Detection of Faults in Power Transformers Using an Expertise Method Depending on DGA

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Abstract- Dissolved gas analysis (DGA) is a diagnostic tool that used to detect the incipient faults of power transformers through the correlation between the content of gases dissolved in transformers oil and a particular malfunction. The early detection of incipient faults in power transformers reduces costly unplanned outages. Some classical methods that depend on gases concentration in transformers oils are used to interpret transformer faults such as Dornenburg, Rogers, Duval triangle and key gases methods. These methods in some cases did not give the same results; therefore, an expertise method is developed to give the fault type according to the dissolved gases concentration in oil. A software code is designed using logic functions to get the type of the faults in transformers. The age of transformer is taken into account in our calculations. The results from the software code illustrate the program reliability as an early detection tool of transformer faults.

Key words: Dissolved gases analysis- transformer oilinterpretation of transformer faults.

I. Introduction

Insulation is an important part of a power transformer, in general, solid and liquid insulation are widely used. During the operational of a transformer, gasses may dissolve in transformer oil; these gasses arise as results of transformer faults such as arcing, corona (partial discharges), overheating of transformer oil or overheating of paper insulation (cellulose). Among the dissolved gasses the combustible gasses are the most dangerous since these gasses may cause the burning and/or explosion of the transformer. The combustible gasses commonly appear in transformer oil are H_2 (Hydrogen), C_2H_6 (Ethane), C_2H_4 (Ethylene) and C_2H_2 (Acetylene) [1-3].

Several artificial intelligence methods such as Fuzzy Logic and Artificial Neural Network (ANN) were developed as a novel technique to interpret the faults in transformer [4-7].

In this paper a suggested method combining the classic dissolved gases analysis (DGA) techniques for diagnosis of fault transformers with logic function is developed. Based on the interpretation of the classical techniques to the cause of transformer faults according to the gases concentration in oil transformer, a system is suggested to give the main cause of the transformer fault with the aid of logic functions that is used as in Fuzzy and Neural Network. A lot of real cases of analyzing the dissolved gases were collected and used to illustrate the reliability of the suggested method. The age of the transformer is taken into account in calculations. In addition, some cases from previous literatures were used to compare their results with the proposed method's results.

II. Classical Methods to Diagnose Transformer Faults

Based on DGA, many interpretative methods have been introduced to diagnose the nature of the incipient deterioration occurred in transformer.

Over the years, several techniques have been developed to facilitate the diagnoses of fault gases such as Dornenburg method [8], Roger's ratio method [9], Key gases method [8], and Duval Triangle method [10] as well as the recently developed techniques such as neural network and fuzzy logic.

A. Key gases method

The key gas method identities the key gas for each type of faults and uses the percent of this gas to diagnose the fault [8]. Key gases formed by degradation of oil and paper insulation are hydrogen (H₂), methane (CH₄), ethane (C_2H_6) , ethylene (C_2H_4) , acetylene (C₂H₂), Carbon monoxide (CO) and oxygen (O_2) . Except for carbon monoxide and oxygen, all other gases are formed from the degradation of the oil itself. Carbon monoxide, carbon dioxide (CO₂), and oxygen are formed from degradation of cellulosic (paper) insulation. Gas type and amounts are determined by where the fault occurs in the transformer and the severity and energy of the event. Events range from low energy events such as partial discharge, which produces hydrogen and trace amounts of methane and ethane, to very high energy sustained arcing, capable of generating all the gases including acetylene, which requires the most energy. The key gas method interprets the incipient faults in transformer according to some significant gases to assign four typical fault types. These gases are called "key gases" [8] which are shown in Fig. 1.

B. Dornenburg ratio method

The Dornenburg method utilizes four calculated gas ratios to indicate a single fault type from three general fault types. This procedure requires significant levels of the gases to the present in order for the diagnosis to be valid. The four ratios and their diagnosis values are given [8]. Dornenburg method uses five individual gases or four-key gas ratios, which are:-



 $R_1 = CH_4/H_2,$ $R_2 = C_2H_2/C_2H_4,$ $R_3 = C_2H_2/CH_4,$ $R_4 = C_2H_6/C_2H_2.$ A flow chart that describes step by step procedure to identify the reason behind transformer faults is found in [8].

C. Roger's ratio method

It is an additional tool that may be used to look at dissolved gases in transformer oil. The Rogers ratio method takes into consideration industrial experiences, laboratory tests, and further theoretical assessment. This method was further modified into an IEC standard [9, 11]. The original Rogers ratio method uses four gas ratios which are CH₄/H₂, C₂H₆/CH₄, C₂H₄/C₂H₆ and C_2H_2/C_2H_4 for diagnosis. The refined Rogers method uses two tables: one defined the code of the ratio, and the other defined the diagnosis rule. The ratio C_2H_6/CH_4 only indicated a limited temperature range of decomposition, but did not assist in further identification of fault. Therefore, in IEC standard 599, the further development of Roger's ratio method was deleted. Roger's ratio method and IEC 599 have gained popularity in industrial practices. However, it may give no conclusion in some cases. This is the "no decision" problem.

A flow chart to describe the step by step application to give the reason of transformer faults is found in [8] and is also based on the thermal degradation principles.

D. Duval triangle method

The Duval Triangle was first developed in 1974 [8]. Three hydrocarbon gases only $(CH_4, C_2H_4 \text{ and } C_2H_2)$ are only used. These three gases are generated as a result of increasing the level of energy necessary to generate gases in transformers in service. Figure 2 indicates the Triangle method. In addition 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.



Fig.2: Duval triangle as a diagnostic tool to detect the incipient faults in transformer.

(T1 the zone of low thermal fault <300°C, T2 the zone of medium thermal fault 300°C<T<700°C, T3 the zone of high thermal fault >700°C, D1 discharge of low energy arcing, D2 discharge of high energy arcing, DT attributes to mixtures of electrical and thermal faults and PD indicates partial discharge)

III. Decision tree as an expertise method

When four classical methods of transformer fault diagnosis such as Key gas method, Dronenburg method, Roger's method and Duval triangle method are applied to interpret the cause of the fault in transformer, conflicts may occurred. To overcome this problem a decision fault tree is developed which contains the information between different faults types. Every fault type takes a number to help us to get the main cause of the transformer fault. This is shown in Figure 3.

A software code in excel sheet is developed using the logic function to get transformer fault from the four classical method that mentioned before; the results depend on the combustible gases that arise when fault occurs in transformer. After determining the fault type from these methods, the program decides the incipient fault type.

The procedures that used to carryout the Excel program are:

In the first, the program determines the fault type according to the classical methods; the second step is choosing a code for each fault as in decision fault tree. The third step is summing the codes for the same faults then the general fault is specified. At the end the program specifies the specific fault from the general fault using if statement and logic functions.

The age of transformer is taken into account in the calculations as the standard level of gases that mentioned in a guide for the interpretation of gas in oil analysis data (SMS-1101-05-T)[12] as a substation maintenance standard. Table.1[12] explains the recommendation guide for maximum safe evolved gas levels in oil immersed equipment.

Gas	Dissolved gas concentration (ppmV)
H_2	20n+50
CH_4	20n+50
C_2H_6	20n+50
C_2H_4	20n+50
C_2H_2	5n+10
CO	25n+500
CO_2	100n+1500
TCG	110n+710

Table	1
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Where, ppmV= part per million, by volume n= Number of years in service. Serious or danger levels are approximately 5-10 times the above values.

The number of years is effect on the Dornenburg results. This fact is shown as in Figures 4 (a and b). When the age of transformer increases, the results will give different transformer faults in case of Dornenburg method. Figure 5 illustrates the final report and Figure 6 explains the form of the excel sheet that is used to explain the main fault in transformer.





Nain cause HIGH THERMAL FA

		(a)				
Name o Samp	Name of station Sample Date			DOMIAT 2010		
Age of transformer	15					
Methane	1081					
Hydrogyne	269					
Acetyline	25					
Ethyline	1725					
Ethane	347					
Co2	1808					
Co	269					
Nitrogyne	84008					
Oxygene	1151					
Fault from Dornenberg	method		NO F	AULT		
Fault from Rogers ratio	method		THERM	1AL >700		
Fault from Duval triangle	method	TH	IERMAL	FAULT>	700	
Fault from key gases n	nethod		THER	MAL OIL		
Main cause		HIC	GH THEF	RMAL FA	ULT	
		(b)				

Fig. 4: The effect of age of the transformer on the result by Dornenburg method.





Fig. 6: The excel sheet that use to give the main cause of transform fault.

IV. Some cases to specify the fault type in transformers

Some oil samples are taken from real transformers which are in operation to carry out the study.

Case 1: (Transformer 66/11 kV)

Date	H_2	CH ₄	C_2H_6	C_2H_4	C_2H_2	СО
14.7.2010	19	3	3	56	0.001	1223

The age of the transformer is assumed 5 years and the gases concentration appear in the result sheet. The fault type from the four classical methods is specified which refer to thermal fault in this transformer and the decision from tree fault is high thermal fault. It is seen from the data that the ppm for Ethyline is high and then the present of it leads to high thermal fault. The result from the lab refers that the fault in transformer is thermal fault >700°C. Therefore, the result by the code is compatible with that from the lab. The result is shown in Fig. 7.

Case 2: (Transformer 220/66 kV)

Date	H ₂	CH ₄	C ₂ H ₆	C_2H_4	C_2H_2	CO
22.5.2011	154	11	14	8	3	487

The software code gives the transformer fault as arcing discharge and the decision from tree fault method defines the fault as High arcing discharge as shown in Figure 8. The Lab result refers that the transformer fault is discharge of high energy. The result reveals that the software code is reliable to determine the transformer fault based on the gas concentrations.

V. Validation of the proposed technique

A comparison between the proposed technique results and the other results in literatures is explained in this section to specify the validation of the proposed method.

Name Sam	of station ple Date	66/11kV 14.7.2010
Age of transformer	5	
Methane	3	
Hydrogyne	19	
Acetyline	0.001	
Ethyline	56	
Ethane	3	
Co2	3168	
Со	1223	
Nitrogyne	89879	
Oxvgene	9620	
Fault from Dornenberg	method	NO FAULT
Fault from Rogers ratio	method	NO FAULT
Fault from Duval triangl	e method	THERMAL FAULT>700
Fault from key gases	method	THERMAL OIL
Main cause		HIGH THERMAL FAULT

Fig. 7: The result of case 1.

Nai	ne of station ample Date	220/66kV 22.5.2011
Age of transforme	r 5	
Methane	11	
Hydrogyne	154	
Acetyline	3	
Ethyline	8	
Ethane	14	
Co2	3395	
Со	487	
Nitrogyne	87727	
Oxygene	2621	
Fault from Dornenb	erg method	NO FAULT
Fault from Rogers r	atio method	HIGH ENERGY ARCING
Fault from Duval tria	ngle method	HIGH ENERGY ARCING 1
Fault from key gas	es method	THERMAL CELLULOSE
Main cau	e	HIGH ARCING DISCHARGE

Fig. 8: The result of case 2.

Example 1 in [13]

The dissolved gases that produced from an actual transformer are as follows;

Date	H_2	CH ₄	C_2H_6	C_2H_4	C_2H_2	CO			
-	64	19	11	82	0.001	459			
The analyzed transformer has a problem of									
high-temp	high-temperature thermal fault as in [13].								
Using the proposed technique and designed									
program (the fi	nal res	sult is s	shown	in Fig.	9.			

	A	В	С	D	E	F	G	H		Г
1				Name o	f station			-		
2				Samp	le Date			-		
3										
4		Age	of transfo	ormer	1					
5			Methane		19					
6		H	lydrogyn	ne	64					
7			Acetyline	e 💿	0.001					
8			Ethyline	1	82					
9			Ethane		11					
10		Co2			51156					
11			Co		459					
12			Nitrogyn	e	-					
13			Oxygene		-					
14										Г
15		Fault fr	om Dorn	nenberg	method		NO	FAULT		Γ
16		Fault fr	om Roge	ers ratio	method		NO	FAULT		Γ
17		Fault fro	om Duval	l triangle	method	Tł	IERMAL	FAULT>	700	Γ
18		Fault	from key	gases n	nethod		THER	MAL OIL		Γ
19										Γ
20										Г
21			Main	cause		HI	GH THE	RMAL FA	ULT	Г
00										

Fig. 9: The result of Example 1 [13].

The final result using the decision tree fault give the same result as in [13].

Example 2 in [3]

The dissolved gases that taken from another transformer are as follows;

Dat	te	H_2	CH ₄	C ₂ H	I ₆ C ₂ H ₄	(C_2H_2		С
-		360	492	54	305		1	58	0
The	ana	lyzed	fault	of	sample	1	in	[3]	is

thermal fault reach to 700°C. The final result from the proposed technique is shown in Figure 10.

_			<u> </u>	-	-	_	-				
	A	В	C	D	E	F	G	н			
1	Name of station -										
2				Samp	le Date			-			
3											
4		Age	of transf	ormer	5						
5			Methane	•	492						
6		- F	lydrogyr	ne	360						
7			Acetylin	e	1						
8			Ethyline		305						
9			Ethane		54						
10		Co2			-						
11			Co		580						
12			Nitrogyn	e	-						
13			Oxygen	•	-						
14											
15		Fault fi	rom Dorr	nenberg	method		NOI	AULT			
16		Fault fr	om Rog	ers ratio	method		THERM	/IAL >700)		
17		Fault fro	o <mark>m Duva</mark>	l triangle	method	300<	THERM.	AL FAUL	T<700		
18		Fault	from key	gases n	nethod	TH	IERMAL	CELLUL	OSE		
19											
20											
21			Main	cause		HI	GH THEF	RMAL FA	ULT		
00			1	1			1	1			

Fig. 10: The result of sample 1 [3].

Also here the proposed technique is able to determine the type of fault as the conclusion of [3].

Example 3 in [14]

The third example to satisfy the validation of the proposed technique will be taken from [14] case III.

Date	H ₂	CH ₄	C ₂ H ₆	C_2H_4	C_2H_2	CO
-	127	24	0.001	32	81	0.001

The analyzed fault as in [14] is arcing not involved cellulose. The proposed technique gives the main cause of the fault as in Fig. 11.



VI. Conclusions

The results from different cases under study reveal that the proposed technique is reliable to use as a diagnostic tools to detect the fault in transformer in its early stage. The conclusions from the real cases explain that the nature of the insulating materials involved in the fault and the nature of the fault itself affect on distribution of dissolved gases. Based on The results from the software code and the lab results, the software code is reliable to produce the transformer fault based on the gas concentrations.

VII. References

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