Novel Approach for Diagnosing the Power Transformer Fault Based on Dissolved Gas Analysis

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ABSTRACT

Transformer oil performs a multiple functions for the transformer viz. provides insulation, cooling, and helps in extinguishing arcs. Due to electrical and thermal faults resulting from unfavorable operational conditions in transformers, the gas generation in transformer oil is induced. Along with aged conditions of transformers, operational factors like abnormal rise in temperature, vigorous electrical fields, electrical discharges, mechanical stresses, insulation deterioration and contaminants cause impending risks of wrong and irreversible harm to the transformers. All over the world the utilities employ the well proven Dissolved Gas Analysis (DGA) to make sure timely and correct diagnostics of the electrical and thermal faults occurring within the transformers, to save time, equipment and expenditure. The Gases, predominantly hydro carbon gases such as hydrogen, methane, ethane, ethylene and acetylene along with carbon monoxide and carbon di-oxide act as fault indicators. Dissolved Gas Analysis (DGA) is a well-established, widely used technique to estimate the condition of oil- immersed transformers. The experimental results of the change in concentration of different combustible gases and their levels in the insulating oil indicates, the development of any incipient faults and the probable nature of fault, early in a transformer to avoid any sudden failure. Probable faults such as hot spots, electrical arcing or partial discharges etc. can all are deducted by this technique. This will also offer helpful data concerning the conditions of the oil and the transformer. The frequency of sampling depends upon the criticality of the nature of the fault occurring in a transformer. It is not enough just to know the concentrations of gases in transformer oil, but it is also important to interpret the results correctly for which various methods are employed. Doernenburg, Rogers, Duval triangle, IEC three ratio method and key gases strategies are some of the classical strategies used to interpret the kind of transformer faults. Most of the Utilities employ manual calculations of ratios to determine the fault conditions, which require more effort and time. The objective of this paper is mainly to obtain the DGA results with available data from DGA test for different methods as given in the Standards by developing user friendly software using Excel and visual basic in a simple method for diagnosing the power transformer faults. For this purpose the available DGA data/results have been obtained from the Utility.

Keywords: Transformer Fault Analysis, Power Transformer, Dissolved Gas Analysis, Diagnostic tool for fault deduction using DGA.

I. INTRODUCTION

Power transformers play a very important role in each transmission and distribution of electrical network. Power distribution has been facing many challenges in order to meet the ever-growing world energy demands. However, the technology of oil- filled transformers has remained virtually unchanged for almost a century of period. Nowadays, in all the utilities, more number of transformers are exposed to various type of stresses and are in danger of not fulfilling the expected life span. Consequently, several of such transformers are to be strategically replaced or repaired in order to maintain uninterrupted power supply for customer satisfaction. It is also very difficult to operate the aged transformers in overload conditions which have become a necessity and leads to a rise in the transformer faults. Further, it is difficult to manage the impact of any sudden failure of transformers. Hence, it is very essential to detect incipient faults in the transformer.

II. DISSOLVED GAS ANALYSIS (DGA)

As discussed above, in operations, transformers are subjected to electrical and thermal stresses, which can cause the degradation of insulating materials. Insulation is an important part of a power transformer, in general, solid and liquid insulation are broadly used. By early deduction of any internal faults developing in power transformers, the expenditure of unplanned outages of power transformers are often reduced. Gasses get dissolved in transformer oil, during the operation of a transformer. These gasses evolved as results of transformer faults such as arcing, corona (partial discharges), overheating of transformer oil or overheating of paper insulation (cellulose). Different types of gases will be in different levels of concentration depending upon the nature of the faults developing in a transformer. Among the dissolved gasses, the flammable gasses (hydro carbon gases) are very critical and any quantum jump in the levels of concentration of such gases may result in a severe/destructive type of transformer fault. The combustible gasses such as H2 (Hydrogen), C2H6 (Ethane), C2H4 (Ethylene) and C2H2 (Acetylene) generally appear in a transformer oil in very low concentration in normal conditions and are easily detectable in ppm levels by Dissolved Gas Analysis(DGA). A mixture of gases ratios in a relative proportion are used to establish a fault. DGA is performed in accordance with IS-10593 or ASTM D3612 or IEC 60567 and IEC IEC-60599.

2.1 Detection Techniques of Dissolved Gases

The DGA technique detects gases in parts per million (ppm) dissolved oil by the use of gas extraction unit and a gas chromatograph. The DGA analysis is performed in the following steps:

1. Collection of oil sample
2. Extraction of gases from the collected sample
3. Detection of gases

There are two methods for detection of gases dissolved in the oil sample such as;

1. Gas chromatography (GC)
2. Optical gas detection

2.2. Types of Faults detectable by DGA

The various types of faults which occur in the transformer could be detected by DGA. The principal faults which can be identified by DGA techniques are

1. Partial discharge (with low energy)
2. Thermal faults (medium energy up to large-scale)
3. Electrical arcing (with high energy discharge)
4. Deterioration of paper insulation to some extent (A few more complementary tests such as Furan analysis and Degree of Polymerization have to be performed to ascertain this.)

2.3. DGA Guide Line Values and Suggestions.

Table 1. Normal limits of dissolved gases for Transformers

Ethane (C_2H_6)	50	150	100 0
Carbon dioxide (CO_2)	3500	5000	120 00
Carbon monoxide (CO)	300	500	700

The above table shows typical, normal safe limits for the DGA gases in a transformer based on its years of service. However it may be pointed out here that the above mentioned limits may not be taken as a permissible limit but has to be taken as guide line limits only. The DGA is more of a trend monitoring technique than based on a specific limit values. When mineral oil contains normal values of dissolved gas, it indicates no incipient fault in the transformer. However, if a considerable increase in Gas levels is noticed (between the previous sample test and the latest sample test), it may indicate some fault development inside the transformer. Before the fault becomes critical and assumes huge proportions, some supplementary actions have to be taken so as to avoid sudden failure of transformer. Such supplementary action includes immediate re-sampling, specifying the periodicity of the next sample, suggestion of other diagnostic tests etc. Hence, any quantum jump in the levels of concentration of fault gases has to be interpreted for further course of remedial actions.

III.DIAGNOSTIC METHODS OF DISSOLVED GASES

Gas	< 4 Yrs in service (ppm)	4– 10 Yrs (ppm)	> 10 Yrs (pp m)
Hydrogen (H_2)	150	300	300
Methane (CH_4)	70	150	300
Acetylene (C_2H_2)	30	50	150
Ethylene (C_2H_4)	150	200	400

There are different methods of DGA interpretation in order to determine the fault in a transformer. Each method uses some gas ratios for fault diagnosis and some compare gas concentrations to the specified levels to evaluate a transformer's condition. IEEE Standard C57.104-2008 describes the following Methods.

1. key gases method
2. Doernenburg ratios method

3. Rogers Ratio method.

IEC Standard 60599 and IS 10593 suggest the following Methods.

1. Three basic gas ratio method
2. Duval triangle method.

3.1. KEY GASES METHOD

The key gas method employs the critical gas concentrations to specify the nature of fault. The various combination of concentration among the hydro carbon gases will specify different types of faults. The Key Gas Method simply utilizes relative percentages of the selected fingerprint gases to identify fault types. This method actually uses four characteristic charts which represent typical relative gas concentrations for four general fault types,i.e. Overheating of Cellulose (OHC), Overheating of Oil (OHO), Partial Discharge (PD) or Arcing, corona. Key gases formed by degradation of oil and paper insulation are hydrogen (H2), methane (CH4), ethane (C2H6), ethylene (C2H4), acetylene (C2H2), Carbon monoxide (CO) and oxygen (O2). 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 based on the kind of fault in the transformer, the severity and energy of the event.

3.2 DOERNENBURG RATIO METHOD

The Doernenburg method utilizes four calculated gas ratios to indicate a particular fault type out of three possible fault types. This procedure requires significant gases levels for the diagnosis to be valid. The four ratios and their diagnosis values are given on Table2. Doernenburg method uses five individual gases or four-key gas ratios, which are:

R1=CH4/H2,R2=C2H2/C2H4, R3=C2H2/CH4,R4=C2H6/C2H2

Table 2. Doernenburg Ratio Method.

Ratios for key Gases - Doernenburg method				
Ratio	Main Ratio		Main Ratio	
	CH4/ H2	C2H2/ C2H4	C2H2/ CH4	C2H6/ C2H2
Therma l Decomposition n	>1	<0.75	<0.3	>0.4
Corona (Low intensit y PD	<0.1	Not signifi cant	<0.3	>0.4
Arcing (High Density PD	<1, >0.1	>0.75	>0.3	<0.4

3.3 ROGER'S RATIO METHOD

The original Rogers ratio method uses four gas ratios which are CH4/H2, C2H6/CH4, C2H4/C2H6 and C2H2/C2H4 for diagnosis. The modified Rogers method uses two tables: one defined the code of the ratio, and the other defined the diagnosis rule. Roger's ratio method gained popularity in industrial practices. However, it may give no conclusion in some cases. This is the drawback of this method. Table 3 shows the codes of Roger’s method to diagnosis the fault in transformer.

Table 3. Roger's Ratio Method

Case	R1 CH4/H2	R2 C2H2 /C2H 4	R3 C2H4 /C2H 6	Suggested fault Diagnosis
0	>0.1 to <1.0	<0.1	<1.0	Unit Normal
1	<0.1	<0.1	<1.0	Low Energy Density arcing - PD
2	0.1 to 1.0	0.1 to 3.0	>3.0	Arcing - High Energy Discharge
3	>0.1 to <1.0	<0.1	1.0 to 3.0	Low temperatur e - Themal
4	>1.0	<0.1	1.0 to 3.0	Thermal <700° C
5	>1.0	<0.1	>3.0	Thermal >700° C

3.4 THREE BASIC GAS RATIO METHOD

Three gas ratios used in this method are methane/hydrogen (CH4/H2), acetylene/ethylene (C2H2/C2H4), and ethylene/ethane (C2H4/C2H6). Often the incipient faults start as, low energy faults and get developed into more serious high energy or high 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 guide lines values has to be seriously viewed as the fault is active. Hence, it is very important to study the trend, in the occurrence of different types of faults. Determining the trend in both the rate of increase of the individual gases and the possibility of occurrence of different types of faults will provide specific information on the internal condition of the transformer. The ratio of CO2 / CO is sometimes used as an indicator of the thermal decomposition of cellulose.

Table 4. Three Basic Gas Ratio Method

Case	**Charact eristics fault**	**acetyle ne/eth ylene**	**metha ne/hyd rogen**	**ethyle ne/ ethan e**
PD	Partial Discharg	NS	< 0.1	< 0.2
D1	Discharg es of Low energy	> 1.0	0.1 - 0.5	> 1.0

D2	Discharges of High	0.6 - 2.5	0.1 - 1.0	> 2.0
T1	Thermal fault (T1)	NS	> 1.0	< 1.0
T2	Thermal fault (T2)	< 0.1	> 1.0	1.0 - 4.0
T3	Thermal fault (T3)	< 0.2	> 1.0	> 4.0

IV.NOVEL APPROACH FOR DIAGNOSING THE POWER TRANSFORMER FAULT BASED ON DGA

The four classical methods of transformer fault diagnosis such as Key gas method, Doernenburg method, Roger's method and Three Basic Gas Ratio Method are applied to obtain the nature of the fault in transformer. A software code in excel sheet is developed using the logic function to get transformer fault from the four classical methods that are mentioned above; the results depend on the combustible gases that arise when fault occurs in transformer. The Visual Basic programme is used as front end interface for entering the Gas values in ppm and to show the consolidated results of all the classical methods. The consolidated results shown by VB front end sheet and the back end main excel sheet are shown in the figure 1 & 2.

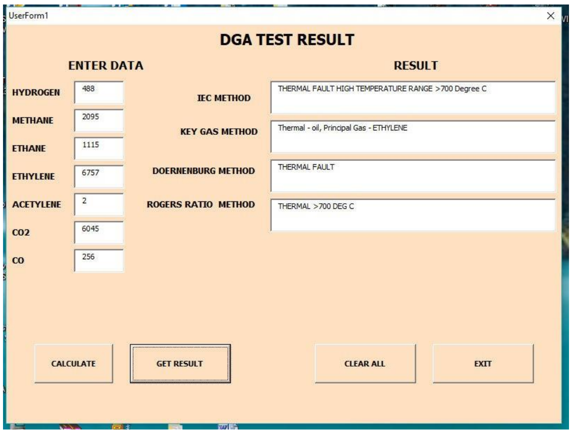

Figure 1: DGA interpretation - VB front end

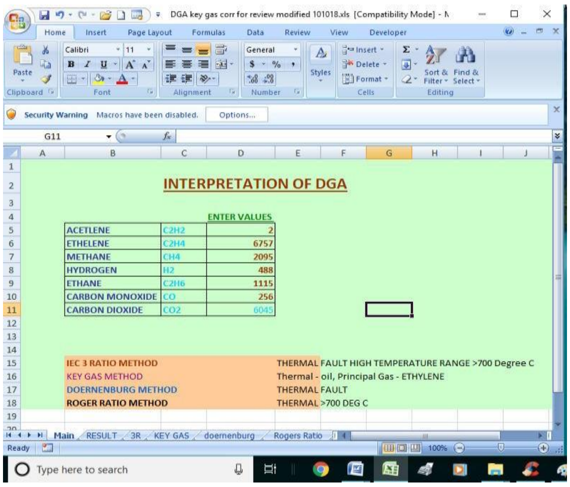

Figure 2: DGA interpretation - Excel Main sheet back end

V.CASE STUDIES TO SPECIFY THE FAULT TYPE IN TRANSFORMER.

A few real time case studies are depicted in Table 5 below where the Transformers were taken out of service on account of high fault gas generations and the findings of the faults in these Transformers by different gas interpretation methodologies and diagnostic accuracy of each interpretation methodology is brought out for different type of faults.

Table 5. Case studies 1 & 2

GAS / METHOD		Case 1 110/11 KV SS 16 MVA Trfr	Case 2 110/11 KV SS 16 MVA Trfr
Hydrogen	H2	140	293
Methane	CH4	17	51
Ethane	C2H6	3	8
Ethelene	C2H4	35	144
Acetlene	C2H2	39	267
Carbon di oxide	CO2	1478	2506
Carbon monoxid e	CO	0	0
Key Gas Method		Electrical - Carona, Principal Gas - Hydrogen	Electrical - Carona, Principal Gas - Hydrogen
Doernenberg Method		Discharge Arcing	Discharge Arcing
Rogers Method		High Energy Discharge Arcing	High Energy Discharge Arcing
IEC Ratio Method		Discharge Of High Energy Density	Discharge Of High Energy Density
LAB RESULT		Thermal/Arcing Fault	Arcing Fault

CASE 1 : 110/11 KV SS

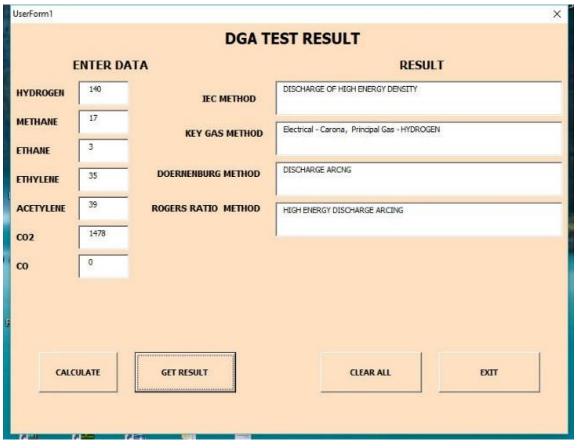

Figure 3 - Case study 1

CASE 2 : 110/11 KV SS

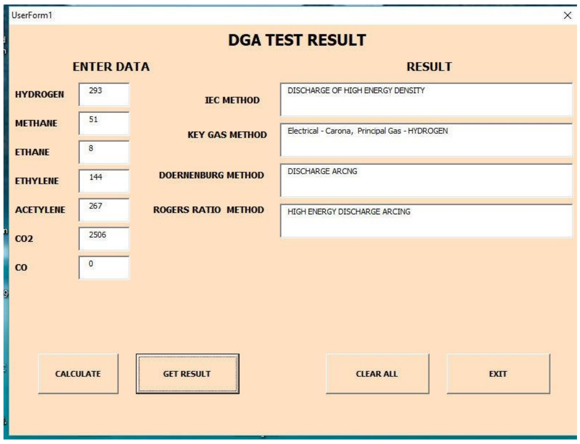

Figure 4- Case study 2

Table 6. Case studies 3 & 4

GAS / METHOD		Case 3 33/11 KV SS 16 MVA Trfr	Case 4 110/33KV SS 25 MVA Trfr
Hydrogen	H2	488	250
Methane	CH4	2095	102
Ethane	C2H6	1115	13
Ethelene	C2H4	6757	300
Acetlene	C2H2	2	534
Carbon di oxide	CO2	6045	3743
Carbon monoxide	CO	256	451

Key Gas Method	Thermal - oil, Principal Gas - Ethylene	Electrical - Arcing, Principal Gas - Acetylene
Doernenberg Method	Thermal Fault	Discharge Arcing
Rogers Method	Thermal >700 Deg C	High Energy Discharge Arcing
IEC Ratio Method	Thermal Fault high temperature range >700 Degree C	Discharge Of High Energy Density
LAB RESULT	Thermal Fault	Thermal/Arcing Fault

CASE 3 : 33/11 KV SS

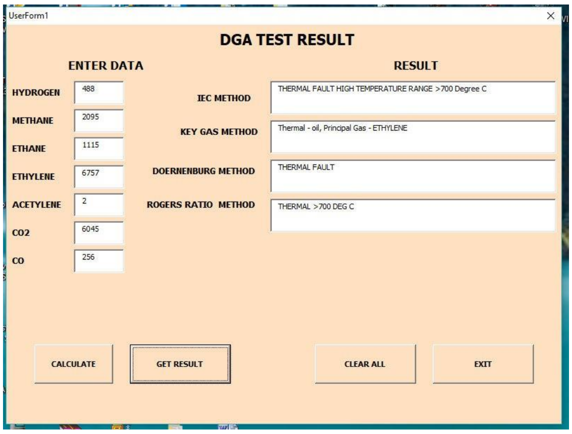

Figure 5- Case study 3

CASE 4 : 110/33 KV SS

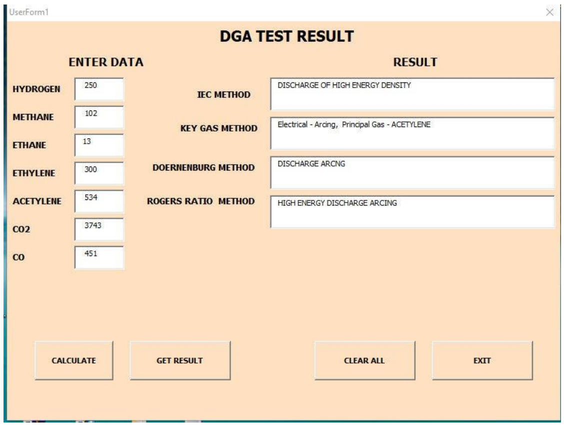

Figure 6 case study 4

Table 5&6 shows the gas concentrations of some fault tripped transformers and the results from the Utility laboratory using manual method and results from the developed software tool. From the above table, we can see that each interpretation methodology indicates different type of fault for the same set of DGA results. This is because each method gives more weightage to some gases.

5.1VALIDATION OF THE PROPOSED TECHNIQUE

As in Figure 3, 4,5&6 and the Table 5, the comparison between the results from the software code and the results from manual method explains the reliability and validation of this software tool for detecting the faults in transformer based on DGA.

VI. CONCLUSION

The results from different cases reveal that the developed software for interpretation of DGA test results is a user friendly and reliable method. This software will be a time saving technique by avoiding manual calculations and will prove very useful for utilities in diagnosing the transformer fault by various methods.Further, from the case studies, it may be inferred that even though different interpretation methodology has been employed for the same set of DGA gas levels, the net result is found to be correct and coinciding with the manual calculations by the utility lab. However, in a few stray cases the interpretation by each methodology may be different to the same set of DGA results. This may be due to the fact that each interpretation methodology has significance for identifying different type of fault taking into account one or two particular gases for the calculation. Under such circumstances, the user based on his service experience has to select suitable interpretation methodology for proper diagnosing of the fault. These DGA interpretation methods can be helpful for prioritization of maintenance scheduling and assigning criticality level to each Transformer.

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