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Fault analysis of High Voltage Power Transformer using Dissolved Gas Analysis

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ABSTRACT: Dissolved gas analysis (DGA) is a diagnostic tool that is used to detect the incipient faults of power transformers through the correlation between the content of gases dissolved in transformer oil and a particular malfunction. Early stage detection of transformer faults can reduce considerably the cost of repairing the damaged transformers and hence maintain the stability of the system. Some classical methods that depend on gas concentration in transformer oil are used to interpret transformer faults such as Key gas method, IEC(Electro technical commission) gas ratio method, Cellulose condition test method, Total combustible gas method, Duval triangle method and extension to Duval triangle. MATLAB program has been developed which performs the DGA analysis faster since only the gas input data is required to arrive at a valid prediction. It gives better and more accurate results to confirm the transformer incipient fault. It reduces the human-error on interpreting the fault on DGA system. Transformer data have been collected from Regional Testing Institute Guwahati, Assam.

KEYWORDS: transformer, dissolved gas analysis (DGA), parts per million (ppm), fault types, diagnostic methods, Duval Triangle.

I.INTRODUCTION

Transformer is one of the most important and critical component of electrical transmission and distribution system. Much attention is needed for maintenance of transformers in order to have fault free electric supply and to maximize the lifetime and efficiency of a transformer. Dissolved gas analysis is a powerful diagnostic technique for detecting incipient faults in oil filled transformers long before they develop into major faults. The transformer in operation is subjected to various stresses like thermal and electrical, resulting in liberation of gases from the hydrocarbon mineral oil, which is used for insulation and cooling. The components of solid insulation also take part in the formation of gases, which are dissolved in the oil. An assessment of these gases would help in diagnosing the internal faults. The health of the oil is reflective of the health of the transformer itself.

II. LITERATURE SURVEY

Michel Duval shows that dissolved gas analysis is very efficient tool to monitor in service transformers to avoid outage and losses of production. The main gases formed as a result of electrical and thermal fault in transformer are H_2, CH_4, C_2H_2, C_2H_4, C_2H_6, CO and CO_2, Whose relative concentration depends upon fault. The IEC-IEEE ratio method is most widely used to detect fault. He suggested developing expert system.

Sukhabir Singh, M.N. Bandyopadhyay have done bibliographic survey over the last 40 years on research and development and on procedure of evaluating fault in power transformer by Dissolved Gas Analysis (DGA).

Alghamdi in 2012 developed methods using visual style windows where the algorithms are based on basic software. A graphic user interface (GUI) is displayed on the monitor that requires input data from the user and the software processes the input for DGA assessment methods. The achieved results are realistic and accurate.

N. A. Muhamad and S.A.M. Ali use lab view with fuzzy logic controlled and built a simulation system to diagnose fault in transformer.

R.R.Rogers has developed ratio technique to interpret fault in power transformer by Dissolved Gas Analysis (DGA).This method proved beneficial for smaller utility, without the need for extended statistical and laboratory investigation, to apply the technique to reduce the overall costs for maintaining power transformers in service.

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Sayed M.Islam , Muhammad Arshad have developed a novel fuzzy based technique for estimation of remaining life of transformer . Most of transformers are operating beyond their expected life .Therefore reliability on transformer cannot be assured.

III. FORMATION OF GASES IN TRANSFORMER OIL IN SERVICE

Mineral insulating oils are complex mixtures of hydrocarbon molecules, in linear (paraffinic) or cyclic (cycloaliphatic or aromatic) form, containing CH_3, $CH_2$and CH chemical groups bonded together. Scission of some of the C-H and C-C bonds as a result of thermal or electrical discharges will produce radical or ionic fragment such as H*, CH3*, CH_2*, CH* or C*, which will recombine to form gas molecules such as hydrogen (H-H), methane (CH_3-H), ethane (CH_3-CH_3), ethylene (CH_2=CH_2) or acetylene (CH≡CH). More and more energy is required to form the above chemical bonds. Hydrogen (H_2),methane (CH_4) and ethane (C_2H_6) are thus formed at low energy level, such as in corona partial discharges or at relatively low temperatures (<500 °C), ethylene (C_2H_4) at intermediate temperatures, and acetylene (C_2H_2) at very high temperatures (> 1000 °C) such as in arcs. The gases dissolve in oil or accumulate above it and are analysed by DGA.

IV. FAULTS DETECTABLE BY DGA

- Partial discharge: A fault of low level energy which usually occurs in gas-filled voids surrounded by oil impregnated material. The main cause of decomposition in partial discharges is ionic bombardment of the oil molecules. The major gas produced is Hydrogen. The minor gas produced is Methane.
- Thermal faults: A small amount of decomposition occurs at normal operating temperatures. As the fault temperature rises, the formation of the degradation gases change from Methane (CH_4) to Ethane (C_2H_6) to Ethylene (C_2H_4). A thermal fault at low temperature (<300˚C) produces mainly Methane and Ethane and some Ethylene. A thermal fault at higher temperatures (>300˚C) produces Ethylene. The higher the temperature the greater the production of Ethylene.
- Arcing: Fault caused by high energy discharge. The major gas produced during arcing is Acetylene. Power arcing can cause temperatures of over 3000˚C to be developed.
- Fault involving insulation: If the cellulose material (insulating paper etc.) is involved carbon monoxide (CO) and carbon dioxide (CO_2) are generated. A normally aging conservator type transformer having a CO_2/CO ratio above 7 should be considered normal and below 3 should be regarded as perhaps indicating a fault involving cellulose, provided the other gas analysis results also indicate excessive oil degradation.

V. DIAGNOSTIC METHODS BASED ON DISSOLVED GASES

There are many DGA methods to interpret fault type. The methods used in this paper are Key gas method, IEC gas ratio method, Cellulose condition test method, Total combustible gas method, Duval triangle method and extension to Duval triangle.

A. Key gas method : Table 1 indicates whether a gas has crossed its permissible limit that would possibly indicate it to be involved in the fault

Table 1:

GAS	Permissible gas limits (ppm) for different gases		
	Less than 4 years of service	*4-10 years in service*	*More than 10 years in service*
Hydrogen	100-150	200-300	200-300
Methane	50-70	100-150	200-300
Acetylene	20-30	30-50	100-150
Ethylene	100-150	150-200	200-400
Ethane	30-50	100-150	800-1000
Carbon monoxide	200-300	400-500	600-700
Carbon dioxide	3000-3500	4000-5000	9000-12000

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B. Total combustible gas method: Table 2 gives the limits for total combustible gases.

Table 2:

Total Combustible Gases	Recommended Action
0 - 500 ppm	Normal ageing, analyse again in 6-12 months
500 – 1200 ppm	Decomposition of oil in excess of normal ageing, analyse after 3 months (monitoring)
1201 – 2500 ppm	More than normal decomposition, analyse frequently to establish trend (in every 1 month)
2500 ppm and above	Substantial decomposition, possibly fault, to be confirmed

Generation of combustible gases above 100 ppm in a 24hour period may need weekly DGA.

C. IEC gas ratio method : The "Basic Gas ratios" as in Table 2 recognized in the International Electro technical Commission (IEC) Standards is equivalent to Doernenberg ratios and Rogers ratios in the ANSI/IEEE C57.104. Three gas ratios are used in this method. They are methane/hydrogen, acetylene/ethylene and ethylene/ethane.

Table 3:

	IEC 599			
		C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6
	Ratios of characteristic gases			
	<0.1	0	1	0
	0.1-1	1	0	0
	1-3	1	2	1
	>3	2	2	2
Case no.	Characteristic faults			
1	No fault	0	0	0
2	Partial discharge of low energy density	1	1	0
3	Discharge of low energy	1-2	0	1-2
4	Discharge of high energy	1	0	2
5	Thermal fault of low temperature <150˚C	0	0	1
6	Thermal fault of low temperature range 150˚C-300˚C	0	2	0
7	Thermal fault of medium temperature range 300˚C-700˚C	0	2	1
8	Thermal fault of low temperature range >700˚C	0	2	2

D. Cellulose condition test: Table 4 indicates the cellulose condition.

Table 4:

Case no.	**Cellulose condition test**	
	Ratio= CO_2/CO	***Characteristics***
1	>7	Normal cellulose
2	5<ratio<=7	Problem with cellulose
3	3<ratio<=5	Rapidly deteriorating cellulose insulation
4	<3	Strong indication of decomposition of cellulose

E. The Duval triangle: Michel Duval of Hydro Quebec developed Duval Triangle method in the 1970s using a database of thousands of DGAs and transformer problem diagnosis. This method has proven to be accurate and dependable over many years and is now gaining popularity. In this method concentration (ppm) of methane (CH_4),

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ethylene (C_2H_4), and acetylene (C_2H_2) are expressed as percentages of the total (CH_4 + C_2H_4 + C_2H_2) and plotted as a point (%CH_4, %C_2H_4, %C_2H_2) in a triangular coordinate system on a triangular chart which has been subdivided into fault zones. The fault zone in which the point is located designates the likely fault type which produced that combination of gas concentrations. The Duval Triangle method, like any other DGA diagnostic method, should be applied only when there is some suspicion of a fault, based on an increase in combustible gas or some other suspicious symptom. Table 5 indicates the faults detectable by Duval triangle.

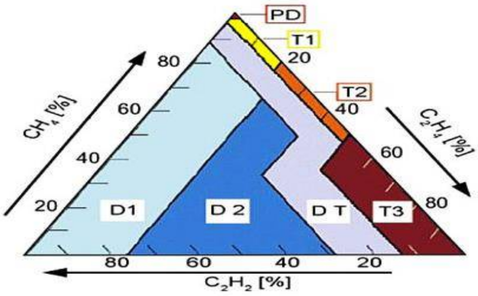

Fig.1: Duval triangle

Table 5:

Faults detectable by Duval triangle		
Symbol	***Fault***	***Examples***
PD	Partial discharges	Discharges of the cold plasma(corona) type in gas bubbles or voids, with the possible formation of X-wax in paper
D1	Discharges of low energy	Partial discharges of the sparking type, inducing pinholes, carbonized punctures in paper. Low energy arcing inducing carbonized perforation or surface tracking of paper, or the formation of carbon particles in oil.
D2	Discharges of high energy	Discharges in paper or oil, with power follow-through, resulting in extensive damage to paper or large formation of carbon particles in oil, metal fusion, tripping of the equipment and gas alarms.
T1	Thermal fault, T<300˚C	Evidence by paper turning brownish (>200˚C) or carbonized (>300˚C).
T2	Thermal fault 300˚C<T<700˚C	Carbonization of paper, formation of carbon particles in oil.
T3	Thermal fault T>700˚C	Extensive formation of carbon particles in oil, metal coloration (800˚C) or metal fusion (>1000˚C).
DT	Thermal and electrical fault	Sometimes both thermal and electrical fault occurs inside the transformer. These faults accelerate the decomposition of electric fluid and solid insulation.

F. Extension to the Duval triangle:

a) Duval Triangle for low temperature faults:

There are five zones in Fig.2 such as: PD- Corona partial discharge, S- Stray gassing of mineral oil (T< 200˚C), C- Hot-spots with carbonization of paper, O- Over-heating, N/D- Not determined. In zone C, the probability of having carbonization of paper is 80 % .

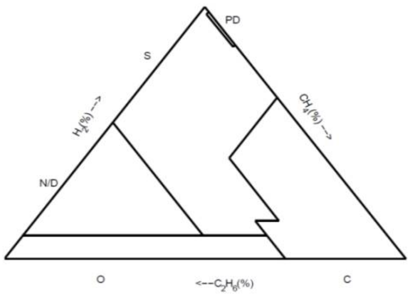

Fig 2: Duval Triangle for low temperature faults

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b) Duval Triangle for high temperature faults :

Fig.3 Duval Triangle is used for high temperature faults. It uses three gases for the analysis such as methane, ethylene and ethane. It is used to get more information about the faults identified as Thermal faults i.e. T2 and T3 in classical Duval triangle. It should not also be used for faults like D1, D2.There are seven zones in this Duval triangle such as: PD- partial discharge, S- Stray gassing of mineral oils (T<200˚C), C- Hot spot with carbonization of paper, O- Over heating (T<250˚C), T2-Thermal faults of high temperature (300˚C<T<700˚C), T3-Thermal faults of very high temperature (T>700˚C), N/D-Not determined. In zone C, the probability of having carbonization of paper is 90 %.

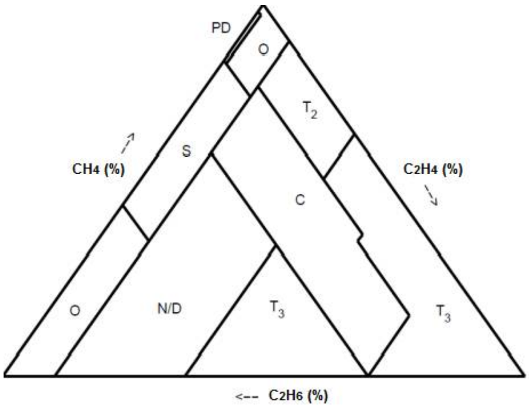

Fig 3: Duval Triangle for high temperature faults

VI. CASE STUDY

DGA data of certain transformers of Assam have been collected from Regional Testing Institute, Guwahati. We have detected the faults of each transformer using the various DGA methods developing MATLAB program and gave our analysis.

1. Transformer no. 1:

Power & voltage class: 25 MVA, 132/33 KV; Age of transformer: 6 months; Date of last filtration: 6 months before; Last topping up: 6 months before.

Gases	Methane (CH_4)	Ethane (C_2H_6)	Ethylene (C_2H_4)	Acetylene (C_2H_2)	Hydrogen (H_2)	Carbon monoxide (CO)	Carbon dioxide (CO_2)
Ppm level of gases	225	12	275	521	164	659	246

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VI (1) a) Key gas method:

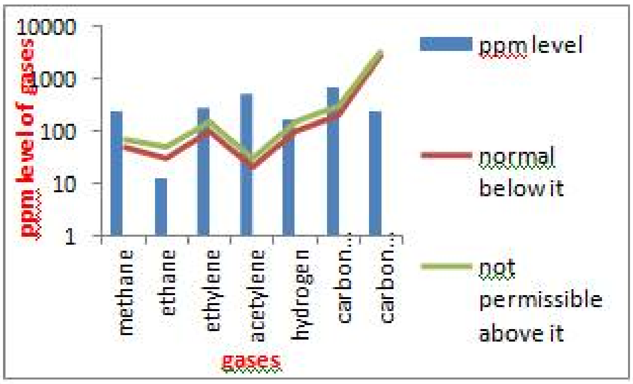

Fig. 4: Bar diagram ppm level of different gases present in transformer no.1

Fig.4 indicates methane , ethylene, acetylene, hydrogen and carbon monoxide ppm levels have crossed the permissible limits.
Methane indicates sparking, Ethylene indicates severe overheating, Acetylene indicates arcing, Hydrogen indicates corona, arcing, Carbon monoxide indicates severe overheating which may involve cellulose but it can be said only after the following tests.

VI (1) b) Total combustible gas method:

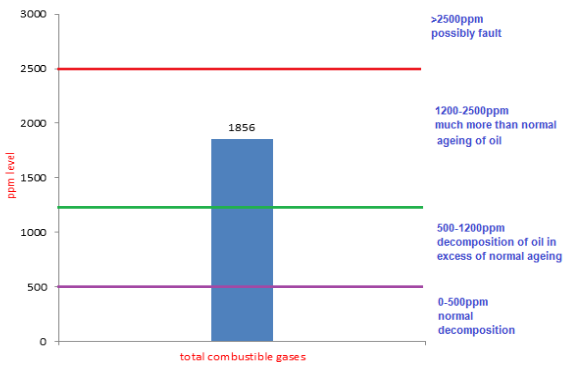

Fig .5: Bar diagram of ppm level of total combustible gases present in transformer no.1

Fig.5 indicates total combustible gas is 1856ppm which indicates that the condition of oil has degraded to a great extent and it must be taken into consideration for analyzing frequently to establish trend (in every 1 month).

VI (1) c) IEC Gas ratio method: IEC Gas Ratio method doesn't give the result as all the three codes don't fall under a particular fault type as in table 3.
VI (1) d) Cellulose condition test: In this case (CO_2/CO) =0.3733 i.e. (CO_2/CO) <3, which shows strong indication of decomposition of cellulose. Furan test should be performed.

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VI (1) e) Duval triangle method:

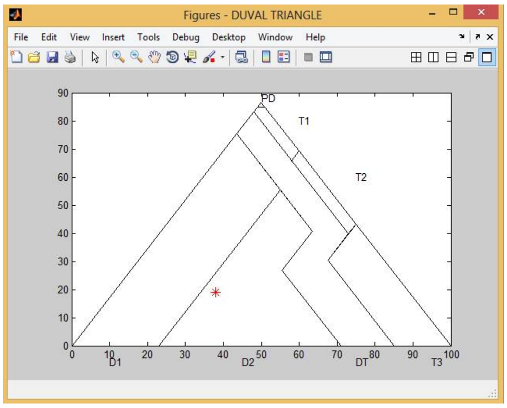

Fig .6: Duval triangle for transformer no. 1

The red asterisk mark in Fig.6 is the fault point indicated by the gases methane, ethylene and acetylene and it is located in the D2 i.e. discharge of high energy zone.

VI (1) f) Fault analysis of transformer no.1:
As the transformer has completed just 6 months of service, with such high level of abnormal gas generation level and also the deteriorating condition of cellulose indicates severe damage. The presence of acetylene is an indicator of arcing; and even low levels of this gas should cause concern. Hence it can be concluded there is discharge of high energy causing cellulose decomposition. Furan test should be performed immediately to confirm the condition of cellulose. However, the high energy required to produce an arc causes all combustible gases to be elevated.

2. Transformer no. 2:

Power & voltage class: 1 MVA, 33/11 KV; Age of transformer: 23 years; Date of last filtration: 4 years before; Last topping up: 1 year before.

Gases	Methane (CH_4)	Ethane (C_2H_6)	Ethylene (C_2H_4)	Acetylene (C_2H_2)	Hydrogen (H_2)	Carbon monoxide (CO)	Carbon dioxide (CO_2)
Ppm level of gases	1547	424	1839	ND	385	88	237

VI (2) a) Key gas method:

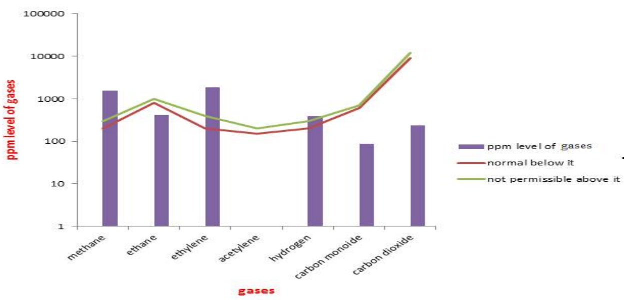

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Fig.7 indicates thermal fault gases methane, ethylene and hydrogen have crossed permissible limit indicating temperature rise. Methane and hydrogen also indicates partial discharge; though it can be confirmed only after the following tests.

VI (2) b) Total combustible gas method:

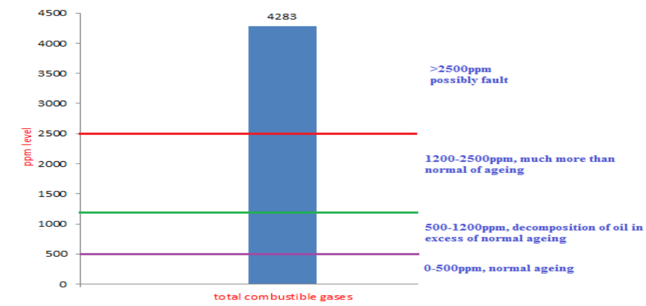

Fig .8: Bar diagram of ppm level of total combustible gases present in transformer no.2

In Fig.8 total combustible gas is 4283ppm which indicates substantial decomposition, possibly fault, to be confirmed.

VI (2) c) IEC Gas ratio method :This test indicates thermal fault of high temperature >700˚C which is to be confirmed after the following tests.

VI (2) d) Cellulose condition test: Here (CO_2/CO) = 2.6932 i.e. (CO_2/CO<3), thus this test shows strong indication of decomposition of cellulose . Furan test should be performed immediately.

VI (2) e) Duval triangle method: The red asterisk mark in Fig 9 which is the indicator of fault is in T3 i.e. Thermal fault >700˚C zone. To get more accurate result we will proceed to the extension of Duval triangle that is Duval triangle for high temperature faults .

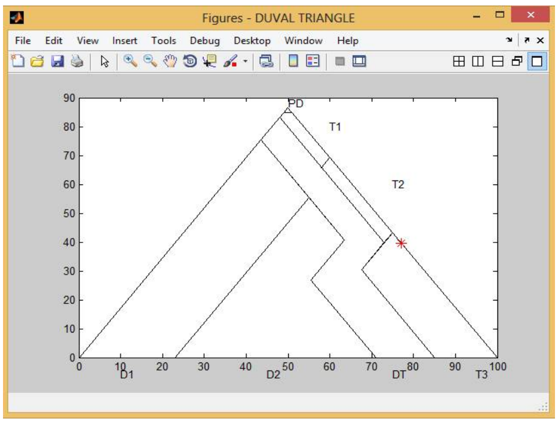

Fig 9: Duval triangle for transformer no. 2

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VI (2) f) Duval triangle method for high temperature faults: In Fig 10. the red asterisk mark which is the indication of

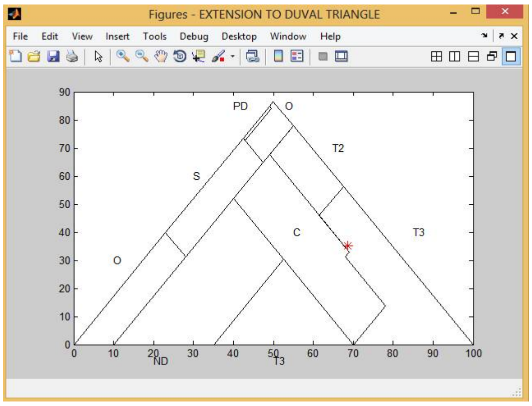

Fig 10: Duval triangle for high temperature faults

VI (2) g) Fault analysis of transformer no.2:

Test indicates thermal fault >700˚C along with thermal decomposition of cellulose. The gases most probably have formed from breakdown of the liquid caused by heat. Heating may be caused by poor contacts on a tap changer, or loose connections on a bushing or a grounding strap or circulating currents in the core due to an unintended core ground. If such high temperature is detected the transformer should be immediately taken out of service.

VI. CONCLUSION

DGA should be performed at regular interval of time to study the trend of gases. An annual DGA is the most important test for liquid insulation. Thus to save a transformer from catastrophic damage concern should be shown. Prevention is better than cure. In this transformer health monitoring the detection time has been reduced as compared to manual diagnosis by using the developed program.

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