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A New Approach with Three Dimension Figure and ANSI/IEEE C57.104 Standard Rule Diagnoses Transformer's Insulating Oil

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Abstract

The dissolved gas analysis (DGA) is an effective method for detecting incipient faults in immersed oil power transformers. In this paper, we investigate the DGA methods and employ the ANSI/IEEE C57.104 standards (guidelines for the interpretation of gases generated in oil-immersed transformers) and IEC Basic Gas Ratio method to design a heuristic power transformer fault diagnosis tool in practice. The proposed tool is implemented by a MATLAB program and it can provide users a transformer diagnosis result. The user keys in the data of H2, CH4, C2H2, C2H4, and C2H6 gases dissolved from the immersed oil transformer's insulating oil measured by ASTM D3612. The analyzed results will be represented in texts and figures. The real measured data of the transformer oil were taken from Taiwan Power Company substations to verify the validation and accuracy of the developed diagnosis tool.

Keywords

Power Transformer Diagnosis, Dissolved Gas Analysis, Total Combustible Gases, Distribution Substation (D/S)

1. Introduction

Immersed-oil power transformers in the power system play an important role as voltage conversion. The transformer's insulating oil can cool the transformer down and strengthen the ability of power supply. A transformer

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fault will cause electricity interruption and may result in a serious problem. Therefore, detection of transformer's fault is very important task. The insulating oil gas analysis (DGA) is a good way to diagnose the transformer fault and has been widely used by many power companies in the world. This is because that the insulating oil analysis can predict incipient faults via the analysis of the gases generated from the insulating oil. If the transformer's fault can be diagnosed accurately, and then the transformer will be well maintained, the electricity interruption caused by transformer's fault can be avoided.

The insulating oil measurement is via chromatography instrument (ASTM D3612). The measured data of nine kinds of gas, namely Ethane (C_2H_6), Hydrogen (H_2), Methane (CH_4), Carbon Dioxide (CO_2), Ethylene (C_2H_4), Acetylene (C_2H_2), Carbon Monoxide (CO), Nitrogen (N_2), and Oxygen (O_2) can be obtained [1]. Any measured data of nine kinds of gas being larger the standard criterion of ASNI/IEEE C57.104 indicated that we have to check what happens in the transformer. In this paper, we investigate the DGA methods and employ the ANSI/IEEE C57.104 Standard Rule and IEC Basic Gas Ratio method to develop a heuristic diagnosis tool which is carried out by a MATLAB program. The user only keys in the measured data of H_2, CH_4, C_2H_6, C_2H_4, and C_2H_2 and the developed diagnosis tool can provide a diagnosis result by texts and figures.

2. Transformer Fault Diagnosis

Total Combustible Gases are made up of H_2, CH_2, C_2H_6, C_2H_4, C_2H_2 and CO, and its definition as follows, is shown in formula (1) (unit ppm):

$$\mathrm{TCG} = \frac{\mathrm{H_2} + \mathrm{CH_2} + \mathrm{C_2H_6} + \mathrm{C_2H_4} + \mathrm{C_2H_2} + \mathrm{CO}}{10^6} \tag{1}$$

The immersed oil transformer's insulating oil along with the transformer operating time and the measured of the cyclical time has made vital relations with its life-span, however its increase value on IEEE C57.104 standard, as shown in formula (2):

$$R = \frac{(S_T - S_O) \times V \times 10^{-6}}{T} \tag{2}$$

where, R is increase of the TCG value (a milliliter/day), S_T is testing value, S_O is previous value, V is measured from the transformer's volume as well as T is measured from the duration of days. So the quantity of the TCG, rely on the R's value which is classified "Normal", "Attention", "Abnormal", and "Danger" etc., four kinds of symptom shown in **Table 1**.

Be based on Dissolved Gas Analysis (DGA), the value of insulating oil has been diagnosed either normality or abnormality in the body of transformer. In recent years, a lot of techniques have been developed to predict diagnosis for the transformer latent failure points by the gas content, such as the Key Gas method, Duval triangle method as well as Dornenberg method, Roger method, Liner SVM diagnosis etc., this paper took the Diagnosis of IEC Basic Gas Ratio method and ANSI/IEEE Standard Rule to design a Transformer Fault Diagnosis Tool by the MATLAB program which described next sections below.

2.1. The IEC Basic Gas Ratio Method

The IEC Basic Gas Ratio method uses 3 sets gas ratios C_2H_2/C_2H_4, CH_4/H_2, and C_2H_4/C_2H_6 as base to engage in diagnosis. Each ratio is distinguished 6 fault's conditions such as Partial discharges, Discharge of low energy, Discharge of high energy, Thermal fault t < 300˚C, Thermal fault 300˚C < t < 700˚C, and Thermal fault t > 700˚C. The result according to IEC method is shown in **Table 2**. The relationship between the fault type and the gas ratio is shown in **Table 2**. Faults often start as incipient, low energy faults which may develop into more serious higher energy or higher temperature faults. When a fault is detected, it is important to determine the trend in the rate of increase of the gas. An increase in gas values of more than 10% per month above the normal values will indicate that the fault is active. It is also important to determine the trend in the occurrence of different types of faults, and to detect early, any deterioration towards a more serious fault [2].

2.2. Diagnosis of Specification for ANSI/IEEE C57.104 Standard

According to the Diagnosis of Specification for ANSI/IEEE C57.104 Standard, the anomalous properties values

Table 1. Periodic table of examination for TCG [1] (unit: ppm).

Case	TCG	Increase	Again Measures Duration	Suggestion
		>30	Month	Normal
Case 1	≤720	10 - 30	Season	Normal
		<10	Year	Normal
		>30	Month	Attention
Case 2	721 - 1920	10 - 30	Month	Attention
		<10	Season	Attention
		>30	Week	Abnormal
Case 3	1921 - 4630	10 - 30	Week	Abnormal
		<10	Month	Abnormal
		>30	Day	Danger
Case 4	>4630	10 - 30	Day	Danger
		<10	Week	Danger

Table 2. The diagnosis of IEC basic code [2].

Case	Characteristic Fault	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6
PD	Partial Discharges	NS1	<0.1	<0.2
D1	Discharge of Low Energy	>1	0.1 - 0.5	>1
D2	Discharge of High Energy	0.6 - 2.5	0.1 - 1	>2
T1	Thermal Fault t < 300˚C	NS1	>1 but NS1	<1
T2	Thermal Fault 300˚C < t < 700˚C	<0.1	>1	1 - 4
T3	Thermal Fault t > 700˚C	<0.22	>1	<4

Note: NS1 stand for No Significance.

from decomposition of the insulating oil were shown in **Table 3**.

3. The New Diagnosis Approach for in Practice

This Paper Follows the Design Flow Chart (Shown in Figure 1)

The diagnosis tool of insulating oil can be diagnosed by well usage of different method and specification after incorporating some kinds of human experience. The flow chart of the proposed diagnostic method is shown in **Figure 1**. With well-designed man-machine interface, the developed program can be implemented by computer to avoid man error and achieve more reliable diagnosis result.

For more simple, precise, and effective to diagnose, I read lots of diagnosis's approach of transformer's insulating oil which were such good paper as "Support Vector Machine-Based Fault Diagnosis of Power Transformer" [4] and "Duval Triangle: A Noble Technique for DGA in Power Transformer" [5], and etc. Eventually, from those methods and approaches were appraised carefully, this paper takes ANSI/IEEE C57.104 Standard Rule and IEC Basic Ratio methods to design the program. The goal is it cans double check to complete accurate diagnosis.

The accuracy of interpretable plots by concept of digital rule establishes during implementation after input the concentration of H_2, CH_4, C_2H_6, C_2H_4, and C_2H_2. This paper designs a set of highly fast way to diagnose of transformer incipient fault by IEC Basic Gas Ratio and the Standard of ANSI/IEEE C57.104 diagnosis method. From the report's from the obtained texts of the ANSI/IEEE C57.104 standard diagnosis and the figure of IEC Basic Gas Ratio to judge what was in body of transformer.

Table 3. Gas content in oil diagnostic [3] (unit: ppm).

Name	Content Value	Property	Name	Content Value	Property
H_2	>1801	Danger	CH_4	>1001	Danger
	>701	Abnormal		>401	Abnormal
	>101	Attention		>121	Attention
	<100	Normal		<120	Normal
C_2H_6	>151	Danger	C_2H_4	>201	Danger
	>101	Abnormal		>101	Abnormal
	>66	Attention		>51	Attention
	<65	Normal		<50	Normal
C_2H_2	>35	Danger	C_2H_2	>2	Attention
	>10	Abnormal		< 1	Abnormal

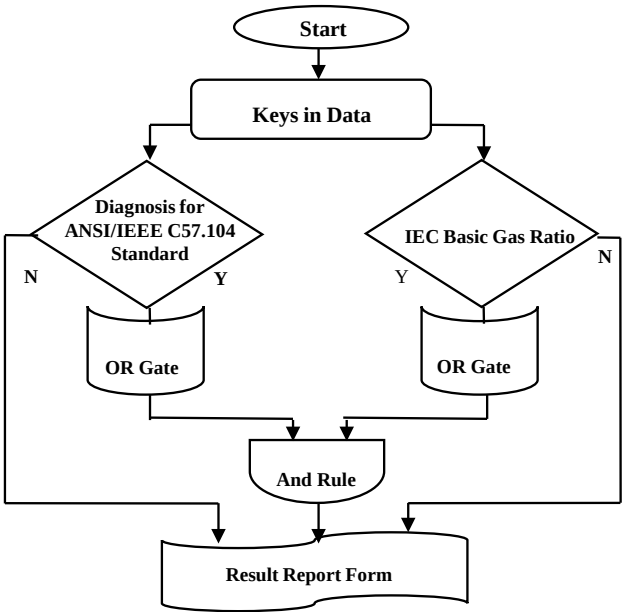

Figure 1. The flow chart of the MATLAB program.

4. Diagnostic Practices and Verification

4.1. Ba Dou D/S #4DTr Case [6]

On March 22nd, 2012 Taiwan Power Company Ba Dou D/S # 4DTr's insulating oil, inspected these gas component content Hydrogen, Methane, Ethane, Ethylene, and Acetylene data are described (in **Table 4**), this data (before repair and after repair) were used the program of MATLAB, shown (in **Table 5** & in **Table 6**) to obtain the result of the judgment by text of ANSI/IEEE standards and plots of the IEC Basic Gas Ratio diagnosis method.

4.2. Digital Logic

Keeping in mind when computers work on digital gate that high or low voltage is considered as 1 or 0. So that using these high or low data is represented for 1 or 0. Electronic circuits must be designed to manipulate these

Table 4. Ba Dou D/S #4DTr gas data (unit: ppm).

Date	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2
2012.03.22 Before Repair	100	149	41	401	5.3
2012.05.21 After Repair	7	6	44	18	0

Table 5. Transformer fault diagnosis tool (Ba Dou D/S #4DTr before repair).

Diagnosis for ANSI/IEEE C57.104 Standard

$^{**}H_2$ == Normal

$^{**}CH_4$ == Attention

$^{**}C_2H_2$ == Normal

$^{**}C_2H_4$ == Danger

$^{**}C_2H_6$ == Normal

Diagnosis for IEC Basic Gas Raito

$^{**}C_2H_2/C_2H_4$ == Normal

$^{**}CH_4/H_2$ == Discharge of High Energy

$^{**}C_2H_4/C_2H_6$ == Temperature Fault > 700˚C

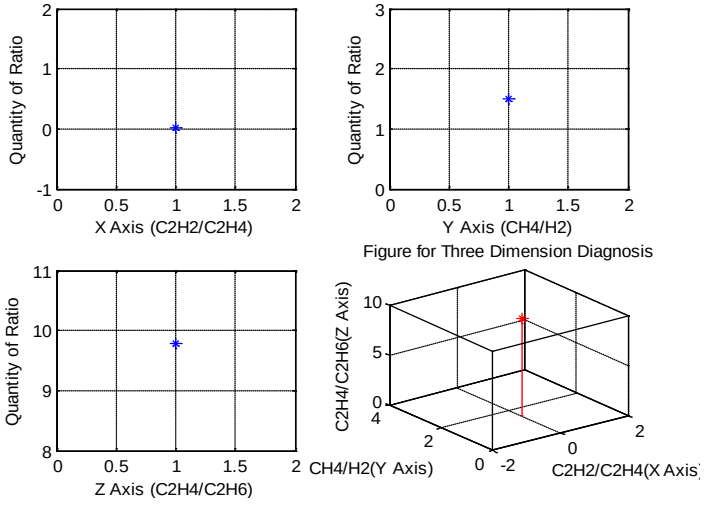

Table 6. Explain for digital symbol with regulating diagnosis.

Name/Ratio	Result of Diagnosis	Digital Symbol	Result of Diagnosis	Digital Symbol
H_2	Danger	1	Abnormal, Attention, Normal	0
CH_4	Danger	1	Abnormal, Attention, Normal	0
C_2H_6	Danger	1	Abnormal, Attention, Normal	0
C_2H_4	Danger	1	Abnormal, Attention, Normal	0
C_2H_2	Danger	1	Abnormal, Attention, Normal	0
		Partial Discharges		1
		Discharge of Low Energy		1
C_2H_2/C_2H_4		Discharge of High Energy		1
CH_4/H_2		Thermal Fault t < 300˚C		1
C_2H_4/C_2H_6		Thermal Fault 300˚C < t < 700˚C		1
		Thermal Fault t > 700˚C		1

positive and negative pulses into meaningful logic (in **Table 7**). Logic gates are the building blocks of digital circuits. Combinations of logic gates form circuits designed with specific tasks in mind [7]. This paper of blocks of digital circuits is shown (in **Figure 2**).

To ensure power supply stable quality and safety, the gases of the insulating oil was shown by Truth Table of logic (in **Table 8**), on 22nd March, 2012 Ba Dou D/S #4Dtr to fulfill the transformer body maintenance which was found out a losing screw which is shown (in **Figure 3**) [6]; Especially, on May 21st, 2012 Taiwan Power Company Ba Dou D/S #4DTr's insulating oil, inspected these gas component content Hydrogen, Methane, Ethane, Ethylene, and Acetylene data are described (in **Table 4**), this data (after repair) was used the program of MATLAB, shown (in **Table 9**) to obtain the result of the judgment. To justify the program provides a quick diagnosis, the results can be used as a tool of transformer maintenance.

4.3. Take Some Case to Confirm

Taking some case (in **Table 10**, **Table 11**) from abnormality of transformer's insulating oil those were confirmed through Taiwan Power Company, then these cases were taken to verify the program in practical.

5. Conclusion

As we know that, how to detect the transformer fault quickly and accurately is not an easy job. In this paper, we have investigated the DGA methods and developed a quick method to diagnose the malfunction of power transformers by using ANSI/IEEE C57.104 diagnosis specification and IEC Basic Gas Ratio method. We have developed the transformer fault diagnosis tool by a MATLAB program. The real measured data of the transformer oil taken from Ba Dou D/S # 4DTr transformer of Taiwan Power Company are used to verify the validation and accuracy of the developed diagnosis tool. This tool will be useful for engineers and technicians who are in charge of transformer's maintenance.

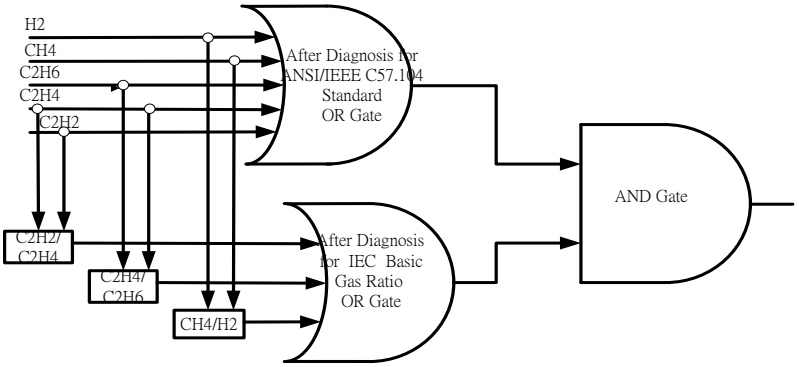

Figure 2. Program for digital flow chart.

Figure 3. A losing screw.

Table 7. OR & AND gate truth table [7].

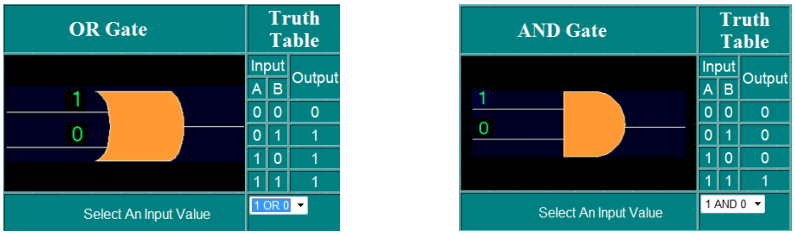

Table 8. Truth table for Ba Dou D/S # 4DTr's insulating oil.

Date	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	C_2H_2/C_2H_4	C_2H_4/C_2H_6	CH_4/H_2	OUT
2012.3.22	0	0	0	1	0	0	1	1	1
2012.5.21	0	0	0	0	0	0	1	1	0

Table 9. Transformer fault diagnosis tool (Ba Dou D/S #4DTr after repair).

Diagnosis for ANSI/IEEE C57.104 Standard

$^{**}H_2$ == Normal

$^{**}CH_4$ == Normal

$^{**}C_2H_2$ == Normal

$^{**}C_2H_4$ == Normal

$^{**}C_2H_6$ == Normal

Diagnosis for IEC Basic Gas Raito

$^{**}C_2H_2/C_2H_4$ == Normal

$^{**}CH_4/H_2$ == Discharge of Low Energy

$^{**}C_2H_4/C_2H_6$ == Partial Discharge

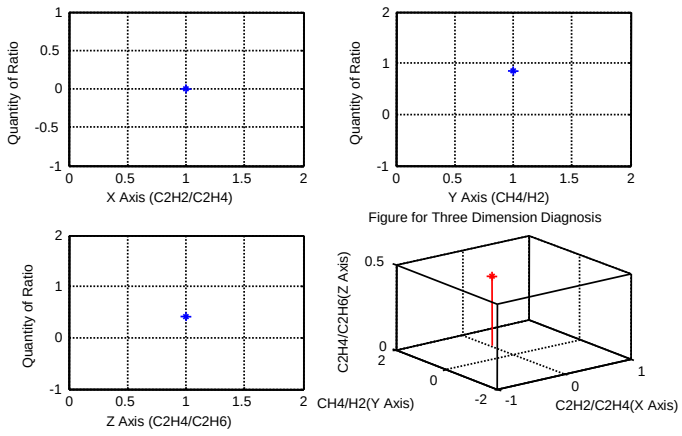

Table 10. Some normality and abnormality of transformer gas data in practical (unit: ppm).

Date	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	TCG
C1 (2007.05.10)	44	41	88	7	10.1	57	247
C2 (2010.09.05)	140	54	79	21	53.8	35	388.1
C3 (2011.08.03)	181	74	84	58	51.4	171	619
C4 (2011.12.26)	935	271	116	330	420	128	2200
C5 (2012.05.10)	239	346	78	787	24	312	1786
C6 (2012.07.08)	48	694	356	1077	0.4	36	2211
C7 (2013.09.23)	133	211	66	384	1.9	411	1207

Table 11. Implementation of the results of the program with stand for digital rule in practical.

Case/Name	Diagnosis for ANSI/IEEE C57.104								Diagnosis for Program out	Repair State
	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	C_2H_2/C_2H_4	C_2H_4/C_2H_6	CH_4/H_2		
C1	0	0	0	0	0	1	0	1	0	N
C2	0	0	0	0	1	1	1	1	1	Ac
C3	0	0	0	0	1	1	1	0	1	Ac
C4	0	0	0	1	1	1	1	1	1	Pd
C5	0	0	0	1	0	0	1	1	1	Ac
C6	0	0	1	1	0	0	1	1	1	Pd
C7	0	0	0	1	0	0	1	1	1	Pd

Symbols: N (Normal), Ac (Arc), Pd (Partial Discharge). 1 (Program out for 1), 0 (Program out for 0), C1 (Case1), C2 (Case2), C3 (Case3), C4 (Case4), C5 (Case5), C6 (Case6), C7 (Case7).

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