System Development for Analysis of Insulating Oil Testing for Power Transformer Condition Assessment

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Abstract: Power transformer encounters electrical and thermal during operation, which is a cause of insulating material and oil degradation leading to a generation of gases dissolved in oil according to the fault type. Early detection of incipient fault is necessary to prevent power supply interruption. The objective of this paper is to develop a program for condition assessment of power transformer. The dissolved gas analysis (DGA) method consisting of the key gas, the total combustible gas, the amount of key gas, the Doernburg ratio, the Roger ratio, and the Duval triangle are adopted for analyzing the insulating oil testing result data. The program is developed using PHP and MySQL database working as a web application for systematical record, analysis, display, and interpreting the historical insulating oil testing results data. The results can be shown on a web browser. The sample insulating oil test results data are analyzed by the DGA methods to identify the actual condition of the power transformer. The results are presented that the DGA methods can be applied to support the power transformer maintenance planning.

***Keywords*—** dissolved gas analysis, condition assessment of power transformer, relational database, web application

I. Introduction

The power transformer has played an important role in the electric power system. Practically, after putting it in service, the condition of the power transformer has slowly deteriorated from its like-new condition. In addition, during operation, power transformers encounter abnormal stress such as lightning strikes, over-voltage., etc., which have a significant impact to accelerate the degradation of insulating material and oil resulting in the generation of gasses dissolved in oil according to different types of faults and finally unexpected failure might occur [1-3]. Power transformer failures are dangerous to operating personnel by a fire or an explosion, and environmental impact as oil leakage, and supply interruption in a wide area for a long time. These lead to impacts on the economy and stability, and reliability in operation. Early detect incipient fault can help to prevent unexpected failure therefore condition assessment of the power transformer is necessary.

Dissolved gas analysis (DGA) is widely used to detect incipient faults in oil-insulated electrical equipment [4]. According to the dissolved gas analysis method, the four possible fault types according to the key gases are as follows. Firstly, thermal fault produces gases such as hydrogen (H2), methane (CH4), ethylene (C2H2), and ethane (C2H6). Secondly, low-intensity partial discharge and very low-level intermittent arcing mainly produce gases such as H2, CH4, and C2H2. Thirdly, high intensity arcing produces high temperature in the power transformer leading to generating C2H2. Lastly, internal fault in insulating oil produces gases such as H2, CH4, C2H2, C2H4, and C2H6 [5], [8]. To early detect the incipient fault types, several diagnosis methods such as the Rogers and Dornenburg ratio methods [5], IEEE Standard C57.104 [6], IEC standard 60599 [7], and Duval Triangle method [4], [8-10] provided guidance for the interpretation of the DGA results to identify the type of fault. The dissolved gases in insulating oil are analyzed to identify the actual condition of the power transformer by using the interpreted methods.

Interpreting the insulating oil testing results is difficult especially when there are many testing results data and symmetrically recorded historical test results data are required. Therefore, the program for analysis of the insulating oil test results data is developed in this work. The

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program works as a web application for recording, analyzing, displaying, and interpreting the insulating oil test results. The interpretation methods are the key gas, total combustible gas, the amount of key gas, Doernberg ratio, roger ratio, and Duval triangle are chosen. The development of the program can be useful in the process of condition assessment and planning for power transformer maintenance in an electric power system.

II. Methodology

In this section, the DGA techniques for analysis of the insulating oil test results data are introduced.

A. Duval Triangle Method

CH4, C2H4, and C2H2 are calculated as percentages using Eq. (1)-(3).

$$\%CH_4 = CH_4 / \left(CH_4 + C_2H_4 + C_2H_2\right) \tag{1}$$

$$\%C_2H_2 = C_2H_2 / \left(CH_4 + C_2H_4 + C_2H_2\right) \tag{2}$$

$$\%C_2H_4 = C_2H_4 / \left(CH_4 + C_2H_4 + C_2H_2\right) \tag{3}$$

Each gas percentage is drawn in the Duval triangle map as shown in Fig. 1 by %CH4 line parallel to %C2H2 line, %C2H2 line parallel to %C2H4 line, and %C2H4 line parallel to %CH4 line. The fault types depend on the location of the intersection point of the three lines. The fault types in the Duval triangle method [4]-[8], corresponding to a coded list providing by IEC 60599 [9], are classified into six zones as shown in Fig 1.

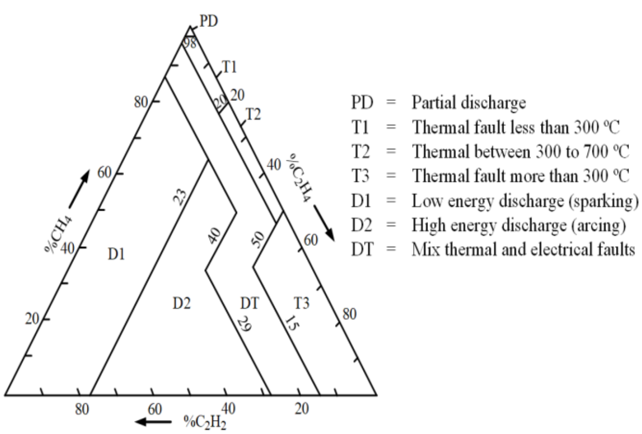
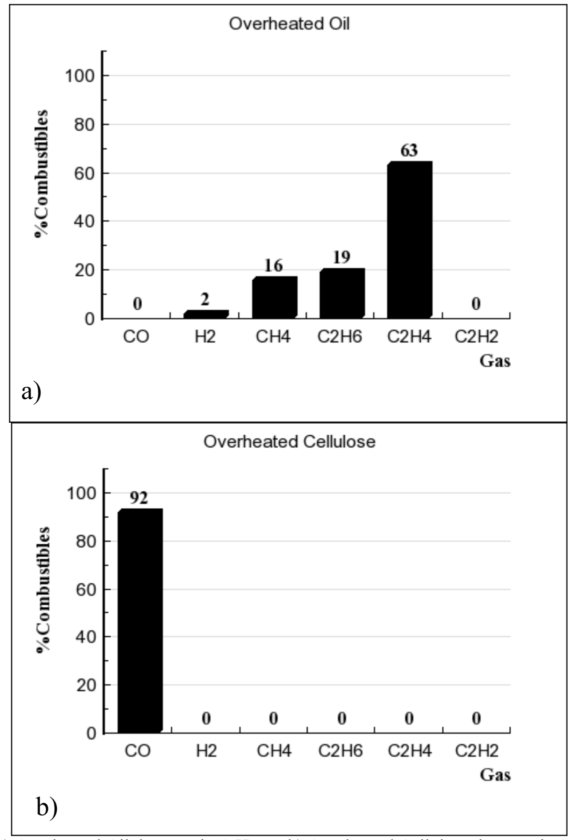
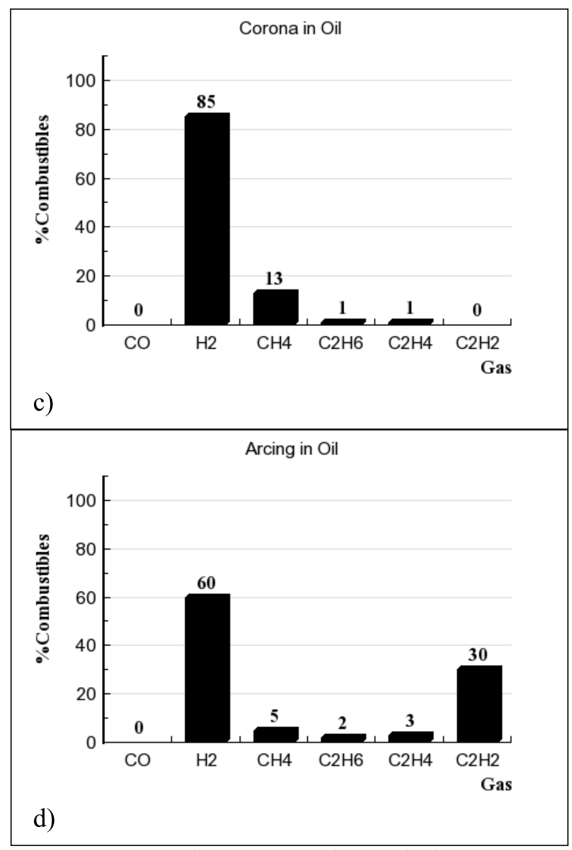


Fig. 1. Duval triangle map [4]



a) Overheated Oil, key gas is C_2H_4 b) Overheated Cellulose, key gas is CO



c) Partial discharge in oil, key gas is H_2 d) Arcing in oil key gas is C_2H_2

Fig. 2. Four possible fault types of Key gas method [2], [5]

B. Key Gas Method

The gases from the insulating oil test results are calculated as a percentage after that they are compared with the patterns of four possible fault types as shown in Fig. 2

C. Dornenburg Ratio Method

The possible three faults types, thermal decomposition, corona (low-intensity PD), and arcing (high-intensity PD) are indicated by using the four gas ratios of CH4/H2, C2H2/C2H4, C2H2/CH4, and C2H6/C2H2 as shown in Table I.

TABLE I
GAS RATIOS AND FAULT TYPES OF DORNENBURG RATIO METHOD [5], [6]

Suggested fault diagnosis	Ratio 1 (R1) CH_4/H_2		Ratio 2 (R2) C_2H_2/C_2H_4		Ratio 3 (R3) C_2H_2/CH_4		Ratio 4 (R4) C_2H_6/C_2H_2	
	Oil	Gas space	Oil	Gas space	Oil	Gas space	Oil	Gas space
1. Thermal decomposition	>0.1	>0.1	<0.75	<0.1	<0.3	<0.1	>0.4	>0.2
2. Corona (low-intensity PD)	<0.1	<0.01	Not significant		<0.3	<0.1	>0.4	>0.2
3. Arcing (high intensity PD)	>0.1 to <1.1	>0.01 to <1.0	>0.75	>0.1	>0.3	>0.1	<0.4	<0.2

D. Rogers Ratio Method

C2H2/C2H4, CH4/H2, and C2H4/C2H6 ratios are used to identify fault types as shown in Table II.

TABLE II
GAS RATIOS AND FAULT TYPES OF ROGER RATIO METHODS [5], [6]

Case	R2 (C_2H_4/C_2H_4)	R1 (CH_4/H_2)	R5 (C_2H_4/C_2H_6)	Suggested fault diagnosis
0	<0.1	>0.1 to <1.0	<0.1	Unit normal
1	<0.1	<0.1	<0.1	Low energy density arcing PD
2	0.1 to 0.3	0.1 to 1.0	>0.3	Arcing high energy discharge
3	<0.1	>0.1 to <1.0	1.0 to 3.0	Low temperature thermal
4	<0.1	>0.1	1.0 to 3.0	Thermal<700 °C
5	<0.1	>1.0	>3.0	Thermal>700 °C

E. The Amounts of Key Gas Method

The fault types are identified by considering the amount of key gas as detailed in Table III.

TABLE III
GAS RATIOS AND FAULT TYPES OF DORNENBURG RATIO METHOD [5], [6]

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

F. Total Combustible Gas (TCG)

The TCG [5], [6] considers a total of each combustible gas that is divided into four ranges. Consequently, the action advice for each range is presented in Table IV.

TABLE IV
ACTION BASED ON TCG METHOD [5]

Condition	TCG (ppm)	Interpretation
1	0 – 500	Satisfactory operation
2	501 – 1,000	Decomposition may be in excess of normal aging (suggesting a need for more frequent analysis)
3	>1,000	Decomposition is significant. The amount of combustible gases could establish a trend. If the amount of combustible gases trend is still constant, then a possible self-healing effect may take place. If the amount of combustible gases trend increase continuously, the transformer is in danger zone.
4	>2,500	Substantial decomposition. The power transformer condition should be carefully inspected to continue the operation or to repair. The monitoring system is recommended.

Each methodology is performed by analyzing the combustible gases from the testing results of the sample oil-insulated. The difference between each methodology is the type of gas used in the analysis such as the Roger ratio, Dornenburg ratio, and Duval triangle use the ratio of combustible gases to identify fault type while the key gas, the TCG, and the amount of key gas use combustible gas to identify fault type.

III. SYSTEM DEVELOPMENT

A. Tools for the Management System Development

The relational database model is applied to work in cooperation with the web application for systematical record, analysis, and display analysis results of testing results data. A web application is created by using working property between PHP and MySQL, therefore, the AppServ program consisting of Apache, PHP, MySQL, and PhpMyAdmin, is used for the management MySQL database. The working procedure of PHP and MySQL database is illustrated in Fig.3.

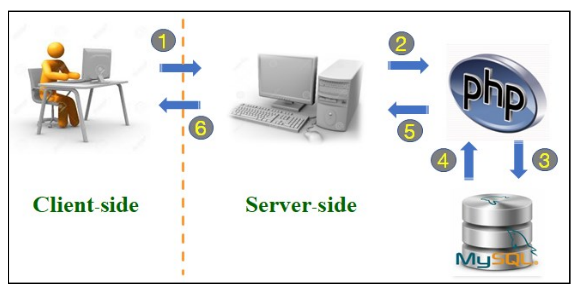


Fig. 3. Working property between PHP and MySQL

Firstly, the client-side requests PHP script from the server-side. Secondly, the server-side searches for the PHP script and comply it. Next, the PHP scribe connects with a set-up database and performs its function according to the written command. Eventually, the PHP script returns the requested data to the Apache server. Finally, the Apache server returns results to the client-side in HTML form.

B. The management Database System Development

Firstly, the corresponding technical data is gathered. The amount of dissolved gas (ppm) such as H2, CH4, C2H2, C2H4, C2H6, CO, and CO2 are inputted into the program for analysis in the next step. In addition, the corresponding data of the power transformer such as installed location, voltage rated, MVA rated, serial number, and day/ month/ year of installation are recorded. Secondly, to systematically record, analyze results, and display the analysis results. The relational database model is designed to work in cooperation with the web application. The E- R diagram is drawn to represent the relationship between Entity and Attribution. Then, the primary key and foreign key are used to link the relationship between Entity and Attribution. Thirdly, the program is created by a PHP language programming and MySQL database. Practically, the sample of the oil-insulated is tested in the laboratory. The testing results are recorded by the corresponding officer, which might be recorded in csv file. Therefore, the testing data can be directly imported into the database or input the data through the webpage. For this work, the received testing data is a csv file therefore it is directly imported to the database. After the program gets gas input data from the first step, the DGA result of insulating oil will be evaluated. The program is coded according to the methods mentioned before. The flowcharts are presented in Fig. 4 to Fig 7, which is shown how the program evaluates the actual condition of the power transformer. Lastly, after, the program analyzes the insulating oil test result. The results will be displayed through a web browser, for example, as shown in Fig. 8.

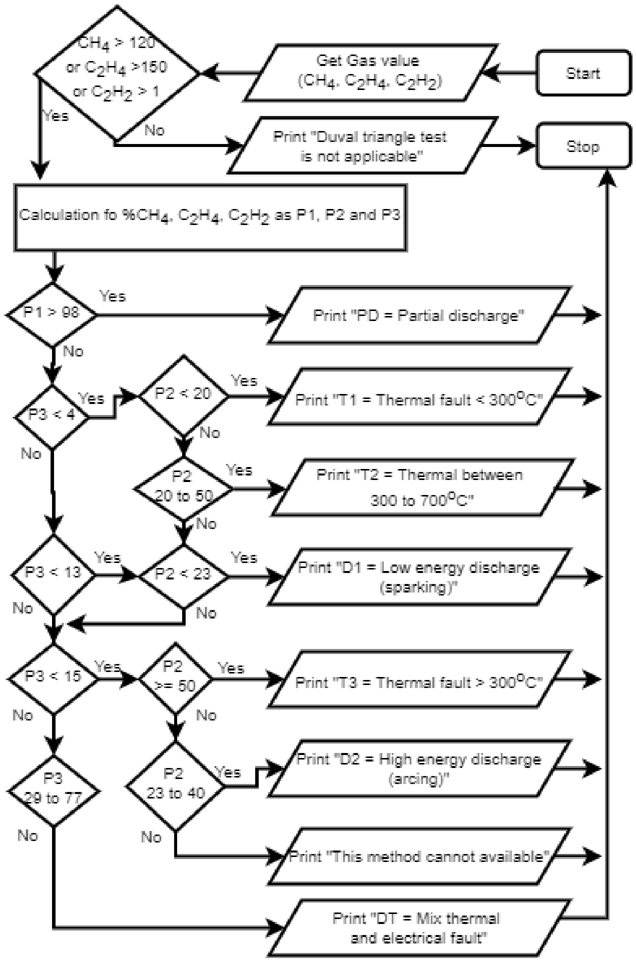


Fig. 4. Flowchart of coding according to Duval triangle method

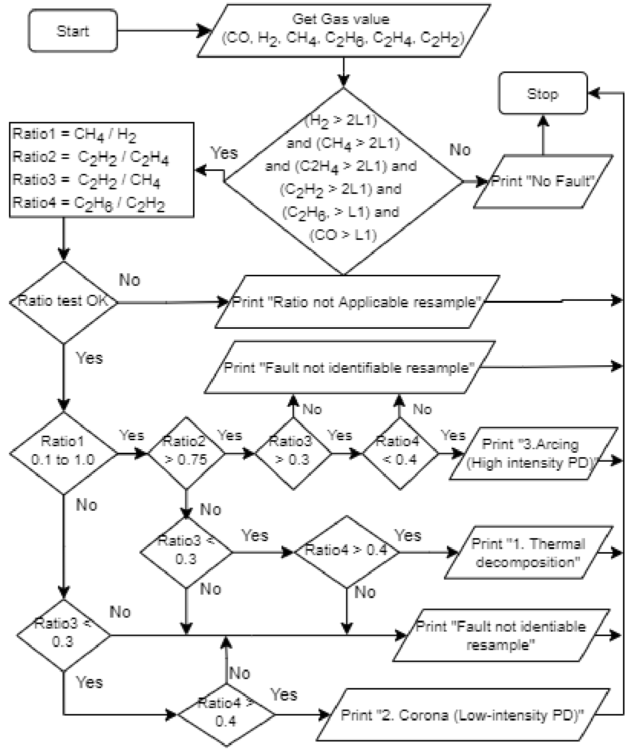


Fig. 5. Flowchart of coding according to Doernenburg ratio method

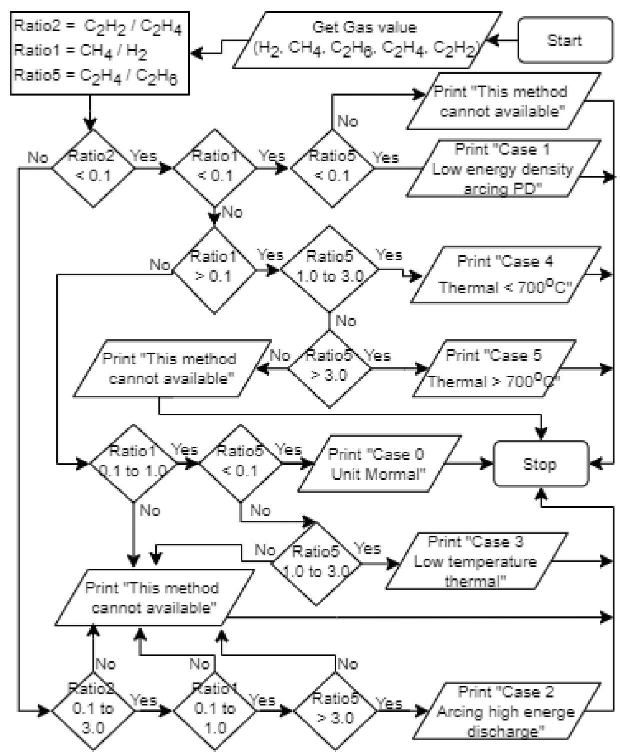


Fig. 6. Flowchart of coding according to Roger ratio method

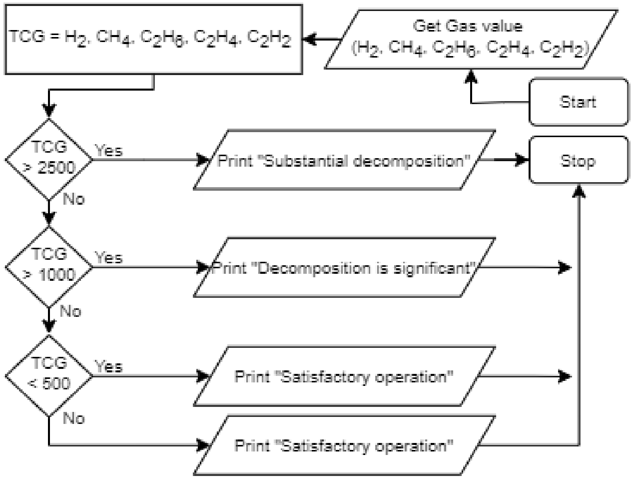


Fig. 7. Flowchart of coding according to TCG method

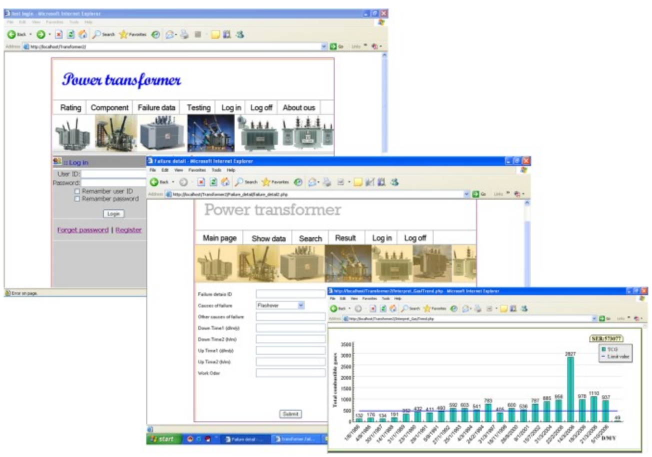


Fig. 8. Example of display results

C. The relational database design

The relational database is designed to systematically record the historical testing results data of the insulating oil. Firstly, the available technical data of the power transformer is analyzed for the systematical record. The technical data such as general data of the power transformer including item, date of record, location, region, position, phase, serial number, MVA rating, HV rating, LV rating, Fist energize, and Manufactures. The testing data such as testing ID, serial number, KV rating, MVA rating, year of transformer, sampling date (d/m/y), oxygen (O2), Nitrogen (N2), carbon dioxide (CO2), carbon monoxide (CO), Hydrogen (H2), Methane (CH4), Acetylene (C2H6), temperature, water, and transformer ID. The technical data is presented in the E-R diagram. In this diagram, the structure of the database is presented by entities, attributes of entities, and the relationship between entities. The serial number of the power transformer is used to be a foreign key to link the relationship between each table. The E-R diagram is shown in Figure 9.

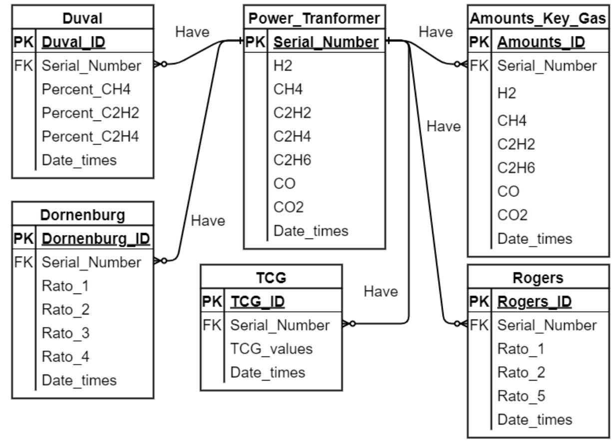


Fig. 9. The E-R diagram of the database design

IV. Results and Analysis

An example of historical testing data of insulating oil is obtained from the center of excellence in Transmission Technology, Electric Generating Authority of Thailand as shown in Table V for the power transformer rating 115/22 kV, 40 MVA is selected in the analysis. The power transformer is put in service in the year 1984. The insulating oil was sampled on 10/2/2006. The dissolved gases were extracted from the sample of the insulating oil in the laboratory and they were recorded by the corresponding officer. The dissolved gases were obtained on 22/2/2006.

TABLE V
THE TEST RESULTS OF SAMPLE MODEL RATING 115/25KV, 40MVA

Gas	CO	CO_2	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2
Value (ppm)	113	2,565	302	278	557	276	893

By applying the key gas method, the gases are calculated in percentage and compared with the faults pattern, which is shown arcing in oil, the key gas is C2H2 as shown in Fig. 10.

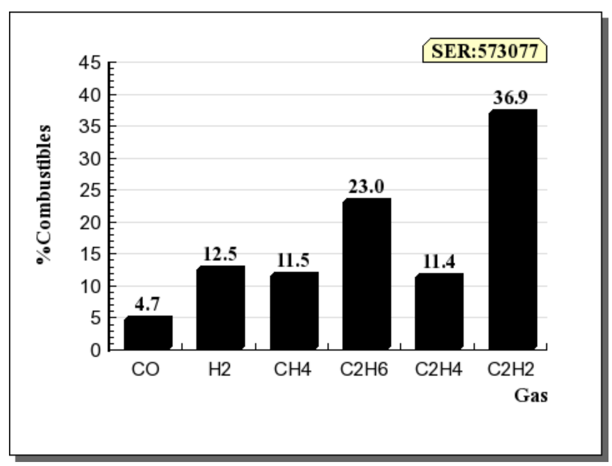


Fig. 10. Fault pattern interpreting by the key gas method

By applying the amount of key gas method, the CO is at a normal level while H2 exceeded the normal level but does not exceed the abnormal level. However, there is a trend occurring an arcing in oil and corona. The historical testing result data is shown that the CH4 is greater than the normal level in the year 2002.

The highest value occurred in the year 2006, as shown in Fig. 11, indicating the sparking in insulating oil occurred. The C2H4 is greater than the abnormal level in the year 2004 and the highest level in the year 2006 as shown in Fig. 12, which is indicated severe overheating.

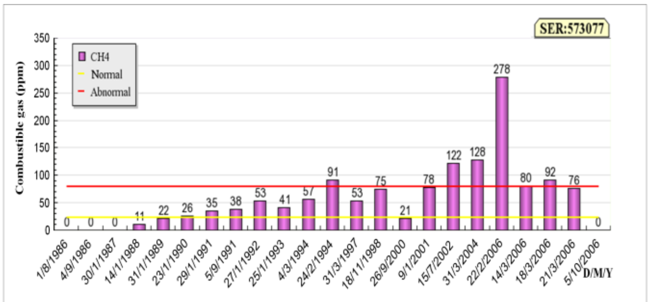


Fig. 11. The amount of CH4 from by the amount of key gas method

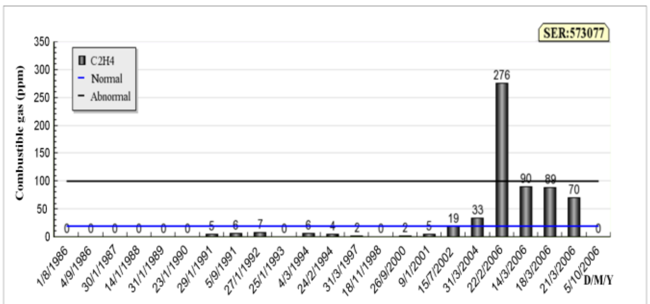


Fig. 12. The amount of C2H4 from by the amount of key gas method

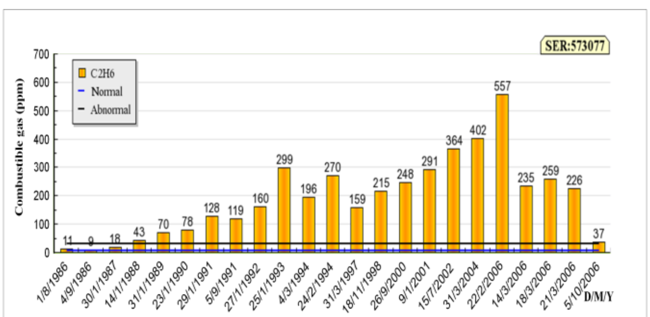


Fig. 13. The amount of C2H6 by the amount of key gas method

The number of C2H6 has exceeded the abnormal limit since 1988 with an increasing trend as seen in Fig. 13. This indicates the problem of local overheating inside the power transformer

By applying the total combustible gas method, the amount of TCG is greater than 2,500 ppm in the year 2006, which is shown that the amount of the dissolved gas in insulating oil substantial decomposition. The power transformer condition should be carefully inspected. The amount of TCG is shown in Fig. 14.

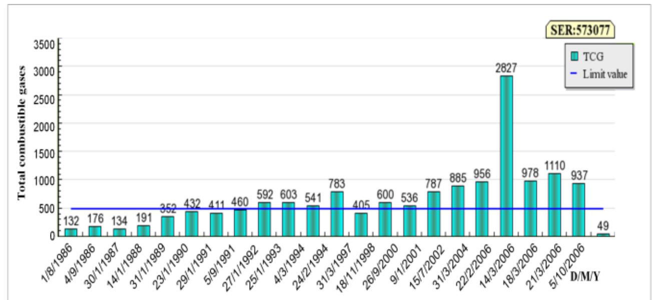


Fig. 14. The amount of TCG and the power transformer lifetime

By applying the Doernenburg ratio method, the gas ratios are shown in Table VI, which is shown occurring an arcing in the insulating oil. While the interpretation by Roger ratio method as shown gas ratio in Table VII, the power transformer is a normal condition.

TABLE VI
THE GAS RATIOS ACCORDING TO THE DOERNBURG RATIO METHOD

Ratio	R1(CH_4/H_2)	R2(C_2H_2/C_2H_4)	R3(C_2H_2/CH_4)	R4(C_2H_6/C_2H_2)
Value	0.92	3.23	3.21	0.62

TABLE VII
THE GAS RATIOS ACCORDING TO THE DOERNBURG RATIO METHOD

Ratio	R1(CH_4/H_2)	R2(C_2H_2/C_2H_4)	R5(C_2H_4/C_2H_6)
Value	0.92	3.23	0.49

By applying the Duval triangle method, the percentages of the three gases are shown in Table VII. The fault is in zone D1, which means occurring of sparking.

TABLE VIII
THE GAS PERCENTAGE ACCORDING TO THE DUVAL TRIANGLE METHOD

Gas	CH_4	C_2H_4	C_2H_2
Value	278	276	893
%ppm	19.21	19.27	61.71

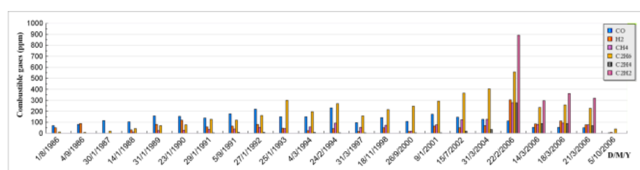


Fig. 15. Relationship between key combustible gases and age of the example power transformer model

From the DGA historical test results for each year, the trend of generating combustible gas can be observed in Fig. 15. The increasing trend of combustible gases relative to the service year of the power transformer can be determined. The abnormal level of combustible gases occurred in 2006 due to arcing in the oil problem. Each combustible gas indicates the cause and severity of the problem that occurred with this power transformer.

V. CONCLUSION

The program works as a web application to systematically record, analyze, and display results. The dissolved gas analysis (DGA) techniques are adopted to identify the fault type for condition evaluation of the actual condition of the power transformer. The developed program is useful for maintenance planning activities to support a decision making the repair or replace the power transformer and online monitoring of the power transformer condition in future work.

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