Combined Dissolved Gas Analysis: A Prescient Methodology for Recognizing Faults in Transformer by MATLAB GUI

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Abstract - *The transformer is one of the most important equipment playing a significant role in Power transmission network. For utilities which require a reliable power supply in the long run, utmost attention on transformers is required. The mineral oil & insulation inside the transformer is subject to high thermal and electrical stresses and thus gasses are formed due to the decomposition of the mineral oil & cellulose. Transformer failure will cause huge loss to Industries & thus as a proactive approach transformers diagnosis of mineral oil must be carried out. Combined Dissolved gas analysis (DGA) is used for assessing oil for dissolved gases formed due to faults in the transformer. Five Classical methods in DGA are Key Gas Method, IEC Ratio method, Rogers Ratio Method, Doernenburg Ratio Method and Duval triangle Method. This paper presents Combined Dissolved Gas Analysis with five classical methods of 100% accuracy when compared to a reliable individual method of 90% accuracy.*

Key Words: DGA, mineral oil, transformer, Fault Analysis, Gas, MATLAB GUI.

1. INTRODUCTION

Power Transformers are one of the most expensive equipment for Utilities. They are operated 24*7 by utilities & industries. For reliable power supply continuous monitoring, routine maintenance & testing is essential. During continuous operation and aging, the transformer insulating materials are subjected to electrical and thermal stresses. These stresses lead to breakdown of insulation and several gases are released. These gases help in identifying the type and severity of fault. Total Combustible Gas analysis, Gas Blanket analysis and dissolved gas analysis are the three different methods for detecting gases. Out of these three methods Dissolved Gas Analysis is proved as most accurate method for condition assessment of transformers.

Most of the power utilities carry out DGA analysis by only one method preferably Key Gas Method. This paper presents computer based MATLAB GUI, developed to combine five DGA interpretation techniques thereby improving the accuracy when compared to most reliable individual method.

2. FORMATION OF GASES IN TRANSFORMER OIL

Gas is formed in mineral oil due to decomposition of cellulose and oil. Decomposition of cellulose and oil takes place due to thermal fault and electrical fault. Electrical faults occur due to Corona (Partial discharge) or Arcing (High energy discharge). Gases formed are CH4, H2, C2H6, C2H4, C2H2, CO2, CO etc. The percentage amount of gases formed in transformer depends on type of fault and its source of formation. Table 1 [4] [3] gives a dissolved gas concentration permissible limit which determines the health of the transformer.

Table -1: Dissolved Gas concentration limit

Gases (in PPM)	Normal	Caution	Abnormal	Danger
Hydrogen	100	101-700	701-1800	>1800
Methane	120	121-400	401-1000	>1000
Acetylene	35	36-50	51-80	>80
Ethylene	50	51-100	101-200	>200
Ethane	65	66-100	101-150	>150
Carbon Monoxide	350	351-570	571-1400	>1400
Carbon Dioxide	2500	2501-4000	4001-10000	>10000
TDCG	720	721-1920	1921-4630	>4630

3. TRANSFORMER FAULT DIAGNOSIS BY CLASSSICAL METHODS

One of the main advantages of Dissolved Gas Analysis over other gas identification methods is it gives early identification of incipient fault. Fig1 shows the steps involved in DGA [7]-[11].

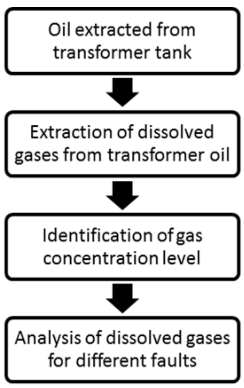

Fig -1: DGA Techniques Flow Chart

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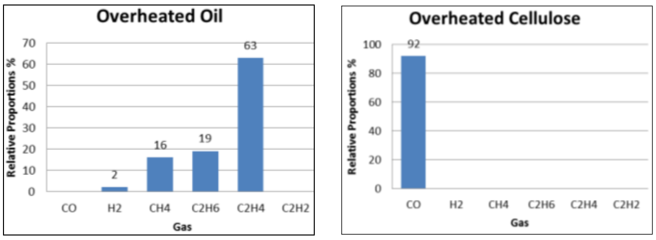
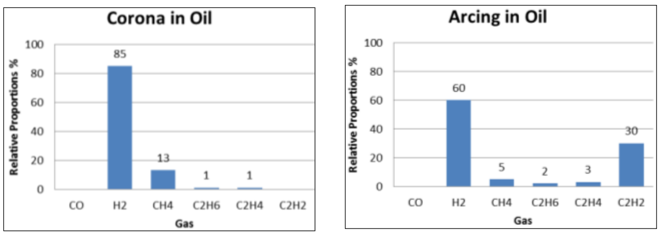
The oil sample is collected from the transformer unit. From this oil sample, the dissolved gas is extracted. The concentration of different gases in ppm is evaluated from the extraction. The concentration values of different gases are analyzed for incipient fault. The five classical methods for detection of incipient faults are Key Gas Method, IEC Ratio Method, Rogers Ratio Method, Dornenburg Method, Duval Triangle.

3.1 Key Gas Method

Key Gas method depends on the percentage of key gas liberated at the time of fault. Fig 2 Shows different incipient faults based on quantity of gases released inside the transformer [5][7]. When the gas crosses the limits, subsequent fault is the root cause.



a) Key Gas: Ethylene b) Key Gas: Carbon Monoxide



c) Key Gas: Hydrogen d) Key Gas: Acetylene

Fig -2: Key Gas Method with Four Faults

3.2 Rogers Ratio Method

As the name suggests this method diagnoses the fault with the help of gas ratios generated at the time of fault. The four gas ratios are CH4/H2, C2H6/CH4, C2H4/C2H6 and C2H2/C2H4 [8][9][3]. One of the main advantages of this method is irrespective of the volume of oil it depends only on ratios of gas released. Table II shows codes for gas ratios. The value of each ratio is calculated, based on these four ratios range, code (0-5) is provided in Table 2. Table 3 shows fault identified with reference to the ratio of gases with code. There are 12 possible causes of incipient faults as shown in Table 3.

Table -2: Gas Ratio Codes [2][3]

Sr.No	Gas Ratios	Ratio Codes	Range	Code
1	CH4/H2	i	<=0.1	5
			0.1-1.0	0
			>=1.0,<3.0	1
			>=3.0	2
2	C2H6/CH4	j	<1.0	0
			>=1.0	1
3	C2H4/C2H6	k	<=1.0	0
			>=1.0,<3.0	1
			>=3.0	2
4	C2H2/C2H4	l	<0.5	0
			>=0.5,3.0	1
			>=3.0	2

Table -3: Different faults based on Rogers Ratio [5]

Sr.No	i	j	k	l	Diagnosis
1	0	0	0	0	No fault. Normal deterioration
2	5	0	0	0	Partial discharge
3	1-2	0	0	0	Slight overheating(<150°C)
4	1-2	1	0	0	Overheating(150C-200°C)
5	0	1	0	0	Overheating(200C-300°C)
6	0	0	1	0	General conductor over heating
7	1	0	1	0	Winding circulating currents
8	1	0	2	0	Core & circulating currents (300C-700°C)
9	0	0	0	1	Flash over without power follow through
10	0	0	1-2	1-2	Arc with power follow through
11	0	0	2	2	Continuous sparking to floating potential
12	5	0	0	1-2	Partial discharge with tracking

3.3 IEC Ratio Method

IEC ratio method is derived from the Roger's Ratio method. In this method, ratio C2H6/CH4 was dropped as it revealed only partial temperature range at the time of decomposition inside the transformer. Following Table 4 shows the IEC Ratio codes with gas ratio range and its code (0-2). [2][3][11]

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Table -4: IEC Ratio Codes [3]

Sr.No	Gas Ratios	Ratio Codes	Range	Code
1	CH4/H2	i	<0.1	1
			0.1-1.0	0
			>1.0	2
3	C2H4/C2H6	k	<1.0	0
			1.0-3.0	1
			>3.0	2
4	C2H2/C2H4	l	<0.1	0
			0.1-3.0	1
			>3.0	2

Table 5 shows fault identified with reference to the ratio of gases with code. There are nine possible causes of incipient faults as shown below.

Table -5: Different faults based on IEC Ratio [3]

Sr.No	i	k	l	Diagnosis
1	0	1	0	Normal ageing
2	1	0	>0	Partial discharge of low energy density
3	1	0	1	Partial discharge of high energy density
4	0	1-2	1-2	Discharge of low energy
5	0	2	1	Discharge of high energy
6	0	1	0	Thermal fault(<150°C) heating
7	2	0	0	Thermal fault(150°C - 300°C)
8	2	1	0	Thermal fault(300°C - 700°C)
9	2	2	0	Thermal fault(>700°C) follow through

3.4 Dornenburg Ratio Method

This method is based on ratios of four gases CH4 / H2, C2H2 /C2H4, C2H2 /CH4 and C2H6 / C2H2 or six gases H2, CH4, C2H4, C2H2, C2H6 and CO. Through this method three types of fault can be analyzed i.e. thermal decomposition, corona and arcing [7][14][15]. This method is valid when the concentration of at least one of the gas H2, CH4, C2H4, or C2H2 must exceed twice the concentration limit. However gases viz. C2H6 and CO must exceed the concentration limit. Table 6 shows the concentration limit of key gases. [4][3]

Table -6: Concentration limit for Dornenburg Ratio Method [4][3]

Sr.No	Key gas	Concentration (PPM)
1	Hydrogen (H2)	100
2	Methane(CH4)	120
3	Acetylene (C2H2)	35
4	Ethylene (C2H4)	50
5	Ethane (C2H6)	65
6	Carbon monoxide (CO)	350

Table 7 gives the diagnosis for different gas ratio range and its subsequent fault

Table -7: Diagnosis by Dornenburg Ratio Method [5]

Fault	CH4 / H2)	C2H2 /C2H4)	C2H2 /CH4	C2H6 / C2H2
Thermal decomposition	>1.0	<0.75	<0.3	>0.4
Partial Discharge (PD)	<0.1	Not significant	<0.3	>0.4
Arcing fault	>0.1 to <1.0	>0.01 to < 0.1	>0.3	<0.4

3.5 Duval Triangle Method

Duval Triangle method is one of the most accurate method when compared to other four methods. This method is based on three gases CH4, C2H4 and C2H2 [9][16]. The problem exists only if at least one of the hydrocarbon gases or hydrogen is greater or equal to L1 level. The gas generated must at the rate of G1 & G2 as shown in Table 8. [10][11]

Table -8: L1 limit and gas generation rates for Duval Triangle Method [3]

Sr.No	Gas	L1 limits	G1 limits (ppm per month)	G2 limits (ppm per month)
1	H2	100	10	50
2	CH4	75	8	38
3	C2H2	3	3	3
4	C2H4	75	8	38
5	C2H6	75	8	38
6	CO	700	70	350
7	CO2	7000	700	3500

If the above conditions as mentioned in table VIII are satisfied then the problem exists. The percentage of each gas with total gas (CH4 + C2H4 + C2H2) is calculated. This percentage of each gas is plotted on the triangular chart which is subdivided into six fault zones. The fault zone where the point is located indicates the type of fault produced in the transformer as shown in Fig3. [10][11]

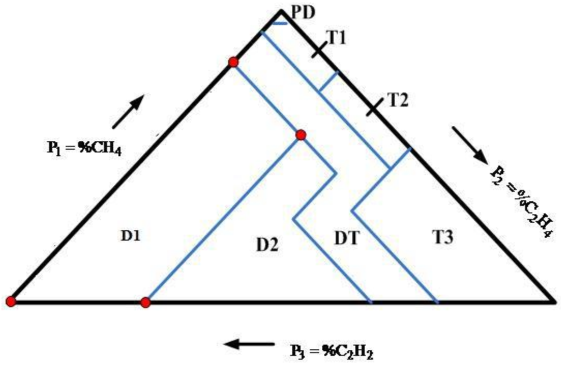

Fig -3: Duval Triangle.

4. COMBINED DGA ANALYSIS

Fig 4. Shows the process for combined dissolved gas analysis by all the five methods which we have discussed, based on the percentage of fault diagnosed by each method the fault is concluded.

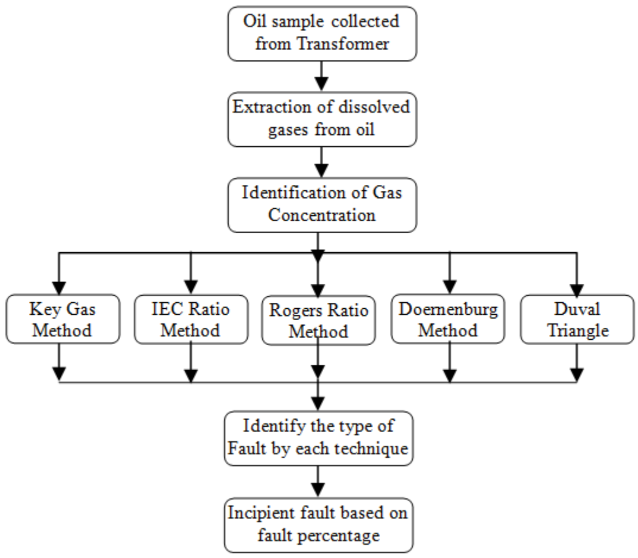

Fig. 4. Block diagram of Combined Dissolved Gas Analysis (DGA) [1].

Table 9 gives the codes for seven different faults

Table -9: Fault classification with codes [6][12]

Sr.No	Fault	Code
1	Normal Condition	F1
2	Thermal faults<300°C	F2
3	Thermal faults 300°C-700°C	F3
4	Thermal faults >700°C	F4
5	Arcing	F5
6	Partial Discharge	F6
7	No prediction	F7

Table -10: Mapping process of each fault with different diagnostic methods

Method	F6	F1	F2	F3	F4	F5	F7
Key Gas	Normal	No prediction	Overheating of Oil	Overheated Cellulose	Arcing	Partial discharge (Corona)	NO PREDICTION
Rogers		Slight over heating<150°C, Overheating 150°C-200°C	General conductor overheating, core & circulating current	Overheating> 700°C	Flash over without power follow, arc with power follow	Partial discharge with tracking	
IEC		Thermal Fault <150°C,thermal fault 150°C-300°C	Thermal Fault 300°C-700°C	Thermal Fault >700°C	Arcing and sparking	Partial discharge of low and high energy density	
Dornenburg		No prediction	Thermal Decomposition		Arcing	Corona	
Duval		Thermal Fault <300°C	Thermal Fault 300°C-700°C	Thermal Fault >700°C	Low energy discharged	PD is mix with electrical and thermal	

The result of the combined analysis is displayed on MATLAB GUI. The above codes are incorporated to provide the incipient fault based on the percentage of the fault 30 data of gases was analysed for DGA by comparing the results with individual methods and combined DGA analysis

5. RESULT AND CONCLUSION

Using MATLAB GUI results for 30 data of gases from different papers were calculated [1]. The result of the tested DGA is as shown in Table XI. It was observed that the most accurate method is duval triangle method with 90% accuracy. However with combine DGA analysis, the percentage of accuracy is 100%. Thus it is preferred to carry out combined DGA analysis, instead of the most accurate individual Duval triangle method for fault analysis in case of internal fault in the transformer.

Table -11: Comparing percentage prediction of individual and combined DGA method

Sr. No	Method	No. of Data tested	Computation		
			Results obtained	No Prediction	% Accuracy
1	Key Gas	30	2	28	7%
2	Dornenburg	30	14	16	47%
3	Rogers	30	11	19	37%
4	IEC	30	25	5	83%
5	Duval	30	27	3	90%
6	Combined DGA	30	30	0	100%

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