Analysis of Failure Statistics and History Test Record for Power Transformer Maintenance

Ekkachai Chaidee, Thanapong Suwanasri and Cattareeya Adsoongnoen*

Abstract— *In this paper, power transformer is selected as pilot equipment for maintenance improvement analysis because of its cost and failure consequence. Due to the degradation of power transformer under its normal and abnormal operating conditions, maintenance activities are vital to restore the condition back to the normal condition. Even though the traditional preventive maintenance is well known and successfully performed in Thailand. However, this method has a high cost. Therefore, the objective of this paper is to improve the drawback by systematical records of the scattering failure statistics and analysis, in order to determine the criticality of each component. Two transformer models of rated voltages 115/22kV and 230/115/22kV have been adopted based on the available technical data, history test record and number in service. The scattering data of failure statistics is gathered, systematically recorded and analyzed. The component with high failure rate must be carefully focused. The known causes of failure could be prevented. The procedure for power transformer condition evaluation is performed by analyzing the history test result from the Dissolved Gas Analysis (DGA) method. The transformer conditions are principally evaluated by the Key Gas method and then verified by the Amount of Key Gas method, the Total Combustible Gas method, and the Rogers Ratios method. As a result, the aging pattern and trend of the power transformer deterioration can be determined.*

Keywords— **Deterioration, dissolved gas analysis, failure statistics, power transformer, preventive maintenance.**

1. INTRODUCTION

Power transformer is one of the most important equipment in electrical power system due to its cost and failure consequence. It is used to transmit power and transform voltage to the suitable level according to the connected equipment. Generally after any service, it will be gradually degraded due to the usage in the normal operating condition and stresses during abnormal conditions such as short-circuit current, overloading, and etc. This results in the aging of power transformer and sometimes leads to failure [1].

In order to restore the degraded condition back to normal and acceptable condition, maintenance activities are vital. Power transformer maintenance is performed by the traditional preventive maintenance according to the pre-determined time schedule, which results in high maintenance cost. Even though, power transformer testing and maintenance are regularly performed with good knowledge and experience, the test results are not centrally and systematically recorded. Consequently, the database management should be firstly established. After that, the technical data and history record can be further analyzed in order to find the critical component of power transformer based on the failure statistic and then by knowing the cause of failure, the preventive measures can be established. Similarly, the equipment reliability can be improved.

Because of the large number of power transformer in Thailand, available technical data, and history test record, two transformer models, which are 230/115/22kV of 44 units and 115/22kV of 107 units, have been selected for this study. Their scattering data of failure statistics is gathered, systematically recorded and analyzed in order to find the critical components according to its number of failure and causes. The condition evaluation has been performed by the analysis of history data of the test record. The Dissolved Gas Analysis (DGA) has been adopted due to the readiness of data and well-known practical experience. The analysis is primarily performed by using the Key Gas method and verified by three method; Roger Ratio method, Amount of Key Gas method and Total Combustible Gas method. The aging and trend of degradation can be forecasted from the analysis result. Consequently the optimal maintenance can be suitably defined according to equipment maintenance demand in the future [2].

2. BASIC THEORY

The failure data for power transformers, obtained by the Power Transformer Maintenance Department at Electricity Generating Authority of Thailand (EGAT), has been presented as an event report. It was recorded by preventive maintenance officer, which is comprised of date, time, location, transformer rating, important failure details and repair/replacement measures. The details of failure are classified into two categories as major/minor

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failures in order to be analyzed in statistic method.

The major failure is defined as an unplanned service interruption of equipment caused by a lack of one or more fundamental functions with or without supply interruption. This results in a sudden change in system operating conditions and requires non-scheduled repair actions [3]. The minor failure is defined as a detection or damage on equipment, which does not lead to a service interruption of equipment. It is not either immediately required a repair action or even could be repaired by a scheduled maintenance measure.

The residual life of power transformer is evaluated from the previous DGA method. This method concerns a procedure stating with extraction, separation, identification and calculation of gas, which resulted from the power transformer usage [4]. After the gas extraction process, gas will be evaluated. There are several methods for this evaluation process, such as the Key Gases, the Key Components Technique, the Amounts of Key Gases, and Total Combustible Gases (TCG) as well as the Ration Analysis methods.

The Key-Gases Method

It is proposed because of its ability to identify the types of general problem occurred with the power transformer. The pattern of gases could refer to the problem. For example, if arc exists in the oil tank, the key gas is Acetylene (C_2H_2). The other generated gases are presented as in Fig. 1.

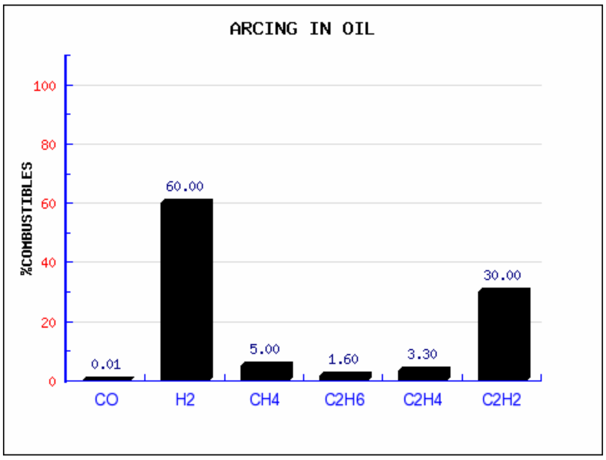

Fig.1. Identification of an Electrical Arc in Oil Problem.

Another example is a corona/partial discharge in oil problem, also different types and levels of gases can be detected as in Fig. 2. The key gas of this phenomenon is Hydrogen (H_2) and other types and their levels are similar noticed [4]-[5].

The Amounts of Key Gases

This method could present damage level of power transformer and its cause by analyzing from the levels of combustible gasses. This leads to the evaluation of power transformer in normal or abnormal conditions. The gas levels for this method are given in Table 1 [4].

Total Combustible Gases

The method defines the level of damage problem by considering of the total combustible gases, which can be classified in different ranges [4] as:

- 0-500 ppm: still be in normal operation and ready to be operated
- 500-1000 ppm: there is a high degradation level of power transformer aging
- > 1000 ppm: in this level, the continuously increasing rate of total combustible gases means that power transformer is in a dangerous level**.**

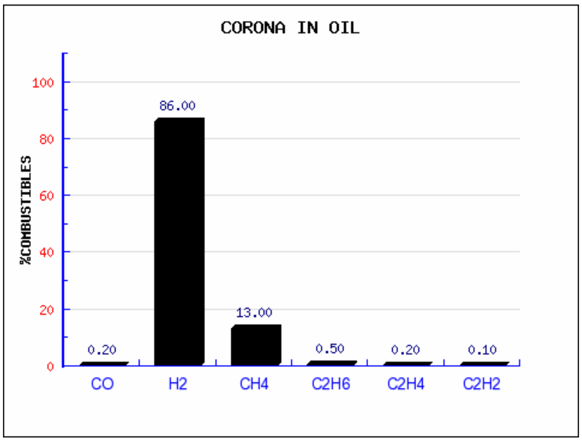

Fig.2. Identification of Corona or Partial Discharge Problem.

Table 1. Guidelines for Combustible Gasses

GAS	NORMAL	AB-NORMAL	INTERPRETA-TION
H_2	< 150 ppm	> 1000 ppm	Arcing,Corona
CH_4	< 25	> 80	Sparking
C_2H_6	< 10	> 35	Local Overheating
C_2H_4	< 20	> 100	Severe Overheating
CO	< 500	> 1000	Severe Overloading
CO_2	< 10000	> 15000	Severe Overloading
N_2	1-10%	N.A	
O_2	0.2-3.5% 0.03%	N.A> 0.5%	Combustibles

Rogers Ratio

It presents the damage level and cause by considering the rations of:

Ratio 1	CH_4/H_2	Ratio 2	C_2H_6/CH_4
Ratio 3	C_2H_4/C_2H_6	Ratio 4	C_2H_2/C_2H_4

After the calculation of all ratios, the results can be compared with the standard values as given in [4]-[5]. Consequently, the cause of damage, level of damage and associated problem can be investigated.

In this paper, the Key Gas method is mainly applied for failure cause analysis. However, the other methods, as the Amounts of Key Gases method for signalling gas level in normal/abnormal operation, the TCG method for showing the TCG level, and Rogers ratio method for displaying the damages by considering the gas ratios, are applied to validate the results.

3. WORKING PROCEDURE

In this paper, the working procedure can be separated into four main steps as database design, web-application design, data selection, data separation and analysis.

Database Design

Database is designed in form of relationship database for a systematic data arrangement, which comprises of firstly, analyzing of technical data, secondly conceptual data model, thirdly model conversion, and finally physical database model.

- The analyzing of technical data is used to record important data of power transformer, such as transformer rating and construction, failure location, causes of failure, and test result [6]-[7].
- The conceptual data model is presented as in the Entity – Relationship diagram (E-R diagram) to describe the power transformer entities and theirs attributes. Those data will be later used for failure analysis.
- The model conversion is used to convert the E-R diagram in the conceptual data model into the logical model. This process transforms data in the E-R diagram to a relative table, which still remains the relationship database model of the power transformer entities and theirs attributes.
- The design of physical database model is the last step of database design. It optimally utilizes the necessary data to be perfectly arranged as a final systematic data by using the Database Management System (DBMS) together with the MySQL program. This program is a famous for systematic data arrangement.

Web Application Design

PHP program is used for web-application while the Apache program is used to function as web-server for website development. The PHP program is used to translate the data to PHP language and then is applied for website development. The PhpMyAdmin program is similarly applied for the data administration and management in MySQL database. The relationship of all programs is shown in Fig. 3.

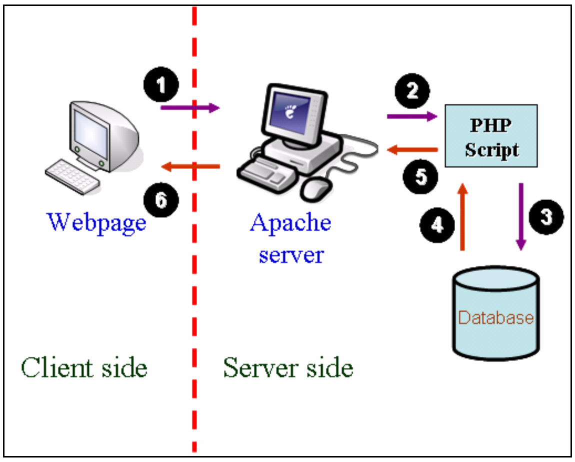

Fig.3. Program Development in Web-Application Design

Data Selection

Data of failure analysis of power transformer is selected from the sample transformers of 115/22 kV and 230/115/22 kV system voltage by considering the quality and quality of recorded data.

Data Separation

The failure records of power transformer are separated depending region, location, type, size, accessory parts and other historical usage data. The failure data will be classified into the major and minor failure categories regarding to their definitions. The failure data would be later on arranged in the database.

Data Analysis

This is data analysis for calculating the failure statistic of the power transformer failure parts. The data is analyzed by using the relevant data, for example region, location, type, size, and causes of failure. The failure is finally calculated in ratio of an individual of failure part by the total failure value of each transformer. The data analysis is applied by using the DGA method because of the readiness of data as well as a good knowledge and experiences of operating personnel. Similarly, this method can be applied for a condition evaluation of power transformer by using Key Gas method. The results will be compared with the Amount of Key Gas method, Rogers Ratio method, and the Total Combustible Gas method in order to forecast the transformer's condition.

4. RESULTS

4.1 Failure Statistic

The failure data during the last 10 years (1996 – 2006) has been used in the analysis. The transformer components are divided into On-Load Tap Changer (OLTC), bushing, main tank, conservator tank, cooling system, protective device and others, which are balance pipe, temperature bulb, sampling valve, oil temperature indication, and etc. The two sample models of power transformer are 107 units of 115/22kV rating and 44 units of 230/115/22kV rating.

115/22kV Power Transformer

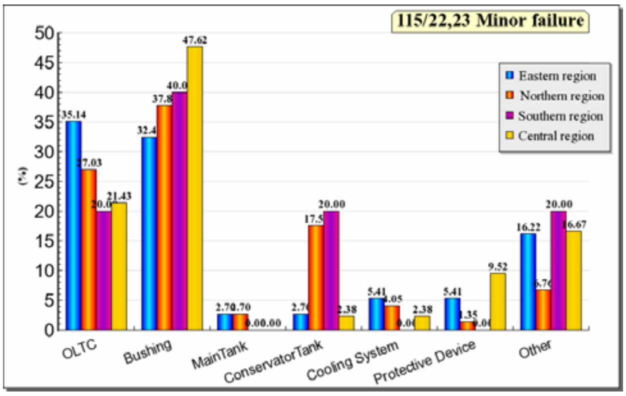

Fig.4. Percentage of Failure at Each Component According to Region for 115/22kV Power Transformer.

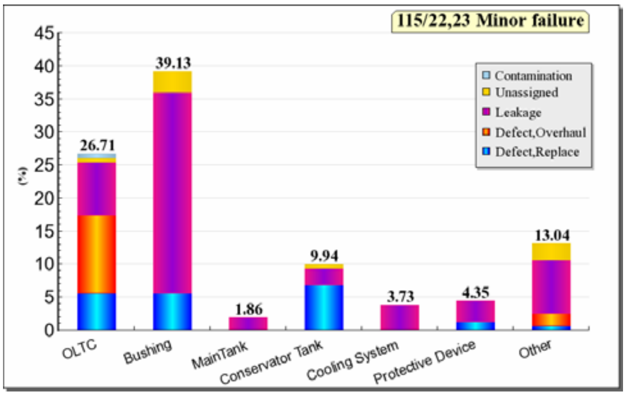

Fig. 5. Percentage of Failure Causes at Each Component for 115/22kV Power Transformer.

The failure results at various components presented in Fig.4 according to regions are as follows:

- 37 minor failures with 24 units in the Eastern region

- 74 minor failures with 50 units in the Northern region

- 5 minor failures with 5 units in the Southern region

- 42 minor failures with 28 units in the Central region

The failure causes are shown in Fig. 5. From the total 158 minor failures of 107 transformer units, the components with high percentage of failure are bushing 39% and OLTC 27%. The major causes of failure are leakage for bushing, and defect/overhaul and leakage for OLTC.

230/115/22kV Power Transformer

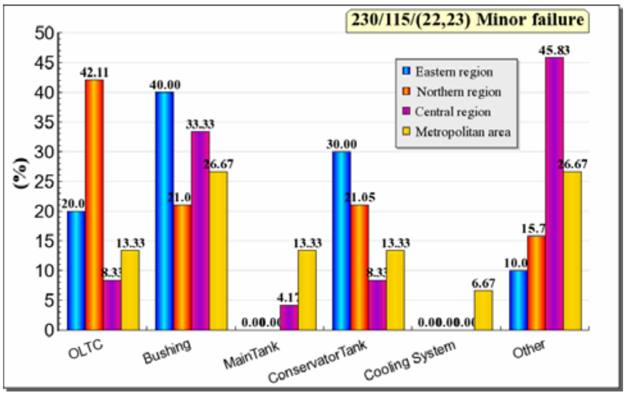

Fig.6. Percentage of Failure at Each Component According to Region for 230/115/22kV Power Transformer.

The failure results at various components presented in Fig. 6 according to region are as follows:

- 10 minor failures with 6 units in the Eastern region

- 19 minor failures with 15 units in the Northern region

- 24 minor failures with 16 units in the Central region

- 15 minor failures with 7 units in the Metropolitan area

The failure causes are shown in Fig. 7. From the total 68 minor failures of 44 transformer units, the components with high percentage of failure are bushing 30% and OLTC 20%. The major causes of failure are leakage for bushing, and defect/replace and defect/overhaul for OLTC.

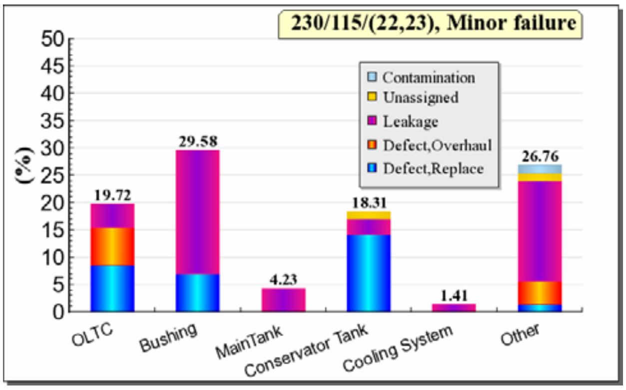

Fig.7. Percentage of Failure Causes at Each Component for 115/22kV Power Transformer.

4.2 Condition Evaluation

The history test record by the DGA test method has been analyzed. The analysis of two power transformers are selected and presented below in order to illustrate the methods and results of analyzing the problem.

The First Transformer

The transformer is of rated 115/22kV, 40MVA, put in service in 1984. The transformer oil was sampled in February 10, 2006 and tested in February 22, 2006. The DGA test results are shown in Table 2.

Table 2. DGA Test Result in February 22, 2006 of the First Transformer

GAS	VALUE	GAS	VALUE
O_2	4125	C_2H_6	557
N_2	23868	C_2H_4	276
CO_2	2565	C_2H_2	893
CO	113	C_3H_6	73
H_2	302	C_3H_8	335
CH_4	278	TCG	2827

The interpretation of the test result has been analyzed by using the four methods.

- ***Key Gases Method***

From Fig. 7 the Key Gas is Acetylene (C_2H_2), which indicates the problem involving the arcing in oil.

- ***The Amount of Key Gases Method***

The amount of CO is in normal level. However, the amount of H_2 exceeded the normal level but below the abnormal limit in the year 2006. The trend of increasing H_2 indicates the arcing and corona problem.

In Fig. 8, since 2002 the amount of CH_4, has exceeded the normal level The highest value was in 2006. This indicates the problem of spark in oil.

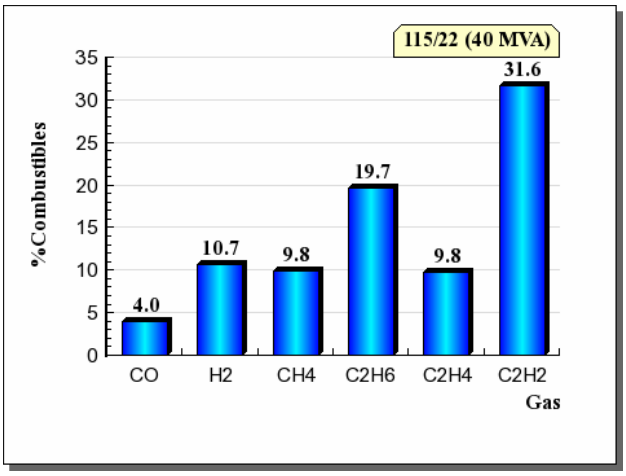

Fig.7. Percentage of Combustible Key Gases for Arcing in Oil Problem

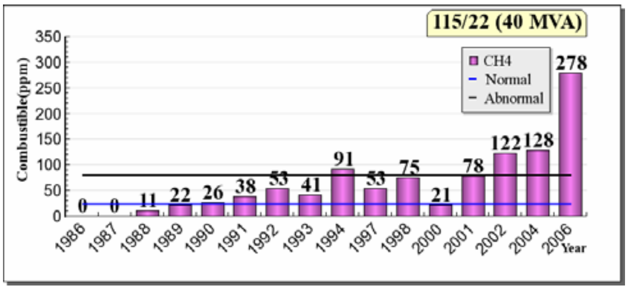

Fig.8. Relationship between Percentage of CH_4 and Age of the First Transformer

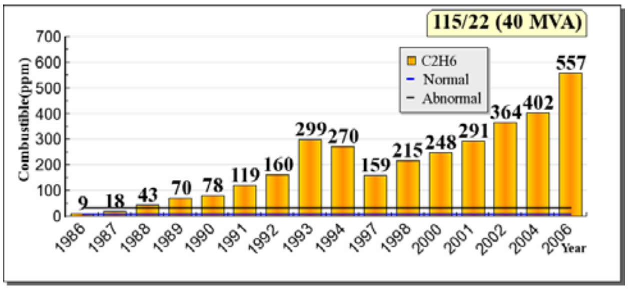

Fig.9. Relationship between Percentage of C_2H_6 and Age of the First Transformer.

As the amount of C_2H_6 shown in Fig.9, it has exceeded the abnormal limit since 1988 with the increasing trend. This indicates the problem of local overheating inside the transformer.

- ***Total Combustible Gases Method***

The amount of C_2H_4 shown in Fig. 10 keeps slowly increasing with the age. It exceeds the normal level in 2004 and reached the highest value in 2006. This indicates the severe overheating problem. Fig. 11 shows the amount of total combustible gases with the slowly increasing trend with the age. The reaching 1000 ppm of TCG in 2006 indicates the significant decomposition. After reaching 1000 ppm, the increasing trend should be carefully observed. If the amount of combustibles remains constant, the decomposition process is stop due to the self-healing effect. If the amount increases, then the unit can be in the danger zone.

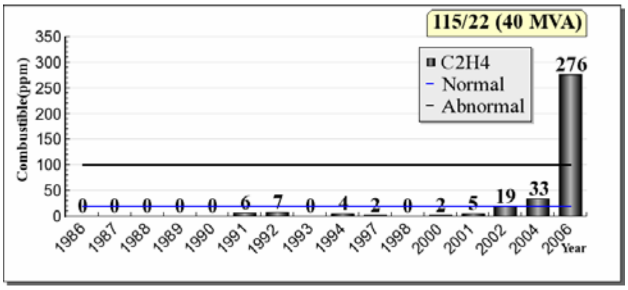

Fig.10. Relationship between Percentage of C_2H_4 and Age of the First Transformer.

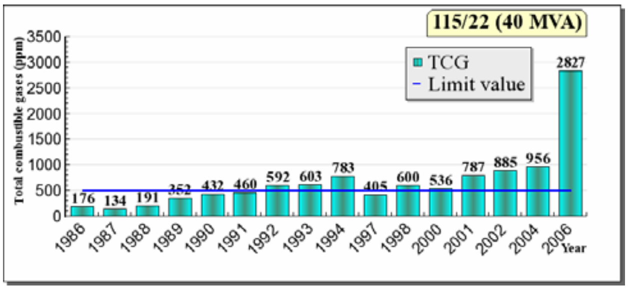

Fig.11. Relationship between the Total Combustible Gases and Age of the First Transformer.

- ***Rogers Ratio Method***

The calculation of gas ratios in Table 3 are compared with the reference table for result interpretation. Three of the four Ratio, CH_4/H_2, C_2H_6/CH_4 and C_2H_4/C_2H_6, fit in the category of over heating 200°-300°C.

Table 3. Rogers Ratio Result of the First Transformer

ROGERS RATIO METHOD APPLIED TO HISTORY CASES			
CH_4/H_2	C_2H_6/CH_4	C_2H_4/C_2H_6	C_2H_2/C_2H_4
0.9205	2.00	0.495	3.235

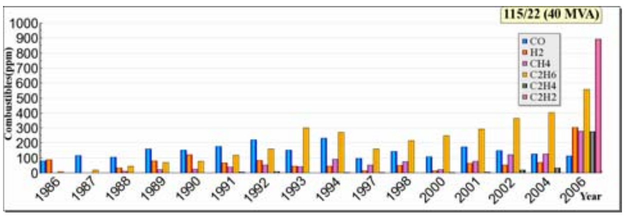

Fig.12. Relationship between Key Combustible Gases and Age of the First Transformer.

From the DGA history test results of this transformer in each year, the trend of generating combustible gas can be observed from Fig. 12. The increasing trend of combustible gases relative to service year of power transformer can be determined. Each combustible gas indicates the cause and severity of the problem occurred with power transformer.

The Second Transformer

The transformer is of rated 115/22kV, 25MVA, put in service in 1986. The transformer oil was sampled in February 13, 2001 and tested in March 9, 2001. The DGA test results are shown in Table 3.

Table 4. DGA Test Result in March 9, 2001 of the Second Transformer

GAS	VALUE	GAS	VALUE
O_2	4901	C_2H_6	0
N_2	30376	C_2H_4	0
CO_2	53048	C_2H_2	0
CO	1387	C_3H_6	0
H_2	1088	C_3H_8	0
CH_4	68	TCG	2543

The interpretation of the test result has been analyzed by the four methods.

- ***Key Gases Method***

From Fig. 13, the key gas is Hydrogen (H_2). If indicates the problem of corona in oil involving the cellulose insulation.

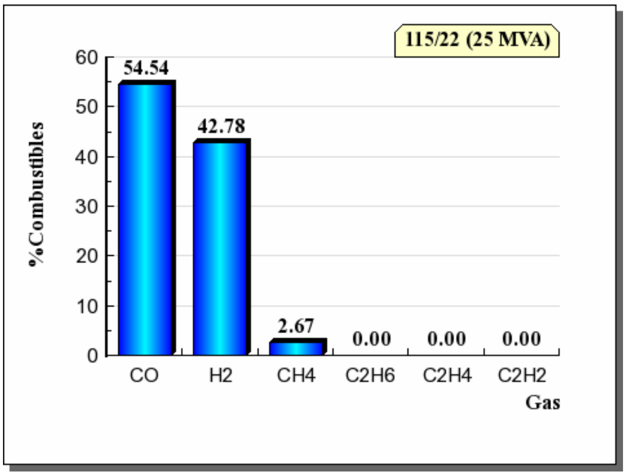

Fig.13. Relationship between Percentage of H_2 and Age of the Second Transformer.

- ***The Amount of Key Gases Method***

The amount of CO and H_2 exceeded the abnormal level in 2001 as shown in Fig. 14. The abnormal of CO indicates the problem of severe overloading, while the abnormal of H_2 indicates the arcing and corona problem.

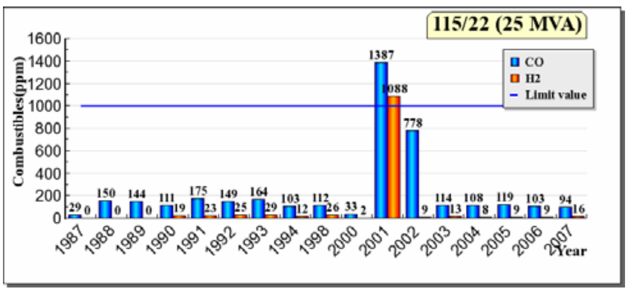

Fig.14. Relationship between Percentage of CO and H_2 and Age of the Second Transformer.

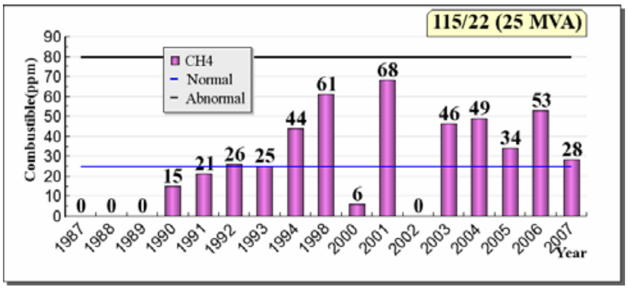

Fig.15. Relationship between Percentage of CH_4 and Age of the Second Transformer

The amount of CH_4, shown in Fig.15, exceeded the normal level since 1994 but still below the abnormal limit.

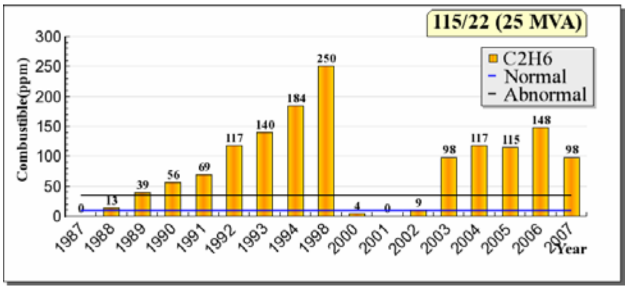

Fig.16. Relationship between Percentage of C_2H_6 and Age of Second Transformer.

The amount of C_2H_6 shown in Fig.16, it exceeded the abnormal limit since 1989 with the increasing trend. This indicates the problem of local overheating inside the transformer. The amount of C_2H_4 stays within the normal limit.

- ***Total Combustible Gases Method***

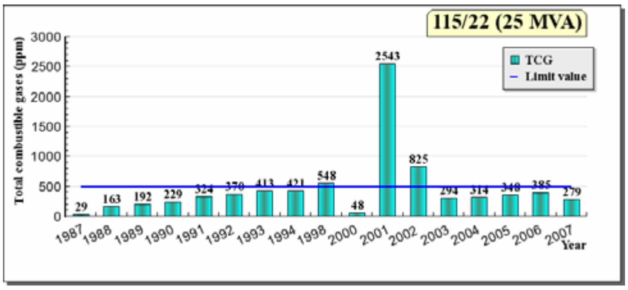

Fig.17. Relationship between total Combustible Gases and Age of the Second Transformer.

Fig. 17 shows the amount of total combustible gases with the slowly increasing trend with the age. The reaching 1000 ppm of TCG in 2001 indicates the significant decomposition. After reaching 1000 ppm, the increasing trend should be carefully observed. If the amount of combustibles remains constant, the decomposition process is stop due to the self-healing effect. If the amount increases, then the unit can be in the danger zone.

- ***Rogers Ratio Method***

The comparison of the calculated gas ratios with the reference table, four ratios fit in the category of partial discharge – corona problem.

Table 5. Rogers Ratio Result of the Second Transformer

ROGERS RATIO METHOD APPLIED TO CASE HISTORIES			
CH_4/H_2	C_2H_6/CH_4	C_2H_4/C_2H_6	C_2H_2/C_2H_4
0.0625	0	0	0

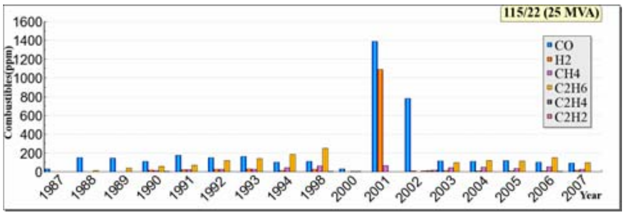

Fig.18. Relationship between Key Combustible Gases and Age of the Second Transformer

From the DGA history test results of this transformer in each year shown in Fig.18, the slow increasing trend of combustible gases relative to service year of power transformer can be determined. The abnormal level of combustible gases occurred in 2001 due to cellulose insulation and partial discharge problem.

5. CONCLUSION AND OUTLOOK

The failure statistic of power transformer was studied in this work by considering the scattering history data of power transformers. The data are collected from 107 units of rated 115/22kV power transformer with total 158 minor failures as well as 44 units of rated 230/115/22 kV power transformer with total 68 minor failures. The results from failure statistic analysis reveal that bushing and on-load tap changer have the highest minor failures due to leakage and defect/replace and defect/overhaul respectively.

The condition evaluation of power transformer was performed by using the Dissolved Gas Analysis method due to the readiness of data as well as knowledge and experience of operating personnel. The history test record was analyzed by the Key Gas method and then compared and verified by the Amount of Key Gas, Total Combustible Gas and Roger Ratio method. Two power transformers of rated 115/22kV 40MVA and 25MVA were presented to illustrate the problem of arcing in oil and cellulose insulation, partial discharge/corona respectively.

In this work, the critical components were determined. It could be conclude that the components should be more focused during maintenance. By knowing the causes of failure, the preventive measures can be determined to improve the reliability of the equipment. The procedure set up in this work can be further adapted to the other equipment in power system.

ACKNOWLEDGMENT

The authors would like to thank the Power Transformer Maintenance Department at EGAT for providing the data, close co-operation and strong support for this work.

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