# Dissolved Gas Analysis based Incipient Fault Diagnosis of Transformer: A Review

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***Abstract: Dissolve Gas Analysis is one of the widely used technique for recognition of incipient fault of oil immersed transformer. The transformer is a very important and critical component of power system. There is a need of proper maintenance and regular diagnosis of incipient fault within transformer oil. The main cause of transformer failure is ageing, deterioration and damage of insulating material. When insulating material is subjected to any incipient fault, combustible gases are generated. These combustible gases are known as key gases. By analysing these gases transformer fault can be detected. This paper represents a review of different DGA methods. The existing DGA diagnostic method consists of mainly Key Gas method, Ratio method (Rogers and Doernenburg and I.E.C. ratio) and Percentage Gas method (Duval triangle).***

***Keywords: Oil insulation, Dissolved Gas analysis, Power transformer, Incipient fault diagnosis.***

## 1. INTRODUCTION

Large power transformer in utility is highly valued, important but complex component of power system. They are working 24 /7 and difficult to remove due to power system constraints..Any type of transformer fault whether incipient or short circuit can cause power outage and many times blackout in large area. In this way it prevents the power quality. Power quality is the main concern for power system [1-6] .Low power quality gives birth to many problems to connected equipment: malfunctioning, instability and short life time are some example of it. So maintain power quality is an important aspect. The replacement of power transformer is very costly and time consuming. So it is important to detect incipient fault as early as possible, forecast it and prevent failures. So that the service interruption time is minimum. In Power transformer, fault broadly classified as internal incipient fault and Internal short circuit fault . In power transformer for the purpose of insulation large amount of solid impregnated cellulose insulators and liquid transformer oil‘s combination used. Incipient fault mainly caused by deteriorated insulation and ageing and major cause of deterioration of insulation and ageing are thermal stress, mechanical stress, electrical stress and moisture. The majority of incipient faults occurring in power transformers give warning in advance of major breakdown through the transformer oil gas analysis, transformer may function well during this but it may causes many serious insulation deterioration problem . When In Oil Immersed Power transformer, fault occurs, there are combustible gases produced. This is due to thermal and electrical discharge effect by insulation material near the fault and is dissolved in the insulation oil. Thermal fault and electrical fault may be further classified as thermal fault as low temperature, median temperature and high temperature while electrical fault are as mainly high energy arcing fault and low energy partial discharge. [7-10].

## 2. DGA APPROACH TO FAULT FINDING

The DGA has requirement of routine oil sampling and some modern technologies for the purpose of online gas monitoring. In normal operation of without fault occurrence, transformer oil contains gases like hydrogen($H_2$), methane($CH_4$), Ethylene($C_2H_4$), Ethane($C_2H_2$), Oxygen($O_2$) and Nitrogen($N_2$) .When fault occurs, the concentration of some of given above gases increases, depending upon fault type and location. These gases can divided in three sub group [1,4, 5, 8-10].

i) Hydrogen gas and hydrocarbon: $H_2$,$CH_4$, $C_2H_4$, $C_2H_2$
ii) Carbon oxides: $CO_2$ and CO
iii) Non faults gases : $O_2$ and $N_2$

The primary step in using gas analysis for fault detecting is correctly diagnosing the fault that generated the gases. If abnormalities occur then insulation oil breaks down into small quantities of gases due to electrical and/or thermal stresses. The composition is depends on the fault type. The recognition of certain level of gases generated in oil-filled transformer in service is often the first available indication of a malfunction that occurs in a transformer and causes failure of it, if not corrected. A possible mechanism of gas generation includes corona discharge, arcing, low energy sparking, overheating of insulation due to overloading, and forced cooling systems failure. Transformer oil fault can be identified according to the above gases generated and the gases that are typical or predominant at various temperatures [11-16]. The fault and dissolved gas concentration can be correlate as follows:

i. $H_2$ and $C_2H_2$: For generation of $C_2H_2$ temperature should be more than 500 $^0$C so if $H_2$ and $C_2H_2$ concentration increased then this is a sign of arcing fault.
ii. $C_2H_6$, $C_2H_4$, $CH_4$, $C_3H_8$/ $C_3H_6$ (propane/propylene) and $H_2$: Increased concentration of $C_2H_4$ along with any one of $C_2H_6$, $CH_4$, and $C_3H_8$/ $C_3H_6$, signify thermal decomposition of the oil. These gases are generated at below 250 C temperatures.
iii. $H_2$and $CH_4$: These are generated if in transformer oil partial discharge (or corona) takes place.
iv. $CO_2$ and CO: If these gases generate then it is indication of thermal ageing or partial discharge (corona) in cellulosic insulation.

$H_2$ and $O_2$: If these gases present together with absence of any hydrocarbon gases, it indicates the presence of water in transformer oil

### *A. DGA Procedure*

In today's scenario DGA technique requires measuring instruments with high accuracy so it is best performed in laboratory. DGA procedure can be explained in following four steps:

i. Transformer oil Sampling
ii. Gases extraction from the oil
iii. Analysis of the extracted gas mixture
iv. Interpretation of gaseous data

### *B. Interpretation of Dissolve Gaseous Analysis*

There are various DGA methods which have been used by organizations and utilities to assess transformer conditions. These DGA interpretation schemes are basically based on empirical assumptions and practical knowledge gathered by experts worldwide. In spite of that, if these interpretation schemes are not applied cautiously, they may incorrectly identify faults because they only indicate possible faults. There may be some cases, in which DGA interpretation schemes may differ in terms of identified faults, which is clearly unacceptable for a reliable fault diagnosis system.

Interpretation schemes are mainly based on defined principles such as gas concentrations, key gases, key gas ratios, and graphical representations. According to IEEE Standard C57.104-2008 the existing DGA diagnosis consists of three types of methods.

- Key Gas Method
- Gas Ratio Method
- Percentage Gas method

Where Gas Ratio method includes Doernenburg ratio, Rogers ratio and I.E.C. ratio while percentage gas method includes Duval triangle[21,22] .There are some method also like Nomograph method which combining key gas ratio and key gas method and CIGRE method .

## 3. DGA METHODS

There are following methods are available for DGA analysis:

### *A. Key Gas Method*

According to IEEE standard C57 104 2008 [1] if there is any faulty state occurred in the power transformer then there is increase in temperature. After significant increase in temperature, the chemical structure of insulating oil disrupts which results in releasing of gases. These released significant gases are called **Key Gases**.

During faulty state, the stresses whether it is thermal or electrical can cause chemical breakdowns in transformer oil. The main degradation products are gases. These significant gases provide the basis for recognition of fault. As we know mineral oil mainly consist of hydrocarbon. During fault these hydrocarbon decomposed into active hydrogen and some hydrocarbon fragments. The produced gases in transformer oil can be regrouped as:

i) Hydrocarbon and hydrogen ($H_2$,$CH_4$, $C_2H_4$, $C_2H_2$, $C_2H_4$ $C_2H_6$)
ii) Carbon oxides ($CO$, $CO_2$) and
iii) Non-fault gases ($N_2$, $O_2$).

**TABLE I. KEY GAS METHOD [1]**

| S. No. | Key gases | General fault condition |
|---|---|---|
| 1. | Methane, Ethane, Ethylene and small amount of acetylene | Thermal condition involving the oil |
| 2. | Hydrogen, methane and small amount of acetylene and ethane | Partial discharge |
| 3. | Hydrogen,Acetylene and Ethylene | Sustained arcing |

***B. Rogers Ratio Method***

For convenient fault diagnosis, gas ratio methods use coding schemes in which we assign certain combinations of codes to specific fault types. These codes are generated by calculating ratios of gas concentrations and comparing the ratios with predefined values which is derived by experience and continually modified. A fault condition is detected when a gas combination fits the code for a particular fault. R. Rogers [5] proposed a most common gas ratio method termed as Rogers ratio method . The Rogers ratio method analyzes four gas ratios: $CH_4/H_2$, $C_2H_6/CH_4$, $C_2H_4/C_2H_6$ and $C_2H_2/C_2H_4$ . Recognition of faulty condition is done via a simple coding scheme based on ranges of the ratios given in table (II). The detectable four conditions of an oil-immersed transformer are normal ageing, partial discharge with or without tracking, and electrical and thermal faults of varying severity. R.A.Hooshmand [16] suggest three gas ratio i.e $CH_4/H_2$, $C_2H_4/C_2H_6$ and $C_2H_2/C_2H_4$ for this method. This method, which is based on thermal degradation principles, is also included in IEEE failure investigations with the gas analysis of each case. However, M.T.Yang [17] give some drawback of Rogers ratio as the diagnosis are not accurate enough.

### *C. Doernenburg Ratio Method*

The Doernenburg Ratio method identifies faults by analyzing gas concentration ratios mainly four gas ratio which are $CH_4/H_2$, $C_2H_2/CH_4$, $C_2H_4/C_2H_6$ and $C_2H_2/C_2H_4$ [1]. This method is based on thermal degradation principles . N.Yadaiah [14] informed that this method uses above ratio to identify thermal faults, corona discharge and arcing. In this method, the ratio procedure is considered valid if the gas concentrations (in ppm) for $H_2$, $CH_4$, $C_2H_2$, and $C_2H_4$ exceed double the value of the fixed limit for each gas and if that for CO and $C_2H_6$ exceeds thrice the value of the fixed limit. Each successive ratio is then compared with certain values to determine. Finally, if all four succeeding ratios for a specific fault type fall within the predetermined values, the diagnosis is confirmed[20-25]., M.T.Yang [17] give some drawback of this method .This method, which is specified in IEEE Standard C57.104-2008 [1], may obtain numerous no interpretation results due to incomplete ratio ranges. According to N.Yadaiah [14] .It can detect only three type of fault and is a very complex method.

**TABLE II. DOERNENBURG RATIO METHOD [1]**

| S. No | Suggested fault diagnosis | Ratio 1(R1) $CH_4/H_2$ | | Ratio 2(R2) $C_2H_2/C_2H_4$ | | Ratio 3(R3) $C_2H_2/CH_4$ | | Ratio 4(R4) $C_2H_6/C_2H_2$ | |
|---|---|---|---|---|---|---|---|---|---|
| | | Oil | Gas space | Oil | Gas space | Oil | Gas space | Oil | Gas space |
| 1. | Thermal decomposition | >1.0 | >1.0 | <0.75 | <1.0 | <0.3 | <0.1 | >0.4 | >0.2 |
| 2. | Partial discharge(low density PD) | <0.1 | <0.01 | | | <0.3 | <0.1 | >0.4 | >0.2 |
| 3. | Arcing(high density PD) | >0.1 to <1.0 | >0.01 to <0.1 | >0.75 | >1.0 | >0.3 | >0.1 | <0.4 | <0.2 |

### *D. IEC Ratio Method*

Three gas ratios i.e. : $CH_4/H_2$,$C_2H_4/C_2H_6$ and $C_2H_2/C_2H_4$ are used to determine incipient failure[29-31]. These three gas ratios have different ranges of code in comparison with the Rogers ratio method. This fault diagnosis scheme recommended by the International Electro technical Commission (IEC) This is originated from the Rogers ratio method excluding the $C_2H_6$ /$CH_4$ ratio since it only indicated a limited temperature range of decomposition. There are four detected conditions i.e. normal ageing, partial discharge of low and high energy density, thermal faults and electrical faults of varying severity but it does not classify thermal and electrical faults into precise subtypes. [18].

***E. Duval Triangle Method***

M.Duval [3] proposed his triangle interpretation for fault recognition. The Duval Triangle Method is based on the use of three gases $CH_4$, $C_2H_4$ and $C_2H_2$ and their Location in a triangular map [5]. In this method for plotting the triangle, gases are transformed into triangular co-ordinates. Partial discharges, electrical faults (high and low energy arcing), and thermal faults (hot spots of various temperature ranges) are the three detectable fault types. Advantage of this method is that it is easily performed, accurate and always provide diagnosis. Shortcomings are that careless implementation can obtain false diagnoses since no region of the triangle is designated as an example of normal ageing. So there is need to be concerned that the permissible amount of dissolved gases should be determined before using this method to analyze transformers which have been in service for the many years. It is an percentage gas method. In percentage of the gas is find by dividing quantity of the gas with total then percentages of total plotted on triangle to obtain the diagnosis.

***F. Nomograph Method***

The Nomograph Method combines the concept of fault gas ratios and the concept of Key Gas threshold. Since the Fault gas data is presented graphically, it simplifies data's interpretation . A nomograph is a series of vertical logarithmic scales used to represent the concentration of individual gases as straight lines drawn between adjacent scales[18]. The straight lines connect points representing the values of individual gas concentrations. Straight lines are diagnostic criteria for determining fault type. By comparing the slopes of line segments with the keys at the bottom of the nomograph, type of fault can be identified. Incipient Fault severity is determined by the position of lines related to the concentration scales. In Nomograph scale the threshold value of each vertical scale is indicated by an arrow. For the slope of a line to be considered significant, at least one of the two tie points should exceed the threshold value. The fault is not considered significant if the tie point lies above a threshold value

***G. CIGRE Method***

The CIGRE Method of DGA combine concept of key gas ratios and gas concentrations. In CIGRE Method there are five key gas ratios considered which are $C_2H_2$ /$C_2H_6$, $H_2$ /$CH_4$, $C_2H_4$ / $C_2H_6$, $C_2H_2$ /$H_2$ and $CO/CO_2$. The key gas concentrations are $C_2H_2$,$H_2$ the sum of carbon hydrides, CO and $CO_2$. A transformer is considered healthy if separate applications of these methods obtain ratios and concentrations that are below limits [32]. The benefit of this method is that this method is capable of detecting two or more faults simultaneously. H.C.Sun [18] reviewed about CIGRE Method that since 1999, CIGRE Task Force 15.01.01 has reconciled deviations and discrepancies among the different interpretation schemes. This method enhances the reliability of fault diagnostics by gathering expert knowledge and incorporating some adjustments, the DGA interpretation method proposed by CIGRE modifies previous interpretation schemes to. The dual step CIGRE interpretation scheme first analyzes key ratios of gas concentrations and key gas concentrations and then compares them to thresholds values. Both step combines to diagnose fault and to take corrective measures.

## 4. CONCLUSION

The prime aim of DGA based analysis is correct recognition of the fault using generated gases during fault. DGA is the most common technique that can use for online incipient fault diagnosis. In DGA the transformer need not to de-energized. This paper has discussed Key gas, Gas ratio and Percentage ratio based approach and it compares seven methods based on these three approaches. Using different DGA approach and technique i.e. Key gas method, Gas ratio method (Rogers or Doernenburg or IEC) or any other separately to examine the transformer, the interpretation may be different. So there is need of optimization. for better diagnosis there is need to work for combining of these approaches and integrating their data for evaluate

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