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A Modern tool to Detect Incipient Faults in Power Transformers by using Gas Chromatography

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ABSTRACT: This paper describes the development and implementation of a tool for the diagnosis of faults in power transformers through the analysis of dissolved gases in oil. The computational system approach is based on the combined use of some traditional criteria of the dissolved gas analysis published in standards. Transformers are one of the most important and complex components of electricity transmission and distribution. To have a reliable electricity supply, it is necessary to give considerable attention to the maintenance of transformers. To maximize the lifetime and efficacy of transformers, it is important to be aware of possible faults that may occur and to know how to prevent them. These faults can all lead to the thermal degradation of the oil and paper insulation in the transformer. For achieving this transformer oil is evaluated by oil contamination test and four type DGA diagnosis method like IEC ratio Method, Rogers's ratio method, Key gas method and Dual triangle method

KEYWORDS: DGA, IEC , Rogers's ratio method, Key gas method and Dual triangle method.

I. INTRODUCTION

The trouble free performance of transformer during service is of paramount importance in power stations to ensure uninterrupted and economic power supply. Transformer operates under complex environmental conditions, variable thermal and electrical stresses during service. As a result of normal ageing process, insulating oil in it breaks down and produces gases like hydrocarbons, hydrogen and carbon oxides which dissolve in oil. But the rate of generation and presence of some combustible gases in large quantities definitely indicate some internal fault. Therefore, it is advisable to detect the faults in its early stage, so that the development of the major faults and thus the damage to transformers can be avoided. Analysis of dissolved gases has been a proven technique in use for the last 2-3 decades for monitoring the health of a transformer in service by sensing incipient fault well in advance before, even the buchholz relay operates. As the health of the oil implies the health of the transformer, the oil should be sampled and tested regularly to evaluate the oil condition and to determine the possible fault type..

II. TESTING METHODS OF TRANSFORMER OIL

2.1. Oil Contamination Test

The tests described here are classified into the following categories: Physical Tests, Electrical Tests and chemical tests.

2.1.1. Breakdown voltage

This is a conventional test intended to reveal the extent of the advisability of carrying out drying and filtration treatment before the oil is introduced in to the apparatus. According to IS:1866-2005 the acceptable minimum breakdown voltage is 40 KV for transformer with rated voltage 72.5KV and below, 50 KV for transformer rated between 72.5KV and 170KV, and 60KV for transformer rated 170KV and above.

2.1.2 Water Content

The presence of water in insulating oils results in poor electrical properties. A low water content in oil is necessary to achieve adequate electric strength and low dielectric loss characteristics. Water in oil (solution) cannot be detected visually and hence indirect methods are used. According to IS:1866-2005 the acceptable maximium water content is 20PPM for transformer with rated voltage 72.5KV and below, 15 PPM for transformer rated between 72.5KV and 170KV, and 10 PPM for transfromer rated 170KV and above.

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2.13.Resistivity

The resistivity of a liquid is a measure of its electrical insulating properties under prescribed conditions. High resistivity reflects low content of free ions and ion-forming particles and normally indicates a low concentration of conductive contaminants. According to IS:1866-2005 the acceptable minimum resistivity 6 x 10^{12} ohm-cm.

2.1.4. Dielectric dissipation factor

This property is a measure of the dielectric losses in oil and hence of the amount of energy dissipated as heat. A low value of dissipation factor indicates low losses and a low level of soluble polar ionic or colloidal contaminants. According to IS: 1866-2005 the acceptable minimum dielectric dissipation factor is 0.015 at 90 ºC for transformer up to 170KV and 0.010 at 90 ºC for transformer rated 170KV and above.

2.1.5. Interfacial tension

This is defined as the molecular attractive force between unlike molecules at an interface and is expressed as Newton per meter. IFT measurements on insulating oils provide a sensitive means of detecting small amounts of soluble polar contaminants and products of oxidation. A high value indicates the absence of such contaminants and low IFT number means a high amount of tiny particles in the oil. According to IS: 1866-2005 minimum acceptable value for IFT is 35 mN/m.

2.1.6. Flash Point

The flash point is the temperature at which a material gives so many vapors, that this vapors when mixed with air forms an ignitable mixture and gives a momentary flash on application of a small pilot flame. The flash point and fire point tests give an indicating of the flammability of oil. According to IS: 1866-2000 minimum acceptable value for Flash point is 140 ºC

2.2. Dissolved Gas Analysis

Dissolved gas analysis is one of the efficient methods for the detection of incipient fault in oil filled electrical apparatus. We can say that DGA is not a science but an art. IEC standard 60599 introduces the basic gas ratio methods, Key gas method and the Dual Triangle method. The IEC gas ratio method uses only three gas ratios. The Dual triangle is based on the relative proportions of the three gases detecting a fault. One problem of the gas ratio methods is that the diagnosis cannot interpret some DGA results, which do not match the ratio codes. The Dual method does not face this problem because all coordinated points must be in the triangle. Total 108 no's transformer tested for oil contamination test and dissolved gas analysis. Out of them 3 no's case study chosen for analyzing Insulating oil condition. And 2 no's case study chosen from other industries for analysis purpose.

III. FORMATION OF GASES IN OIL FILLED TRANSFORMERS

The Buchholtz relays operate by the accumulation of gases in transformers. The accumulation may be sudden, due to severe arcing fault or more gradual as in the case of slow deterioration of insulation. The principle of mechanism of gas formation in the transformer Tank can be classified given below:

Oxidation, Vaporization, Insulation decomposition Oil breakdown, Electric action

3.1 Oxidation

Carbon dioxide is liberated predominantly during the process of oxidation. This process begins when small quantities of oil combine chemically with the dissolved oxygen in the oil resulting in formation of traces of organic acids. These acids react with the metal of the transformer, forming metal based soaps. These soaps dissolve in the oil and act as catalyst to accelerate the process of oxidation.

3.2 Vaporization

The vaporization occurs for oil at about 280^0 c and for water at about 100^0c. the false alarm of Bucholtz relays may be attributed to the fact that the condensation of water vapor takes place, when the excess moisture in the tank is vaporized by a heat sources. False alarm can also occur, when the hydrocarbons the constituents of the insulating oil vaporized

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3. 3 Insulation Decomposition

The solid insulates in Power transformers are of mainly cellulose or resinous type. Viz., paper, pressboard, cotton. Resins and vanishes. These substances contain in their molecular structure substantial amounts of oxygen, carbon and hydrogen. Between temperature 150^0c-400^0c, the insulation breakdown results in liberation of hydrogen, carbon dioxide and carbon monoxide. Above 400^0c, the gases formed are relatively less.

3.4 Oil Breakdown

The direct breakdown of oil by arcing results in cracking of the oil. The aromatic contents breakdown into simple hydro-carbon gases and hydrogen. Acetylene and methane are major constituents. Other hydro-carbon gases may also be liberated due to cracking, if the necessary temperature is maintained for their stable formation.

3.5 Electrolytic action

Hydrogen and oxygen are liberated during an electrolytic action. Presence of minute and small particles of fibres within the oil leads to electrolytic action. Light hydro carbon gases may also be present if the solid insulation is involved.

IV. GAS CHROMATOGRAPHIC PRINCIPLE AND THEORY

4.1. Gas chromatography

It is a specialized form of the general chromatographic technique, in which the mobile phase is a carrier gas and stationary phase is solid absorbent. The carrier gas after pressure reduction passes through the chromatographic column containing the solid absorbent. The solid absorbents are fine granulated particles of chemicals like alumina, silica gel and molecular sieves, etc. the column is situated in a thermostatically controlled oven.

4.2 Detectors

The sensitivity of any gas chromatographic instrument depends on the sensitivity of the detector, which is the most important part of the system. The two detectors in vogue for dissolved gas analysis are:
(a) Thermal conductivity detector or katharometer
(b) Flame ionization detector

4.2.1 Karthometer

The karthometer measures the change in thermal conductivity f a heated wire by effluent gases which flow on it. The carrier gas flows at an evenly controlled rate across the two filaments. One filament is in the chromatographic column and another in a dummy column. The two filaments form arms of a bridge circuit. A change in the specific heat and thermal conductivity due to the passing of eluted gases over one filament disturb the balance of the bridge resulting in change of voltage which is amplified and recorded. A karthometer with 4-12 volts for heating the wire is used.

4.2.2. Flame Ionization Detector

The flame ionization detector is more sensitive than the thermal conductivity detector. This detector utilizes an inflammable mixture of hydrogen, oxygen and nitrogen. The carrier gas on emerging from the column is burnt at a small jet connected to the column outlet. The jet is protected in draught free enclosure having a collecting grid. An EMF applied across the flame changes its resistances. This change in resistance is determined. Presence of an eluted vapor is indicated by a large fall in the resistance due to the ionization of organic molecule in the flame.

4.3Recorder

Most of the gas chromatographic instruments use strip chart recorders which draw the finished chromatogram on a moving strip of paper. There are two types of recorders, viz.,
1. Galvanometer Type
2. Potentiometer type

4 .3.1 Galvanometer type

Galvanometer recorders are relatively cheap but require larger signal than is supplied by most of the detectors.

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4.3.2Potentiometer Type:

Potentiometer records are more sensitive and use the off-balance EMF from a bridge to operate synchronous motor which adjusts a slide wire contact until the bridge is balanced. The slide wire contact is connected to a pen which records the position of balance on moving chart strip.

V. EXTRACTION OF DISSOLVED GASES AND ANALYSIS

Extraction: Extraction of gases from the oil is an important stop to be taken after sampling. Unless complete extraction of gases is achieved. The results obtained will be erroneous.

Firstly, achieving high vacuum is a difficult process. For very accurate results, the vacuum system is to be adopted. This method is time-consuming whereas Torricelli vacuum method is comparatively simple and consume less time. This method does not require any liquid nitrogen Trap, etc. both method are discussed below. The apparatus used is the one developed by BARC (Bhabha Atomic Research Center, Bombay.)

The gas extraction assembly consists of mercury reservoir, degassing flask, oil reservoir, rotary vacuum pump, etc. to achieve high vacuum, a mercury diffusion pump, liquid nitrogen cold trade are included in series with the rotary vacuum pump. A moved gauge can also be included to measure the vacuum.

5.1 Procedure: The vacuum of the degassing flask connecting tubes and bulbs (V1, V2) are determined. The gas extraction apparatus should withstand high vacuum. Therefore. The stop cocks are high vacuum stop cooks and they should be greased properly employing high vacuum grease.

The mercury reservoir is filled with mercury without air bubbles up to C2. The length of connecting flexible tubing is of a meter length.

The degassing flask with iron rotor is kept in a water bath maintained at 100^0c on a hot plate magnetic stirrer. The entire unit is evacuated with the help of rotary vacuum pump by suitable manipulation of the stop cocks. When the required vacuum is achieved, the oil from the oil reservoir is let in to the degassing vessel and stirred till complete degassing is achieved. By manipulating the height of the mercury column, the gases evolved are compressed to the known volume. The necessary pressure and volume correction are made and the total volume of gases evolved for known amount of oil is calculated.

VI. INTERPRETATIONS OF RESULTS

Knowledge of solubility of Hydrocarbon and fixed gases at different temperature, in insulating oils would help in interpretation of gas analysis. Solubility of different gases at 25^0c of Pugh and Wagner is shown below. The permissible concentration of dissolved gases in the oil of a healthy transformer laid down by M/S. Transformations Union AC of West Germany is given in Appendix I.

Gas	%by volume	Gas	%by volume
Hydrogen	7	Ethane	280
Oxygen	16	Ethylene	280
Nitrogen	8.6	Acetylene	400
Argon	15	Propylene	1200
Carbon Monoxide	9	Propane	1900
Carbon Dioxide	120	Butane	4000
Methane	30		

Table 1

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VII. GENERAL METHODS

7.1.1 Arcing in oil without any solid insulating material, the gas mixture obtained approximately will be

Gas	%by volume
Hydrogen	60-80%by volume
Acetylene	10-25%by volume
Methane	1.5-3.5%by volume
Ethylene	1-2%by volume

Table 2

In addition, it consists of air dissolved in oil. Besides high percentage of hydrogen and acetylene, absence of appreciable quantities of CO and CO_2 reflects the above type of arcing fault.

7.1.2 Arcing through the solid insulation

The gases evolved due to an arc under oil, with the participation of solid insulating materials like paper or pressboard also contain large quantities of hydrogen and acetylene accompanied by large quantity of CO. the percentage of methane may also be higher than in the first case.

7.1.3 Partial discharge in the cellulose and oil insulation

In this ease, the main gases formed are hydrogen, methane, carbon monoxide, carbon dioxide, Acetylene is not present.

7.1.4 Thermal decomposition of the oil

The thermal decomposition occurs at 400^0C and increases with the increase of temperature and the gases formed are low molecular hydrocarbons, mainly methane, ethane, ethylene and also hydrogen. At temperature of 600^0c, the gas mixture almost exclusively consists of methane and hydrogen. Carbon dioxide is also formed, but is decomposed at higher temperatures

VIII. RESULTS

8.1 Dissolved gases in inhibited transformer oil limits

Gas	Lessthan4yrs.in service (ppm)	4-10yrs. In service (ppm)	More than 10yrs.in service(ppm)
H_2	100/150	200/300	200/300
CH_4	50/70	100/150	200/300
C_2H_2	20/30	30/50	100/150
C_2H_4	100/150	150/200	200/400
C_2H_6	30/50	100/150	800/1000
CO_2	3000/3500	4000/5000	9000/12000

Table 3

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8.2 Characteristic Cases Associated With Various Faults

Dissolved Gases	Associated Faults
Methane $\mathbf{CH_4}$	Low Temperature Hot Spot
Ethane $\mathbf{C_2H_6}$	High Temperature Hot Spot
Ethylene $\mathbf{C_2H_4}$	Strong Over Heating
Acetylene $\mathbf{C_2H_2}$	arcing
Hydrogen H_2	Partial Discharge
CO_2& CO	Thermal Decomposition of paper Insulation

Table 4

8.3 Key Gas method

Total concentration of CO dissolved in the oil is 33.23%, H2 is 42.40%, CH4 is 6.25%, C2H6 is 1.77%, C2H4 is 8.33% and C2H2 is 7.97%.The high percentage of high percentage of H2 indicates for corona in oil. Also low energy of discharge produces Hydrogen and methane with small quantity of ethane and ethylene. Comparable amount of carbon monoxide and carbon dioxide may result due to discharge in cellulose. All over transformer condition found highly in suspect condition. From above result is found that all key gases are found high.

The Below Shows graphical representation of % dissolved gases concentration in the oil.

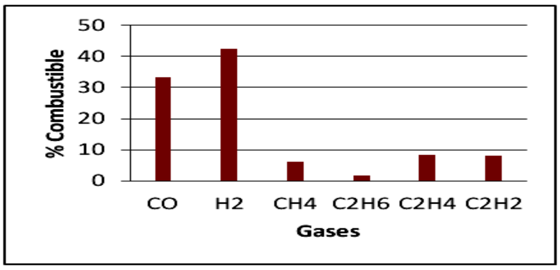

Table 5

IX. ADVANTAGES OF GAS CHROMATOGRAPHY

Gas chromatography is not the only method of analyzing the gases dissolved in minute concentration. There is rough method, viz., or sat apparatus method. To detect hydrogen, acetylene and carbon monoxide. This apparatus does not give a quantitative measurement. Therefore, it restricts the interpretation of results since the ratio of component gases in any mixture is important in fault diagnosis. Another limitation of this instrument is that it cannot give an indication of the rate of evaluation of the gases and thereby, detection of incipient type faults cannot be easily done.

To prevent damage or total loss or the equipment itself. This would be particularly helpful while monitoring transformers of 220KV and above. Considering the prohibitive cost of transformers and longtime taken for repair and replacement of the transformers.

X. CONCLUSION

DGA is power fool tool for predicting of transformer incipient fault at early stages .Transformer insulating oil is analyzed for prediction of transformer incipient fault at early stages. From that condition of power transformer is accomplished by two main methods. Oil contamination test indicates whether oil is contaminated or deteriorated. In oil contamination test dielectric strength, IFT, acidity, water content, resistivity and dissipation factor test preformed. With a view to make this analysis popular in our country, CPRI has developed a chromatograph system and this facility can be utilizes and there interested parties. CPRI has already carried out the evaluation work on dissolved gas analysis in respect of oil samples received from various Electricity Boards, Electrical utilizes etc.

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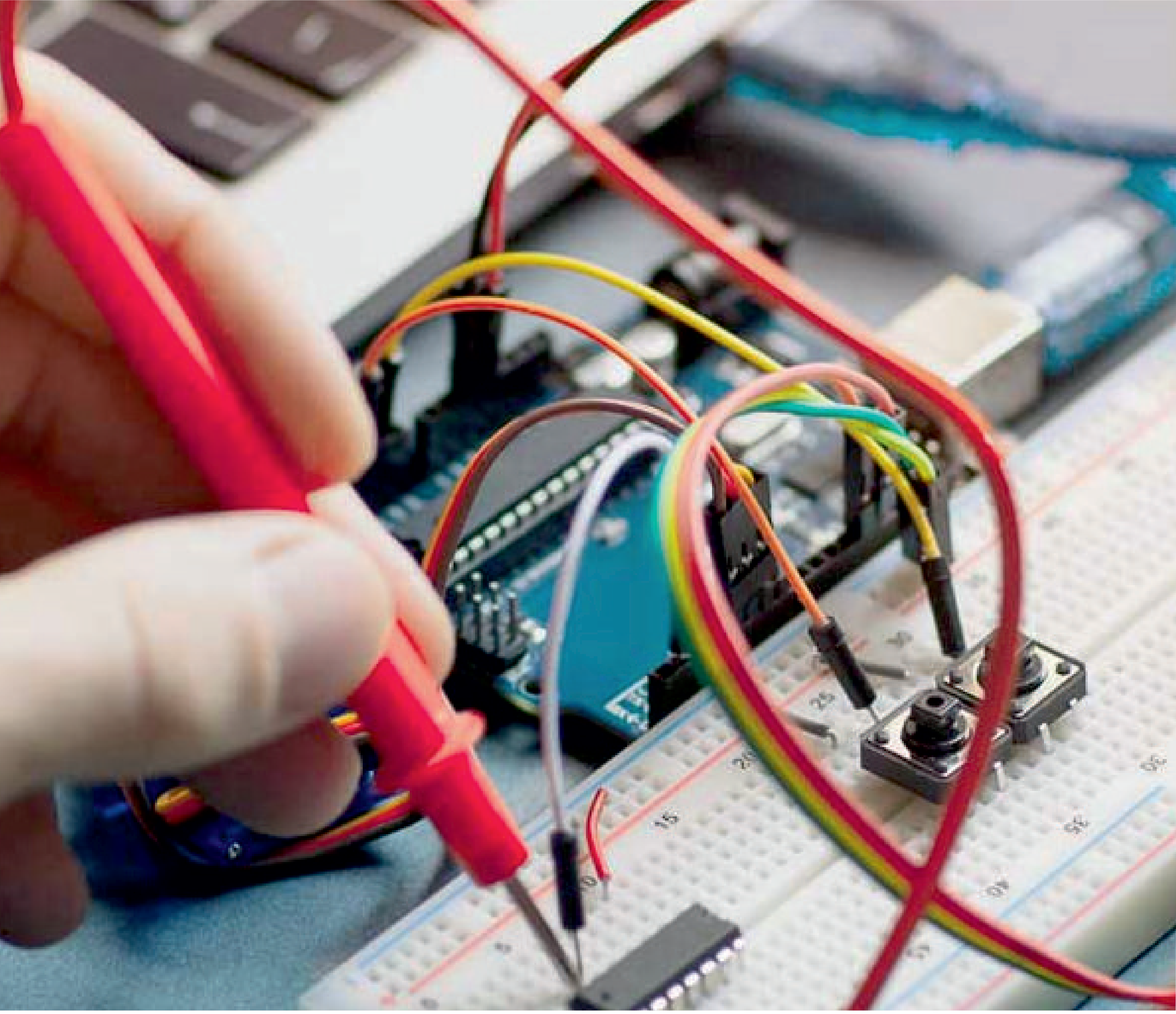

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