Engineering, 2015, 7, 203-211
Published Online April 2015 in SciRes. http://www.scirp.org/journal/eng
http://dx.doi.org/10.4236/eng.2015.74016

A Hybrid Diagnosis Approach on Transformer's Insulating Oil

Ming-Jong Lin

Department of Electronic Engineering, Southern Taiwan University of Science and Technology, Tainan City, Taiwan
Email: l430107@yahoo.com.tw, u018794@taipower.com.tw

Received 12 March 2015; accepted 7 April 2015; published 8 April 2015

Abstract

The immersed-oil power transformer is so vital equipment in power system that maintenance-engineers take more monitor from transformer's insulating oil to diagnose what is condition of operation. Then the dissolved gas analysis (DGA) is known for an effective technique on detecting incipient faults in oil-immersed power transformers. In this paper, a practical method is presented which consists of the Roger & Dernenber Ratio Methods, the Linear SVM diagnosis, the Key Gas method and the Specification ANSI/IEEE C57.104 Standard. Thus, incipient faults in power immersed-oil transformers can be directly identified by a report's form which is so easy understood that we can accurate of diagnosis transformer. The user only keys in the measured data of main gases such as H_2, CH_4, C_2H_2, C_2H_4, C_2H_6, and CO those gases were must decompose via ASTM-D3612. The diagnosis result was showed in texts. This paper was taken some data from Taiwan and Siemens Power Company to verify the program that was validation and accuracy of the transformer's insulating oil diagnosis tool.

Keywords

Power Transformer Diagnosis, Dissolved Gas Analysis, Total Combustible Gases, ANSI/IEEE C57.104 Standard

1. Introduction

Immersed-oil power transformer's insulating oil, to strengthen insulation and cut temperature of operation down of transformer for ability of supply. If the Dissolved Gas Analysis (DGA) of insulating oil is not to meet maintenance code that it will pose transformer great threaten. Thus the diagnosis of insulating oil is regarded as an important task. The insulating oil has to through chromatography instrument (ASTM D3612) yield some gases

How to cite this paper: Lin, M.-J. (2015) A Hybrid Diagnosis Approach on Transformer's Insulating Oil. *Engineering*, **7**, 203-211. http://dx.doi.org/10.4236/eng.2015.74016

such as 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) and so on. Then those gases Hydrogen (H_2), Methane (CH_4), Ethane (C_2H_6), Ethylene (C_2H_4), Acetylene (C_2H_2), and Carbon Monoxide (CO) are named Total Combustible Gas (TCG) [1]. The dissolved gas analysis (DGA) is a common effective technique on detecting incipient faults in oil-immersed power transformers. The present work investigated the DGA methods and employed the ANSI/IEEE C57.104 Standard Rule, the Linear SVM Method, the Roger & Doernenber Ratios, and the Key Gas Method to develop a fast immersed-oil power transformer diagnosis approach which was named "a hybrid diagnosis approach". The major character of the program is simultaneously shown what the four types diagnosed results on a report's form by texts. The Hybrid diagnosis approach was validated and confirmed so easy and analysis to use at any condition of transformer insulating oil. Then the approach is proved from a lot of causes which is efficiency and accuracy.

2. Transformer Fault Diagnosis

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

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

When the immersed oil transformer's insulating oil is along with the transformer operating time and the measured of the cyclical time has a vital relation with its life-span. If the diagnosis of time and approach were unapt that will pose a great threat with transformer.

2.1. The ANSI/IEEE C57.104 Standard Rule

When it comes diagnosis of transformer's insulating oil. Every electrical engineer is required to take the ANSI/ IEEE C57.104 Standard Rule as base to compare with analysis because ANSI/IEEE C57.104 Standard Rule is strictly standard and the best effective diagnosis tool for Immersed-oil power transformer's insulating oil.

The ANSI/IEEE C57.104 Standard Rule has shown H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, and CO, then any gas of content is from 0 to ∞ disguised to four kinds symptom—"Normal", "Attention", "Abnormal", and "Danger", taking H_2 for a sample, its content value is less property Normal, over 101 property attention, over 701 property Abnormal, or over 1801 property Danger. The Four kinds of symptom were shown in **Table 1**. It is widely applicable in diagnosis of transformer insulating oil around the world.

Table 1. Gas content in oil diagnostic [2], 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	CO	>1400	Danger
	>10	Abnormal		>571	Abnormal
	>2	Attention		>351	Attention
	<1	Normal		<350	Normal

2.2. The Roger and Dornenburg Ratio Method

The Roger's ratio method and Dornenburg's ratio method are recognized as an effective tool for diagnosis of transformer's insulating oil. Ones methods are accord with the Standards IEC 60599 and IEEE C57.104 as the framework of the diagnosis and transformer maintenance system. They take the gas ratios such as CH_4/H_2, C_2H_2/C_2H_4, C_2H_2/CH_4, C_2H_6/C_2H_2 and C_2H_4/C_2H_6 for base to compare diagnosis. Each set the value of percentage is shown in **Table 2** [3] [4]. The diagnosis principles of the Roger and Dornenburg ratio methods list in **Table 2**.

2.3. The Linear SVM Diagnosis

As of 1999, Japanese electric Association collected 1033 transformers fault of record to analysis what was up from transformer's insulating oil diagnosis. Then it is developed to obtain an insulating oil diagnostic method by Support Vector Machine theory which was called "The Linear SVM (Support Vector Machine) diagnostic method", the method will take H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, and CO of the component data that involve into the formula with the value of the coefficient (Z) to calculated and diagnose inside the condition of transformer, the coefficients of the formula shown in **Table 3** [2]. The result of Z is "positive", which means transformer operation normal; on the contrary, Z is "negative", which may operate in abnormalities of condition. The abnormality's phenomenon was classified "Overheating", "Electric Arc", "Overheating + Discharge" and "Oil Mixes In" four kinds of fault type that it is rely on the "Z of condition". If the formula shown "negative value" over two, you should get the larger value to make diagnostic analysis. Formula equation is shown behind.

Formula: $Z = a * H_2 + b * CH_4 + c * C_2H_6 + d * C_2H_4 + e * C_2H_2 + f * CO + g$.

Table 2. The roger & dornenburg ratios [3] [4].

		Fault Type				
		T1	T2	T3	D1	D2
Ratio Symbol	Gas Ratio	Thermal Fault <300˚C	Thermal Fault 300˚C - 700˚C	Thermal Fault >700˚C	Low Energy Discharge	High Energy Discharge
			Dornenburg Ratios			
R1	CH_4/H_2		1.0 < R1		R1 < 0.1	0.1 < R1 < 1.0
R2	C_2H_2/C_2H_4		R2 < 0.75			0.75 < R2
R3	C_2H_2/CH_4		R3 < 0.3		R3 < 0.3	0.3 < R3
R4	C_2H_6/C_2H_2		R4 < 0.4		0.4 < R4	R4 < 0.4
			Roger Ratios			
R1	CH_4/H_2	1.0 < R1	1.0 < R1	1.0 < R1	R1 < 0.1	0.1< R1 <1.0
R2	C_2H_2/C_2H_4	R2 < 0.1	R2 < 0.1	R2 < 0.1	R2 < 0.1	1.0 < R2 < 3.0
R5	C_2H_4/C_2H_6	1.0 < R5 < 3.0	1.0 < R5 < 3.0	3.0 < R5	R5 < 1.0	3.0 < R5

Table 3. The Linear SVM discriminant formula and the a - g coefficient [2].

$Z = a * H_2 + b * CH_4 + c * C_2H_6 + d * C_2H_4 + e * C_2H_2 + f * CO + g$									
	Formula	(A) H_2	(B) CH_4	(C) C_2H_6	(D) C_2H_4	(E) C_2H_2	(F) CO	G	Diagnosis result
	(3)	0.01815	−0.01365	0.02362	−0.12971	−7.32744	0.01223	2.21713	Abnormal
	(4)	-	-	-	−0.06095	−11.21398	-	5.82626	Abnormal
Coefficient	(5)	0.015052	0.032666	−0.019081	−0.034072	0.084326	−0.002029	2.4662	Overheating
	(6)	0.006088	−0.046683	0.124659	0.015673	−0.06937	0.016078	−1.19747	Electric Arc
	(7)	−0.010295	−0.068228	0.023078	0.057307	0.16239	0.002373	0.79497	Overheating + Discharge
	(8)	−0.033417	0.11355	−0.108216	0.029086	0.034658	−0.019222	1.1711	Oil Mixes in

2.4. The Key Gas Method

When Transformer fault occurred from the gas content of TCG that ones were distinguished into four typical fault types, namely such as Overheating, Corona, Arcing, and Paper Fiber Overheating and so on: 1) Overheating because the insulating oil or insulating paper aging deterioration occurs, then it was decomposed dominating of C_2H_4 (63%), C_2H_6 (19%), CH_4 (17%), and C_2H_2 (1%); 2) Corona was decomposed mainly H_2 (84%), CH_4 (12%), C_2H_6 (3%), and C_2H_2 (1%); 3) Arcing was decomposed mainly H_2 (62%), C_2H_2 (32%), CH_4 (3%), C_2H_4 (2%), and C_2H_6 (1%); 4) Paper Fiber Overheating was decomposed mainly CO (92%), CH_4 (3%), H_2 & C_2H_6 (2%), and C_2H_4 (1%). Those gases made up of the rate percentage of each gas that they are shown in **Figure 1**. By construction of rate of insulating oil composed to diagnosis transformer fault types that were called "the Key Gas method" [5].

3. The Diagnosis Approach for Practice

The Design Flow Chart (Show in Figure 2)

In order to get my diagnostic experience across the field of diagnosis of transformer insulating oil, I made a heuristics program which consists of the ANSI/IEEE C57.104 Standard Rule, the Linear SVM Method, the Roger & Doernenber Ratios, and the Key Gas Method for diagnosis of transformer incipient fault. Form the flow chart, the transformer's insulating oil through the decomposition chromatographic analysis (ASTM D3612) to produce nine kinds of gases such as H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2, N_2, and O_2 and so on., While we only took H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, and CO for the detective data keyed in the application of program which will be carry out the result of diagnosis by tests. It was shown **Figure 2**.

4. Practical Diagnosis and Verification

4.1. Diagnostic Practice Case 1 & Case 2

For provability, from the Siemens Company reported data by Ivanka Atanasova-Hohiein in November of 2014,

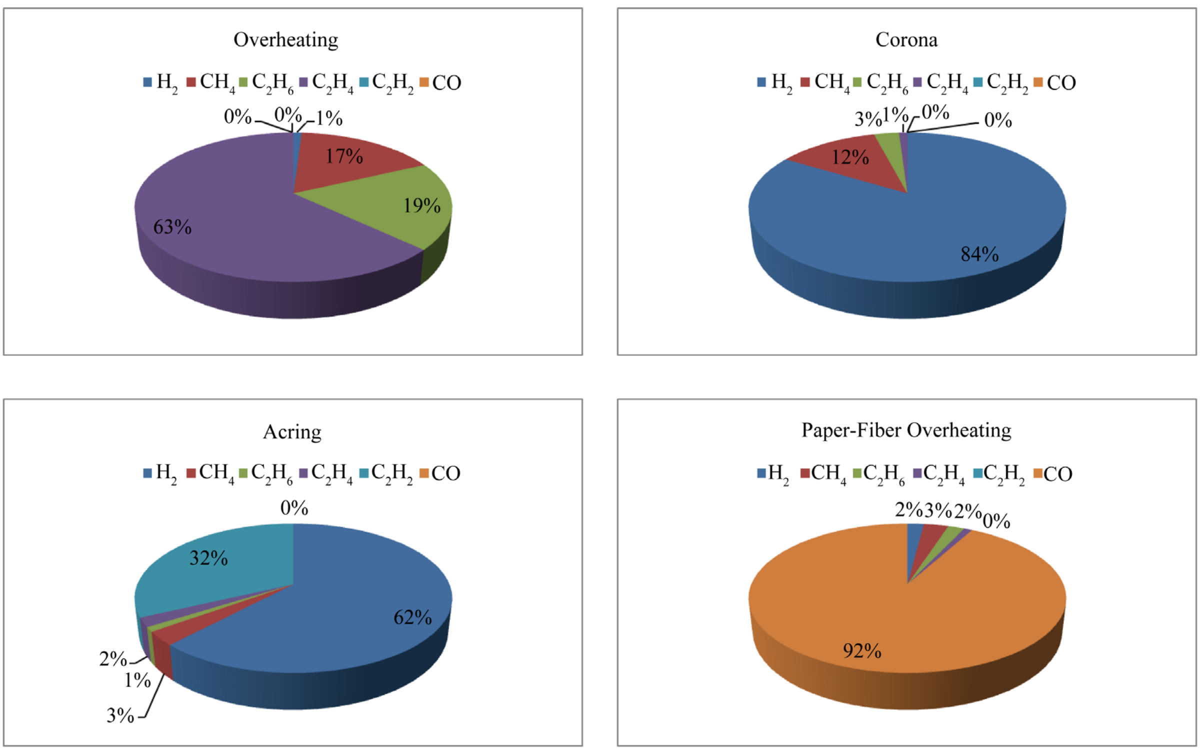

Figure 1. The gas content of typical faults proportion.

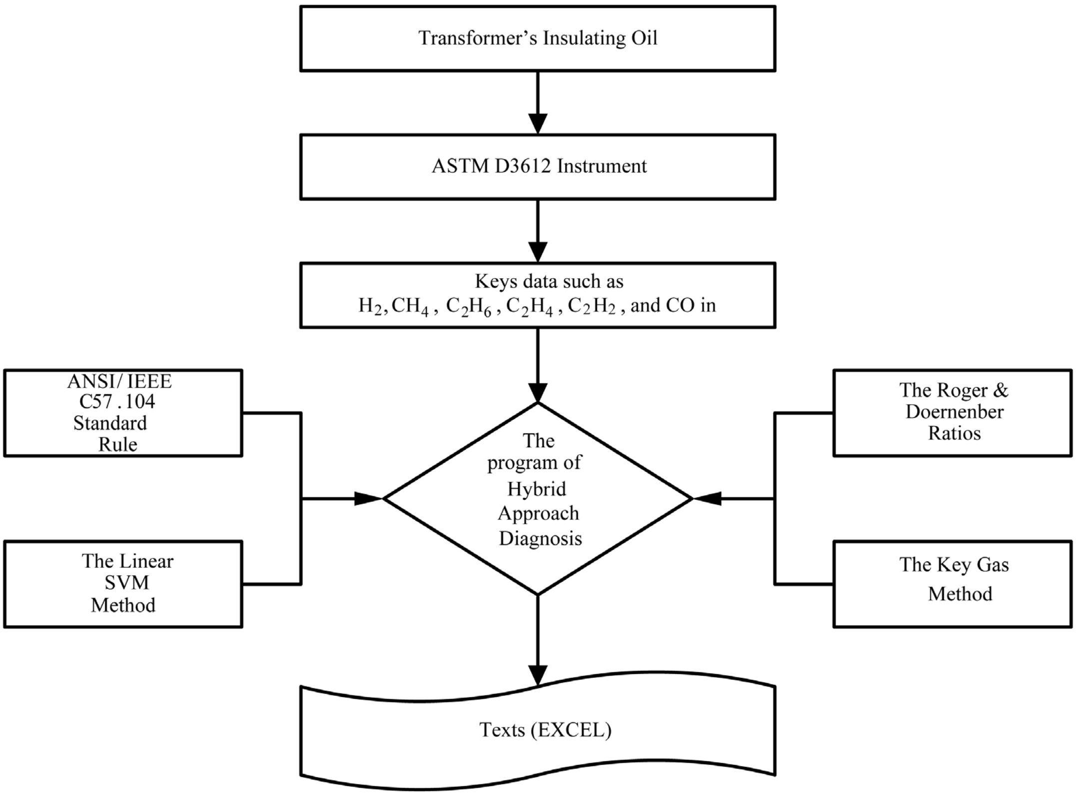

Figure 2. Diagnostic flowchart.

taking two cases data that shown in **Table 4** to double check the program , we keyed those number of gases in the diagnostic program then the result of diagnosis that were shown four kinds results in **Figure 3** by texts simultaneously [6]. For convenient comparison, taking practically fault pictures of abnormality of phenomenon were shown in **Figure 4** and **Figure 5** that they were found out from implementing of transformer internal maintenance. From those data verify "A Hybrid Diagnosis Approach of EXCEL program" does provide a quick diagnosis of transformer incipient fault exactly.

4.2. Take Some Cases to Confirm

For approving the hybrid diagnosis approach is more validated than others diagnosis ones. Taking four cases in **Table 5**, exception the case #4 was validated no incipient fault in others three cases (#1 - #3) were confirmed what had incipient fault by transformer's internal maintenance [8]. Then those cases of text description were shown in **Table 6** and the programs were shown from case 1 - case 4 in **Figure 6**. The data of diagnosis were taken from Research Institute of Taiwan Power Company to verify the diagnostic approach that it was well in diagnosis of transformer insulating oil.

5. Conclusion

Although it is difficult to be diagnosis and analysis of transformer's insulating oil correctly. Because the amount of gas changes a little that will influence the result of diagnosis a huge, so how to judge that is a significant task. **Figures 3-5** data were taken from the report of Siemens Company by Ivanka Atanasova-Hohiein in November of 2014, then **Table 6** data, taken from Research Institute of Taiwan Power Company. The data of **Figure 3** and **Table 5** were taken from known fault transformer insulating oil. The fault point of the figure (**Figure 4**, **Figure 5**), that were taken from maintenance in. The purpose of the above is to validate the feasibility of the Hybrid Diagnosis Approach. This paper, the major advantage was not only showed various results of diagnosis out on a report form, but also provided those results to compare analysis. The Hybrid diagnosis approach is validated and confirmed so easy and analysis to use at any condition of transformer insulating oil. This diagnosis approach

Table 4. Ivanka Atanasova-Hohiein reports gas data in November of 2014 [7], unit: ppm.

Date	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO
2012.05 (A)	1967	8008	2013	8323	57	253
2012.05 (B)	128	25	5	81	288	143

Hybrid Diagnosis Approach unit: ppm

Testing	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	State
	1967	8008	2013	8323	57	253	

Testing	Item	State
The ANSI/ IEEE C57.104 Standard Rule	H_2 Content Value's Result	Danger
	CH_4 Content Value's Result	Danger
	C_2H_6 Content Value's Result	Danger
	C_2H_4 Content Value's Result	Danger
	C_2H_2 Content Value's Result	Danger
	CO Content Value's Result	Normal
The Linear SVM Discriminant Formual Diagnosis	Abnormal	−1517.99
	Abnormal	−1140.49
	Overheating	−24.04
	Electric arc	18.44
	Overheating + Discharge	−32.55
	Oil mixes in	866.44
The Roger & Doernenbeg Combination Diagnosis	T1 (Thermal Fault <300˚C)	FALSE
	T2 (Thermal Fault 300-700˚C)	FALSE
	T3 (Thermal Fault >700˚C)	TRUE
	D1 (Low Energy Partial Discharge)	FALSE
	D2 (High Energy Discharge)	FALSE
The Key Gas Method Diagnosis	Overheating	TRUE
	Corna	FALSE
	Arcing	FALSE
	Paperfiber Overheating	FALSE

2012.05 (A Case)

Hybrid Diagnosis Approach unit: ppm

Testing	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	State
	128	25	5	81	288	143	

Testing	Item	State
The ANSI/ IEEE C57.104 Standard Rule	H_2 Content Value's Result	Attention
	CH_4 Content Value's Result	Normal
	C_2H_6 Content Value's Result	Normal
	C_2H_4 Content Value's Result	Attention
	C_2H_2 Content Value's Result	Danger
	CO Content Value's Result	Normal
The Linear SVM Discriminant Formual Diagnosis	Abnormal	−2114.74
	Abnormal	−3228.74
	Overheating	26.35
	Electric arc	−17.37
	Overheating + Discharge	49.64
	Oil mixes in	8.78
The Roger & Doernenbeg Combination Diagnosis	T1 (Thermal Fault <300˚C)	FALSE
	T2 (Thermal Fault 300-700˚C)	FALSE
	T3 (Thermal Fault >700˚C)	FALSE
	D1 (Low Energy Partial Discharge)	FALSE
	D2 (High Energy Discharge)	TRUE
The Key Gas Method Diagnosis	Overheating	FALSE
	Corna	TRUE
	Arcing	FALSE
	Paperfiber Overheating	FALSE

2012.05 (B Case)

Figure 3. Transformer fault diagnosis approach.

Figure 4. A thermal problem [7].

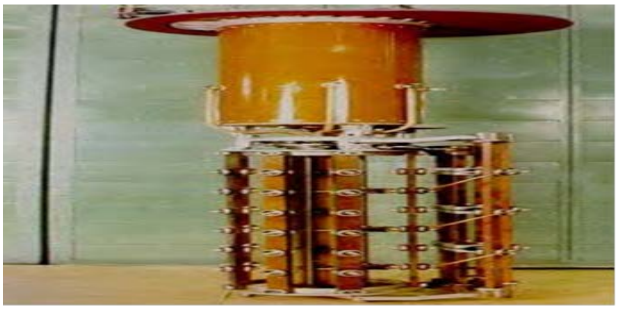

Figure 5. Uptight OLTC [7].

Table 5. Some in practical transformer gas data [8], unit: ppm.

Date	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO
C1 (2012.05.10)	239	346	78	787	24	312
C2 (2012.10.01)	185	601	208	590	1.7	72
C3 (2013.09.23)	133	211	66	384	1.9	411
C4 (2012.12.12)	13	3	12	10	0.2	310

Table 6. In practical implementation of the results.

Testing	Hybrid Diagnosis Approach unit: ppm	State	C1 State	C2 State	C3 State	C4 State
	H_2 128, CH_4 25, C_2H_6 5, C_2H_4 81, C_2H_2 288, CO 143					
The ANSI/IEEE C57.104 Standard Rule	H_2 Content Value's Result	At	At	At	At	N
	CH_4 Content Value's Result	N	At	Ab	At	N
	C_2H_6 Content Value's Result	N	At	D	At	N
	C_2H_4 Content Value's Result	At	D	D	D	N
	C_2H_2 Content Value's Result	D	Ab	N	N	N
	CO Content Value's Result	N	N	N	At	N
The Linear SVM Discriminant Formual Diagnosis	Abnormal	−2114	−270	−85	−55	3
	Abnormal	−3228	−311	−49	−38	2
	Overheating	26	−9	0	−3	1
	Electric arc	−17	9	8	10	5
	Overheating + Discharge	49	26	−3	9	2
	Oil mixes in	8	41	56	16	−5
The Roger & Doernenbeg Combination Diagnosis	T1 (Thermal Fault < 300˚C)	False	False	True	False	False
	T2 (Thermal Fault 300˚C - 700˚C)	False	False	False	False	False
	T3 (Thermal Fault > 700˚C)	False	True	False	True	False
	D1 (Low Energy Partial Discharge)	False	False	False	False	False
	D2 (High Energy Discharge)	True	False	False	False	False
The Key Gas Method Diagnosis	Overheating	False	True	True	True	False
	Corna	True	False	False	False	False
	Arcing	False	False	False	False	False
	Paper-fiber Overheating	False	False	False	False	False

Symbols: N (Normal), Ab (Abnormal), At (Attention), D (Danger), F (False).

Hybrid Diagnosis Approach unit: ppm							
Testing	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	State
	239	346	78	787	24	312	
The ANSI/IEEE C57.104 Standard Rule	H_2 Content Value's Result						Attention
	CH_4 Content Value's Result						Attention
	C_2H_6 Content Value's Result						Attention
	C_2H_4 Content Value's Result						Danger
	C_2H_2 Content Value's Result						Abnormal
	CO Content Value's Result						Normal
The Linear SVM Discriminant Formual Diagnosis	Abnormal						−270.45
	Abnormal						−311.26
	Overheating						−9.55
	Electric arc						−9.51
	Overheating + Discharge						26.27
	Oil mixes in						41.76
The Roger & Doernenbeg Combination Diagnosis	T1 (Thermal Fault <300˚C)						FALSE
	T2 (Thermal Fault 300-700˚C)						FALSE
	T3 (Thermal Fault >700˚C)						TRUE
	D1 (Low Energy Partial Discharge)						FALSE
	D2 (High Energy Discharge)						FALSE
The Key Gas Method Diagnosis	Overheating						TRUE
	Corna						FALSE
	Arcing						FALSE
	Paperfiber Overheating						FALSE

2012.05.10 (Case 1)

Hybrid Diagnosis Approach unit: ppm							
Testing	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	State
	185	601	208	590	1.7	72	
The ANSI/IEEE C57.104 Standard Rule	H_2 Content Value's Result						Attention
	CH_4 Content Value's Result						Abnormal
	C_2H_6 Content Value's Result						Danger
	C_2H_4 Content Value's Result						Danger
	C_2H_2 Content Value's Result						Normal
	CO Content Value's Result						Normal
The Linear SVM Discriminant Formual Diagnosis	Abnormal						−85.82
	Abnormal						−49.19
	Overheating						0.81
	Electric arc						8.09
	Overheating + Discharge						−3.06
	Oil mixes in						56.56
The Roger & Doernenbeg Combination Diagnosis	T1 (Thermal Fault <300˚C)						TRUE
	T2 (Thermal Fault 300-700˚C)						FALSE
	T3 (Thermal Fault >700˚C)						FALSE
	D1 (Low Energy Partial Discharge)						FALSE
	D2 (High Energy Discharge)						FALSE
The Key Gas Method Diagnosis	Overheating						TRUE
	Corna						FALSE
	Arcing						FALSE
	Paperfiber Overheating						FALSE

2012.10.01 (Case 2)

Hybrid Diagnosis Approach unit: ppm							
Testing	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	State
	133	211	66	384	1.9	411	
The ANSI/IEEE C57.104 Standard Rule	H_2 Content Value's Result						Attention
	CH_4 Content Value's Result						Attention
	C_2H_6 Content Value's Result						Attention
	C_2H_4 Content Value's Result						Danger
	C_2H_2 Content Value's Result						Normal
	CO Content Value's Result						Attention
The Linear SVM Discriminant Formual Diagnosis	Abnormal						−55.39
	Abnormal						−38.88
	Overheating						−3.66
	Electric arc						10.48
	Overheating + Discharge						9.84
	Oil mixes in						16.88
The Roger & Doernenbeg Combination Diagnosis	T1 (Thermal Fault <300˚C)						FALSE
	T2 (Thermal Fault 300-700˚C)						FALSE
	T3 (Thermal Fault >700˚C)						TRUE
	D1 (Low Energy Partial Discharge)						FALSE
	D2 (High Energy Discharge)						FALSE
The Key Gas Method Diagnosis	Overheating						TRUE
	Corna						FALSE
	Arcing						FALSE
	Paperfiber Overheating						FALSE

2013.09.23 (Case 3)

Hybrid Diagnosis Approach unit: ppm							
Testing	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	State
	13	3	12	10	0.2	310	
The ANSI/IEEE C57.104 Standard Rule	H_2 Content Value's Result						Normal
	CH_4 Content Value's Result						Normal
	C_2H_6 Content Value's Result						Normal
	C_2H_4 Content Value's Result						Normal
	C_2H_2 Content Value's Result						Normal
	CO Content Value's Result						Normal
The Linear SVM Discriminant Formual Diagnosis	Abnormal						3.72
	Abnormal						2.97
	Overheating						1.58
	Electric arc						5.36
	Overheating + Discharge						2.07
	Oil mixes in						−5.88
The Roger & Doernenbeg Combination Diagnosis	T1 (Thermal Fault <300˚C)						FALSE
	T2 (Thermal Fault 300-700˚C)						FALSE
	T3 (Thermal Fault >700˚C)						FALSE
	D1 (Low Energy Partial Discharge)						FALSE
	D2 (High Energy Discharge)						FALSE
The Key Gas Method Diagnosis	Overheating						FALSE
	Corna						FALSE
	Arcing						FALSE
	Paperfiber Overheating						FALSE

2012.12.12 (Case 4)

Figure 6. Transformer fault diagnosis approach for C1 - C4.

will be useful for engineers and technicians those who are in charge of transformer's maintenance.

References

[1] IEEE (2012) C57.104—IEEE Guide for the Interpretation of Gases Generated in Oil—Immersed Transformers. Minutes of WG Meeting Nashville, Tennessee.

[2] Mollman, A. and Pahlavanpour, B. (1999) New Guidelines for Interpretation of Dissolved Gas Analysis in Oil-Filled Transformers. *Electra*, *CIGRE France*, **186**, 30-51.

[3] IEC (1999) Guide to the Interpretation of Dissolved and Free Gasses Analysis. IEC Standard 60599, IEC Publ. 60599.

[4] Singh, S. and Bandyopadhyay, M.N. (2010) Duval Triangle: A Noble Technique for DGA in Power Transformers. *International Journal of Electrical and Power Engineering*, **4**, 193-197. http://dx.doi.org/10.3923/ijepe.2010.193.197

[5] Electric Cooperative Research Council (2009) The Revised Guidelines of Power Transformers. Vol. 1, Heisei 21 Years.

[6] Qi, Y.G., Ming, L.K., Sing, G.B., Sung, S.U. and Xia, S. (2012) Nan Cou E/S #4 ATr Overhaul Report. Taiwan Power Company Institute.

[7] Atanasova-Höhlein, I. (2014) DGA-Method in the Past and for the Future. Siemens Company. https://www.energy.siemens.com/mx/pool/hq/services/power-transmission

[8] Than, C.F., Qing, C.J. and Than, L.Y. (2012) Nan Cou E/S # 4 ATr Overhaul Report. Future Electric Co. Ltd.