will be use as an indicator of the condition of the solid insulation of the transformer. The main reason this method is choose is because the reliable readings that were obtained from both transformers are the DGA results. This plant does not conduct DP test because it required a sample of paper from the solid insulation which is appropriate for an in-service transformers. Besides, the second best method to analyse the aging of cellulose paper which is Furan Analysis cannot be take into count because the reading of 2FAL is not enough in order for the assessment to be conducted. Thus, the third best method which is DGA technique is used because the results obtained was enough and approriate in order for the assessment to be conducted. Therefor, the key gas method is used based on the ratio of CO2/CO.

The reason why ratio of CO2/CO will be use to conduct this study is because except for CO and CO2, other gases are formed due to the decomposition of oil. CO and CO2 reflect as a good source of paper monitoring. Furthermore, the ratio CO2/CO is considered as the major factor in cellulose degradation. The amount of both gases will increase with the increase of the transformer temperature. However under certain circumstances, it may be difficult to determine which gas is predominant. In this state, secondary gases which are methane (CH4) and ethylene (C2H4) should be taken into account. The indicator that can be used to see the condition of the transformer base on the ratio of CO2/CO can be found in table 3.2.

Table 3.2: Condition According to CO2/CO Ratio[11]

Ratio of CO2/CO	**Condition**
ratio ≤ 3	severe paper degradation
$3 \leq$ ratio ≤ 10	normal
ratio ≥ 10	Thermal fault with the involvement of cellulose

3.3 Unreliability for a Given Operating Time Analysis via Reliasoft Software

Weibull++ 9 software is a reliability and life data analysis software which is used to perform the unreliability for a given operating time analysis instead of using manual calculation. The step by step procedures required by this software are as in Appendix A of page 60.

3.4 Weibull Analysis By Using Cumulative Distribution Function in Excel

Median rank is usually used to estimate the cumulative distribution function, F(x). The median rank estimate for F(x) can be calculated by using equation 3.1[18].

$$\hat{F}(x) = \frac{O_i - 0.3}{n + 0.4} \tag{3.1}$$

Where O_i is the modified order of failure of the *i*th data point. A modified order of failure is only needed if censored data is involved. In this study, cencored data is involved. The modified order of failure is computed from equation 3.2

$$O_i = O_{i-1} + I_i \tag{3.2}$$

Where I_i is the increament for the $_i$th failure, and is computed from equation 3.3

$$I_i = \frac{(n+1) - O_p}{1 + c} \tag{3.3}$$

Where n is the total number of points in the data set, both censored and uncensored, c is the number of points remaining in the data set including the current point, and O_p is the order of the previous failure. Example of cumulative distribution function estimates are shown in Table 3.3.

Table 3.3 Example of cumulative distribution function

Time to Fail	Ii	Oi	F(x)
150 c			
157 c			
167 c			
179	1.3000	1.3000	0.0806
183 c			
209	1.4625	2.7625	0.1986
216 c			
217 c			
235	2.0475	4.8100	0.3637
235.1	2.0475	6.8575	0.5288
248 c			
257	3.0713	9.9288	0.7765

After obtaining the data of F(x), the graph of the transformers unreliability can be plotted by using the age of the transformer as the X-axis, and the median rank F(x) in percentage as the Y-axis.

The method used to calculate the value of Beta and Eta is by using least square method. The procedure are :

1. Firstly, y-axis need to be plotted. The equation 3.4 was used to calculate the value of y-axis.

$$\boldsymbol{y = \ln(T)} \tag{3.4}$$

2. Secondly, the x-axis was plotted by using equation 3.5

$$\boldsymbol{x = \ln(-\ln(1 - median\ rank))} \tag{3.5}$$

3. Then shape, β can be obtained by using equation 3.6.

$$\text{Shape,}\boldsymbol{\beta} = \frac{\mathbf{1}}{\boldsymbol{slope(y,x)}} \tag{3.6}$$

4. The value of eta, n can be obtained by using equation 3.7.

$$\boldsymbol{scale, n = exp}\left(\frac{\boldsymbol{-x\ intercept}}{\boldsymbol{slope}}\right) \tag{3.7}$$

After obtaining the value of y-axis, x-axis, beta and eta, the data were arranged in table as in table 3.4.

Table 3.4 : Arrangement of y-axis, x-axis, beta and eta data

Sample (n)	**Condition**	**Age (month)**	**Median Rank (%)**	**X-axis**	**Y-axis**
1	S/F	……	…….	…….	……..
2	S/F				

3.5 Prediction Of Transformer Lifetime

After performing the Unreliability For The Given Operating Time via Reliasoft Software and Parameter Estimation technique, the transformer aging assessment will be conducted according to the results. The results will be used to predict the lifetime of the transformer with the assist of the oil and coil temperature readings.

3.6 Flow Chart of Project

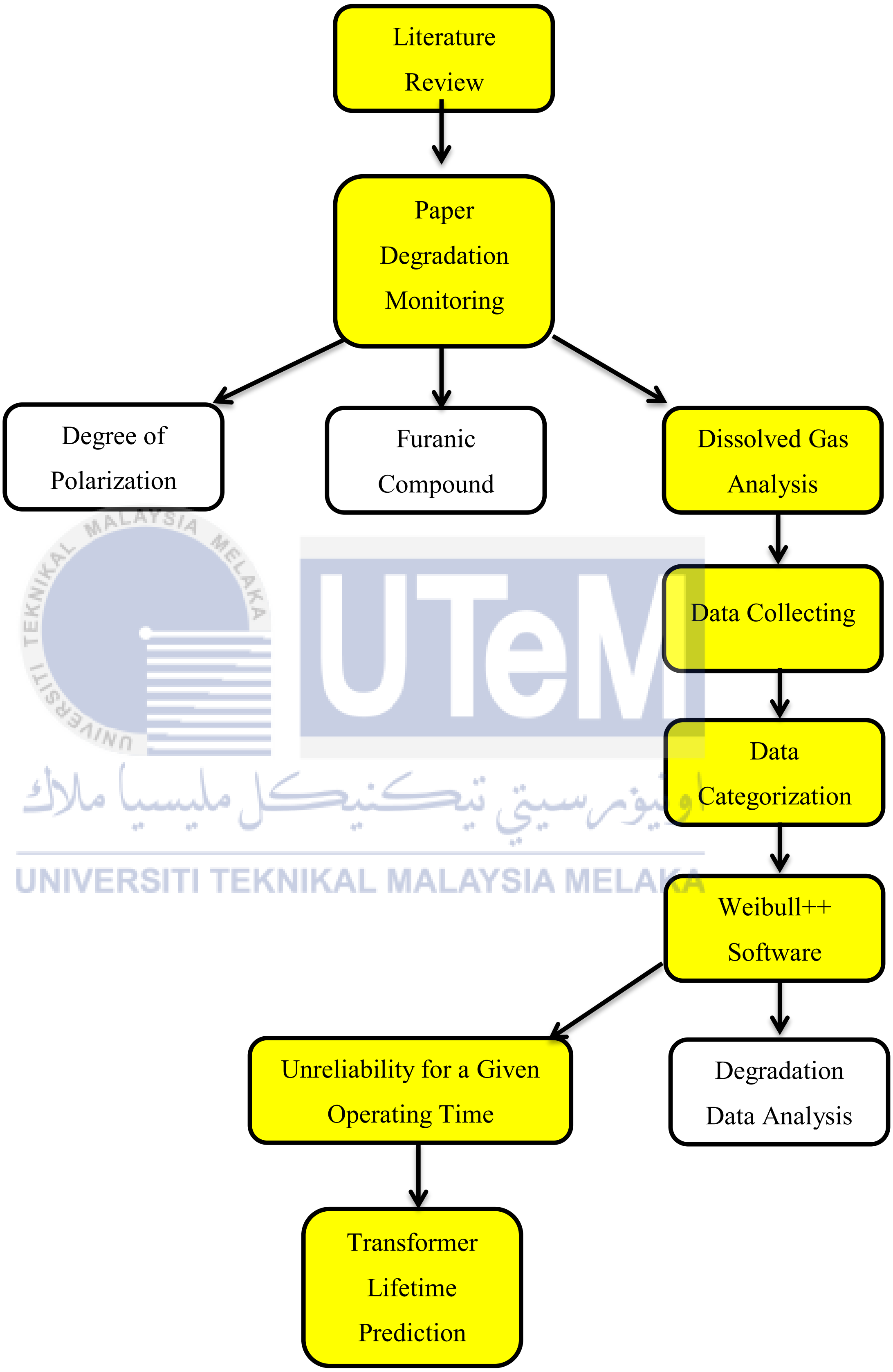

Figure 3.7 : Flow Chart of Project

3.7 Project Gantt Chart and Project Key Milestones

Table 3.8 : Schedule of Project Tasks (Gantt Chart)

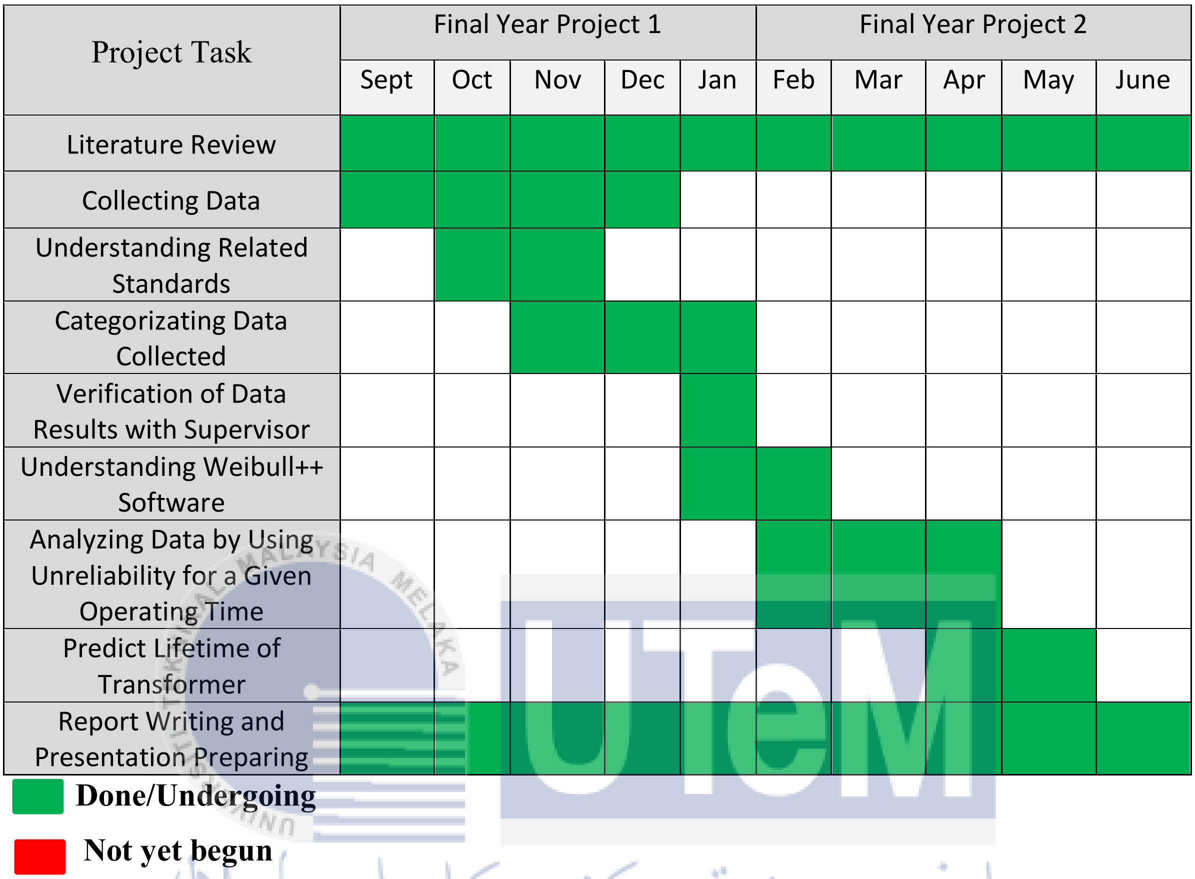

Table 3.9 : Project Milestone

Project Task	Expected Date
Literature Review	September 2014 to June 2015
Data Collecting	End of October 2014
Understanding Related Standards	Early November 2014
Categorizing of Data Collected	January 2015
Analyzing Data By Using Method Chosen	April 2015
Verification Result With Supervisor	May 2015
Analysis & Discuss The Results	June 2015
Report Writing and Presentation Preparation	September 2014 to June 2015

3.8 Summary

The methodology to execute this study which start by collecting parameters followed by categorization of parameters levels into Acceptable (S) or Not Acceptable (F) in Life Data Analysis using Weibull++9 are well described in this chapter.

CHAPTER 4

RESULT AND DISCUSSION

4.0 Introduction

In this chapter different parameter levels collected from 2 different units of in-service Malakoff's power transformer in Malakoff Prai Power Plant (PPSB), will be shown and analyse in-order to determine their paper insulation conditions. The data collected are dissolved gases, coil temperature and oil temperature and is tabulated in Table 4.1, Table 4.2, Table 4.3, and Table 4.4.

Dissolved Gas Analysis for the generator transformer was done annually in order for the purpose of monitoring the condition of the transformer. However, there have been cases where the analysis had been done for a intervals of six months. Besides, the reading of oil temperature and coil temperature had been recorded during the time where the oil samples had been taken. Furthermore, both temperature readings were being monitored all the time. Due to that, the temperature readings had been taken once a week.

4.1 Data Collected from Generator Transformer 463600KVA, 132/19kV

4.1.1 Dissolved Gas Analysis

The results obtained from the Dissolved Gas Analysis was tabulated. Table 4.1 shows the results for a set of parameter which are hydrogen, oxygen, nitrogen, methane, ethane, ethylene, acetylene, carbon monoxide, and carbon dioxide.

Table 4.1: Dissolved Gas Analyis (ASTM D3612), Expressed in PPM

Date	Hydrogen	Oxygen	Nitrogen	Methane	Ethane	Ethylene	Acetylene	Carbon Monoxide	Carbon Dioxide
25/06/07	101	18028	67790	34	73	2	ND	144	1893
09/10/07	100	18155	65625	24	55	3	ND	105	2851
11/12/07	95	20066	77446	28	63	1	ND	110	882
21/01/09	7	16222	60427	7	18	ND	ND	36	646
11/07/11	4	25443	47149	18	35	2	ND	216	1912
23/02/12	4	22914	48730	28	45	5	ND	445	1237
07/05/13	4	19003	56000	22	32	2	ND	361	2167
20/08/13	2	27414	68896	18	27	ND	ND	248	2082
21/08/13	2	26745	71012	15	21	ND	ND	245	1917
18/02/14	3	22018	68725	22	27	ND	ND	401	2712

4.1.2 Oil and Coil Temperature

The readings of both oil and coil temperature for the generator transformer had been recorded and tabulated as in table 4.2.

Table 4.2: Temperature of Oil and Coil in ^oC

Date	Oil Temperature ^oC	Coil Temperature ^oC
13/04/08	34	34
21/01/09	48	54
05/03/09	48	62
11/07/11	61	62
23/02/12	60	52
07/05/13	52	
20/08/13	53	63
20/08/13	53	63
21/08/13	63	64
18/02/14	58	68

4.2 Data Collected from Auxiliary Transformer 23000KVA, 19/6.6kV

4.2.1 Dissolved Gas Analysis

The results obtained from the Dissolved Gas Analysis was tabulated. Table 4.3 shows the results for a set of parameter which are hydrogen, oxygen, nitrogen, methane, ethane, ethylene, acetylene, carbon monoxide, and carbon dioxide.

Table 4.3: Dissolved Gas Analyis (ASTM D3612), Expressed in PPM

Date	Hydrogen	Oxygen	Nitrogen	Methane	Ethane	Ethylene	Acetylene	Carbon Monoxide	Carbon Dioxide
09/10/07	29	18237	71275	73	149	8	ND	73	494
11/12/07	28	18763	79205	65	116	6	ND	63	304
21/01/09	5	16179	59924	17	35	3	ND	70	435
08/05/10	2	40145	51642	18	34	4	ND	175	634
11/07/11	1	26409	48126	7	12	1	ND	87	337
23/02/12	3	22034	48711	16	30	ND	ND	225	1886
07/05/13	4	18446	54731	34	51	6	ND	696	1315
20/08/13	4	27853	69131	43	65	6	ND	784	1830
21/08/13	4	25591	71196	38	54	5	ND	767	1691
18/02/14	4	23271	69594	37	47	8	ND	846	1807

4.2.2 Oil and Coil Temperature

The readings of both oil and coil temperature for the generator transformer had been recorded and tabulated as in table 4.4.

Table 4.4: Temperature of Oil and Coil in ^{o}C.

Date	Oil Temperature ^{o}C	Coil Temperature ^{o}C
11//12/07	48	46
27/12/07	44	44
21/01/09	48	50
05/03/09	44	48
11/07/11	52	51
23/02/12	52	54
07/05/13	50	NR
20/08/13	45	49
21/08/13	47	51
18/02/14	44	48

4.3 Paper Degradation Parameters from In-Service Transformers

All data were collected under the supervision of Malakoff's Electrical Engineer by following a the procedure approved by Malakoff. Data were verified by the competent personal and as such they were undeniable. Table 5.1, Table 5.2, Table 5.3, and Table 5.4 show parameter levels collected from the 2 different units of in-service Malakoff's power transformer in Malakoff Prai Power Plant (PPSB). The specifications of these transformers are 463600KVA, 132/19kV for the Generator Transformer and 23000KVA, 19/6.6kV for the Auxiliary Transformer with both liquid and solid insulation.

As shown, Table 4.1 and Table 4.3 consists of ten columns. The first column represented the date when the analysis report completed while the second column until the eight column represented the hydrogen, oxygen, nitrogen, methane, ethane, ethylene, and acetylene level in parts per million (ppm). Data were collected by taking oil sample from each transformer.

Follow by the nine column which represented the carbon monoxide level in parts per million (ppm) and it is gathered from each transformer oil sample using Gas Chromatography technique analysis. For all the data, the recorded carbon monoxide level is between 36 ppm and 445 ppm for GSUT and between 63 ppm and 846 ppm for UAT.

Lastly the tenth column represented the carbon dioxide level in parts per million (ppm) and it is gathered from each transformer oil sample using Gas Chromatography technique analysis. For all the data, the recorded carbon dioxide level is between 646 ppm and 2851 ppm for GSUT and between 304 ppm and 1886 ppm for UAT.

As shown, Table 4.2 and Table 4.4 consist of 3 columns. The first column represented the date when the analysis report completed. The second column represented the oil temperature. Data were collected by taking what was displayed on the temperature panel of each transformer.For all the data, the recorded oil temperature varies between 34^{o}C to 63^{o}C for GSUT and between 44^{o}C to 52^{o}C for AUT.

Lastly the third column represented the coil temperature. Data were collected by taking what was displayed on the temperature panel of each transformer. For all the data, the recorded coil temperature varies between 34 ^{o}C to 68 ^{o}C for GSUT and between 44 ^{o}C to 54 ^{o}C for UAT.

4.4 Interpretation of Temperature Parameters

It has been reported that ageing will not take place until a temperature of 90^{o}C is exceeded [3]. Furthermore, the acceleration of the aging process was in the temperature range of 110^{o}C to 140^{o}C.

As mentioned in section 4.3, the recorded temperature for all data varies between 34 ^{OC} to 68 ^{OC} for GSUT and between 44 ^{OC} to 54 ^{OC} for UAT. This means that under ideal condition, both transformers can continue their life. However, it is wise to decrease the operating temperature where possible as the aging of insulation paper dependent on temperature. This is one way of improving life and reliability of the insulation paper specifically and the transformer generally.

4.5 Interpretation of Carbon Monoxide and Carbon Dioxide Parameters

Based on suggested interpretation as in Table 3.1 and Table 3.2 on page 32 and page 33, both units of transformer's data of carbon monoxide and carbon dioxide show various stage state conditions. CO and CO_2 represent a good source of paper monitoring and the ration of CO/CO_2 is considered as the major factor in cellulose degradation [11]. As shown in Table 3.2, there are three stages for interpreting the ration of CO/CO_2.Ratio below 3 indicate severe paper degradation, ratio between 3 to 10 indicate normal condition, while ratio larger than 10 indicate thermal fault with the involvement of cellulose.

Table 4.5 : Generator Step-Up Transformer and Unit Auxiliary Tranformer CO_2/CO ratio

Age (month)	**Generator Step-Up Transformer**			**Unit Auxiliary Tranformer**		
	CO (ppm)	**CO_2 (ppm)**	**CO_2/ CO**	**CO (ppm)**	**CO_2 (ppm)**	**CO_2/CO**
5	40	265	6.6	20	133	6.7
20	94	477	5.1	84	143	1.7
33	204	1954	9.6	99	558	5.6
42	156	1510	9.7	77	575	7.5
48	144	1893	13.1	66	512	7.8
52	105	2851	27.2	73	494	6.8
54	110	882	8.0	63	304	4.8
54				445	1237	2.8
67	36	646	17.9	70	435	6.2
84	54	876	16.2	92	558	6.1
97	216	1912	8.9	87	337	3.9
104	445	1237	2.8	225	1886	8.4
120	361	2167	6.0	696	1315	1.9
121	315	3458	11.0	846	2195	2.6
122	248	2082	8.4	784	1830	2.3
122	245	1917	7.8	767	1691	2.2
128	401	2712	6.8	846	1807	2.1

4.6 CO_2/CO Ratio Condition

Based on suggested interpretation as in Table 3.2, there are three stages for interpreting the ration of CO/CO_2.Ratio below 3 indicate severe paper degradation, ratio between 3 to 10 indicate normal condition, while ratio larger than 10 indicate thermal fault with the involvement of cellulose. Instead of 3 early categories, there are only 2 state of condition under interpretation either the transformer's paper insulation is still remain in operation(S) or failure(F).

Table 4.6 : Condition of Generator Step-Up Transformer and Unit Auxiliary Tranformer Based on CO_2/CO ratio

Age (month)	**Generator Step-Up Transformer**		**Unit Auxiliary Tranformer**	
	CO_2/ CO	**F/S Condition**	**CO_2/ CO**	**F/S Condition**
5	6.6	S	6.7	S
20	5.1	S	1.7	F
33	9.6	S	5.6	S
42	9.7	S	7.5	S
48	13.1	F	7.8	S
52	27.2	F	6.8	S
54	8.0	S	4.8	S
54			2.8	F
67	17.9	F	6.2	S
84	16.2	F	6.1	S
97	8.9	S	3.9	S
104	2.8	F	8.4	S
120	6.0	S	1.9	F
121	11.0	F	2.6	F
122	8.4	S	2.3	F
122	7.8	S	2.2	F
128	6.8	S	2.1	F

Figure 4.1 shows a probability graph which is a graph for unreliability for a given operating time, F(t) in percentage versus time (t) in months obtained by using Reliasoft Weibull Software and excel for the GSUT while figure 4.2 shows a probability graph which is a graph for unreliability for a given operating time, F(t) in percentage versus time (t) in months obtained by using Reliasoft Weibull Software and excel for the UAT.

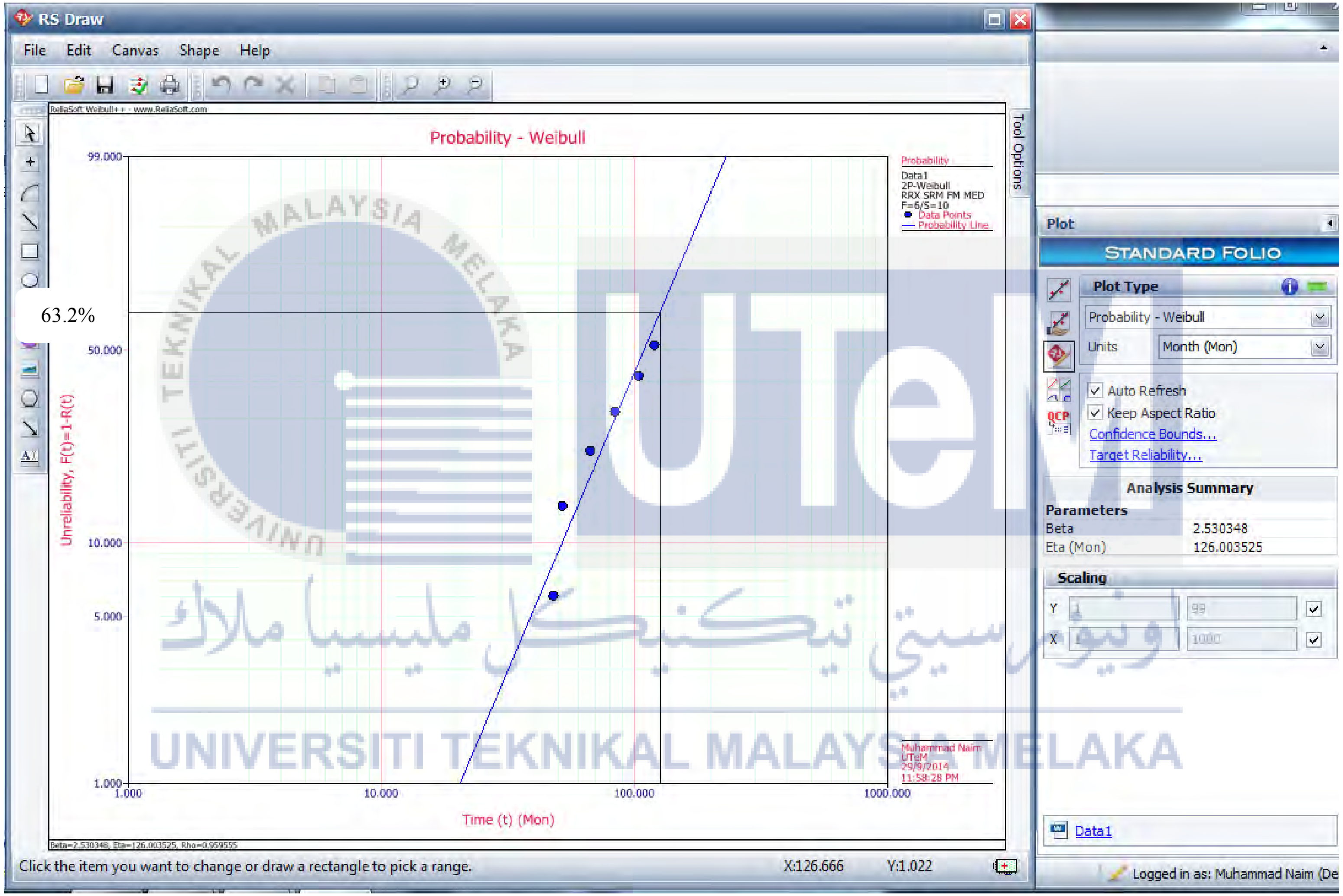

Figure 4.1(a) : Probability of CO_2/CO Ratio versus Time for GSUT using Reliasoft

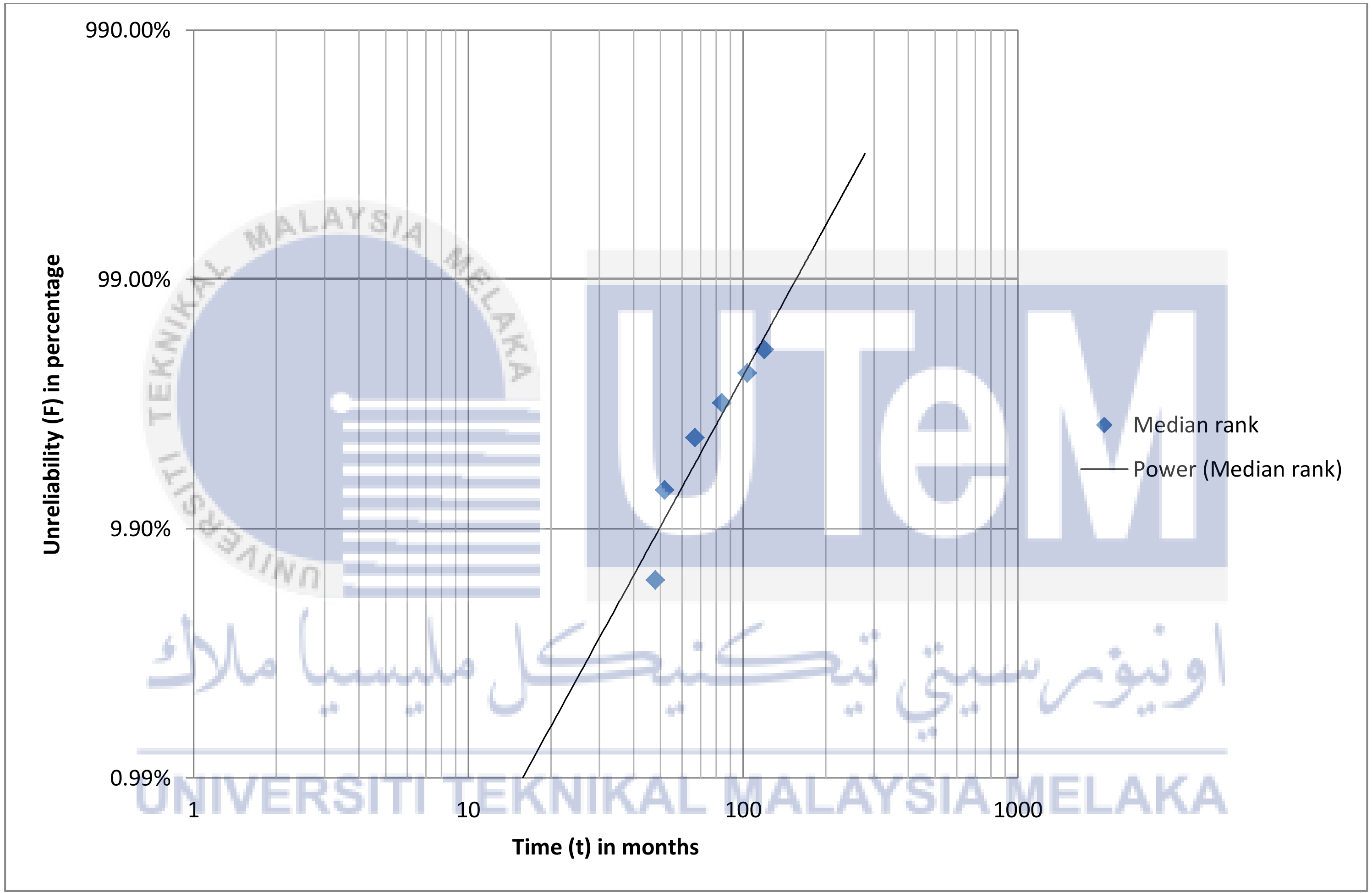

Figure 4.1(b) : Probability of CO_2/CO Ratio versus Time for GSUT using Excel

Referring to figure 4.1 (a) and figure 4.2 (a), both consists of x-axis and y-axis. X-axis represents the time (t) in months and Y-axis represent the unreliability for a given operating time, F (t) in percentage. Referring to figure 4.1 (b) and figure 4.2 (b), both consist of x-axis and y-axis. X-axis represents the time (t) in months and Y-axis represent the median rank in percentage which was calculated manually.

Analyzing figure 4.1 (a) which represented the GSUT probability graph plotted using reliasoft, a straight line was plotted at the point 63.2% from the y-axis. Then from the point where the straight line intercept of the line plotted by the software, a another straight line was plotted downwards to the x-axis. The value of the point that intersect the x-axis represent the eta, η which is 126.666 months. Based on the graph that was automatically plotted by reliasoft, the eta,η obtained was 126.003525 and beta,β was 2.530348.

Referring to figure 4.1 (a), based on the BX information which are calculated automatically by using reliasoft, it indicate 20.4569 months at 1% and 230.4088 at 99% respectively. This means that within 20.4 months of the transformer operating time, there would only be 1% failure for the GSUT while there would be 99% failure after 230.4 months of operation.

Table 4.7 : BX Information and Mean Life of CO2/CO for GSUT

CO2/CO Ratio	BX Information at		Mean Life (months)
	1% (months)	99% (months)	
	20.45690	230.4088	111.8324

Analyzing figure 4.1(b) which represented the GSUT probability graph plotted using excel, a straight line was obtained by plotting the transformer age in month versus median rank in percentage. The eta,η value obtained from figure 4.1(b) was 126.0994 and beta,β was 2.518316.

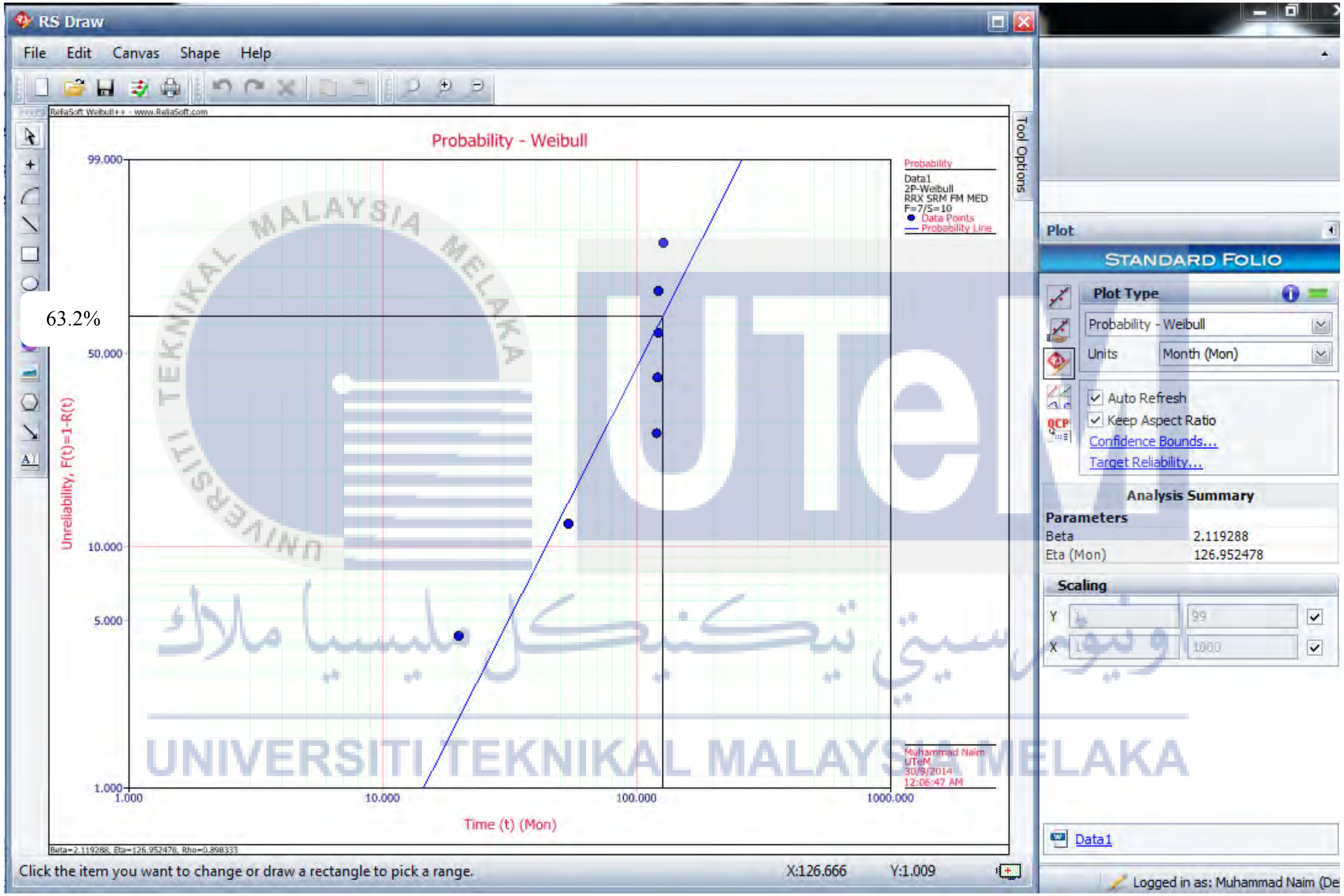

Figure 4.2 (a) : Probability of CO_2/CO Ratio versus Time for UAT using Reliasof

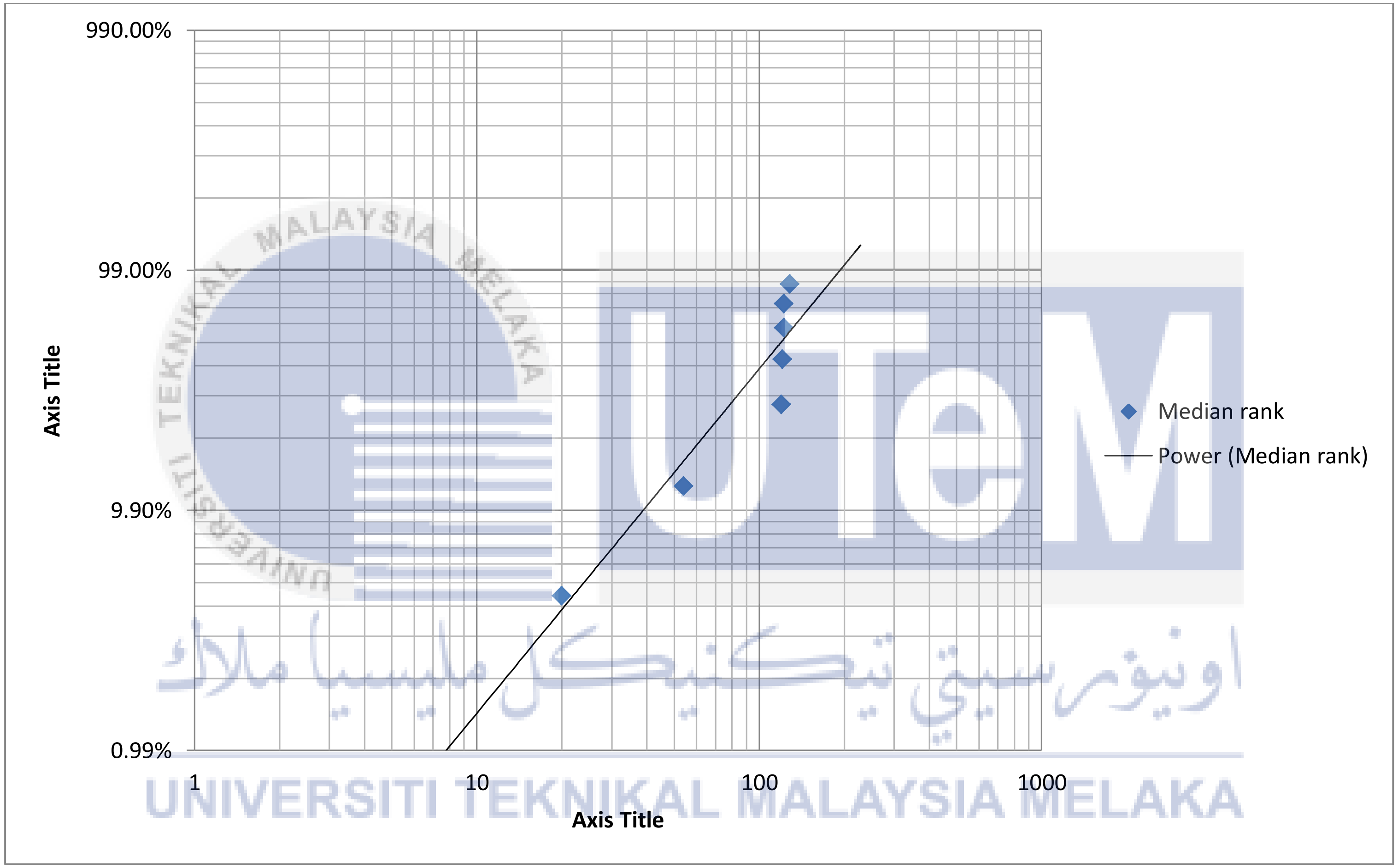

Figure 4.2 (b) : Probability of CO_2/CO Ratio versus Time for UAT using Excel

Analyzing figure 4.2(a) which represented the UAT probability graph, a straight line was plotted at the point 63.2% from the y-axis. Then from the point where the staright line intercept at the line plotted by the software, a another straight line was plotted downwards to the x-axis. The value of the point that intersect the x-axis represent the eta,η which is 126.666 months. Based on the graph that was automatically plotted by reliasoft, the eta,η obtained was 126.952478 and beta,β was 2.119288.

Referring to figure 4.1(a), based on the BX information which are calculated automatically by using reliasoft, it indicate 14.4862 months at 1% and 260.9745 at 99% respectively. This means that within 14.5 months of the transformer operating time, there would only be 1% failure for the UAT while there would be 99% failure after 260.9 months of operation.

Table 4.8 : BX Information and Mean Life of CO2/CO for UAT

CO2/CO Ratio	BX Information at		Mean Life (months)
	1% (months)	99% (months)	
	14.4862	260.9745	112.4350

Analyzing figure 4.2(b) which represented the GSUT probability graph plotted using excel, a straight line was obtained by plotting the transformer age in month versus median rank in percentage. The eta,η value obtained from figure 4.1(b) was 127.0189 and beta,β was 2.111543.

4.7 Transformers Life Assessment

Table 4.9 : BX Information for Life Assessment

Transfomer	BX information at 1%		BX information at 99%		Mean Life (months)
	Reliasoft (month)	Excel (month)	Reliasoft (month)	Excel (month)	
GSUT	20.45690	17.5000	230.40880	178.00000	111.83240
UAT	14.48620	8.00000	260.97450	198.00000	112.43500

Table 4.10 : ETA and BETA information for Life Assessment

Transformer	ETA (month)		Beta	
	Reliasoft (month)	Excel (month)	Reliasoft (month)	Excel (month)
GSUT	126.003525	126.0994	2.530348.	2.518316.
UAT	126.952478	127.0189	2.119288	2.111543

By referring to table 4.9, for GSUT reliasoft indicates that there would be 99% failure after 230 months operating while excel indicates that there would be 99% failure after 178 months operating. The result from reliasoft and excel has an error between 20%-24%. Thus it is accepetable and this result is strengthened by the value of eta,η and beta,β obtained. By referring to table 4.10, eta,η value from reliasoft is 126.0035 months and beta,β value is 2.5303 while eta,η value from excel is 126.0994 and beta,β value is 2.5183. The result from reliasoft and excel for eta,η and beta,β is approximately the same. Thus the result was acceptable and but result from reliasoft was used to assess the GSUT transformer life which is 230 months.

By referring to table 4.9,for UAT reliasoft indicates that there would be 99% failure after 260 months operating while excel indicates that there would be 99% failure after 198 months operating. The result from reliasoft and excel has an error between 20%-24%. Thus it is accepetable and this result is strengthened by the value of eta,η and beta,β obtained. By referring to table 4.10, eta,η value from reliasoft is 126.9524 months and beta,β value is 2.119288 while eta,η value from excel is 127.0189 and beta,β value is 2.1115. The result from reliasoft and excel for eta,η and beta,β is approximately the same. Thus the result was acceptable and but result from reliasoft was used to assess the UAT transformer life which is 260 months.

Although both GSUT and UAT life span were predicted for 230 months and 260 months, their life span period is possible to decrease if the current problem with the CO_2/CO ratio is not fixed in th near future. This is because, referring to figure 2.15 on page 27, the beta,β value for both trasformers obtained were above 1. This indicate that the failure rate increase with time.

4.8 Summary

In this assessment, the transformer temperature recorded cannot be categorized between still remain in operation (S) condition of failure (F) condition because it does not exceed 90^{o}C. Thus the ratio of CO_2/CO was used because it was the most stable and reliable data obtained from both transformers. Furthermore CO and CO_2 represent a good source of paper monitoring and the ratio of CO_2/CO is considered as the major factor in cellulose degradation [11]. Ratio below 3 and ratio above 10 indicated fault and it can be categorize as failure(F) condition.

Reliasoft indicated that the GSUT would be at 99% failure after 230 months and the UAT would be at 99% failure after 260 months. According to the result obtained, the UAT had will be operating at longer time compared to the GSUT. This result is valid and acceptable because the KVA rating of the GSUT is 463600KVA, 132/19kV which is larger that the KVA rating of the UAT which is 23000KVA, 19/6.6kV. GSUT was opeating at high KVA than the UAT so the GSUT should had a shorter life span under same maintainence condition.

Furthermore, this result can be validated because Malakoff Prai Power Plant only obtain the contract to produce electricity for only 21 years. Both transformer life span is approximately between 19.5 years and 22 years. Although reliasoft predicted that GSUT life span was 230 months and UAT was 260 months, both transformers can still in service after that period of time but it would not be recommended.

Lastly, the life span of both transformer could be extended by reducing the operating temperature and also by performing maintainance regularly.

CHAPTER 5

CONCLUSION

5.0 Conclusion

As conclusions from this study, the ratio of CO2/CO from the disolved gas analysis could be used as an indicator for paper insulating ageing. Results indicate that temperature and ratio of CO_2/CO played an important role in the degradation of the paper insulation. Both transformers oil and coil temperature recorded below 90^oC indicating that they are in normal working condition. The ratio of CO_2/CO play the most important role in the paper degradation compared to other gases. The unreliability for a given Operating Time by reliasoft could be used to predict the life span of both transformers based on the ratio of CO_2/CO. The life of the insulation can be extended by reducing the transformer operating temperature and maintaining the ratio of CO_2/CO between 3 to 10.

5.1 Recommendation

Recommendation for future works, the data of temperature and dissolved gas analysis will be continue collected. Besides performing life assessment for Malakoff's Prai Power Plant transformers, transformers located at other Malakoff's Power Plant will be considered.

REFERENCES

[1] J. Dai, Z. D. Wang, P. Jarman, "Moisture and Aging Effect on the Creepage Discharge Characteristics at the Oil/Transformer-board Interface under Divergent Field",IEEE 2008, pp 662-665.

[2] Norazhar Abu Bakar, A. Abu-Siada, S. Islam, "A Review on Chemical Diagnosis Techniques for Transformer Paper Insulation Degradation",AUPEC 2013.

[3] Zalizah Poniran, Zulkarnain Abdul Malek, "Life Assessment of Power Transformer via Paper Ageing Analysis", IEEE POWER ENG 2007, pp 460-465.

[4] P. Verma, M Roy, R.K. Tiwari, S. Chandra, "Generation of Furanic Compounds in Transformer Oil under Accelerated Thermal and Electrical Stress",IEEE 2005,pp 112-116.

[5] Mr.K Baburao, Mr.NM Bhangre, Mr.AM Wagle, Mr. A. Venkatasami, Mr. Sushil E Chaudhari, " The experience of DP and Furan in Remnant Life Assessment of Power Transformer",IEEE 2007.

[6] Xin Wang, Xin Zhang, "An Investigation into the Operation Life of Transformers",CICED 2012.

[7] A.M.Emsley,X.Xiao,R.J.Heywood,M.Ali, "Degradation of Cellulosic Insulation in Power Transformers.Part 2:Formation of Furan Products in Insulating Oil", IEE Proc-Sci Meas Technol, Vol 147, No 3, May 2000, pp110-114.

[8] R.J.Heywood,A.M.Emsley,M.Ali, "Degradation of Cellulosic Insulation in Power Transformers. Part 1: Factors Affecting the Measurement of the average Viscometric degree of polymerization of New and Aged Electrical Papers", IEE Proc-Sci Meas Technol, Vol 147, No 2, March 2000, pp 86-90.

[9] Chengfeng Yang, "Life Assessment Methods of Large and Medium-Sized Power Transformers", Suzhou Nuclear Power Research Institute,China.

[10] An-xin Zhao, Xiao-jun Tang, Zhong-hua Zhang, Jun-hua Liu, " The DGA Interpretation Method Using Relative Content of Characteristic Gases and Gas-ratio Combinations for Fault Diagnosis of Oil-immersed Power Transformers", IEEE Conference Proceedings of ISEIM 2014, pp 124-127.

[11] A. Abu-Siada, S. Islam, "A New Approach to Identify Power Transformer Critically and Asset Management Decision based on Dissolved Gas-in-Oil Analysis", IEEE Transactions on Dielectric and Electrical Insulation, Vol. 19, No. 3; June 2012, pp 1007-1012.

[12] D. Zhou, N Azis, G. Y. Yang and Z. D. Wang, "Examining Acceptable Dissolved Gas Analysis Level of In-Service Transformers", IEEE International Conference on High Voltage Engineering and Application, Shanghai, China, September 17-20, 2012, pp 612-616.

[13] Reliasoft Corporation (2009), "Reliability and Life Data Analysis" Reliasoft Publishing, pp 15-18

[14] http://www.reliasoft.com/newsletter/2q2001/degradation.htm

[15] IEEE Std C57.104-2008, "IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers", pp 10.

[16] http://reliawiki.org/index.php/Parameter_Estimation

[17] http://www.weibull.com/hotwire/issue14/relbasics14.htm

[18] http://www.engineeredsoftware.com/nasa/pe_cum_dist_function.htm

[19] http://machinedesign.com/technologies/unlocking-weibull-analysis

[20] A.M.Emsley, R.JHeywood, M.Ali and X.Xiao, "Degradation of Cellulosic Insulation in Power Transformers.Part 4: Effects of Ageing on the Tensile Strength of Paper", Proc-Sci Meas Technol, Vol 147, No 6, November 2000, pp285-290.

[21] Raif Sakin, Irfan Ay, "Statistical Analysis of Bending Fatique Life Data Using Weibull Distribution in Glass-fiber Reinforced Polyester Composites", Material and Design 29 (2008), pp1170-1181.

[22] D.H Shroff, A.W Stannett, "A Review of Paper Aging in Power Transformers", IEE Proceedings, Vol. 132, Pt. C, No. 6, November 1985, pp312-319.

[23] Qiang Liao, Xiaoyang Wang, Dan Ling, Zhenlin Xiao, Hong-Zhong Huang, "Equipment Reliability Analysis Based on the Mean-Rank Method of Two-Parameter Weibull Distribution", IEEE 2011

[24] Diane I. Gibbons, Lonnie C. Vance, "Estimators for the 2-Parameter Weibull Distribution with Progressively Censored Samples", IEEE Transactions On Reliability, Vol. R-32, No. 1, April 1983, pp95-99.

[25] Albert H. C. Tsang, Andrew k. S. Jardine, "Estimators of 2-Parameter Weibull Distributions from Incomplete Data with Residual Lifetimes", IEEE Transactions On Reliability, Vol. 42, No. 2, 1993 June, pp291-298.

[26] Toshiyuki Shimokawa, Min Liao, " Goodness-of-Fit Tests for Type-I Extreme-Value and 2-Parameter Weibull Distributionss", IEEE Transactions On Reliability, Vol. 48, No. 1, 1999 March, pp79-86.

[27] Rudolph van der Merwe, Eric A. Wan, "The Square-Root Unscented Kalman Filter For State And Parameter-Estimation", IEEE 2001, pp3461-3464

APPENDIX A – OBTAINING THE UNRELIABILITY FOR A GIVEN OPERATING TIME VIA RELIASOFT SOFTWARE

1. Click the ‘Create a new standard repository’ as in Figure A1

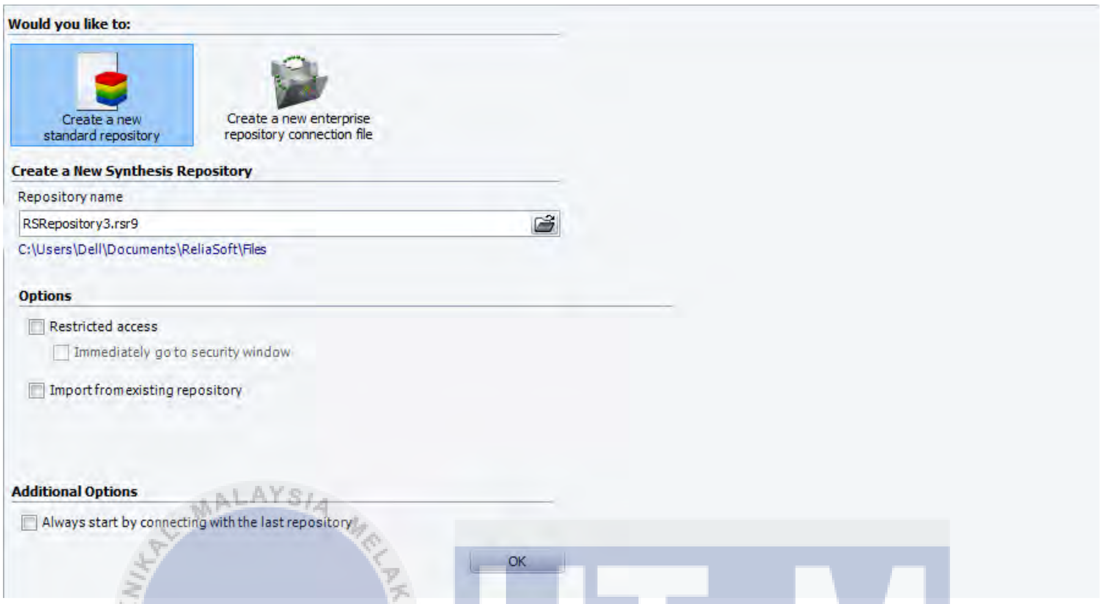

Figure A1 : Weibull++9 Software’s Main Page

2. Select “Standard Folios” as in Figure A2.

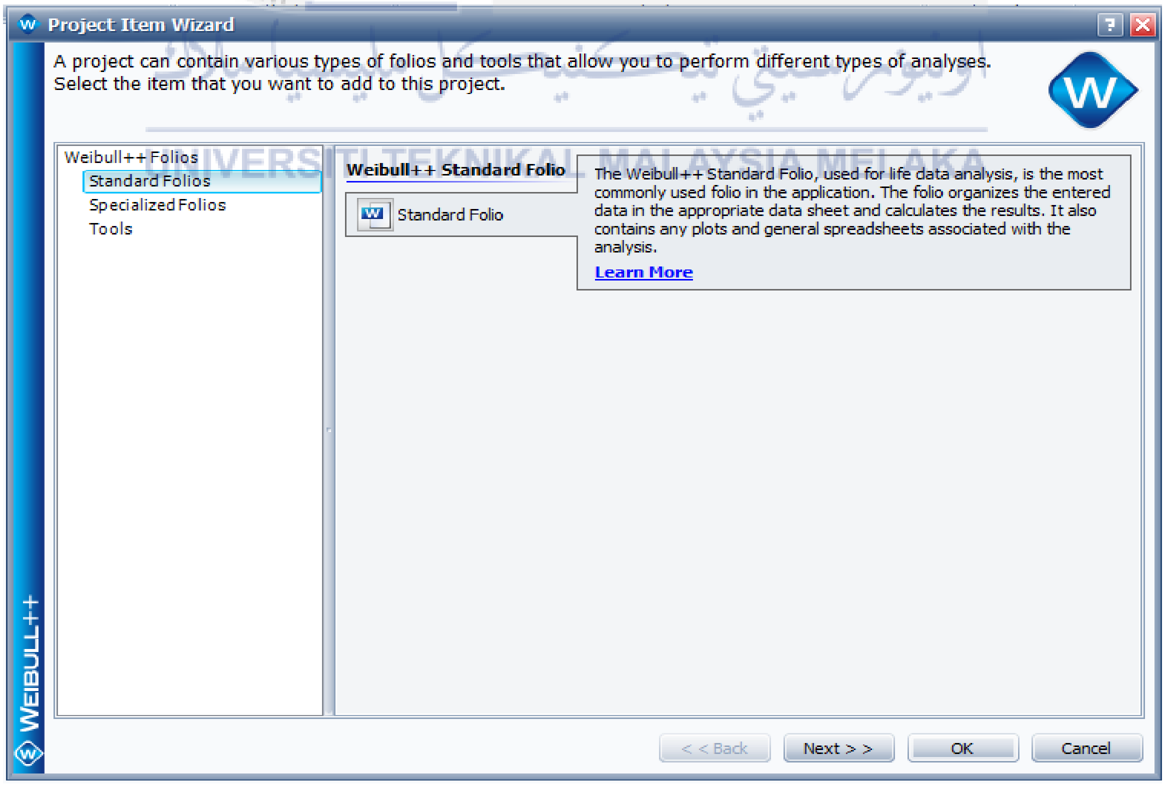

Figure A2 : Standard Folios Selection

3. Then, select "My data set contains suspensions(right censored data) as data type

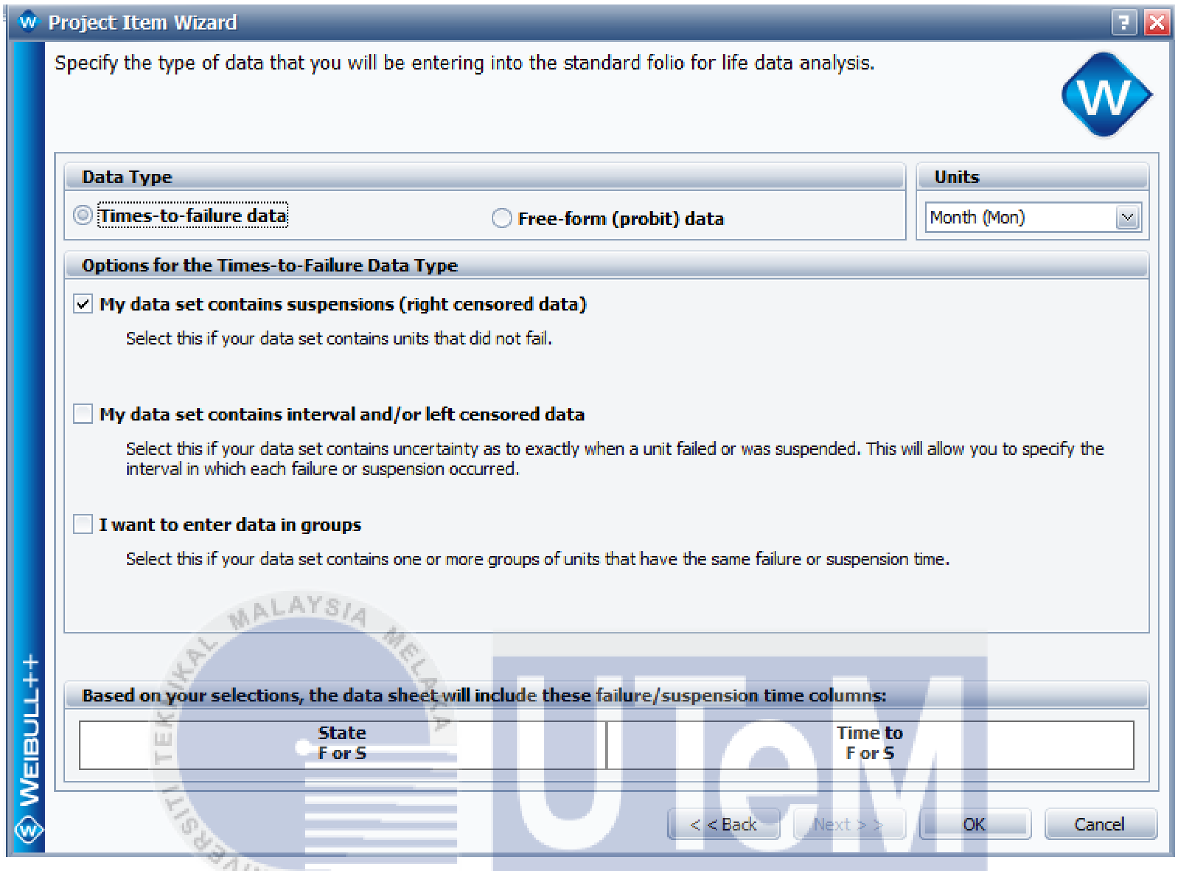

Figure A3 : Data Type Selection

4. Finally, insert the condition of data whether F or S and Time to F or S in month

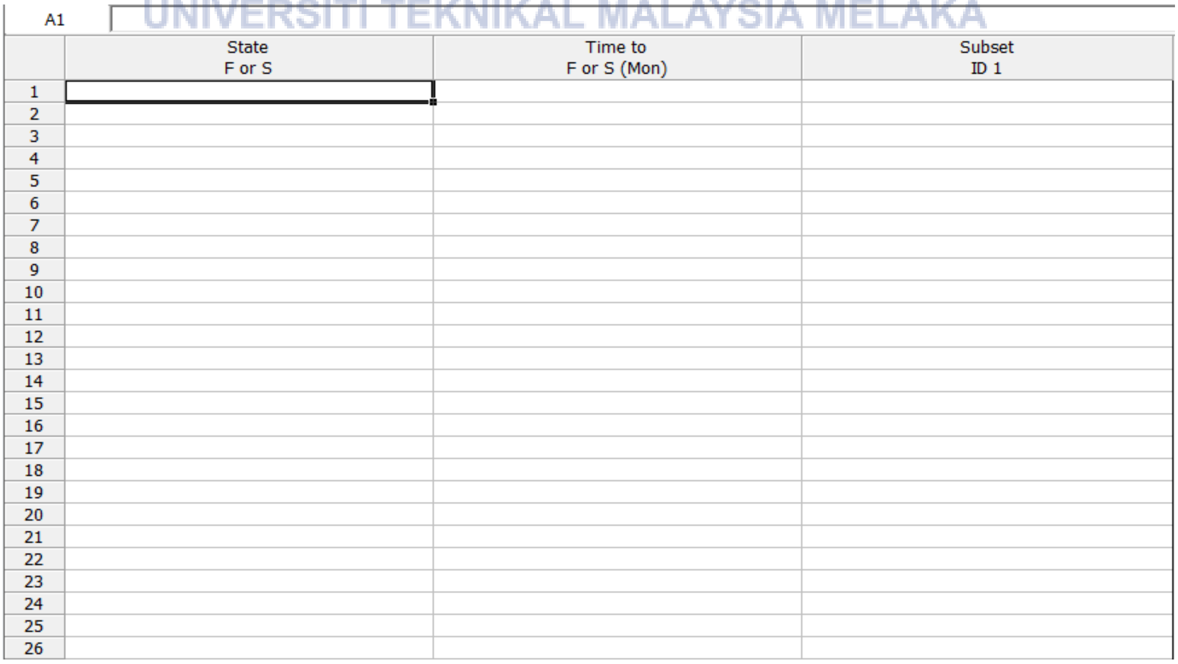

Figure A4 : Inserting Data

APPENDIX B – Table for Parameter Estimation by Using Microsoft Excel for Generator Step-Up Transformer

Table B1 : Generator Step-Up Transformer Parameter Estimation

No. of Data	F/S Condition	Age (month)	Ii	Oi	Median Rank (%)	X-axis	Y-axis
1	S	5					
2	S	20					
3	S	33					
4	S	42					
5	F	48	1.307692	1.307692	6.14	-2.75808	3.871201
6	F	52	1.307692	2.615385	14.12	-1.188257	3.951244
7	S	54					
8	F	67	1.438462	4.053846	22.89	-1.34735	4.204693
9	F	84	1.438462	5.492308	31.66	-0.96579	4.430817
10	S	97					
11	F	104	1.643956	7.136264	41.68	-0.61748	4.644391
12	F	120	1.643956	8.780220	51.71	-0.31757	4.787492
13	S	121					
14	S	122					
15	S	122					
16	S	128					

APPENDIX C – Table for Parameter Estimation by Using Microsoft Excel for Unit Auxiliary Transformer

Table C1 : Unit Auxiliary Transformer Parameter Estimation

No. of Data	**F/S Condition**	**Age (month)**	**Ii**	**Oi**	**Median Rank (%)**	**X-axis**	**Y-axis**
1	S	5					
2	F	20	1.058824	1.058824	4.36	-3.110244	2.995732
3	S	33					
4	S	42					
5	S	48					
6	S	52					
7	D	54					
8	S	54	1.411765	2.470588	12.47	-2.015591	3.988984
9	S	67					
10	S	84					
11	S	104					
12	S	120					
13	F	121	2.588235	5.058824	27.35	-1.140964	4.787492
14	F	122	2.588235	7.647059	42.22	-0.600377	4.795791
15	F	122	2.588235	10.23529	57.10	-0.166900	4.804021
16	F	122	2.588235	12.82353	71.97	0.240629	4.804021
17	F	128	2.588235	15.41176	86.86	0.707389	4.852030