CHAPTER 1
INTRODUCTION

1.1 Background of Study

Power transformer is a complex and vital component of the power transmission and distribution system. Power Transformer at Gas Processing Plant, PETRONAS Gas Berhad main substation had been in service for a long time, approximately more than 10 years. There are two units of power transformer at Gas Processing Plant B that step down from 132kV to 33kV, five units of power transformer that step down from 33kV to 6.6kV and eight units of power transformer that step down from 6.6kV to 415V. Since power transformer is a vital component, the failure risk is of prime importance. Hence, the author study on the condition monitoring tests that had been carried out to the power transformer at PETRONAS Gas Berhad, and analyst them. The author will focus on study the current state condition of the power transformer also the trending pattern and acceptance criteria of the condition monitoring data available from plant. The standard that been used by most PETRONAS plants and refineries is PTS which is PETRONAS Technical Standards. For the power transformer, the technical specification such as design, test, rating and so on is based on the PTS with amendments or supplements to IEC (International Electro technical Commission) 76 for power transformer and IEC 726 for dry type power transformer. Hence, the author will be study on those standards that been used by PETRONAS Gas Berhad for commissioning the power transformer. Then, the outcome from the analysis will be followed recommendation for improvement.

1.2 Problem Statement

Early fault detection and condition assessment of power transformer are important in order to avoid any tripping or damage to the transformer. The testing on the power transformer will be carried out during plant turn around or plant shut down, which was due to the schedule. During normal operation days, there was no maintenance except for physical checked. The possibility of the power transformer to trip and fail is quite high and it can cause unscheduled outages, huge losses and damages to the whole load system of a plant. Therefore, it is substantial to monitor the state of health of a power transformer in view its huge capital cost.

1.3 Objectives and Scope of Study

1.3.1 *Objectives*

- To analyse the current state of condition for power transformer using the condition monitoring data.
- To propose recommendations to mitigate the risk of failure of a power transformer.

1.3.2 *Scope of Study*

- Literature review on condition monitoring method on power transformer such as oil analysis, dielectric strength, furan analysis, and sweep frequency response analysis (SFRA), ratio test analysis, tan delta etc.
- Analyze the current state condition of the power transformer.
- Study the trending pattern and acceptance criteria of the condition monitoring data available from plant.
- Propose remedial action to improve the condition of the power transformer.

CHAPTER 2
LITERATURE REVIEW

2.1 Condition Monitoring and Preventive Maintenance

Basically, transformer is designed to withstand the normal stresses and most of the abnormal stresses they are exposed to, during the life of the transformer. There are a few stages of the life cycle for a transformer that determined the transformer to achieve the life period that been designed by manufacturer [6]. These stages starting from the initial specification and design to the refurbishment decisions made in mid to late life [6]. These stages include:

- design (including substation design and insulation coordination practices)
- manufacture
- storage
- erection
- commissioning
- operation
- maintenance
- life assessment
- refurbishment
- repair

Condition Monitoring is one of the important maintenance planned for early detection to the critical components more over to power transformer, due to the high failure risk. After detecting the abnormality, it is important to carry out offline tests to determine the overall integrity and assessment to avoid unscheduled outages that can result to financial losses and environmental damages [11]. But, with poor asset management, transformer can result in premature aging and failure.

The transformer is exposed to a few in-service stresses, which are, electrical stress, thermal stress, mechanical stress and chemical or environment stress. Electrical stress such as nominal voltage, power frequency over voltages, lightning and switching over voltages, mean while for thermal stress such as losses and faults that produced heat. For mechanical stress, it can be vibration and forces from supplying fault currents. Lastly, the chemical or environment stress can be resulted from oxidation of dissolved oxygen and deterioration from other contaminants. These stresses, which may be normal or abnormal, act upon the various components of the transformer causing the components to age and generally degrade [6].

Transformer's maintenance at Gas Processing Plant, PGB were done monthly, based on the maintenance schedule. Basically, the visual inspection and physical check were carried out, such as; to check the temperature, liquid and oil level, leaks in liquid, dirt accumulations on high-voltage bushings, unusual sound or vibrate, rusting, and discolored connections which indicate excessive heat [1]. But, the testing on the power transformer, such as oil analysis, IR test, ratio check will be carried out during plant turn around or plant shut down, which was due to the schedule, approximately 3-4 years time. The most concern part for one's power transformer is the insulation since insulation is the weakest link in the power transformer [2]. Hence, to supervise the condition of one's power transformer, a close monitoring of the electrical, mechanical, chemical and other properties on insulation to be taken seriously by Continuously and Organize Condition Monitoring System.

We can see from figure below that PGB had done the Condition Based Maintenance for equipment in the plant. But, the analyzing and keeping of every data had not been done properly in the plant, which can be resulted to unexpected failure.

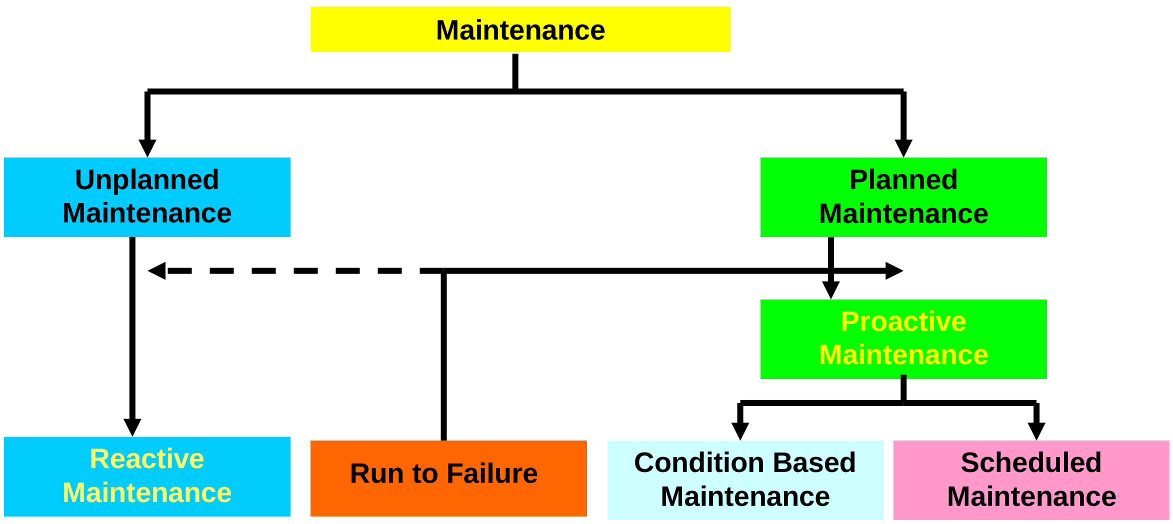


Figure 1: Figure above shows the maintenance plan of work for plant operation of PETRONAS Gas Berhad [16].

2.2 PETRONAS Technical Standard (PTS) and IEC Standard

Since the power transformer is from PETRONAS Gas Berhad, the author will be study on the PETRONAS Technical Standard (PTS) that been used for all PETRONAS plants and refineries. For power transformer, the standard that been used in PTS is based on amendments and supplements to IEC (International Electro technical Commission) 76 for power transformer and IEC 726 for dry type power transformer [3]. The general standards that been used for power transformer at PGB is based on the IEC 60076-1, while for temperature rise; PTS used the standards from IEC 60076-2. Based on PTS, the insulation levels, dielectric tests and external clearances in air for power transformer are referring to IEC 60076-3. Meanwhile the ability to withstand short circuit is based on IEC 60076-5.

2.3 Oil Analysis Test

Oil analysis test are the test on the oil for the power transformer such as neutralization, moisture content, colour, density, dielectric breakdown, dielectric dissipation factor (DDF), and interfacial tension (IFT). The oil is used as the insulation material inside the transformer. Oil insulator inside the transformer is the important material inside oil-filled transformer because instead act as the electrical insulation material; it is also act as the coolant for the transformer to dissipate heat losses [4]. The analysis of the properties of the oil and the concentration of various contaminants in the oil provides valuable information on the condition of the oil and the various other components of the power transformer**.** Application of testing the oil over many decades had shown that the composition of the gases in the volume of oil can be detected and used to identify the types of fault [5].

2.3.1 *Neutralization Number*

Neutralization value is done purposely to measure the concentration of acidic contaminants in the oil. The increasing of value for neutralization number signifying the oil started to oxidize [12]. Then, the oxidation of the oil can produce acidic compound that can affect the performance of the transformer in a few ways; cause the corrosion, accelerate the aging of the cellulose-based insulating material, increase the solubility of water in the paper and high level of acidity can result in producing sludge that will poorer thermal performance of the power transformer [6].

2.3.2 *Moisture Content*

Moisture was producing by aging of the paper insulation, also from the transformer's ages due to breathing system or poor gaskets, etc. Old transformer oil that has started to oxidize has a higher saturation level for water than new oil; water is also produced during oxidation both from oil and paper, which will further accelerate the breakdown of the paper. The moisture content in the transformer oil gives an indication of the water content in the paper insulation [12]. The high moisture concentrations can cause premature aging of the paper insulating system, reduction in the dielectric strength of the paper insulation and failure of the transformer from the evolution of water [6].

2.3.3 *Oil Dielectric Breakdown Strength*

This test measures the ability of the oil to withstand dielectric breakdown or electrical stress at power frequencies without failure [6]. A low value for the dielectric-breakdown voltage generally serves to indicate the presence of contaminants such as water, dirt, moist fibers of cellulose, or other conducting particles in the fluid. The breakdown voltage depends on the water and particle content of the oil. It is particularly important to check this before starting-up a new transformer and also when the transformer oil and paper insulation start to deteriorate, because the deterioration process generates water and particles [12].

2.3.4 *Interfacial Tension*

The combination of interfacial tension (IFT) with power factor (DDF), provide an early warning signal when deterioration of the oil start. IFT also gives information on the surface tension of the oil, which is dependent upon the presence of polar oxidation products in the oil [6]. If the oil oxidizes, IFT reduces and neutralization number increases, which give us Oil Quality Index:

$$OQL = IFT / NN \quad [6]$$

The units of measurement are mN/N.

2.3.5 *Dielectric Dissipation Factor (DDF)*

DDF is very sensitive to contaminants and ageing products. In some oxidation stability tests, the DDF is measured in the oil after the ageing test to indicate the ability of the oil to withstand oxidation [12] and with conjunction with neutralization value and interfacial tension; DDF is used to determine when the transformer requires reclamation. DDF also used to help the identification of the cause of high power factor in windings [6].

2.4 Dissolved Gas Analysis (DGA)

The usage of relationship between gases generated in transformer to different types of transformer faults by dissolved gas analysis (DGA) is the most widely used technique to monitor the condition and to diagnose faults of a transformer [13]. By applying DGA analysis to the transformer oil, early detection of possibility fault can be recognized. Then, some precaution or prevention application can be carried out to the suspected transformer. When the power transformer is exposed to high temperature, the transformer oil may be oxygen-decomposed and split decomposed, and then generates the hydrogen and low molecule gases [7].

Basically, number of “key gases” that can present information on the fault in oil of the power transformer are; hydrogen produced by partial discharges, ethane produced by overheating, acetylene produced by arcing and CO and CO2 produced by overheating of the paper insulation [6]. However, the presents of these gases are based on the concentration (ppm) and compared to the reference (max) that been guided by PTS and IEC for power transformer. In addition, DGA requires more detailed analysis by calculation of the ratios of the various gasses and reference to IEC 60599 and PTS.

Two main materials inside power transformer that produced gases inside ones transformer are insulating oil and paper insulation. Mineral insulating oil come from complex mixtures of hydrocarbon molecules, containing CH_3, CH_2 and CH chemical groups bonded together. Separation of some of the C-H and C-C bonds as a result of thermal or electrical discharges (PD) will produce radical or ionic fragment such as H*, CH3*, CH2*, CH* or C*, which will recombine to form gas molecules such as hydrogen (H-H), methane (CH3-H), ethane (CH3-CH3), ethylene (CH2=CH2) or acetylene (CHCH) [15]. To break and form the chemical bonds above, more and more energy is required.

The formation of hydrogen (H_2), methane (CH_4) and ethane (C_2H_6) result from low energy level such as in corona partial discharges or at relatively low temperatures which is < 500 °C. While the formation of ethylene (C_2H_4) at intermediate temperatures, between 500 °C to 1000 °C. Lastly, when the temperature above 1000 °C, acetylene (C_2H_2) will be produced, such as when arcs happened [15].

Whilst, for paper insulation, which was the composition of complex cellulosic molecules, mostly in cyclic form, containing CH_2, CH and CO chemical groups. The weaker bonds of C-O molecular can resulted to gas formation at temperatures a low as 100 °C. The formation of CO_2 is favored at the lower temperatures, while CO is formed above 200 °C but significant amounts of the other gases (H_2, hydrocarbons) are also formed [15]. When temperatures increase to 300 °C and above, paper insulation will become carbon due to complete carbonization of insulation paper [15]. The presents of oxygen in oil mostly due to the case of air breathing transformer, but also in sealed or nitrogen-blanketed ones because of leaks and a decrease in oxygen content usually indicates an excessive temperature in the transformer [15]. There are a few methods in analyzing DGA information such as Roger Ratio Method, Doernenburg Ratio Method, Key Gases Method, IEC Ratio Method, Duval Triangle Method and a few more. During this study, the author will analyze the DGA information using Roger Ratio Method and Duval Triangle method.

2.4.1 *Roger Ratio Method*

The Roger's method utilizes four gas ratios: CH4/H2, C2H6/CH4, C2H4/C2H6 and C2H2/C2H4. Diagnosis of faults is accomplished via a simple coding scheme based on ranges of the ratios as shown in tables 2 and 3 below [14].

Table 1: Gas Ratio Codes [14].

Gas Ratios	Ratio Codes
CH_4/H_2	i
C_2H_6/CH_4	j
C_2H_4/C_2H_6	k
C_2H_2/C_2H_4	l

Table 2: Roger's Ratio Codes [14].

Ratio Code	Range	Code
i	<=0.1 >0.1,<1.0 >=1.0,<3.0 >=3.0	5 0 1 2
j	<1.0 >=1.0	0 1
k	<1.0 >=1.0, <3.0 >=3.0	0 1 2
l	<0.5 >=0.5, <3.0 >=3.0	0 1 2

The combination of the coding gives 12 different types of transformer faults. The type of faults based on the code is shown in table 4 below [14].

Table 3: Classification based on Roger's Ratio Codes [14]

i	j	k	l	Diagnosis
0	0	0	0	Normal deterioration
5	0	0	0	Partial Discharge
1-2	0	0	0	Slight overheating <150^{o}C
1-2	1	0	0	Overheating 150^{o}C – 200^{o}C
0	1	0	0	Overheating 200^{o}C - 300^{o}C
0	0	1	0	General conductor overheating
1	0	1	0	Winding circulating currents
1	0	2	0	Core and tank circulating current, overheated joints
0	0	0	1	Flashover without power follow through
0	0	1-2	1-2	Arc with power follow through
0	0	2	2	Continuous sparking to floating potential
5	0	0	1-2	Partial discharge with tracking (note CO)

During analyzing the data using Roger Ratio Method, the author made used of the application from http://www.nttworldwide.com/rogers.htm to analyze the data. But, the result from the application will be referred to the tables above in order to get more information from the analysis.

2.4.2 *Duval Triangle Method*

Duval Triangle Method is a method in analyzing DGA data by using three hydrocarbon gases. The gases are, CH_4 (Methane), C_2H_4 (Ethylene) and C_2H_2 (Acetylene) that correspond to the increasing levels of energy necessary to generate gases in transformers in service [15]. The reason of selecting CH_4

(Methane) for the Triangle, rather than H_2 (Hydrogen) [15] even though the formation of H_2 is same with CH_4 are:

- H_2 represent very low energy faults such as PDs, where it is produced in large quantities, same with CH_4.
- But, CH_4 provides better overall diagnosis results for all the other types of faults than when using H_2.
- H_2 diffuses much more rapidly than the hydrocarbon gases from the oil through gaskets and even metal welds.
- Therefore, gas ratios using H_2 are probably more affected by the loss of this gas than those using hydrocarbons gases only, which have much lower and comparable diffusion rates.

Below is the example of triangle that been used in analyzing DGA.

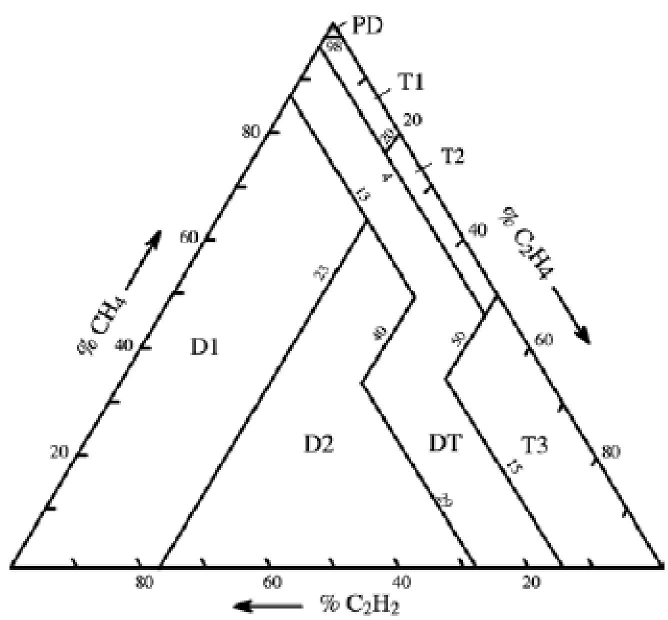


Figure 2: Figure above shows the Duval Triangle for analyzing. [15]

The triangle have triangular coordinates (X, Y, Z), with each side representing proportions of CH_4, C_2H_4 and C_2H_2, from 0% to 100% for each gas. Below are the steps to form the triangular analysis using one set of data:

1) Label each concentration of three gases with (CH_4) = A, (C_2H_4) = B and (C_2H_2) = C, in ppm.
2) Sum of all concentrations of three gases, S (ppm) = A + B + C
3) Calculate the relative proportion of the tress gases in %.

$X = \% \ CH_4 = 100\ (A/S)$,

$Y = \% \ C_2H_4 = 100\ (B/S)$,

$Z = \% \ C_2H_2 = 100\ (C/S)$

4) Plot X, Y and Z in the Triangle, which will result in one point. Then, by referring to the table 4, the fault of the transformer can be predicted.

Below is the table to the 6 zones of individual faults (PD, D1, D2, T1, T2 or T3), an intermediate zone DT has been attributed to mixtures of electrical and thermal faults in the transformer [15]:

Table 4: Examples of faults detectable by DGA [15]

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

2.5 Furan Analysis

Furfuraldehyde is one of the most stable liquid residues of cellulose degradation [5]. From the concentration of furanic compound in the oil, the condition of the paper insulation can be predicted. The Furan concentration can assess the remaining age of the paper by correlation that been found between the concentration of Furans and the mechanical tensile strength of the paper [6]. The Furan Compound that been measured are 2-furfurylalcohol (2FOL), 5-hydroxymethyl-2-furfural (5HMF), 2-furfural (2FAL), 2-acetylfuran (2ACF), and 5-methylfuran (5MEF). If there is some concentration of these furan compounds, the result will be compared with reference that is based on the standard, BS148 (Furan).

2.6 Ratio & Insulation Resistance Test

The winding turn's ratio test is useful to determine whether or not there are any shorted turns or open winding circuits in the transformers. Meanwhile, Insulation Resistance (IR) test provides more information on the condition of electrical insulation. IR test reveals the quality of transformer insulation and the degree of the dryness. When a DC voltage is applied across the specimen, three separate currents flow, the geometric capacitance currents, Ic, the leakage current, Ir and the polarization current, Irp. Summation of these currents, I_T is the current measured by the test set and displayed as Insulation Resistance [6]. There are three factors that influencing IR test, which are temperature, surface condition and humidity. IR tested at or above rated voltage to be certain there are no excessive leakage paths to ground or between windings. These are conducted with the transformer completely disconnected from the line and load. But, the ground should not be removed.

2.7 Sweep Frequency Response Analysis (SFRA) Test

Frequency Response Analysis is a diagnostic tool that is used to help identify possible deformations and movements in the transformer's core and coil assembly and other internal faults. The movement or distortion of the winding or lead structure of power transformer can take place due to short circuit forces, or loss of rigidity and tightness associated with shrinking caused by ageing of insulation. There are a few ways to do SFRA; example is one method that depending on the use of a network analyzer to measure the response to a sweeping frequency signal injected into a transformer winding [6]. Then, the calculation can be made by the division of output signal to the input signal with unit, decibel.

2.8 Tan Delta Test

Tan Delta is one of diagnostic method of testing insulation materials for equipment. Tan Delta test also called Loss Angle or Dissipation Factor testing is done to try to predict the remaining life expectancy of one's equipment. If the insulation of an insulator such as cable is free from defects, like water trees, electrical trees, moisture and air pockets, etc., the insulator approaches the properties of a perfect capacitor. It is very similar to a parallel plate capacitor with the conductor and the neutral being the two plates separated by the insulation material in a perfect capacitor, the voltage and current are phase shifted 90 degrees and the current through the insulation is capacitive.

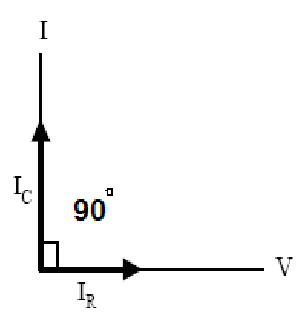


Figure 3: Perfect capacitor angle

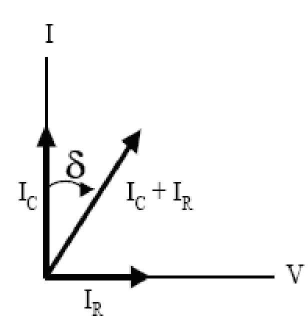


Figure 4: The angle of delta

If there are impurities or leakage in the insulation, the resistance of the insulation decreases, resulting in an increase in resistive current through the insulation. It is no longer a perfect capacitor. The current and voltage will no longer be shifted 90 degrees. It will be something less than 90 degrees. The extent to which the phase shift is less than 90 degrees is indicative of the level of insulation contamination, hence quality/reliability. This “Loss Angle” is measured and analyzed.

From the figure 2 above, the tangent of the angle δ is measured by measuring $\tan \delta = I_R/I_C$, the quality of the cable insulation can be determined. In a perfect cable, the angle would be nearly zero. An increasing angle indicates an increase in the resistive current through the insulation, meaning that the contamination. With greater the angle of δ, the insulator performance becomes poorer [8].

2.9 Partial Discharge (PD) Test

Partial Discharge Test is commonly called “PD” Test. PD test can be defined as localized electrical discharge in insulator which only partially bridges the insulation between conductors [1]. From the definition, PD test is the testing method on the insulators for electrical equipments to test the strength and life time of the insulators. However, PD measurements, at prominent stresses performed during operation life had been found to be injurious to the insulation, predominantly, Oil Impregnated Cellulose Paper (OIP) [2]. The author include PD test here is for recommendation for the test of cable because; Partial Discharge Test will test the partial discharge for insulation material of the power transformer. With small amount of energy, partial discharges may lead to progressive deterioration of the dielectric properties of the insulators [1]. After initiation, partial discharges can propagate and develop into electrical trees. Electrical trees can cause major faults such as current fault to earth, or between phases of a 3-phase system and so on [9].

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification of the Project

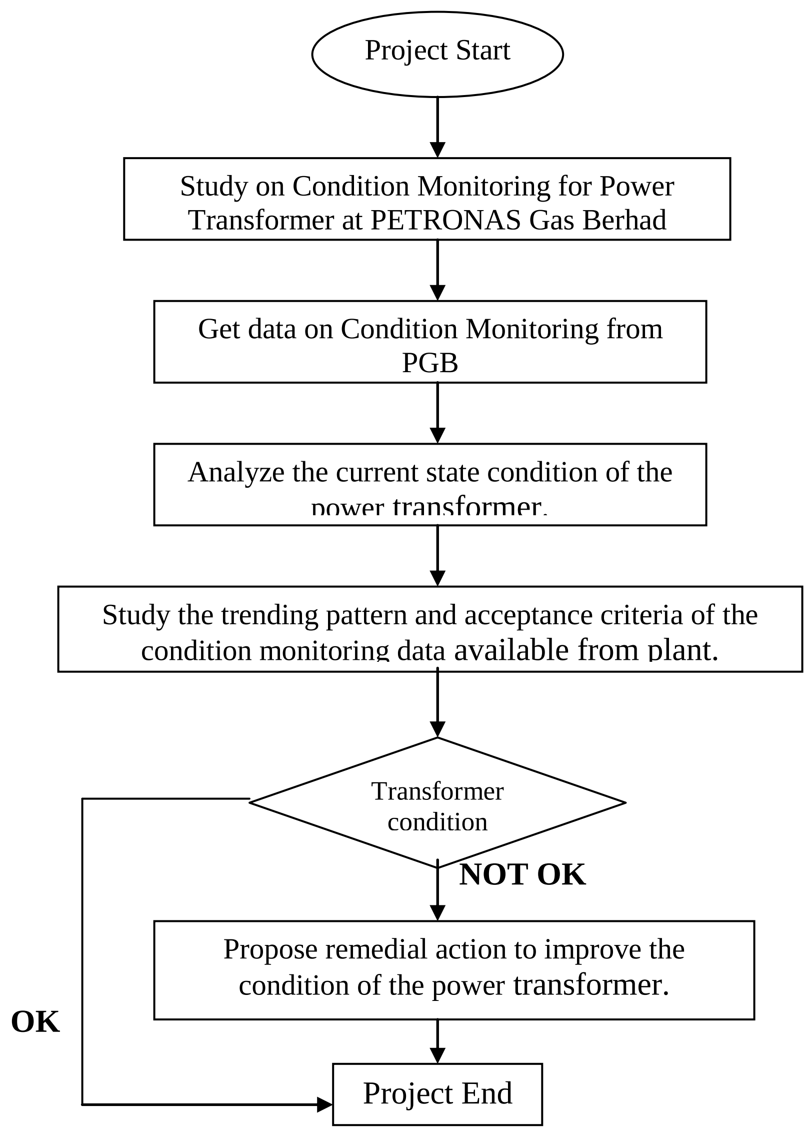


Figure 5: Flow chart of project

CHAPTER 4

RESULT AND DISCUSSION

4.1 Results and Discussion for DGA Analysis

In this chapter, the author divided the result and discussion for each group of data, such as, the result and discussion for DGA analysis will be in one group, and so on. Below are the result and discussion for DGA analysis using Roger Ratio Method and Duval Triangle Method, including the analysis for gas formation in service (references to Duval Conference Paper [15]):

4.1.1 Result of analysis for TR5-AB-01 (132kV/33kV)

Table 5: DGA Testing Data for TR5-AB-01

DGA (TR5-AB-01) 132kV/33kV			
TEST	SEPT 2006	SEPT 2007	REFERENCES (MAX)
HIDROGEN(H_2)	1	5	100
OXYGEN(O_2)	1786	1685	NOT SPECIFIED
NITROGEN(N_2)	9796	9466	NOT SPECIFIED
METHANE(CH_4)	8	23	120
CARBON MONOXIDE (CO)	29	43	350
CARBON DIOXIDE(CO_2)	464	703	5000
ETHYLENE(C_2H_4)	0	0	50
ETHANE(C_2H_6)	4	12	65
ACETYLENE(C_2H_2)	0	0	35

Analysis of gas formation in service for 2 years:

1) The presence of hydrogen H_2, methane CH_4 and ethane C_2H_6 be a sign of overheating in low temperature (<500^oC) or at low energy level such as in corona PDs inside the transformer oil.
2) Decrease in oxygen content usually indicates an excessive temperature in the transformer.
3) The increase of carbon dioxide CO_2 shows the rotting of paper insulation due to overheating, basically >100^oC at paper insulation.

By using Roger Ratio Method from (http://www.nttworldwide.com/rogers.htm):

Table 6: Analysis (Referring to **APPENDIX A**):

Ratio Code	Code	
	14th Sept 2006	21st Sept 2007
i	2	2
j	0	1
k	0	0
l	0	0
Result based on **table 3**	Slight overheating <150^oC	Overheating 150^oC – 200^oC

By using Duval Triangle Method

Table 7: Summation of calculation for A, B, C, S, X, Y & Z for two years.

Years	A (ppm)	B (ppm)	C (ppm)	S (ppm)	X (%)	Y (%)	Z (%)
2006	8	0	0	8	100	0	0
2007	23	0	0	23	100	0	0

Analysis from the Triangle in **APPENDIX L** and assessment with **table 4:**

- The point located at PD region for both years. Discharges of the cold plasma (corona) type in gas bubbles or voids, with the possible formation of X-wax in paper.

Discussion:

From Roger Ratio Method and Duval Triangle Method, and also with the gas formation in the oil, shows that transformer ***TR5-AB-01*** having excessive temperature or overheating to the oil filled and also to the paper insulation, approximately $150^{o}C - 200^{o}C$.

4.1.2 Result of analysis for TR5-AB-02 (132kV/33kV)

Table 8: DGA Testing Data for TR5-AB-02

DGA (TR5-AB-02) 132kV/33kV			
GAS (ppm)	SEPT 2006	SEPT 2007	REFERENCES (MAX)
HIDROGEN (H_2)	1	6	100
OXYGEN (O_2)	1455	2579	NOT SPECIFIED
NITROGEN (N_2)	7287	16254	NOT SPECIFIED
METHANE (CH_4)	9	40	120
CARBON MONOXIDE (CO)	28	71	350
CARBON DIOXIDE (CO_2)	467	1082	5000
ETHYLENE(C_2H_4)	0	0	50
ETHANE (C_2H_6)	7	24	65
ACETYLENE (C_2H_2)	0	0	35

Analysis of Gas Formation in service for 2 years:

1) The presence of hydrogen H_2, methane CH_4 and ethane C_2H_6 be a sign of overheating in low temperature (<500^{o}C) or at low energy level such as in corona PDs inside the transformer oil.
2) The formation of CO_2 is favored at the lower temperatures, while CO is formed above 200 °C but significant amounts of the other gases (H_2, hydrocarbons) are also formed [15].

By using Roger Ratio Method from (http://www.nttworldwide.com/rogers.htm):

Table 9: Analysis (Referring to **APPENDIX B**):

Ratio Code	Code	
	14th Sept 2006	21st Sept 2007
i	2	2
j	0	0
k	0	0
l	0	0
Result based on **table 3**	Slight overheating <150^{o}C	Slight overheating <150^{o}C

By using Duval Triangle Method

Table 10: Summation of calculation for A, B, C, S, X, Y & Z for two years.

Years	A (ppm)	B (ppm)	C (ppm)	S (ppm)	X (%)	Y (%)	Z (%)
2006	9	0	0	9	100	0	0
2007	40	0	0	40	100	0	0

From the Triangle in **APPENDIX L** and assessment with **table 4:**

- The point located at PD region for both years. Discharges of the cold plasma (corona) type in gas bubbles or voids, with the possible formation of X-wax in paper.

Discussion:

From Roger Ratio Method and Duval Triangle Method, and also with the gas formation in the oil, shows that transformer ***TR5-AB-02*** having excessive temperature or overheating to the oil filled and also to the paper insulation, approximately <500^{o}C.

4.1.3 Result of analysis for TRD-BD-01 (33kV/6.6kV)

Table 11: DGA Testing Data for TRD-BD-01

DGA (TRD-BD-01) 33kV/6.6kV			
TEST	SEPT 2006	SEPT 2007	REFERENCES (MAX)
HIDROGEN(H_2)	5	14	100
OXYGEN(O_2)	43173	34155	NOT SPECIFIED
NITROGEN(N_2)	94924	82176	NOT SPECIFIED
METHANE(CH_4)	2	4	120
CARBON MONOXIDE (CO)	196	222	350
CARBON DIOXIDE(CO_2)	2448	2651	5000
ETHYLENE(C_2H_4)	1	0	50
ETHANE(C_2H_6)	0	0	65
ACETYLENE(C_2H_2)	0	0	35

Analysis of Gas Formation in service for 2 years:

1) The presence of hydrogen H_2, methane CH_4 and ethane C_2H_6 be a sign of overheating in low temperature (<500^oC) or at low energy level such as in corona PDs inside the transformer oil.
2) Decrease in oxygen content usually indicates an excessive temperature in the transformer.
3) The formation of CO_2 is favored at the lower temperatures, while CO is formed above 200 °C but significant amounts of the other gases (H_2, hydrocarbons) are also formed [15].
4) Presence of ethylene indicates the medium intermediate overheating (500 °C to 1000 °C).

By using Roger Ratio Method from (http://www.nttworldwide.com/rogers.htm):

Table 12: Analysis (Referring to **APPENDIX C**):

Ratio Code	Code	
	14th Sept 2006	21st Sept 2007
i	0	0
j	0	0
k	0	0
l	0	0
Result based on **table 3**	Normal deterioration	Normal deterioration

By using Duval Triangle Method

Table 13: Summation of calculation for A, B, C, S, X, Y & Z for two years.

Years	A (ppm)	B (ppm)	C (ppm)	S (ppm)	X (%)	Y (%)	Z (%)
2006	2	1	0	3	66.67	33.33	0
2007	4	0	0	4	100	0	0

From the Triangle in **APPENDIX L** and assessment with **table 4:**

- For 2006, the point located at T2 region, which indicates, Carbonization of paper, formation of carbon particles in oil with thermal fault, 300 <T<700 °C

- For 2007, the point located at PD region, which indicated partial discharge, Discharges of the cold plasma (corona) type in gas bubbles or voids, with the possible formation of X-wax in paper.

Discussion:

From Roger Ratio Method, the result give overall overview of normal deterioration, while from Duval Triangle Method, and also with the gas formation in the oil, shows that transformer ***TRD-BD-01*** having *medium intermediate overheating* to the oil filled approximately (500 °C to 1000 °C) also carbonization of paper, with thermal fault, 300 <T<700 °C.

4.1.4 Result of analysis for TR5-BD-01 (33kV/6.6kV)

Table 14: DGA Testing Data for TR5-BD-01

DGA (TR5-BD-01) 33kV/6.6kV			
TEST	SEPT 2006	SEPT 2007	REFERENCES (MAX)
HIDROGEN(H_2)	3	13	100
OXYGEN(O_2)	47944	35212	NOT SPECIFIED
NITROGEN(N_2)	91198	81288	NOT SPECIFIED
METHANE(CH_4)	5	7	120
CARBON MONOXIDE (CO)	284	345	350
CARBON DIOXIDE(CO_2)	5978	6368	5000
ETHYLENE(C_2H_4)	3	0	50
ETHANE(C_2H_6)	2	0	65
ACETYLENE(C_2H_2)	0	0	35

Analysis of Gas Formation in service for 2 years:

1) The presence of hydrogen H_2, methane CH_4 and ethane C_2H_6 be a sign of overheating in low temperature (<500°C) or at low energy level such as in corona PDs inside the transformer oil.
2) Decrease in oxygen content usually indicates an excessive temperature in the transformer.
3) The formation of CO_2 is favored at the lower temperatures, while CO is formed above 200 °C but significant amounts of the other gases (H_2, hydrocarbons) are also formed [15]. The value for CO_2 is high, above the references value.
4) Presence of ethylene indicates the medium intermediate overheating (500 °C to 1000 °C).

By using Roger Ratio Method from (http://www.nttworldwide.com/rogers.htm):

Table 15: Analysis (Referring to **APPENDIX D**):

Ratio Code	Code	
	14th Sept 2006	21st Sept 2007
i	1	0
j	0	0
k	1	0
l	0	0
Result based on **table 3**	Winding circulating currents	Normal deterioration

By using Duval Triangle Method

Table 16: Summation of calculation for A, B, C, S, X, Y & Z for two years.

Years	A (ppm)	B (ppm)	C (ppm)	S (ppm)	X (%)	Y (%)	Z (%)
2006	5	3	0	8	62.5	37.5	0
2007	7	0	0	7	100	0	0

From the Triangle in **APPENDIX L** and assessment with **table 4:**

- For 2006, the point located at T2 region, which indicates, Carbonization of paper, formation of carbon particles in oil with thermal fault, 300 <T<700 °C
- For 2007, the point located at PD region, which indicated partial discharge, Discharges of the cold plasma (corona) type in gas bubbles or voids, with the possible formation of X-wax in paper.

Discussion

From Roger Ratio Method, the result give overall overview of normal deterioration and *winding circulating currents* for 2006, while from Duval Triangle Method, and also with the gas formation in the oil, shows that transformer ***TR5-BD-01*** having *medium intermediate overheating* to the oil filled approximately (500 °C to 1000 °C) also carbonization of paper, with thermal fault, 300 <T<700 °C.

4.1.5 Result of analysis for TR5-BD-02 (33kV/6.6kV)

Table 17: DGA Testing Data for TR5-BD-02

DGA (TR5-BD-02) 33kV/6.6kV			
TEST	SEPT 2006	SEPT 2007	REFERENCES (MAX)
HIDROGEN(H_2)	3	6	100
OXYGEN(O_2)	47092	35855	NOT SPECIFIED
NITROGEN(N_2)	96020	87239	NOT SPECIFIED
METHANE(CH_4)	5	6	120
CARBON MONOXIDE (CO)	259	298	350
CARBON DIOXIDE(CO_2)	6089	6035	5000
ETHYLENE(C_2H_4)	3	0	50
ETHANE(C_2H_6)	3	3	65
ACETYLENE(C_2H_2)	0	0	35

Analysis of Gas Formation in service for 2 years:

1) The presence of hydrogen H_2, methane CH_4 and ethane C_2H_6 be a sign of overheating in low temperature (<500^oC) or at low energy level such as in corona PDs inside the transformer oil.
2) Decrease in oxygen content usually indicates an excessive temperature in the transformer.
3) The formation of CO_2 is favored at the lower temperatures, while CO is formed above 200 °C but significant amounts of the other gases (H_2, hydrocarbons) are also formed [15]. The value for CO_2 is high, above the references value.
4) Presence of ethylene indicates the medium intermediate overheating (500 °C to 1000 °C).

By using Roger Ratio Method from (http://www.nttworldwide.com/rogers.htm):

Table 18: Analysis (Referring to **APPENDIX E**):

Ratio Code	Code	
	14th Sept 2006	21st Sept 2007
i	1	1
j	0	0
k	1	0
l	0	0
Result based on table	Winding circulating currents	Slight overheating <150^oC

By using Duval Triangle Method

Table 19: Summation of calculation for A, B, C, S, X, Y & Z for two years.

Years	A (ppm)	B (ppm)	C (ppm)	S (ppm)	X (%)	Y (%)	Z (%)
2006	5	3	0	8	62.5	37.5	0
2007	6	0	0	6	100	0	0

From the Triangle in **APPENDIX L** and assessment with **table 4:**

- For 2006, the point located at T2 region, which indicates, Carbonization of paper, formation of carbon particles in oil with thermal fault, 300 <T<700 °C

- For 2007, the point located at PD region, which indicated partial discharge, Discharges of the cold plasma (corona) type in gas bubbles or voids, with the possible formation of X-wax in paper.

Discussion

From Roger Ratio Method, the result give *winding circulating currents* for 2006, while from Duval Triangle Method, and also with the gas formation in the oil, shows that transformer ***TR5-BD-02*** having *medium intermediate overheating* to the oil filled approximately (500 °C to 1000 °C) also carbonization of paper, with thermal fault, 300 <T<700 °C.

4.1.6 Result of analysis for TR6-BD-01 (33kV/6.6kV)

Table 20: DGA Testing Data for TR6-BD-01

DGA (TR6-BD-01) 33kV/6.6kV			
TEST	SEPT 2006	NOV 2007	REFERENCES (MAX)
HIDROGEN(H_2)	10	12	100
OXYGEN(O_2)	42752	29814	NOT SPECIFIED
NITROGEN(N_2)	96350	73880	NOT SPECIFIED
METHANE(CH_4)	6	0	120
CARBON MONOXIDE (CO)	380	264	350
CARBON DIOXIDE(CO_2)	6503	5155	5000
ETHYLENE(C_2H_4)	2	1	50
ETHANE(C_2H_6)	4	2	65
ACETYLENE(C_2H_2)	0	0	35

Analysis of Gas Formation in service for 2 years:

1) The presence of hydrogen H_2, methane CH_4 and ethane C_2H_6 be a sign of overheating in low temperature (<500^oC) or at low energy level such as in corona PDs inside the transformer oil.
2) Decrease in oxygen content usually indicates an excessive temperature in the transformer.
3) The formation of CO_2 is favored at the lower temperatures, while CO is formed above 200 °C but significant amounts of the other gases (H_2, hydrocarbons) are also formed [15]. The values for CO2 and CO are high, above the references value.
4) Presence of ethylene indicates the medium intermediate overheating (500 °C to 1000 °C).

By using Roger Ratio Method from (http://www.nttworldwide.com/rogers.htm):

Table 21: Analysis (Referring to **APPENDIX F**):

Ratio Code	Code	
	14th Sept 2006	29th November 2007
i	0	2
j	0	0
k	0	0
l	0	0
Result based on **table 3**	Normal deterioration	Slight overheating <150^oC

By using Duval Triangle Method

Table 22: Summation of calculation for A, B, C, S, X, Y & Z for two years.

Years	A (ppm)	B (ppm)	C (ppm)	S (ppm)	X (%)	Y (%)	Z (%)
2006	6	2	0	8	75	25	0
2007	0	1	0	1	0	100	0

From the Triangle in **APPENDIX L** and assessment with **table 4:**

- For 2006, the point located at T2 region, which indicates, Carbonization of paper, formation of carbon particles in oil with thermal fault, 300 <T<700 °C
- For 2007, the point located at T3 region, which indicates extensive formation of carbon particles in oil, metal coloration with (800 °C) or metal fusion (> 1000 °C).The thermal fault is T >700 °C.

Discussion

From Roger Ratio Method, the result give overall overview of normal deterioration, while from Duval Triangle Method, and also with the gas formation in the oil, shows that transformer ***TR6-BD-01*** having *medium intermediate overheating* to the oil filled approximately (500 °C to 1000 °C) also carbonization of paper, with thermal fault, 300 <T<700 °C for 2006. The thermal fault had increase up to >700 °C in 2007 with extensive formation of carbon particles in oil.

4.1.7 Result of analysis for TR6-BD-02 (33kV/6.6kV)

Table 23: DGA Testing Data for TR6-BD-02

DGA (TR6-BD-02) 33kV/6.6kV			
TEST	SEPT 2006	NOV 2007	REFERENCES (MAX)
HIDROGEN(H_2)	6	7	100
OXYGEN(O_2)	44912	32497	NOT SPECIFIED
NITROGEN(N_2)	94595	77114	NOT SPECIFIED
METHANE(CH_4)	6	0	120
CARBON MONOXIDE (CO)	291	245	350
CARBON DIOXIDE(CO_2)	5420	4957	5000
ETHYLENE(C_2H_4)	2	1	50
ETHANE(C_2H_6)	5	1	65
ACETYLENE(C_2H_2)	0	0	35

Analysis of Gas Formation in service for 2 years:

1) The presence of hydrogen H_2, methane CH_4 and ethane C_2H_6 be a sign of overheating in low temperature (<500^oC) or at low energy level such as in corona PDs inside the transformer oil.
2) Decrease in oxygen content usually indicates an excessive temperature in the transformer.
3) The formation of CO_2 is favored at the lower temperatures, while CO is formed above 200 °C but significant amounts of the other gases (H_2, hydrocarbons) are also formed [15]. The value for CO_2 is high, above the references value.
4) Presence of ethylene indicates the medium intermediate overheating (500 °C to 1000 °C).

By using Roger Ratio Method from (http://www.nttworldwide.com/rogers.htm):

Table 24: Analysis (Referring to **APPENDIX G**):

Ratio Code	Code	
	14th Sept 2006	29th November 2007
i	1	2
j	0	0
k	0	1
l	0	0
Result based on **table 3**	Slight overheating <150^oC	Data is not definable using Roger ratio

By using Duval Triangle Method

Table 25: Summation of calculation for A, B, C, S, X, Y & Z for two years.

Years	A (ppm)	B (ppm)	C (ppm)	S (ppm)	X (%)	Y (%)	Z (%)
2006	6	2	0	8	75	25	0
2007	0	1	0	1	0	100	0

From the Triangle in **APPENDIX L** and assessment with **table 4:**

- For 2006, the point located at T2 region, which indicates, Carbonization of paper, formation of carbon particles in oil with thermal fault, 300 <T<700 °C
- For 2007, the point located at T3 region, which indicates extensive formation of carbon particles in oil, metal coloration with (800 °C) or metal fusion (> 1000 °C).The thermal fault is T >700 °C.

Discussion

From Duval Triangle Method, and also with the gas formation in the oil, shows that transformer ***TR5-BD-01*** having *medium intermediate overheating* to the oil filled approximately (500 °C to 1000 °C) also carbonization of paper, with thermal fault, 300 <T<700 °C for 2006. The thermal fault had increase to >700 °C in 2007 with extensive formation of carbon particles in oil. Data is not definable using Roger Ratio method.

4.1.8 Result of analysis for TR5-DE-62 (6.6kV/415V)

Table 26: DGA Testing Data for TR5-DE-62

DGA (TR5-DE-62) 6.6kV / 433 V		
TEST	NOV 2007	REFERENCES (MAX)
HIDROGEN(H_2)	566	100
OXYGEN(O_2)	9579	NOT SPECIFIED
NITROGEN(N_2)	20848	NOT SPECIFIED
METHANE(CH_4)	3	120
CARBON MONOXIDE (CO)	50	350
CARBON DIOXIDE(CO_2)	784	5000
ETHYLENE(C_2H_4)	0	50
ETHANE(C_2H_6)	0	65
ACETYLENE(C_2H_2)	0	35

Analysis of Gas Formation in service for 1 year:

1) The hydrogen level is above the references value. This are because, (might be) the form of significant amounts of the other gases such as hydrogen during the decomposition of paper insulation.
2) H_2 diffuses much more rapidly than the hydrocarbon gases from the oil through gaskets and even metal welds.
3) H_2 represent very low energy faults such as PDs, where it is produced in large quantities, same with CH_4.

By using Roger Ratio Method from (http://www.nttworldwide.com/rogers.htm):

Table 27: Analysis (Referring to **APPENDIX H**):

Ratio Code	Code
	29th Nov 2007
i	2
j	0
k	0
l	0
Result based on **table 3**	Slight overheating <150^{o}C

By using Duval Triangle Method

Table 28: Summation of calculation for A, B, C, S, X, Y & Z for one year.

Years	A (ppm)	B (ppm)	C (ppm)	S (ppm)	X (%)	Y (%)	Z (%)
2007	3	0	0	3	100	0	0

From the Triangle in **APPENDIX L** and assessment with **table 4:**

- For 2007, the point located at PD region, which indicated partial discharge, Discharges of the cold plasma (corona) type in gas bubbles or voids, with the possible formation of X-wax in paper.

Discussion

Overall, the result fro transformer ***TR5-DE-62*** shows high level of hydrogen, this is might due to H_2 diffuses much more rapidly than the hydrocarbon gases from the oil through gaskets and even metal welds.H_2 also represent very low energy faults such as PDs, in align with Duval Triangle and Roger Ratio, which is slight overheating, <150^{o}C.

4.1.9 Result of analysis for TR5-DE-52 (6.6kV/415V)

Table 29: DGA Testing Data for TR5-DE-52

DGA (TR5-DE-52) 6.6kV / 433 V		
TEST	NOV 2007	REFERENCES (MAX)
HIDROGEN(H_2)	1058	100
OXYGEN(O_2)	8943	NOT SPECIFIED
NITROGEN(N_2)	21042	NOT SPECIFIED
METHANE(CH_4)	0	120
CARBON MONOXIDE (CO)	74	350
CARBON DIOXIDE(CO_2)	1257	5000
ETHYLENE(C_2H_4)	0	50
ETHANE(C_2H_6)	0	65
ACETYLENE(C_2H_2)	0	35

Analysis of Gas Formation in service for 1 year:

1) The hydrogen level is above the references value. This are because, (might be) the form of significant amounts of the other gases such as hydrogen during the decomposition of paper insulation.
2) H_2 diffuses much more rapidly than the hydrocarbon gases from the oil through gaskets and even metal welds.
3) H_2 represent very low energy faults such as PDs, where it is produced in large quantities, same with CH_4.

By using Roger Ratio Method from (http://www.nttworldwide.com/rogers.htm):

Table 30: Analysis (Referring to **APPENDIX I**):

Ratio Code	Code
	29^{th} Nov 2007
i	2
j	0
k	0
l	0
Result based on **table 3**	Slight overheating <150^{o}C

By using Duval Triangle Method

Table 31: Summation of calculation for A, B, C, S, X, Y & Z for one year.

Years	A (ppm)	B (ppm)	C (ppm)	S (ppm)	X (%)	Y (%)	Z (%)
2007	0	0	0	0	0	0	0

From the Triangle in **APPENDIX L** and assessment with **table 4:**

- Data is not definable using Duval Triangle Method.

Discussion

Overall, the result for transformer ***TR5-DE-52*** shows high level of hydrogen, this is might due to H_2 diffuses much more rapidly than the hydrocarbon gases from the oil through gaskets and even metal welds.H_2 also represent very low energy faults such as PDs, but, from Duval Triangle Method, data is definable and using Roger Ratio, show slight overheating, <150^{o}C.

4.1.10 Result of analysis for TR5-DE-61 (6.6kV/415V)

Table 32: DGA Testing Data for TR5-DE-61

DGA (TR5-DE-61) 6.6kV / 433 V		
TEST	NOV 2007	REFERENCES (MAX)
HIDROGEN(H_2)	413	100
OXYGEN(O_2)	6502	NOT SPECIFIED
NITROGEN(N_2)	15220	NOT SPECIFIED
METHANE(CH_4)	2	120
CARBON MONOXIDE (CO)	45	350
CARBON DIOXIDE(CO_2)	650	5000
ETHYLENE(C_2H_4)	0	50
ETHANE(C_2H_6)	0	65
ACETYLENE(C_2H_2)	0	35

Analysis of Gas Formation in service for 1 year:

1) The hydrogen level is above the references value. This are because, (might be) the form of significant amounts of the other gases such as hydrogen during the decomposition of paper insulation.
2) H_2 diffuses much more rapidly than the hydrocarbon gases from the oil through gaskets and even metal welds.
3) H_2 represent very low energy faults such as PDs, where it is produced in large quantities, same with CH_4.

By using Roger Ratio Method from (http://www.nttworldwide.com/rogers.htm):

Table 33: Analysis (Referring to **APPENDIX J**):

Ratio Code	Code
	29th Nov 2007
i	2
j	0
k	0
l	0
Result based on table	Slight overheating <150^{o}C

By using Duval Triangle Method

Table 34: Summation of calculation for A, B, C, S, X, Y & Z for one year.

Years	A (ppm)	B (ppm)	C (ppm)	S (ppm)	X (%)	Y (%)	Z (%)
2007	0	0	0	0	0	0	0

From the Triangle in **APPENDIX L** and assessment with **table 4:**

- Data is not definable using Duval Triangle Method.

.

Discussion

Overall, the result for transformer ***TR5-DE-61*** shows high level of hydrogen, this is might due to H_2 diffuses much more rapidly than the hydrocarbon gases from the oil through gaskets and even metal welds.H_2 also represent very low energy faults such as PDs, but, from Duval Triangle Method, data is definable and using Roger Ratio, show slight overheating, <150^{o}C.

4.1.11 Result of analysis for TR5-DE-51 (6.6kV/415V)

Table 35: DGA Testing Data for TR5-DE-51

DGA (TR5-DE-51) 6.6kV / 433 V		
TEST	NOV 2007	REFERENCES (MAX)
HIDROGEN(H_2)	1570	100
OXYGEN(O_2)	8874	NOT SPECIFIED
NITROGEN(N_2)	20614	NOT SPECIFIED
METHANE(CH_4)	3	120
CARBON MONOXIDE (CO)	67	350
CARBON DIOXIDE(CO_2)	1352	5000
ETHYLENE(C_2H_4)	0	50
ETHANE(C_2H_6)	0	65
ACETYLENE(C_2H_2)	0	35

Analysis of Gas Formation in service for 1 year:

1) The hydrogen level is above the references value. This are because, (might be) the form of significant amounts of the other gases such as hydrogen during the decomposition of paper insulation.
2) H_2 diffuses much more rapidly than the hydrocarbon gases from the oil through gaskets and even metal welds.
3) H_2 represent very low energy faults such as PDs, where it is produced in large quantities, same with CH_4.

By using Roger Ratio Method from (http://www.nttworldwide.com/rogers.htm):

Table 37: Analysis (Referring to **APPENDIX K**):

Ratio Code	Code
	29th Nov 2007
i	2
j	0
k	0
l	0
Result based on table	Slight overheating <150°C

By using Duval Triangle Method

Table 38: Summation of calculation for A, B, C, S, X, Y & Z for one year.

Years	A (ppm)	B (ppm)	C (ppm)	S (ppm)	X (%)	Y (%)	Z (%)
2007	0	0	0	0	0	0	0

From the Triangle in **APPENDIX L** and assessment with **table 4:**

- Data is not definable using Duval Triangle Method.

Discussion

Overall, the result for transformer ***TR5-DE-61*** shows high level of hydrogen, this is might due to H_2 diffuses much more rapidly than the hydrocarbon gases from the oil through gaskets and even metal welds.H_2 also represent very low energy faults such as PDs, but, from Duval Triangle Method, data is definable and using Roger Ratio, show slight overheating, <150^{o}C.

4.2 Result and Discussion for Oil Quality Testing

Table 39: Oil Quality Testing Data for TR5-AB-02

OIL QUALITY TESTING (TR5-AB-02) 132kV/33kV				
TEST	SEPT 06	SEPT 07	REFERENCES	STANDARD
NEUTRALIZATION VALUE	0.01	0.02	0.3mgKOH/g (MAX)	IEC422 (NV)
MOISTURE (H2O)CONTENT	8	10	30 ppm MAX	IEC422 USED OIL
COLOUR	L 1.5	L 1.0	1.0-2.5	ASTM (C SCALE)
DENSITY, g/cm3	0.8726	0.8726	0.895 MAX	SELECT
DIELECTRIC BREAKDOWN	73	74	30 kV (min)	IEC422 USED OIL
POWER FACTOR (DDF)	0.0029	0.0013	0.5 MAX	IEC422 (PF) 90C USED
INTERFACIAL TENSION (IFT)	43	NO RESULT	>24 Mn/m MIN	IFT60422 USED OIL

Table 40: Oil Quality Testing Data for TR5-AB-01

OIL QUALITY TESTING (TR5-AB-01) 132kV/33kV				
TEST	SEPT 06	SEPT 07	REFERENCES	STANDARD
NEUTRALIZATION VALUE	0.01	0.02	0.3mgKOH/g (MAX)	IEC422 (NV)
MOISTURE (H2O)CONTENT	6	13	30 ppm MAX	IEC422 USED OIL
COLOUR	L 1.5	L 1.0	1.0-2.5	ASTM (C SCALE)
DENSITY, g/cm3	0.8727	0.8726	0.895 MAX	SELECT
DIELECTRIC BREAKDOWN	61	43	30 kV (min)	IEC422 USED OIL
POWER FACTOR (DDF)	0.0028	0.00389	0.5 MAX	IEC422 (PF) 90C USED
INTERFACIAL TENSION (IFT)	44	NO RESULT	>24 Mn/m MIN	IFT60422 USED OIL

Table 41: Oil Quality Testing Data for TRD-BD-01

OIL QUALITY TESTING (TRD-BD-01) 33kV/6.6kV			
TEST	SEPT 2006	SEPT 2007	REFERENCES
NEUTRALIZATION VALUE	0.02	0.03	0.3mgKOH/g (MAX)
MOISTURE (H2O)CONTENT	6	7	30 ppm MAX
COLOUR	2	2	1.0-2.5
DENSITY, g/cm3	0.876	0.876	0.895 MAX
DIELECTRIC BREAKDOWN	58	75	30 kV (min)
POWER FACTOR (DDF)	0.0233	0.0222	0.5 MAX
INTERFACIAL TENSION (IFT)	27	NO RESULT	>24 Mn/m MIN

Table 42: Oil Quality Testing Data for TR5-BD-01

OIL QUALITY TESTING (TR5-BD-01) 33kV/6.6kV			
TEST	SEPT 2006	SEPT 2007	REFERENCES
NEUTRALIZATION VALUE	0.01	0.02	0.3mgKOH/g (MAX)
MOISTURE (H2O)CONTENT	4	9	30 ppm MAX
COLOUR	L 1.5	L 1.5	1.0-2.5
DENSITY, g/cm3	0.8749	0.8748	0.895 MAX
DIELECTRIC BREAKDOWN	67	66	30 kV (min)
POWER FACTOR (DDF)	0.0023	0.00312	0.5 MAX
INTERFACIAL TENSION (IFT)	37	NO RESULT	>24 Mn/m MIN

Table 43: Oil Quality Testing Data for TR5-BD-02

OIL QUALITY TESTING (TR5-BD-02) 33kV/6.6kV			
TEST	SEPT 2006	SEPT 2007	REFERENCES
NEUTRALIZATION VALUE	0.01	0.03	0.3mgKOH/g (MAX)
MOISTURE (H2O)CONTENT	5	8	30 ppm MAX
COLOUR	2	2	1.0-2.5
DENSITY, g/cm3	0.8758	0.8757	0.895 MAX
DIELECTRIC BREAKDOWN	65	66	30 kV (min)
POWER FACTOR (DDF)	0.0132	0.01334	0.5 MAX
INTERFACIAL TENSION (IFT)	31	NO RESULT	>24 Mn/m MIN

Table 44: Oil Quality Testing Data for TR6-BD-01

OIL QUALITY TESTING (TR6-BD-01) 33kV/6.6kV			
TEST	SEPT 2006	SEPT 2007	REFERENCES
NEUTRALIZATION VALUE	0.02	0.016	0.3mgKOH/g (MAX)
MOISTURE (H2O)CONTENT	8	10	30 ppm MAX
COLOUR	2	2	1.0-2.5
DENSITY, g/cm3	0.8773	NO RESULT	0.895 MAX
DIELECTRIC BREAKDOWN	62	81	30kV (min)
POWER FACTOR (DDF)	0.0033	NO RESULT	0.5 MAX
INTERFACIAL TENSION (IFT)	28	NO RESULT	>24 Mn/m MIN

Table 45: Oil Quality Testing Data for TR6-BD-02

OIL QUALITY TESTING (TR6-BD-02) 33kV/6.6kV			
TEST	RESULT	RESULT	REFERENCES
NEUTRALIZATION VALUE	0.01	0.016	0.3mgKOH/g (MAX)
MOISTURE (H2O)CONTENT	8	7	30 ppm MAX
COLOUR	L 1.5	L 1.5	1.0-2.5
DENSITY, g/cm3	0.8769	NO RESULT	0.895 MAX
DIELECTRIC BREAKDOWN	52	86	30 kV (min)
POWER FACTOR (DDF)	0.0123	NO RESULT	0.5 MAX
INTERFACIAL TENSION (IFT)	32	NO RESULT	>24 Mn/m MIN

Discussion

From the 2 years of data that available from plant, not much analyzing can be done, and the qualities of the oil are still under the limit value for all test. But, we can see the increment in all values of the oil quality test, even though not much increase, but, still increasing.

4.3 Result and Discussion for Furan Analysis.

For furan analysis, the author manages to get 2 years data for TR6-BD-01 and 02:

Table 46: Furan Compound Data for TR6-BD-01

FURAN COMPOUND: CONCENTRATION (ppb) (TR6-BD-01) 33kV/6.6kV			
TEST	RESULT	RESULT	REFERENCES (MAX)
2-FURFURYLALCOHOL (2FOL)	N/D	N/D	
5-HYDROXYMETHYL-2-FURFURAL (5HMF)	N/D	N/D	
2-FURFURAL (2FAL)	N/D	21	
2-ACETYLFURAN (2ACF)	N/D	92	
5-METHYLFURAN (5MEF)	N/D	8	
TOTAL OF FURANS (ppb)	N/D	121	1000 ppb MAX

Table 47: Furan Compound Data for TR6-BD-02

FURAN COMPOUND: CONCENTRATION (ppb) (TR6-BD-02) 33kV/6.6kV			
TEST	RESULT	RESULT	REFERENCES (MAX)
2-FURFURYLALCOHOL (2FOL)	N/D	N/D	
5-HYDROXYMETHYL-2-FURFURAL (5HMF)	N/D	N/D	
2-FURFURAL (2FAL)	N/D	9	
2-ACETYLFURAN (2ACF)	N/D	70	
5-METHYLFURAN (5MEF)	N/D	N/D	
TOTAL OF FURANS (ppb)	N/D	79	1000 ppb MAX

Discussion

The furan analysis also do not give much information to current condition of the power transformer since the data that the author get form the plant is only 1 year data. The value for each of the furanic compound is still zero and the summation of detectable furanic compound still below the maximum total, which is 1000 ppb.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Condition monitoring is widely been used to monitor the condition of the power transformer since power transformer (moreover high voltage) could cause a lot of damages, losses and fatality. Below is the figure of the strength of the transformer (mechanical strength or dielectric strength) and the stresses that are applied to the transformer.

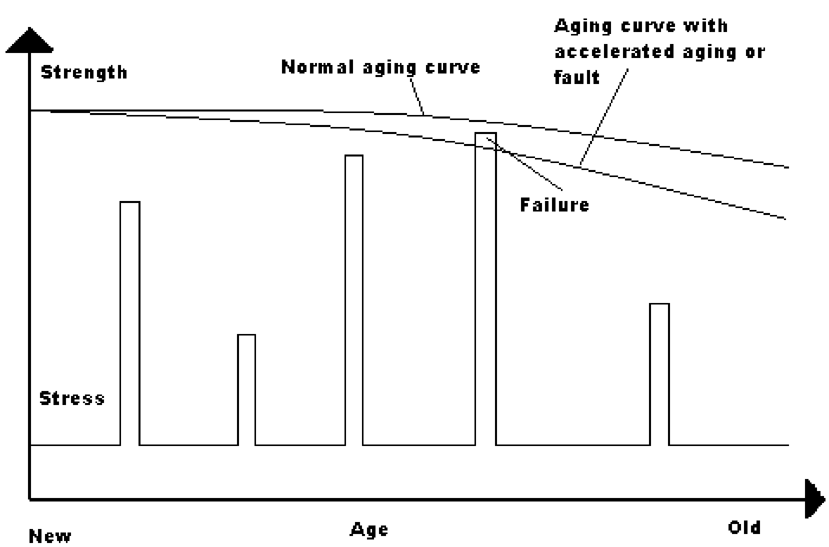


Figure 6: Strength of a transformer [6].

When new, the transformer should withstand all normal stresses (abnormal stresses such as lighting and switching impulses). The lower strength curve represents the premature deterioration of the strength of the transformer in the case where the transformer is not effectively maintained. Hence, the condition monitoring and proceed with condition assessment are the best procedure and method to make sure the power transformer will reach or exceed the life cycle that had been designed.

In conclusion, there a few of the transformer that having some problems, such as medium intermediate overheating, carbonization of insulation paper, circulating winding current and thermal fault. Detail of each result can be viewed in chapter 4, result and discussion. The responsible party should give attention to the power transformer that shows some trait of failure. But, these results should be deeply examined and study based on the latest DGA results and compared with a few more results to get most accurate result.

After completing this study, the author had gain very beneficial knowledge regarding condition monitoring for power transformer. All in all, the study hopefully will contribute to the improvement of the power transformer condition at the PETRONAS Gas Berhad plant after analyzing its current state of condition for improvement and propose recommendations. From the research, the author will be exposed to the practical environments and gain a lot of beneficial knowledge while universities parties will have a good relationship with outside companies.

5.2 Recommendation

The author had divided the recommendation into a few categories, which are as below.

5.2.1 Procedure to be taken for thermal faults

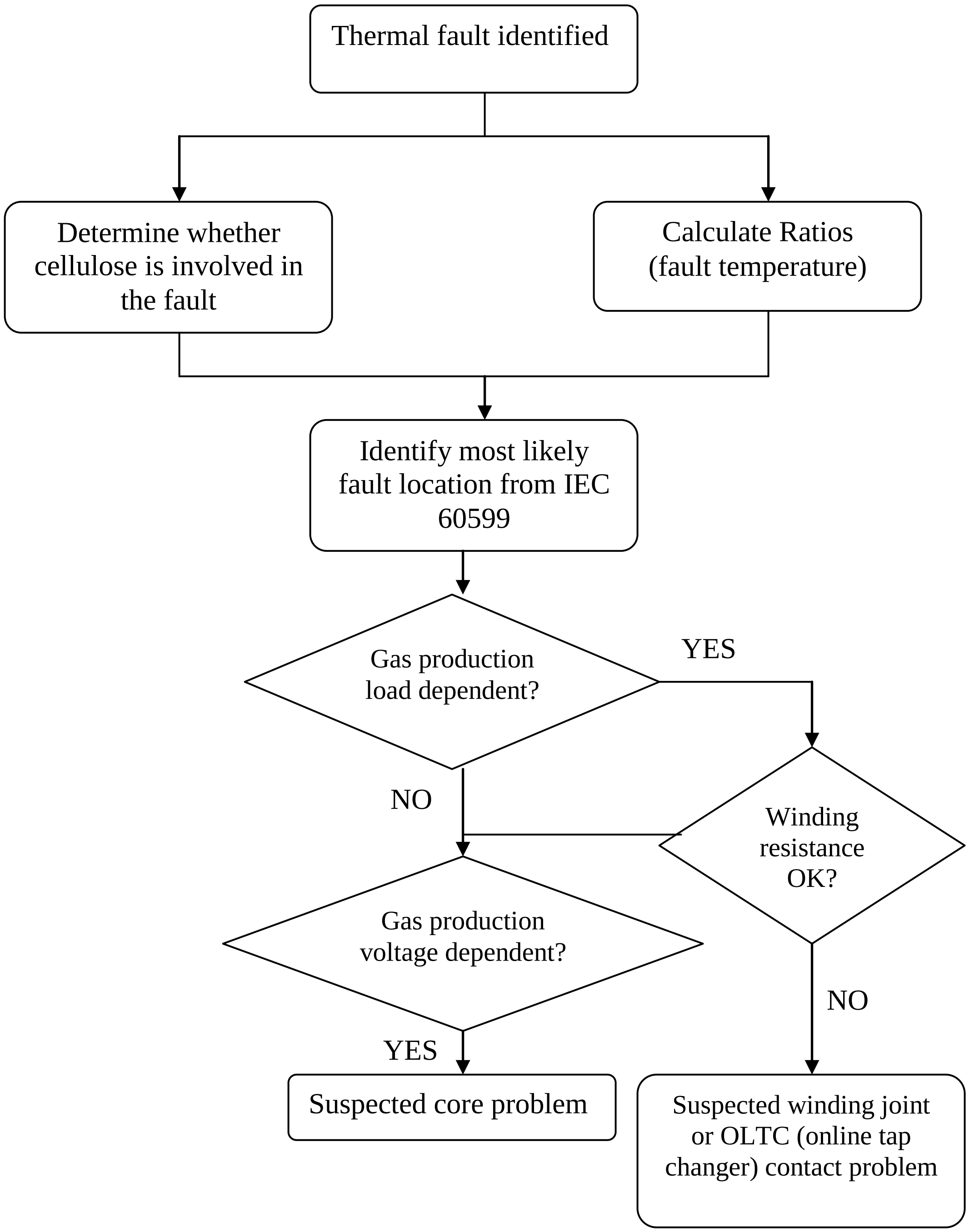


Figure 7: Flow diagram of thermal fault.

Even though we had detected the thermal fault in side power transformer through DGA analysis, but we had difficulty to detect which exactly the location of the component that causing the thermal fault. Overheating can occur in numerous locations such as in core, windings, on load tap changer contacts (OLTC), bushings and the tank. IEC 60599, in Table A.1, provides good guidance in determining the type of component involved in the overheating.

More information at times can be expanded by adjusting the loading on the transformer as described below:

- Load dependency which is the load on the transformer is held steady at a number of predetermined levels and the rate of gas production measured. If the rate of gas production can be correlated with the transformer load then the fault is most likely in the winding circuit. The measurement of winding resistance may then confirm that the problem is a high resistance joint or contact [6].
- Flux (Voltage) dependency which is the transformer is left for a period energized on one side only. This condition is repeated at a number of tap positions and the rate of gas production measured. If the rate of gas production can be correlated with the tap position then the fault is most likely in the iron circuit [6].

5.2.2 Procedure for arching or discharge fault

Table A.1 of IEC 60599 also provides good guidance in determining the type of component involved in any discharging or arcing. The location of discharges and arcing on external parts of winding or on the bottom of bushings can be known by performing Ultrasonic Emission Survey of the transformer. The procedure been summarizes in figure 8.

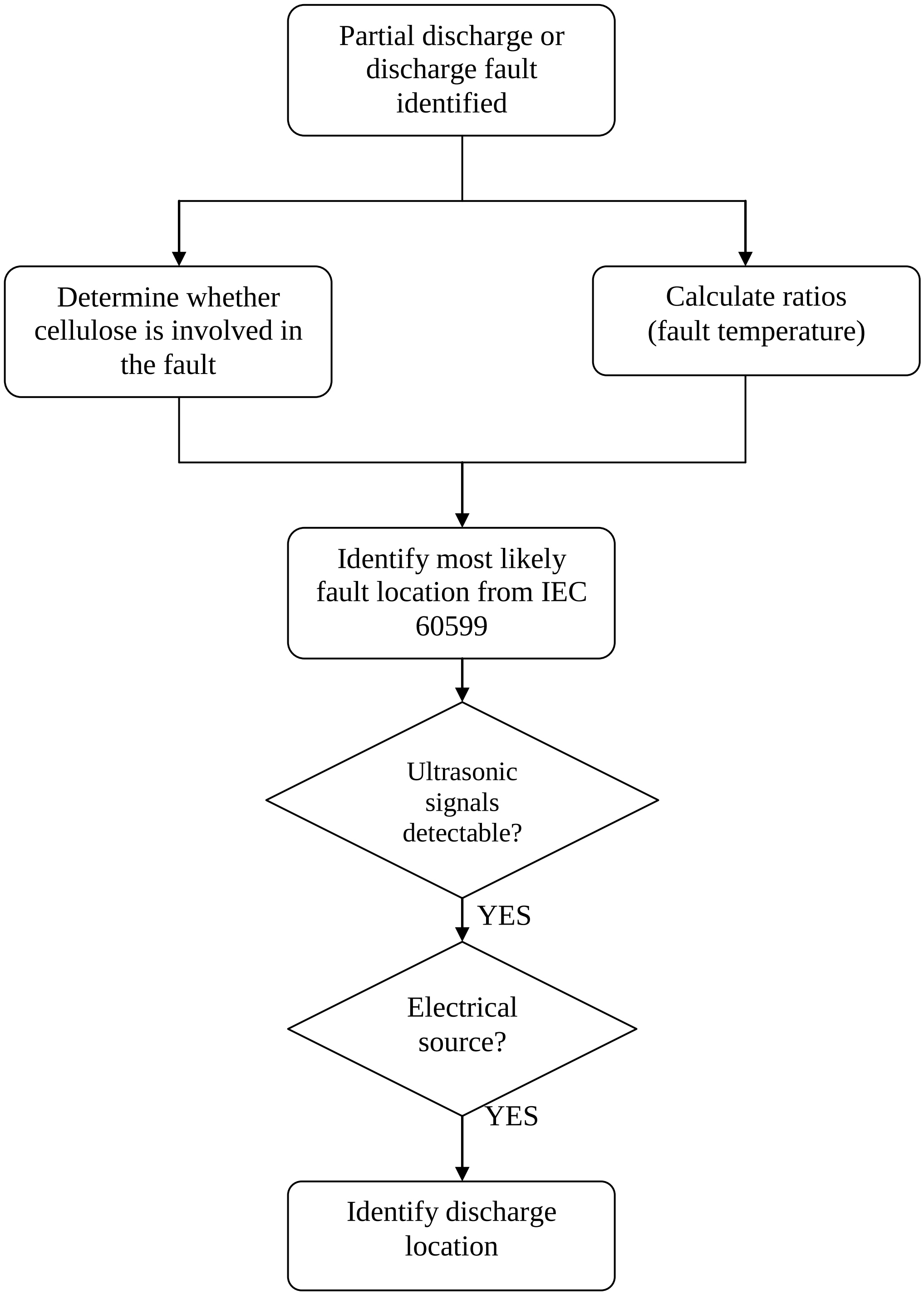


Figure 8: Flow diagram of arching or partial discharge

5.2.3 Improvement the condition monitoring work at PETRONAS Gas Berhad

- To keep the results data for every test in safe and organize filing in order to easily access of the data.
- To apply Partial Discharge test to Power Transformer cable as part of insulation test to the cable.
- To conduct Tan Delta test in order to monitor the insulation condition of the transformer windings, bushings etc.
- To conduct SFRA test routinely and fixed after fault.

5.2.4 Recommendation to this project

- Further study on the other test when there are available test data.
- Create health check for power transformer using any software such as Microsoft Excel, Matlab etc.

REFERENCES

[1] Training Module Electrical, *Transformer Module E08*, Capability & Improvement Dept. 2004, PETRONAS Gas Berhad.

[2] D. Pandurangiah*, Ch. Chakradhar Reddy*, T.P Govindana, Manoj Mandlika and T.S. Ramu* *Estimation of Remaining Life of Power Transformer*, IEEE Conference Paper (2008).

[3] PETRONAS TECHNICAL STANDARDS (PTS) 33.65.40.31, October 2001.

[4] Bharat Heavy Electricals Limited, *Transformer*, Mc Graw Hill, 2005, pp 34.

[5] M.K. Domun, *Condition Monitoring of Power Transformers by Oil Analysis Techniques.*

[6] TNB Transmission, Malaysia, *Power Transformer, Asset Management Strategy*, Revision No.2, 20 November 2002.

[7] Hongsheng Hu, Suxiang Qian, Jian Cao, *Monitoring and Fault Diagnosing System Design for Power Transformer Based on Temperature Field Model and DGA Feature Extraction*, IEEE Conference Paper , (June 2008).

[8] High Voltage, *Tan Delta Cable Testing* *www.hvinc.com/downloads/**Tan_Delta**_FAQ*

[9] IPEC High Voltage Ltd 2007, *What is Partial Discharge?* www.ipechv.co.uk

[10] Thanapong Suwanasri, Ekkachai Chaidee & Cattareeya Adsoongnoen, *Failure Statistics and Power Transformer Condition Evaluation by Dissolved Gas Analysis Technique*, IEEE Conference Paper, Beijing (April, 2008)

[11] Muhammad Arshad and Syed M. Islam, *Power Transformer Condition Monitoring and Assessment for Strategic Benefits*, http://www.itee.uq.edu.au

[12] Transformer Hand Book, NYNAS Naphthenics AB

[13] K. O. Wong, Dr. T. K. Saha, *Expert System for the Fault System for the Fault Diagnosis of Oil-Filled Power Transformer Using DGA.*

[14] Siva Sarm, D.V.S.S. and G.N.S. Kalyani, ANN Approach for Condition Monitoring of Power Transformer using DGA. 2004 IEEE Region 10 Conference, TENCON 2004.

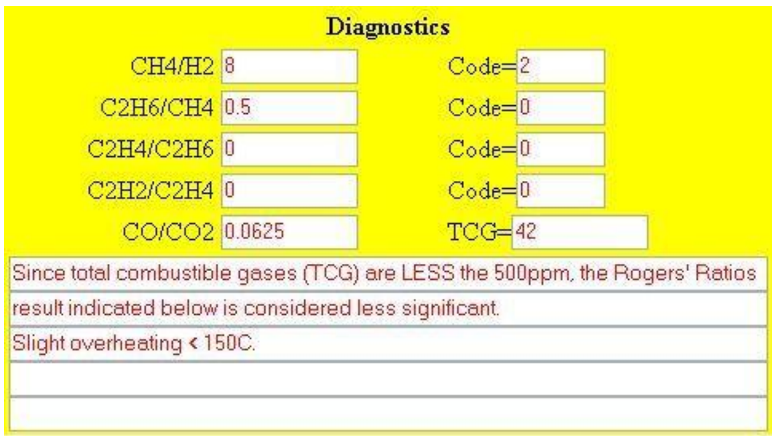
[15] Michel Duval, *Dissolved Gas Analysis and the Duval Triangle*, 2006 Conference Paper.

[16] Maintenance A Presentation Slide for visitors, PGB.

APPENDICES

APPENDIX A

DGA (TR5-AB-01) 132kV/33kV

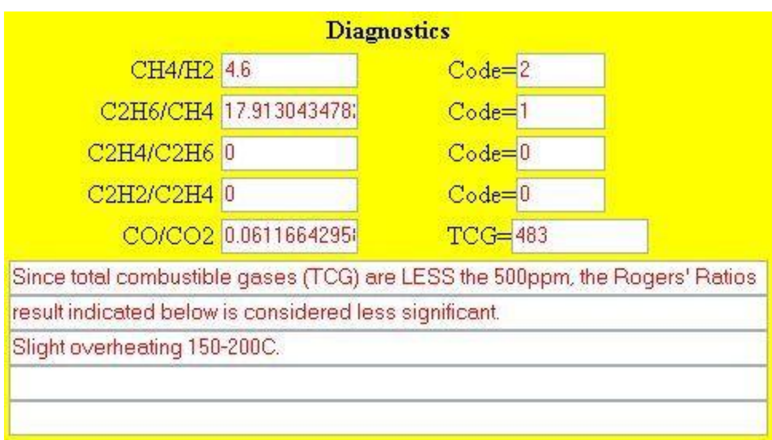


Diagnostics

CH4/H2	8	Code=	2
C2H6/CH4	0.5	Code=	0
C2H4/C2H6	0	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0625	TCG=	42

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Slight overheating < 150C.

Diagnosis from 14th Sept 2006



Diagnostics

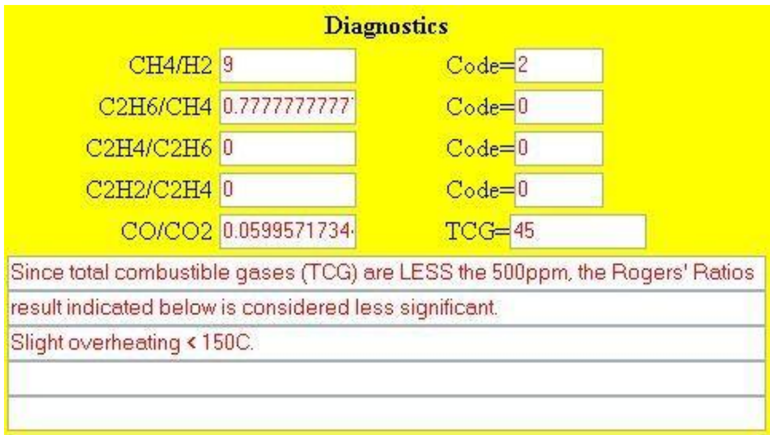
CH4/H2	4.6	Code=	2
C2H6/CH4	17.913043478:	Code=	1
C2H4/C2H6	0	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0611664295!	TCG=	483

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Slight overheating 150-200C.

Diagnosis from 21st Sept 2007

APPENDIX B

DGA (TR5-AB-02) 132kV/33kV

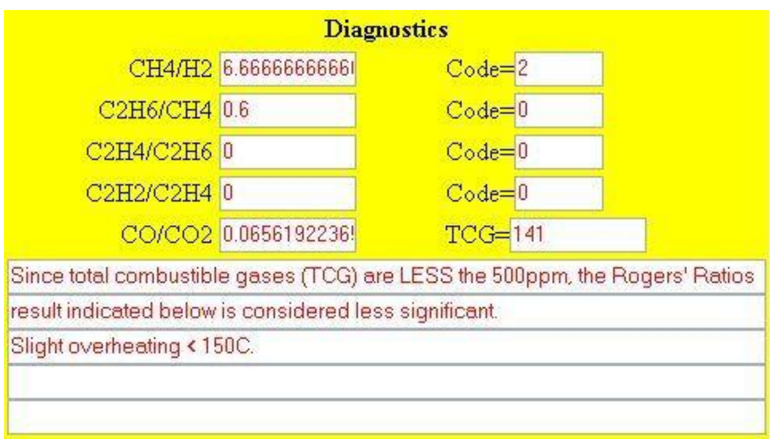


Diagnostics

CH4/H2	9	Code=	2
C2H6/CH4	0.7777777777	Code=	0
C2H4/C2H6	0	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0599571734	TCG=	45

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Slight overheating < 150C.

Diagnosis from 14th Sept 2006



Diagnostics

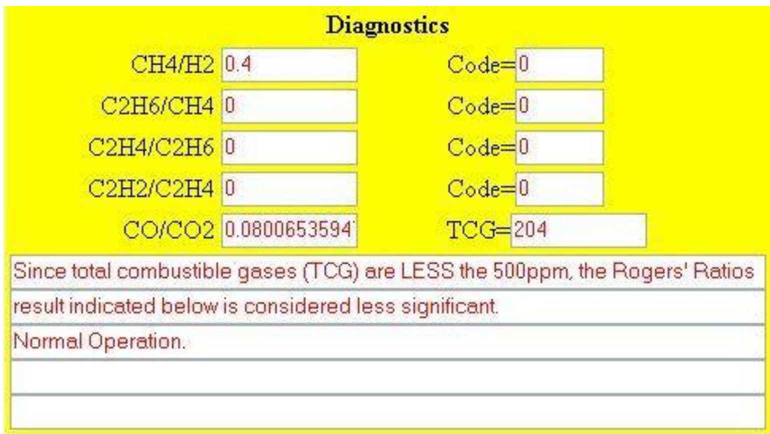
CH4/H2	6.66666666666	Code=	2
C2H6/CH4	0.6	Code=	0
C2H4/C2H6	0	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0656192236	TCG=	141

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Slight overheating < 150C.

Diagnosis from 21st Sept 2007

APPENDIX C

DGA (TRD-BD-01) 33kV/6.6kV

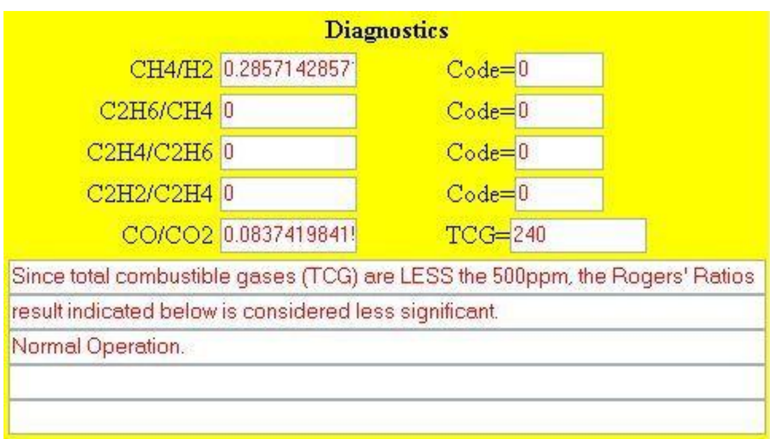


Diagnostics

CH4/H2	0.4	Code=	0
C2H6/CH4	0	Code=	0
C2H4/C2H6	0	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0800653594	TCG=	204

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Normal Operation.

Diagnosis from 14th Sept 2006



Diagnostics

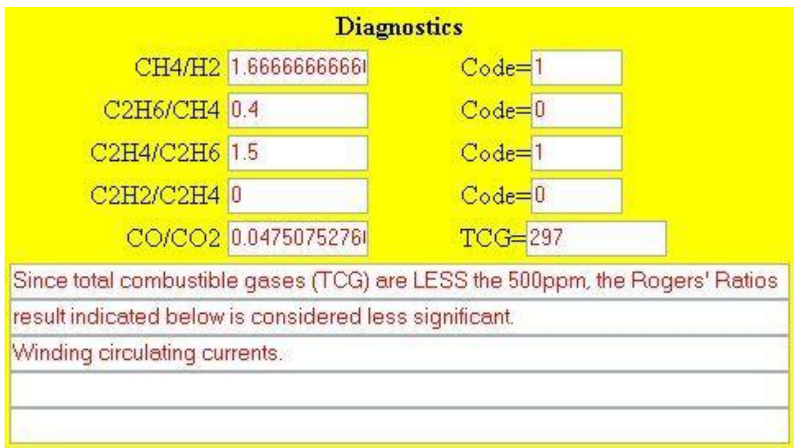
CH4/H2	0.2857142857	Code=	0
C2H6/CH4	0	Code=	0
C2H4/C2H6	0	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0837419841	TCG=	240

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Normal Operation.

Diagnosis from 21st Sept 2007

APPENDIX D

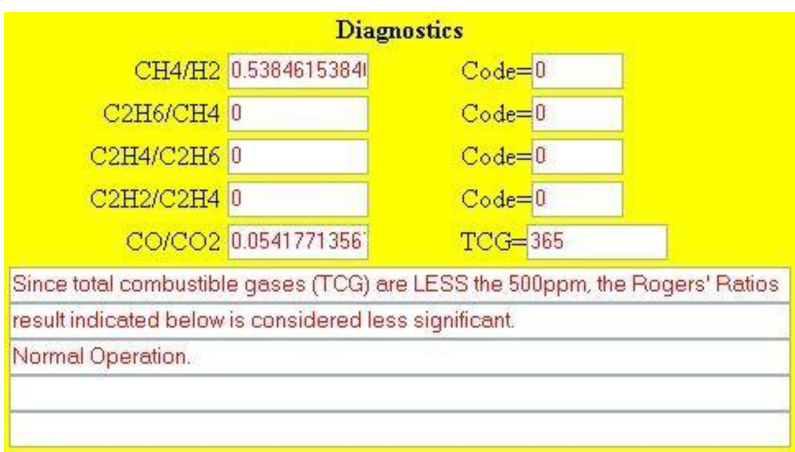
DGA (TR5-BD-01) 33kV/6.6Kv


Diagnostics

CH4/H2	1.6666666666	Code=	1
C2H6/CH4	0.4	Code=	0
C2H4/C2H6	1.5	Code=	1
C2H2/C2H4	0	Code=	0
CO/CO2	0.0475075276	TCG=	297

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Winding circulating currents.

Diagnosis from 14th Sept 2006


Diagnostics

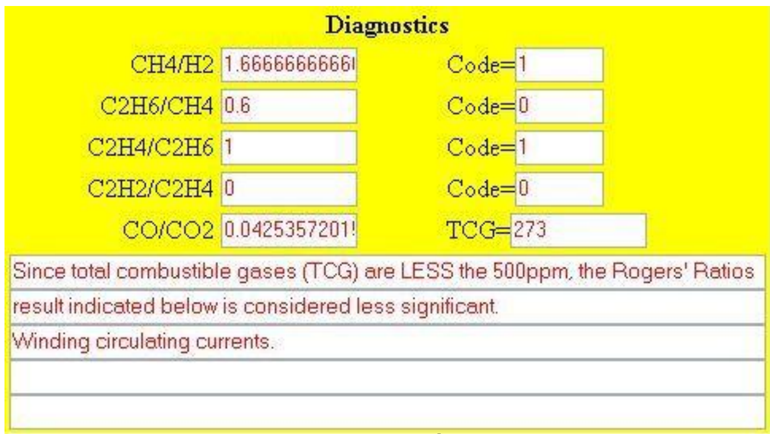
CH4/H2	0.5384615384	Code=	0
C2H6/CH4	0	Code=	0
C2H4/C2H6	0	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0541771356	TCG=	365

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Normal Operation.

Diagnosis from 21st Sept 2007

APPENDIX E

DGA (TR5-BD-02) 33kV/6.6kV

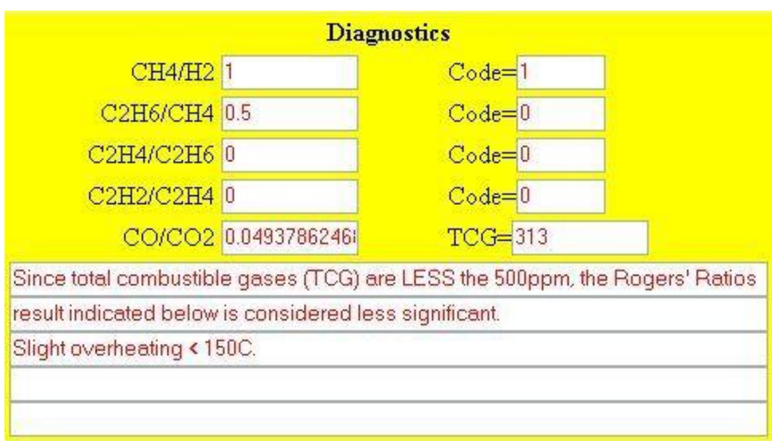


Diagnostics

CH4/H2	1.6666666666	Code=	1
C2H6/CH4	0.6	Code=	0
C2H4/C2H6	1	Code=	1
C2H2/C2H4	0	Code=	0
CO/CO2	0.0425357201!	TCG=	273

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Winding circulating currents.

Diagnosis from 14th Sept 2006



Diagnostics

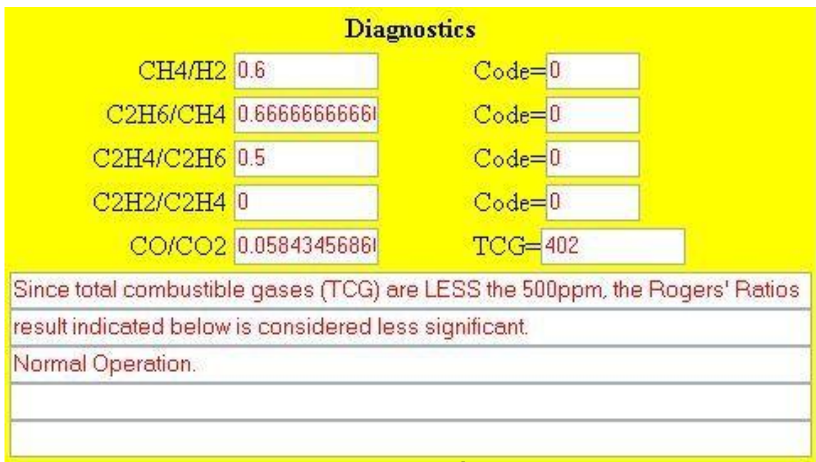
CH4/H2	1	Code=	1
C2H6/CH4	0.5	Code=	0
C2H4/C2H6	0	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0493786246	TCG=	313

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Slight overheating < 150C.

Diagnosis from 21st Sept 2007

APPENDIX F

DGA (TR6-BD-01) 33kV/6.6kV

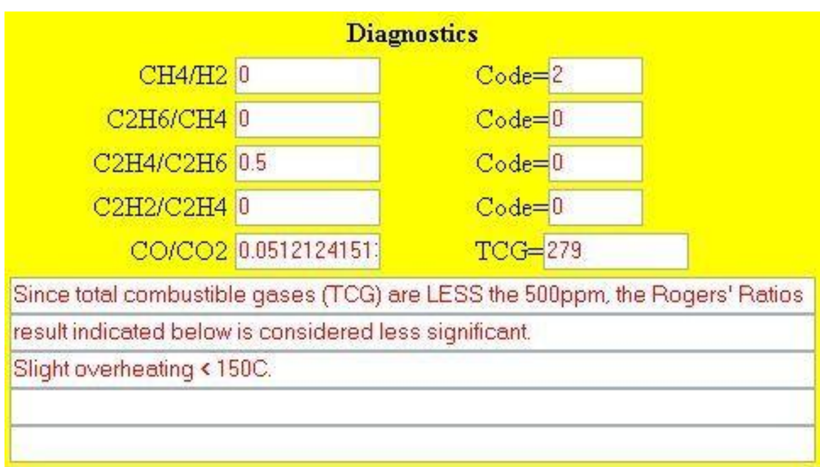


Diagnostics

CH4/H2	0.6	Code=	0
C2H6/CH4	0.6666666666(	Code=	0
C2H4/C2H6	0.5	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0584345686(	TCG=	402

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Normal Operation.

Diagnosis from 14th Sept 2006



Diagnostics

CH4/H2	0	Code=	2
C2H6/CH4	0	Code=	0
C2H4/C2H6	0.5	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0512124151:	TCG=	279

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Slight overheating < 150C.

Diagnosis from 29th November 2007

APPENDIX G

DGA (TR6-BD-02) 33kV/6.6kV

Diagnostics

CH4/H2	1	Code=	1
C2H6/CH4	0.8333333333:	Code=	0
C2H4/C2H6	0.4	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0536900369	TCG=	310

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Slight overheating < 150C.

Diagnosis from 14th Sept 2006

Diagnostics

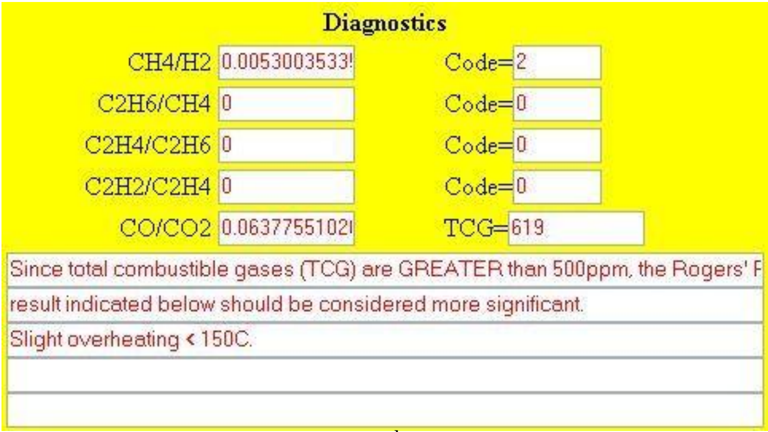
CH4/H2	0	Code=	2
C2H6/CH4	0	Code=	0
C2H4/C2H6	1	Code=	1
C2H2/C2H4	0	Code=	0
CO/CO2	0.0492462311!	TCG=	254

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Data is not definable using Rogers' Ratio.

Diagnosis from 29th November 2007

APPENDIX H

DGA (TR5-DE-62) 6.6kV/415V



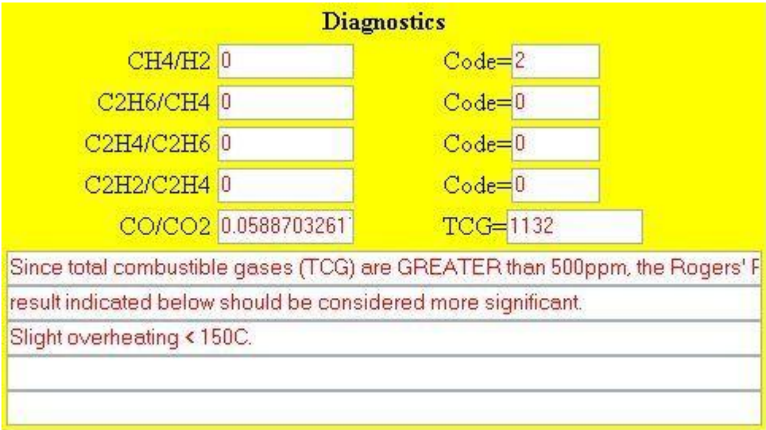
Diagnostics			
CH4/H2	0.0053003533	Code=	2
C2H6/CH4	0	Code=	0
C2H4/C2H6	0	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0637755102	TCG=	619

Since total combustible gases (TCG) are GREATER than 500ppm, the Rogers' R
result indicated below should be considered more significant.
Slight overheating < 150C.

Diagnosis from 29th November 2007

APPENDIX I

DGA (TR5-DE-52) 6.6kV/415V



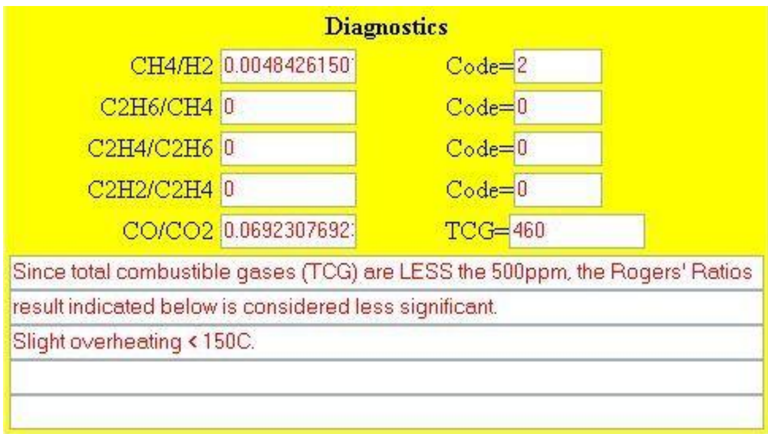
Diagnostics			
CH4/H2	0	Code=	2
C2H6/CH4	0	Code=	0
C2H4/C2H6	0	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0588703261	TCG=	1132

Since total combustible gases (TCG) are GREATER than 500ppm, the Rogers' R
result indicated below should be considered more significant.
Slight overheating < 150C.

Diagnosis from 29th November 2007

APPENDIX J

DGA (TR5-DE-61) 6.6kV/415V



Diagnostics

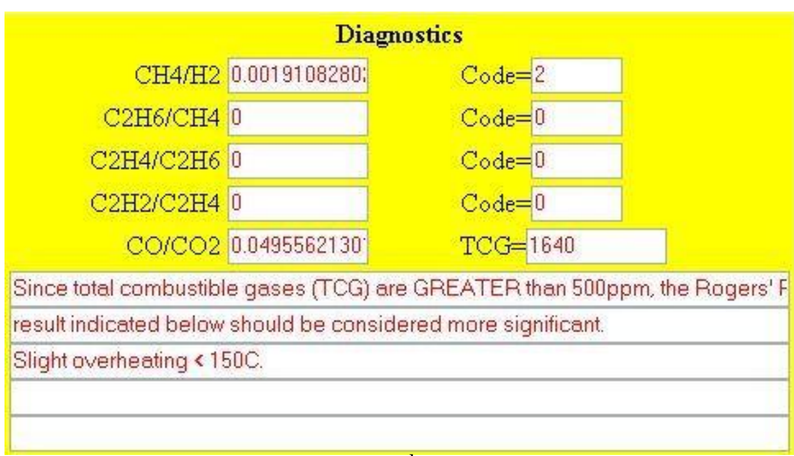
CH4/H2	0.0048426150	Code=	2
C2H6/CH4	0	Code=	0
C2H4/C2H6	0	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0692307692	TCG=	460

Since total combustible gases (TCG) are LESS the 500ppm, the Rogers' Ratios
result indicated below is considered less significant.
Slight overheating < 150C.

Diagnosis from 29th November 2007

APPENDIX K

DGA (TR5-DE-51) 6.6kV/415V



Diagnostics

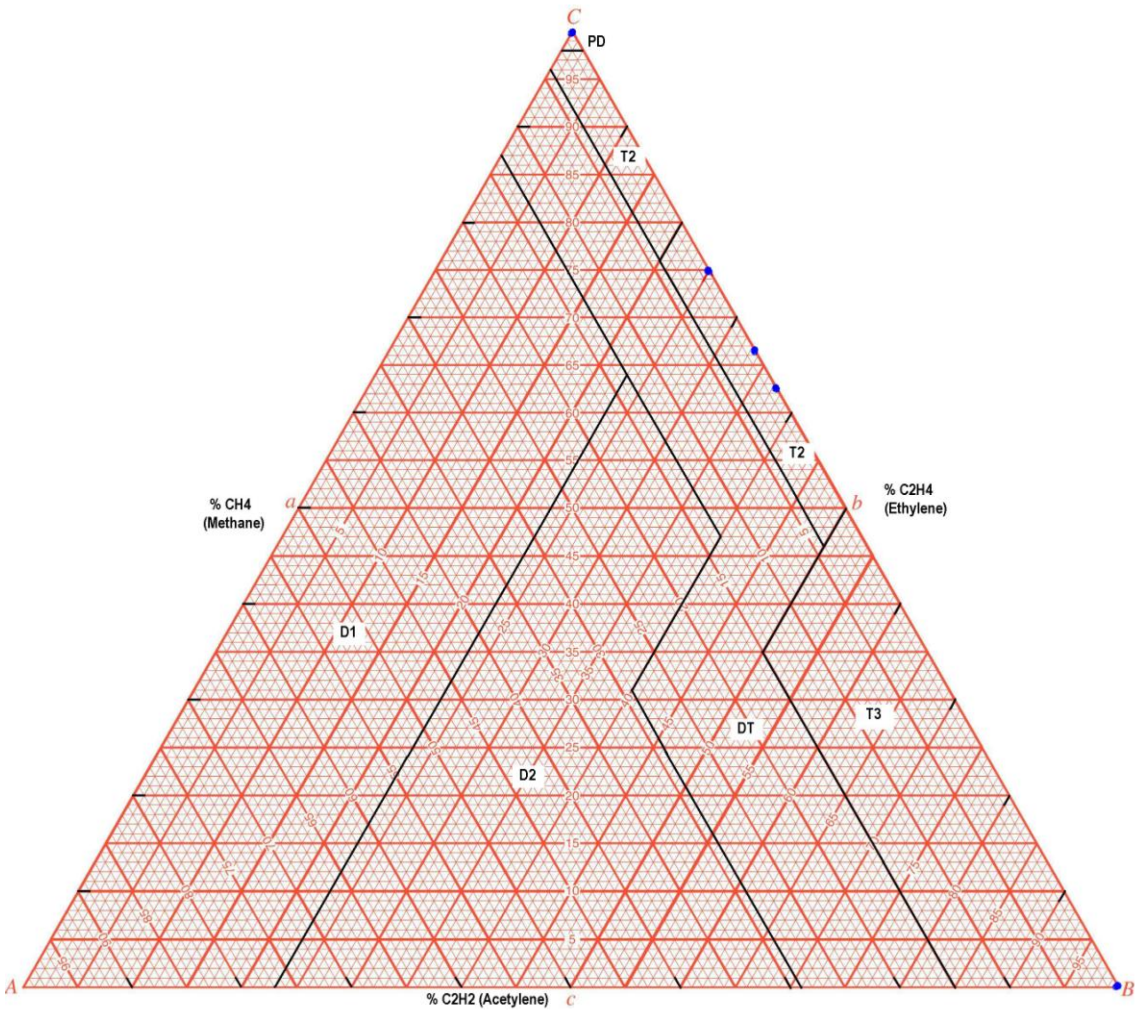
CH4/H2	0.0019108280	Code=	2
C2H6/CH4	0	Code=	0
C2H4/C2H6	0	Code=	0
C2H2/C2H4	0	Code=	0
CO/CO2	0.0495562130	TCG=	1640

Since total combustible gases (TCG) are GREATER than 500ppm, the Rogers' F
result indicated below should be considered more significant.
Slight overheating < 150C.

Diagnosis from 29th November 2007

APPENDIX L

DUVAL TRIANGLE METHOD



APPENDIX M

PROJECT' GANTT CHART

	weeks																	
	semester break	1	2	3	4	5	6	7	8	9	1week break	10	11	12	13	14	exam week	semester break
Literature review on Condition Monitoring test at PGB																		
Get data on Condition Monitoring from PGB, ASAGA & TNBR																		
Analyse the current state condition of the power transformer.																		
Study the trending pattern and acceptance criteria of the condition monitoring data (FYP2)																		
Propose remedial action to improve the condition of the power transformer.(FYP2)																		
Submission of progress report																		
Poster Presentation																		
Submission of draft report																		
Submission of final report																		
Oral presentation																		