A REVIEW OF DISSOLVED GAS ANALYSIS AND TRANSFORMER HEALTH CONDITION

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ABSTRACT

Power transformers are important equipment of power system. The fault free operation of power transformers is a factor of major economic importance. Dissolved Gas Analysis (DGA) of transformer oil is one of the most effective power transformer condition monitoring tools. It has been proven that the generation of certain gases within a transformer is an excellent indicator that a failure is pending. DGA is a sensitive and reliable technique for detecting incipient fault condition in oil-immersed transformers. The overall health condition of the transformer strongly depends on the quality of insulation system within the power transformer. This paper deals with different DGA approaches such as Key Gas, Dornenburg Ratio, Rogers Ratio, IEC Ratio, Nomograph and Duval Triangle Method. Key Gas Method uses individual gas levels for detecting faults. Dornenburg Ratio Method and Rogers Ratio method uses the ratio of gas concentrations to indicate fault types. IEC Ratio Method uses the same three ratios as in Rogers Ratio Method but suggests different ratio ranges and interpretations. Nomograph method improves the accuracy by graphically representing the fault gas data. Duval triangle method uses values of three gases and they are transformed into triangular coordinates. The life of a transformer mainly depends on the life of its insulation system. Degree of polymerization, amount of CO and CO_2, amount of furans, interfacial tension and acid number, oxygen level and moisture are the potential factors that affect the quality of insulation in a transformer. This study compares the effectiveness of dissolved gas analysis methods and also different factors affecting the insulation strength of the transformer.

Keyword: - *Dissolved Gas Analysis, Power Transformers, Interfacial Tension, Insulation, Furans.*

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1. INTRODUCTION

Power transformers are vital link in power system. Monitoring and diagnostic techniques are essential to decrease maintenance and to improve reliability of the equipment. The fault free operation of power transformers is a factor of major economic importance and safety in power supply utilities. The electrical windings in a power transformer consist of paper insulation immersed in insulating oil, hence transformer oil and paper insulation are essential sources to detect incipient faults, fast developing faults and generally reflects the health condition of the transformers.

Thermal and electrical stresses that occur within normal operating transformers cause insulation oil to break down and to release small quantities of gases. The composition of these gases depends on the fault type. Gases produced due to oil decomposition are hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4) and acetylene (C_2H_2). Paper decomposition produces carbon monoxide (CO) and carbon dioxide (CO_2) [1-2].

Dissolved gas analysis (DGA) is a sensitive and reliable technique for detecting incipient fault conditions in oil-immersed transformers. DGA requires routine oil sampling and modern technologies for online gas monitoring. DGA approaches can evaluate the ageing process, deteriorating cellulose material of the transformer oil, the degree of polymerization and Furan analysis. By sampling and examining the insulating oil of transformers, ratios of specific gas concentrations, their generation rates and total combustible gases are often used as the attributes for classification by diverse DGA approaches.

2. DGA INTERPRETATION SCHEMES

Various DGA methods have been used by organizations and utilities to assess transformer conditions. These DGA interpretation schemes are based on empirical assumptions and practical knowledge gathered by experts worldwide. Interpretation schemes are generally based on defined principles such as gas concentrations, key gases, key gas ratios and graphical representations. Key Gas Analysis, Dornenberg and Rogers Ratio Methods, Nomograph, IEC Ratio and Duval Triangle are the common schemes mentioned in IEEE Standard C57.104-2008.

2.1 Key Gas Method

The Key Gas Method is based on the quantity of fault gases that are released from the insulating oil as the chemical structure breaks at varying temperatures in the transformer [3-4]. The presence of the fault gases depends on the temperature or energy that disrupts the chemical structure of the insulating oil. This method uses individual gas levels for detecting faults. The significant and proportion of the gases are called "key gases".

Table -1: Key Gases and their Fault Interpretations

Key Gases	Fault Type
O_2 & N_2	Non-fault condition
CH_4 & C_2H_6	Low temperature overheating of oil
C_2H_4	High temperature overheating of oil
CO & CO_2	Overheating of cellulose insulation
H_2	Corona
C_2H_2	Arching

This test is important and most frequently performed because it provides the first indication of a problem. The hydrocarbon molecules of mineral oil decompose and form active hydrogen and hydrocarbon fragments, which then combine into gases. This method relates key gases to fault types and attempts to detect four fault types, including overheating of oil, overheating of cellulose, partial discharge (corona) and arching. The concentrations of key gases are expressed in parts per million (ppm). This method is simple, but they are not widely accepted as reliable diagnostic tools for power transformers.

2.2 Dornenburg Ratio Method

This method uses the ratio of gas concentrations to indicate fault types. Gas ratio methods use coding schemes that assign certain combinations of codes to specific fault types. A fault condition is detected when a gas combination fits the code for a particular fault. The codes are generated by calculating ratios of gases concentrations and comparing the ratios with predefined values derived experience and continually modified.

The Dornenburg Ratio Method [5] uses four gas concentration ratios such as CH_4/H_2, C_2H_2/C_2H_4, C_2H_2/CH_4 and C_2H_6/C_2H_2, which can be used to identify thermal faults, corona discharge and arching. Each successive ratio is compared with certain values and if all four succeeding ratios for a specific fault fall within the predetermined values, the diagnosis is confirmed. In this scheme, the ratio procedure is considered correct if the gas concentrations (in ppm) for H_2, CH_4, C_2H_2 and C_2H_4 exceed twice the relevant L1 concentrations shown in Table 2. However, the method may obtain numerous "no interpretation" results due to incomplete ratio ranges.

Table -2: Concentration of Dissolved Gas

Key Gas	L1 Concentrations (ppm)
Hydrogen (H_2)	100
Methane (CH_4)	120
Carbon monoxide (CO)	350
Acetylene (C_2H_2)	35
Carbon monoxide (CO)	50
Acetylene (C_2H_2)	65

Table -3: Dornenburg Ratio Method Concentration Ratios

Suggested Fault Diagnosis	CH_4/H_2		C_2H_2/C_2H_4		C_2H_2/CH_4		C_2H_6/C_2H_2	
	Oil	Gas space	Oil	Gas space	Oil	Gas space	Oil	Gas space
Thermal Decomposition	>1.0	>0.1	<0.75	<1.0	<0.3	<0.1	>0.4	>0.2
Corona	<0.1	<0.01	Not significant		<0.3	<0.1	>0.4	>0.2
Arching	>0.1 <0.1	>0.01 <0.1	>0.75	>1.0	>0.3	>0.1	<0.4	<0.2

2.3 Rogers Ratio Method

The most common gas ratio method is the Rogers Ratio Method [6], which distinguishes more thermal fault types compared to the Dornenburg Ratio Method. Instead of needing significant concentrations of the key gases, the Rogers Ratio Method can be used when the concentrations exceed the values listed in Table 2 (rather than double). Values of three gas ratios and suggested fault types are shown in Table 4.

Table -4: Ratios for Key Gases- Rogers Ratios Method

Suggested Fault Type	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6
Normal	<0.1	>0.1 to <1	<1
Partial discharge	<0.1	<0.1	<1
Arching	0.1 to 3	0.1 to 1	>3
Low temperature thermal fault	<0.1	>0.1 to <1	1 to 3
Thermal fault <700°C	<0.1	>1	1 to 3
Thermal fault >700°C	<0.1	>1	>3

This method is effective because it correlates the results of numerous failure investigations with the gas analysis of each case. Since the method does not consider dissolved gases below normal concentration values, a precise implementation of the method may still misinterpret data.

2.4 IEC Ratio Method

This method uses the same three ratios as in Rogers Ratio Method but suggests different ratio ranges and interpretations. The fault diagnosis scheme recommended by the International Electrotechnical Commission (IEC) [7] deals with four conditions such as normal ageing, partial discharge of low and high energy density, thermal faults and electrical faults of varying intensity. IEC 60599-1978 (first version) is based on simple coding scheme while IEC 60599-1999 (second version) uses revised ratio ranges directly. 3D graphical representation of ratio ranges is another improvement of second version. Faults that cannot be diagnosed are plotted onto the graph so that its nearest distance to a certain fault region can then be observed. Table 5 shows the interpretations.

Table -5: Suggested IEC Ratio Method Diagnosis

Case	Characteristic fault	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6
PD	Partial discharges	Not significant	<0.1	<0.2
D1	Discharges of low energy	>1	0.1-0.5	>1
D2	High energy discharges	0.6-2.5	0.1-1	>2
T1	Thermal faults<300°C	Not significant	>1 but Not significant	<1
T2	Thermal faults>300°C and <700°C	<0.1	>1	1-4
T3	Thermal faults>700°C	<0.2	>1	>4

2.5 Nomograph Method

The Nomograph Method [7] improves the accuracy by incorporating gas ratios and the concept of Key Gas threshold. It simplifies interpretation by graphically presenting fault gas data. A nomograph is a series of vertical logarithmic scales for representing the concentration of individual gases as straight lines drawn between adjacent scales. The line connects points representing the values of individual gas concentrations. The diagnostic tool for determining fault types is straight lines. Fault types are identified by visually comparing the slopes of line segments with the keys at the bottom of the nomograph. Position of lines related to the concentration scales indicates the fault severity. An arrow is used to indicate the threshold value of each vertical scale. 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.

2.6 Duval Triangle Method

This method uses values of only three gases CH_4, C_2H_2 and C_2H_4 and their location in a triangular map [8]. Gases are transformed into triangular co-ordinates. There are six potential fault zones within the triangle. This method is easily performed but careless implementation can obtain false diagnosis. The permissible amount of dissolved gases should be determined before using this method to analyze transformers. One drawback of the gas ratio methods is that some results can fall outside codes and gives “no interpretations”. This does not occur in Duval Triangle Method because it is a closed system. It always provides a diagnosis, with a low percentage of wrong diagnosis. Fig. 1 shows the coordinates and fault zones of Duval Triangle.

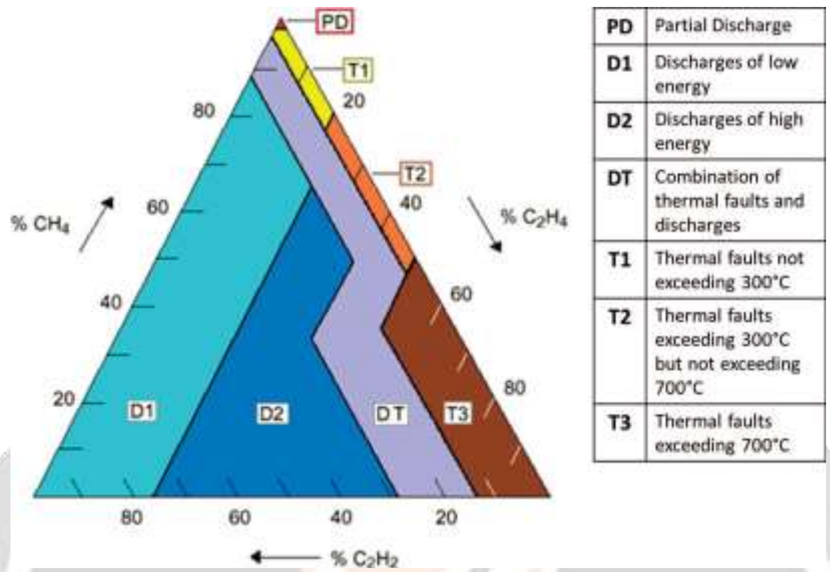

Fig -1: Coordinates and Fault Zones in the Duval Triangle Method

3. TRANSFORMER HEALTH CONDITION

The quality of insulation system within power transformers reflects the overall health condition of the transformer. A timely and reliable maintenance decision along with the remaining operational life estimation of the asset can be identified through the measurements of some parameters reflecting the degradation rate of the transformer dielectric insulation

3.1 Degree of Polymerization (DP)

DP is defined as the number of monomeric units in a macromolecule or polymer. The cellulose molecule is made up of a long chain of glucose rings which form the mechanical strength of molecule and the paper. When cellulose is aged by thermal stress, the molecular chains are broken. When the insulation is new, the DP is typically between 1000 and 1400 [1]. When DP reaches around 200, the insulation has reached the end of life. All mechanical strength of the insulation has been lost and the transformer must be replaced.

3.2 Amount of CO & CO_2

CO increment rate in insulating oil along with CO_2/CO ratio provide valuable information about paper degradation activity. IEEE Standard C57.104 Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers [3] gives status conditions based on accumulated values of CO_2 and CO. CO_2 value in between 0-2500 ppm and CO value in between 0-350 ppm indicates normal operation. CO_2 value greater than 10000 ppm and CO value greater than 1400 ppm indicate imminent risk and complete degradation of the paper insulation.

3.3 Oxygen Level

Under the same temperature conditions, cellulose insulation in low oxygen oil will last 10 times longer than insulation in high oxygen oil. Above 2000 ppm, oxygen in the oil greatly accelerates paper deterioration. If the oxygen level reaches 10000 ppm, the oil should be de-gassed. High atmospheric gases normally indicate that a leak has developed in a bladder and diaphragm in the conservator.

3.4 Furans

Furan is a heterocyclic organic compound, consisting of a five-membered aromatic ring with four carbon atoms and one oxygen. When cellulose insulation decomposes due to overheating, furans are developed. The most important is 2-furfuraldehyde. In healthy transformers, there are no detectable furans in the oil, or they are less than 100 ppb (parts per billion). When significant damage to paper insulation has occurred, furan level increases to 3000 ppb and it indicates the end of expected life of paper insulation.

3.5 Moisture

Moisture, especially in the presence of oxygen, is hazardous to transformer insulation. Each time the moisture is doubled in a transformer, the life of the insulation is doubled by one-half. The life of the transformer is the life of the paper and the life of the paper is extended by keeping out moisture and oxygen. When the transformer is energized, water begins to migrate to the coolest part of the transformer and the site of the greatest electrical stress. This location is normally the insulation in the lower one-third of the winding. Paper insulation has a much greater affinity for water than oil.

3.6 Interfacial Tension and Acid Number

Interfacial tension (IFT) is the force that holds the surface of a particular phase together and is normally measured in dynes per centimeter. Clean oil will make a very distinct line on top of the water and give an IFT number of 40 to 50 dynes per centimeter. As oil ages, it is contaminated by tiny particles of the oil and paper insulation. Then particles in oil weaken interfacial tension and lower the IFT number. Oil must be reclaimed when the IFT number falls to 25 dynes per centimeter to prevent sludging [1].

Acid number is the mass of potassium hydroxide (KOH) in milligrams that is required to neutralize one gram of chemical substance. Acid number is used to quantify the amount of acid present in the oil. High acid number indicates more acid in the oil. New transformer oil contains practically no acid. Oxidation of insulation and oil forms acids as transformer ages. Acid attacks metals inside the tank and form more sludge. Sludging begin when acid number reaches 0.40. So the oil should be reclaimed when the acid number reaches 0.20 mg KOH/gm.

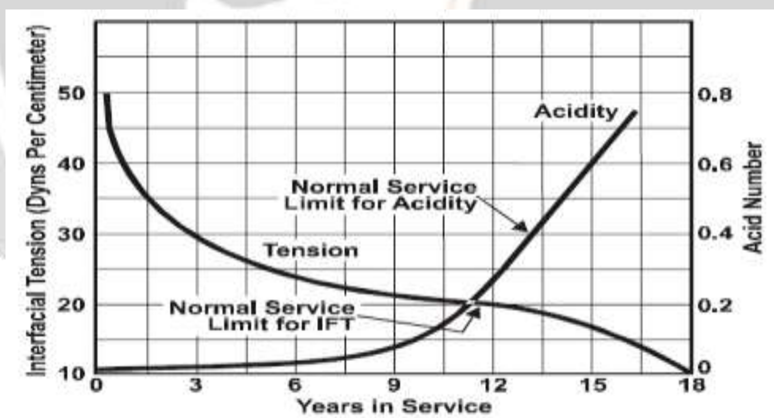

Fig -2: Service Limits for Transformer Oil

4. CONCLUSION

The key objective in fault gases analysis is correctly diagnosing that fault that generated by the detected gases. This study analyzed six most common methods of Dissolved Gas Analysis: Key Gas, Dornenburg Ratio, Rogers Ratio, IEC Ratio, Nomograph and Duval Triangle Method. The factors which play an important role in the quality of transformer oil and paper insulation are also studied. Using multiple DGA techniques to analyze transformer faults may obtain different or conflicting fault interpretations. Most DGA approaches rely on expert analysis, which could be insensitive to slowly developing and insignificant faults. Therefore, optimizing the combination of various diagnostic techniques is an important issue.

6. REFERENCES

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