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Case Studies-Health Monitoring of Power Transmission Equipment Using Insulating Oil Analytical Methods

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This paper presents cases which are encountered during routine monitoring of oil DGA for the 400 kV class and 765 kV class equipments (transformers and reactors). Fault detection of the four equipments was conducted based the DGA and equipment were then subjected to preventive actions.

Using Dissolved Gas Analysis excess values of C_2H_2 gas were reported for 1st case and preventive actions were taken. The equipment is being monitored further. In 2nd case, a rapid rise in H_2 gas content was observed and the improper processing during the past oil filling activity were then ractified. In 3rd case the equipment suddenly tripped with loud sound and the existence of high energy electrical fault were evident in DGA as well as site inspection. Fault had happened because of gradual weakening of phase – phase insulation inside the main tank up to approximately 45 kA of fault current. In the 4th case, Duval Pentagon Analysis showed the system continuously in thermal fault zone Upon inspection severe damages were observed in lead insulation, copper of neutral lead, wooden turret CT supports and neutral turret CT insulation. For the 5th case high energy discharge observed in DGA was confirmed with diverter switch inspection.

Keywords: *Dissolved Gas Analyses (DGA), Duval Pentagon, thermal fault, electrical fault, energy discharge.*

1.0 INTRODUCTION

Transformers and Reactors constitute major portion of the capital equipment in the power utility sector; failure of above mentioned equipment may cause sudden outages, and thus are important assets. Insulating oil being an integral part of transformer and reactors is subjected to varieties of conditions such as moisture ingress, thermal and electric stresses, and aging. It is also an excellent indicator of underlying problems and teething issues which are either inherent in the equipment or because of external factors influencing the operation of the electrical equipment. By measuring the extent of the degradation of insulating oil, monitoring the DGA levels, power transmission equipment health can be diagnosed.

In this paper the case studies are discussed wherein uncalled outages of equipment have been avoided by taking preventive actions in time, based on Dissolved gas Analyses (DGA). Gas Chromatography (GC) in combination with various analytical tools including Duval Pentagon Analysis was used to estimate the parameters as representative of equipment condition.

The thermal and/or electrical faults break down the insulating materials and release gaseous products as a result of decomposition. The gases generated under abnormal electrical or thermal

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stresses are hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen (N_2) and oxygen (O_2) which get dissolved in oil. Collectively these gases are known as fault gases, which are routinely detected and quantified at extremely low level, typically in parts per million (ppm) in DGA. [1] The experimental results of the GC indicated the level and the change in concentration of fault gases in the insulating oil which were used as indicator of undesirable events occurring inside the equipment. [2, 3] The relative ratios of the detected gases of equipment are used to determine the associated fault with it. [2-4]

With the one or combination of thermal, electrical, or corona faults, the total gas (combustible) content may rise with increased rates. Different algorithms are used to detect the faults associated with total gas generation and rise

For example IEC [5] and Roggers's ratio [6] uses three different gas ratios to analyze the system state. While Dornenburg's analyses uses four different gas rations to analyze three different faults in gases.

IEC [5] limits for internal and external OLTC is mentioned in Table 1.

TABLE 1:
IEC LIMITS FOR INDIVIDUAL GASES

Gases	Limits (External OLTC)	Limits (Internal OLTC)
H_2	60-150	75-150
CH_4	40-110	35-130
C_2H_2	3-50	80-270
C_2H_4	60-280	110-250
C_2H_6	50-90	50-70
CO	540-900	400-850
CO_2	5100-13000	5300-12000

Duval's Triangle makes use of triangular phenomenon between three gases CH_4, C_2H_4, and C_2H_2 and based upon the % gas ratios system state is analyzed as shown in Figure 1.

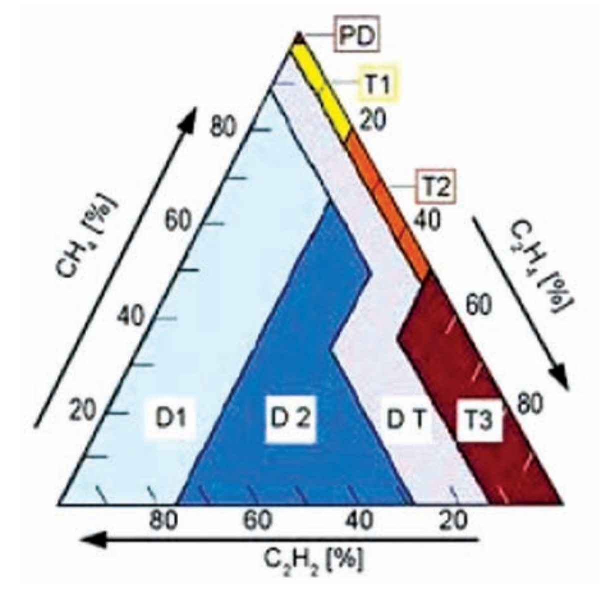

FIG 1: DUVAL TRIANGLE [7]

Similarly, Duval Pentagon method exploits a pentagon representing all five gases named H_2, C_2H_6, CH_4, C_2H_4 and C_2H_2 at its five summits. [8] Each summit of the pentagon corresponds to one gas and the relative percent of the gas is plotted between percentage center (0 %) and the summit (100 %). For example relative percentage of CH_4 is plotted on the axis between pentagon center (0% CH_4) and CH_4 summit (100 % CH_4). Similar is for H_2, C_2H_6, C_2H_4 and C_2H_2 summit. The relative percentage of one gas for example H_2 is the percentage ratio of H_2 to sum of all five hydrocarbons as shown in equation no 1

$$\%H = \frac{H_2(ppm)}{H_2 + CH_4 + C_2H_2 + C_2H_4 + C_2H_6(ppm)} \quad \ldots(1)$$

In practice to position the DGA centroid points, the summit i.e., units on each gases are limited to 40%. From the DGA ppm values, the relative % gas among the five summit gases is calculated and is plotted based on its corresponding gas axis percentage value (Figure 2). [9]

In this article fault detection of the four equipment was conducted using Duval Pentagon method and were subjected to preventive measurements while for one equipment post failure Duval Pentagon analyses was conducted that was found in line with post failure inspection conducted at the site.

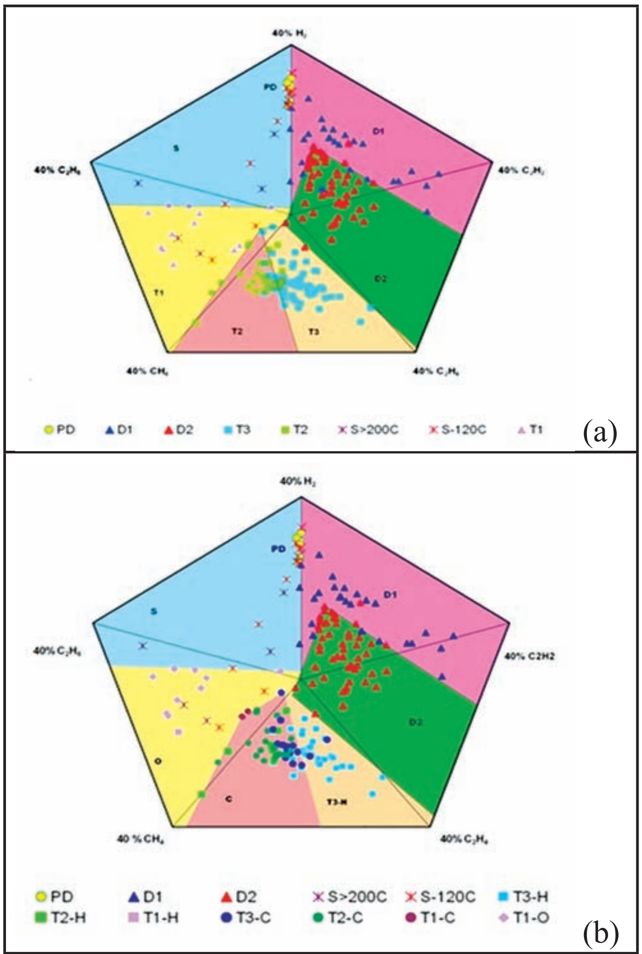

FIG 2 (A, B): DUVAL PENTAGON [8]

1.1 Dissolved Gas Analyses

DGA was performed using 7697A Head Space (HS), 7890B Gas Chromatograph (GC) of Agilent Technologies. For DGA the oil samples are taken in the syringe provided the filled syringe contains no air bubble. The oil sample from the syringe is injected into vacuumed and Argon (Ar) filled crimped vials. And the vials are then subjected to HS of the GC, where it's heated at 70˚C such that the dissolved gas escapes the vials through columns and are absorbed onto carrier gas (Ar) in the column at different rate. The gases exit the column into detector unit (In this case its Thermal Conductivity Detector and Flame Ionization Detector) where they are identified based on retention time and quantified.

2.0 CASE STUDIES

Duval Pentagon observation from the Equipment A (Rating 765 kV, Capacity 500 MVA) indicated that the equipment was subjected to transition of fault zone T2 (thermal fault 300˚C-700˚C) to T1 orO (thermal fault <300˚C or <250˚C) through S and PD (i.e., stray gassing <200˚C and Corona partial discharge) to D1 i.e., low energy discharge. This transition of fault gave excessive rise of acetylene (C_2H_2) and Hydrogen (H_2) gas in oil. The excess values were reported and preventive actions were taken by taking the unit out of service for internal inspection. Post processing / filtration the equipment resides in D1 Fault zone only and being monitored further (Figure 3).

For the equipment B (Rating 400 kV, Capacity 80 MVAR) the dissolved gas analysis indicated rise of hydrogen gas at a very high rate and hence the equipment was subjected to weekly observation. The Duval pentagon analysis indicated that after one week of the charging the equipment was in T1 fault zone and then it continuously remained in D1 zone. Upon further study it was determined that fault was not electrical in nature, and rise in H2 was because of improper processing during the past oil filling activity (which had been carried out about three months back).

Equipment C (Rating 400 kV, Capacity 315 MVA) suddenly tripped with loud sound and pressure rise inside the main tank. Duval Pentagon analysis before tripping showed gradual transition towards fault zone D1. However, the gases had subsided to a very low level before the failure.

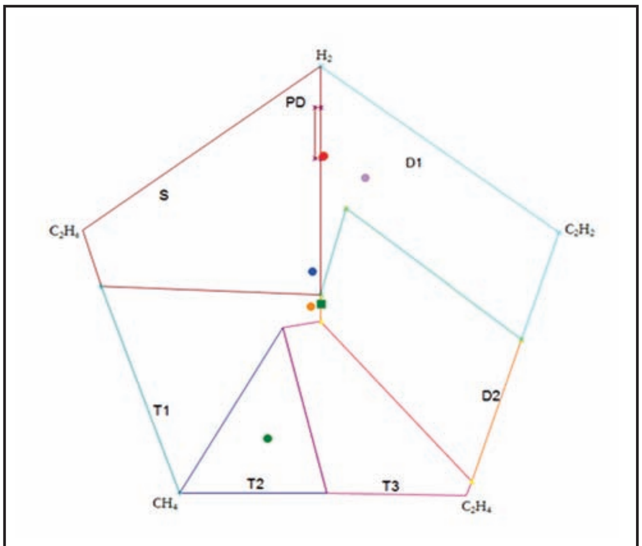

FIG3: DUVAL PENTAGON ANALYSIS OF EQUIPMENT A

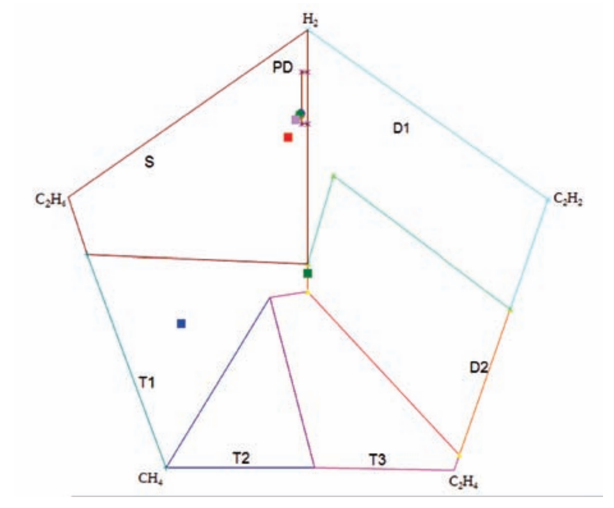

FIG 4: DUVAL PENTAGON ANALYSIS OF EQUIPMENT B

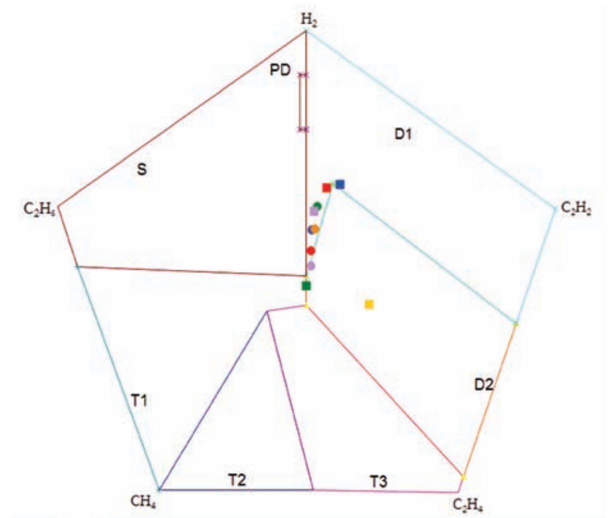

FIG 5: DUVALPENTAGONANALYSISOFEQUIPMENT C

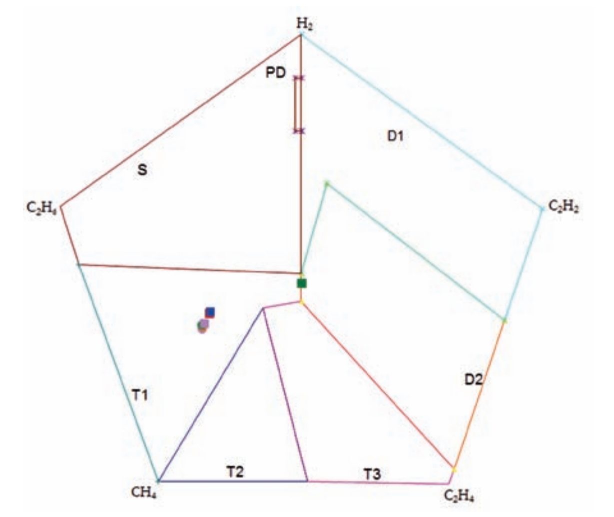

FIG 6: DUVALPENTAGONANALYSISOFEQUIPMENT D

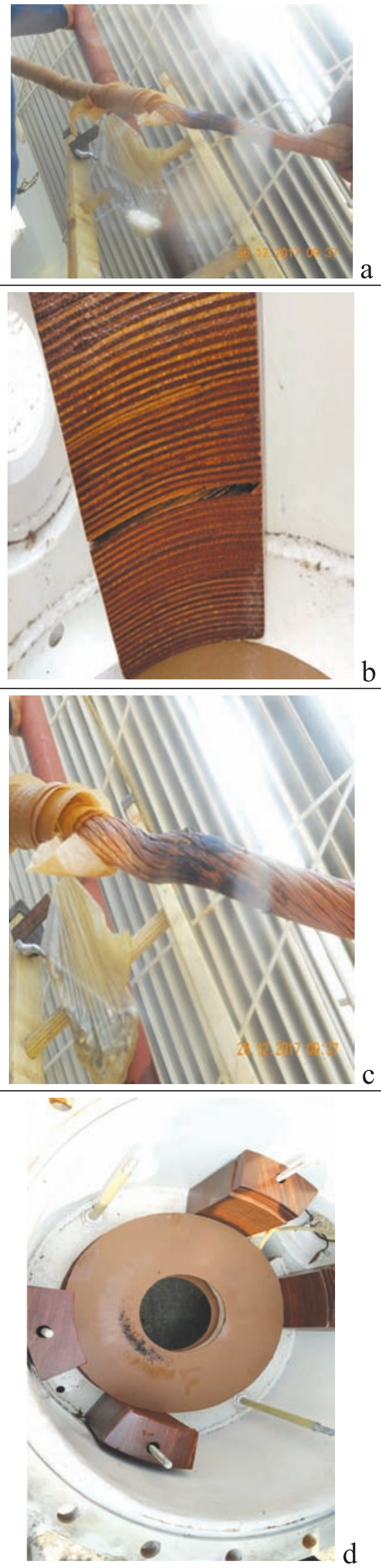

FIG 7: PHOTOGRAPHS OF INTERNAL INSPECTION OF EQUIPMENT D INDICATING (A) NEUTRAL LEAD PAPER INSULATION AFFECTED (B) CRACKED TURRET CT SUPPORT (C) NEUTRAL LEAD COPPER BLACKENED (D) TURRET CT BARRIER AFFECTED.

Oil DGA carried out post tripping indicated excessive value of dissolved gases; it remained in D2 i.e. high energy discharge zone. Upon internal inspection (post failure) it was confirmed that there was a phase – phase fault (very high energy) with a fault current amounting to approximately 45 kA. Fault had happened because of gradual weakening of phase – phase insulation inside the main tank.

As per Duval pentagon analysis equipment D (Rating 765 kV, Capacity 110 MVAR) continuously remained in T1-O fault zone. It was decided to take up the equipment out of service for internal inspection based on the DGA analysis and following were the findings:

Neutral connection lead insulation had been damaged (paper blackened). Heating of copper of neutral lead has been observed.

Wood supports of neutral turret CT (two nos. out of four) had cracked.

Carbonization of insulation was observed in the vicinity of neutral turret CT.

In this case, acoustic PD measurement was also carried out prior to opening the job for internal inspection and the discharges happening inside the main tank were localized accurately.

For Equipment E, Duval pentagon analysis of tap changer compartment oil indicated very high energy discharges, D2. The unit also had a history of problems with tap changer of a particular manufacturer.

Based upon the DGA analysis, diverter switch inspection was undertaken and presence of discharges was confirmed. They had occurred due to poor oil quality in the diverter compartment, which in this case had been subjected to 245 kV voltage by virtue of tap changer design.

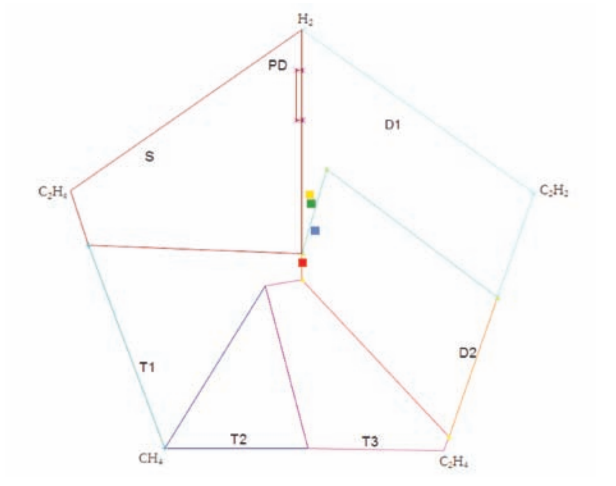

FIG 8: DUVAL PENTAGON ANALYSIS OF EQUIPMENT E

TABLE 2 CHRONOLOGICAL DISSOLVED GAS PARAMETERS OF EQUIPMENT E			
Readings (ppm)	1st reading	2nd reading	3rd reading (before charging)
H_2	201	212	66
CH_4	29	27	12
C_2H_4	53	49	24
C_2H_6	3	3	1
C_2H_2	11.5	10	4.4
CO	549	525	211
CO_2	2889	2649	1430

Further all the three cases were scored based on dielectric strength, moisture content and Interfacial tension. They all fell in the category of good oil condition. Poor quality of oil was evident after the equipment C tripped (post failure) (Table 3). From the case studies it can be seen that the Duval pentagon DGA analysis is an excellent tool for condition monitoring and provides valuable inputs for condition assessment. Although Duval pentagon analysis can provide qualitative inputs, however critical values of individual fault gases remain important to receive warnings.

Table 3: Classification of Insulating oil based on Dielectric Strength (DS), water parts per millian (PPM) and Interfacial tension (IFT) with

Individual Ratings E: Excellent, G: Good, M: marginal, P: Poor, B: Very Poor.

TABLE 3

Ratings	DS kV	PPM (mg/kg)	IFT (N/m)
E	≥80	≤10	≥45
G	65≤DS<80	10<PPM≤20	30≤DS<45
M	50≤DS<65	20<PPM≤30	24≤DS<30
P	40≤DS<50	30<PPM≤40	14≤DS<24
B	<40	>40	<14

3.0 CONCLUSION:

In this paper five case studies are discussed where DGA was conducted using GC and Duval Pentagon Analyses. Four equipment named A, B, D and E were subjected to preventive inspection based upon DGA findings. For equipment C the DGA was used as post mortem too. The fault obtained (i.e., high energy discharge) was in coordination with the on-site inspection findings. DGA found to be an excellent tool to be used in transmission utility for conditioning monitoring.

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REFERENCE

Articles in Journals:

[1] POWERGRID CORPORATION OF INDIA LIMITED, “Procedure of DGA Interpretation in POWERGRID”, Doc: D2-04-06-01-01, 2007, PP 1-14.

[2] Standard Test Method for Analysis of Gases Dissolved in Electrical Insulating Oil by Gas Chromatography, ASTM 3612 (02), 2012.

[3] Rohit Arora, Different DGA Techniques for Monitoring of Transformers, “International Journal of Electronics and Electrical Engineering”, Vol. 1, No. 4, December, 2013

[4] M.Wang,A.J.Vandermaar,K.D.Srivasatava, “Review of Condition Assessment of Power Transmission in Services, IEEE Electrical Insulation Magzene, Vol. 18, No. 6, 2002

[5] Oil-filled electrical equipment – Sampling of gases and analysis of free and dissolved gases – Guidance IEC 60567-ed-4.0, 2011-10

[6] R. R. Rogers, "Concepts used in the development of the IEEE and IEC codes for the interpretation of incipient faults in power transformers by dissolved gas in oil analysis," IEEE Transactions on Electrical Insulation, Technical Report, Central Electricity Generating Board, Transmission Development and Construction Division, Guilford, vol. EI-13, no. 5, pp. 349-354, 1978.

[7] M. Duval, “The Duval triangle for load tap changers, non-mineral oils and low temperature faults in transformers,” IEEE Electrical Insulation Magazine, vol. 24, no. 6, 2008.

[8] Michel Duval, Laurent Lamarre, IEEE Electrical Insulation Magazine, Volume: 30, Issue: 6, November-December 2014, PP 9-12

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