

Diagnostic Tool for Transformer Fault Detection Based on Dissolved Gas Analysis

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Abstract: Dissolved gas analysis (DGA) is a diagnostic tool that used to detect the incipient faults of power transformers through the correlation between the content of gases dissolved in transformers oil and a particular malfunction. Transformer failures are often due to the lack of the dielectric strength of oil insulation and will lead to a negative impact on electrical power systems. Early stage detection of transformer faults can reduce considerably the cost of repairing the damaged transformers and hence maintain the stability of the system. Some classical methods that depend on gases concentration in transformers oils are used to interpret transformer faults such as Dornenburg, Rogers, Duval triangle and key gases methods. These methods in some cases did not give the same results; therefore, an expertise method is developed to assess the kind of fault based on the DGA. A software code is designed using logic functions to get the type of the faults in transformers from laboratory data DGA based. A comparison between the laboratory results and the code results will be accomplished. This comparison explains that the code is reliable to determine the transformer fault. The age of transformer is taken into account in our calculations. The results from the software code illustrate the program reliability as an early detection tool of transformer faults.

Key words: Dissolved gases analysis- transformer oil- interpretation of transformer faults.

I. Introduction

Insulation is an important part of a power transformer, in general, solid and liquid insulation are widely used. The cost of unplanned outages of power transformers can be reduced by the early detection of such internal faults. During the operational of a transformer, gasses may dissolve in transformer oil; these gasses arise as results of transformer faults such as arcing, corona (partial discharges), overheating of transformer oil or overheating of paper insulation (cellulose). Among the dissolved gasses the combustible gasses are the most dangerous since these gasses may cause the burning and/or explosion of the transformer. The combustible gasses commonly appear in transformer oil are H₂ (Hydrogen), C₂H₆ (Ethane), C₂H₄ (Ethylene) and C₂H₂ (Acetylene) [1-8].

IEEE Standard C57.104-2008 describes the key gases, Doernenburg ratios, and Rogers Ratio method [9]. IEC Standard 60599 introduces the three basic gas ratio methods and the Duval triangle method [10]. Though these methods are easy to use, their performances require improvement. The IEC gas ratio method uses only three gas ratios. The Duval triangle is based on the relative proportions of the three gases for detecting a fault. Dissolved gases in oil-filled electrical equipment are very complex. DGA demonstrates better performance when a combination of gas ratios and relative proportions of gases are used to identify the fault [11].

Several artificial intelligence methods such as Fuzzy Logic and Artificial Neural Network (ANN) were developed as a novel technique to interpret the faults in transformer [12-15].

In this paper a suggested method combining the classic dissolved gases analysis (DGA) techniques for diagnosis of fault transformers with logic function is developed. Based on the interpretation of the classical techniques to the cause of transformer faults according to the gases concentration in oil transformer, an expertise system is suggested to give the cause of the transformer fault with the aid of logic functions that is used as in Fuzzy and Neural Network. A lot of real cases of analyzing the dissolved gases were collected and used to illustrate the validity of the proposed expertise method. The age of the transformer is taken into account in the calculations. In addition, some cases from previous literatures were used to compare their results with the proposed method's results.

II. Classical Methods to Diagnose Transformer Faults

Based on DGA, many interpretative methods have been introduced to diagnose the nature of the incipient deterioration that occurs in transformers.

Over the years, several techniques have been developed to facilitate the diagnoses of fault gases such as Dornenburg method [9], Roger's ratio method [16], Key gases method [9], and Duval Triangle method [7]. The interpretation of transformer faults using previous methods is based on the heuristic methods which depend on the experience of the analyst as well as it doesn't contain any mathematical formula. In order to overcome the

drawback of the above mentioned methods, various recent techniques have been developed such as neural network and fuzzy logic to analysis incipient fault in transformers [12-14, 17].

II. A. Key gases method

The key gas method identifies the key gas for each type of faults and uses the percent of this gas to diagnose the fault [9]. 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. Events range from low energy events such as partial discharge, which produces hydrogen and trace amounts of methane and ethane, to very high energy sustained arcing, capable of generating all the gases including acetylene, which requires the most energy. The key gas method interprets the incipient faults in transformer according to some significant gases to assign four typical fault types. These gases are called “key gases” [9] and are shown on Fig. 1.

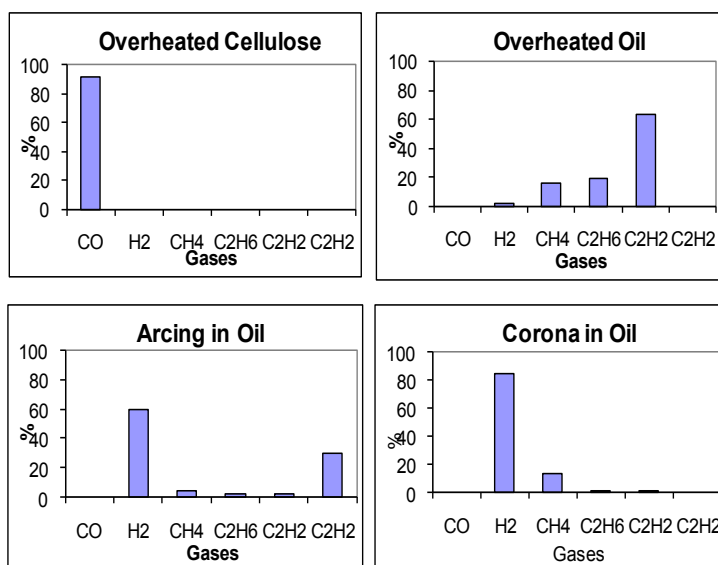


Fig. 1: Kay gas method and four typical faults.

II. B. Dornenburg ratio method

The Dornenburg method utilizes four calculated gas ratios to indicate a single fault type out of three general fault types. This procedure requires significant gases levels for the diagnosis to be valid. The four ratios and their diagnosis values are given on Table1[9]. Dornenburg method uses five individual gases or four-key gas ratios, which are:

$$R_1 = CH_4/H_2,$$

$$R_2 = C_2H_2/C_2H_4,$$

$$R_3 = C_2H_2/CH_4,$$

$$R_4 = C_2H_6/C_2H_2.$$

Table 1 is used as a diagnostic ratio for Key gas method and Doernenburg method.

Table 1: Key gas ratio-Doernenburg [9]

| | Ratios for Key Gases | | | |
|--------------------------|---------------------------------|--|--|--|
| | Main Ratio | | Auxiliary ratio | |
| | CH ₄ /H ₂ | C ₂ H ₂ /C ₂ H ₄ | C ₂ H ₆ /C ₂ H ₂ | C ₂ H ₂ /CH ₄ |
| Thermal Decomposition | >1 | <0.75 | >0.4 | <0.3 |
| Corona (Low intensity PD | <0.1 | Not significant | >0.4 | <0.3 |
| Arcing (High Density PD | <1, >0.1 | >0.75 | <0.4 | >0.3 |

II. C. Roger's ratio method

It is an additional tool that may be used to look at dissolved gases in transformer oil. The Rogers ratio method takes into consideration industrial experiences, laboratory tests, and further theoretical assessment. This

method was further modified into an IEC standard [7, 10, 16]. The original Rogers ratio method uses four gas ratios which are CH_4/H_2 , C_2H_6/CH_4 , C_2H_4/C_2H_6 and C_2H_2/C_2H_4 for diagnosis. The refined Rogers method uses two tables: one defined the code of the ratio, and the other defined the diagnosis rule. The ratio C_2H_6/CH_4 indicated only a limited temperature range of decomposition, but did not assist in further fault identification. Therefore, in IEC standard 599, the further development of Roger's ratio method was deleted. Roger's ratio method and IEC 599 have gained popularity in industrial practices. However, it may give no conclusion in some cases. This is the "no decision" problem.

Table 2 shows the codes of regor's method to diagnosis the fault in transformer.

Table 2: codes for Roger's method [9]

| CH_4/H_2 | C_2H_2/CH_4 | C_2H_4/C_2H_6 | C_2H_2/C_2H_4 | Diagnosis |
|------------|---------------|-----------------|-----------------|---|
| 0 | 0 | 0 | 0 | Normal deterioration |
| 5 | 0 | 0 | 0 | Partial discharge |
| 1/2 | 0 | 0 | 0 | Thermal fault lower than 150°C |
| 1/2 | 1 | 0 | 0 | Thermal fault (150-200°C) |
| 0 | 1 | 0 | 0 | Thermal fault (200-300°C) |
| 0 | 0 | 1 | 0 | Overheating in the cables |
| 1 | 0 | 1 | 0 | Circulating currents in the windings |
| 1 | 0 | 2 | 0 | Circulating currents in the tank and core, overheating in conexions |
| 0 | 0 | 0 | 1 | Conexions discharges |
| 0 | 0 | 1/2 | 1/2 | Arcing (high energy) |
| 0 | 0 | 2 | 2 | Low intensity continuous discharge |
| 5 | 0 | 0 | 1/2 | Partial discharge involving solid insulation |

II. D. Duval triangle method

The Duval Triangle was first developed in 1974 [7, 9] by Michel Duval using a database of about 1000 DGAs and transformer diagnoses results. Three hydrocarbon gases only (CH_4 , C_2H_4 and C_2H_2) are used. These three gases are generated as a result of increasing the level of energy necessary to generate gases in transformers in service. The Duval Triangle is shown on Fig. 2 and the legend is on Table 3. In addition to the 6 zones of individual faults (PD, D1, D2, T1, T2 or T3), an intermediate zone DT has been attributed to mixtures of electrical and thermal faults in the transformer.

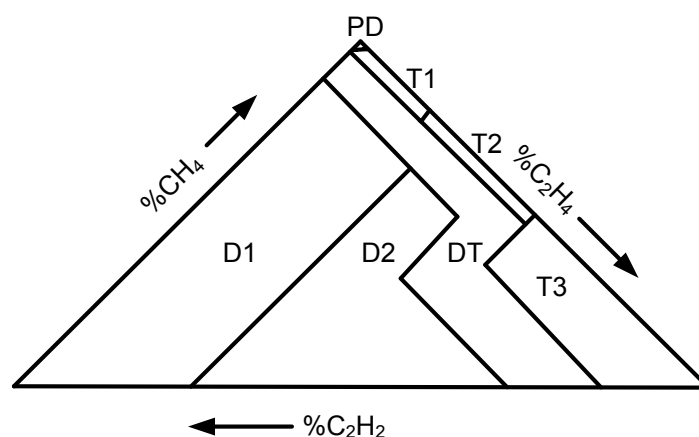


Fig.2: Duval triangle as a diagnostic tool to detect the incipient faults in transformer.

Table 3: legend of Duval triangle

| Legend |
|--|
| PD=Partial Discharge |
| T1=Thermal fault less than 300°C |
| T2=Thermal fault between 300 °C and 700 °C |
| T3=Thermal fault greater than 700 °C |
| D1=Low energy discharge (sparking) |
| D2=High energy Discharge (arcing) |
| DT=Mix of thermal and electrical fault |

III. Decision Tree as an Expertise Method

When four classical methods of transformer fault diagnosis such as Key gas method, Dronenburg method, Roger's method and Duval triangle method are applied to interpret the cause of the fault in transformer, conflicts may occurred. To overcome this problem a decision fault tree is developed which contains the information between different faults types. Every fault type takes a number to help us to get the main cause of the transformer fault. This is shown in Figure 3.

A software code in excel sheet is developed using the logic function to get transformer fault from the four classical method that mentioned before; the results depend on the combustible gases that arise when fault occurs in transformer. After determining the fault type from these methods, the program decides the incipient fault type.

The procedures that used to carryout the Excel program are:

In the first, the program determines the fault type according to the classical methods; the second step is choosing a code for each fault as in decision fault tree. The third step is summing the codes for the same faults then the general fault is specified. At the end the program specifies the specific fault from the general fault using if statement and logic functions.

The age of transformer is taken into account in the calculations as the standard level of gases that mentioned in a guide for the interpretation of gas in oil analysis data (SMS-1101-05-T)[18] as a substation maintenance standard. Table.4[18] explains the recommendation guide for maximum safe evolved gas levels in oil immersed equipment.

Table 4

| Gas | Dissolved gas concentration (ppmV) |
|-------------------------------|------------------------------------|
| H ₂ | 20n+50 |
| CH ₄ | 20n+50 |
| C ₂ H ₆ | 20n+50 |
| C ₂ H ₄ | 20n+50 |
| C ₂ H ₂ | 5n+10 |
| CO | 25n+500 |
| CO ₂ | 100n+1500 |
| TCG | 110n+710 |

Where, ppmV= part per million, by volume, n= Number of years in service. Serious or danger levels are approximately 5-10 times the above values.

The number of years is effect on the Dornenburg results. This fact is shown as in Figures 4 (a and b). When the age of transformer increases, the results will give different transformer faults in case of Dornenburg method.

Figure 5 illustrates the final report and Figure 6 explains the form of the excel sheet that is used to explain the main fault in transformer.

IV. Some Cases to Specify the Fault Type in Transformers

Some oil samples are taken from real transformers which are in operation to carry out the study. Table 5 shows the gases concentration of some real transformer and the results from the laboratory and from the proposed expertise method.

It is seen from Table 5 that, when the C₂H₂ is increased above 2 ppm, the expected fault in transformer is arcing discharge. If the dominant gases are CH₄ and C₂H₆, hence the expected fault is medium thermal fault. The high thermal fault is expected when CH₄ and C₂H₄ are the dominant gases.

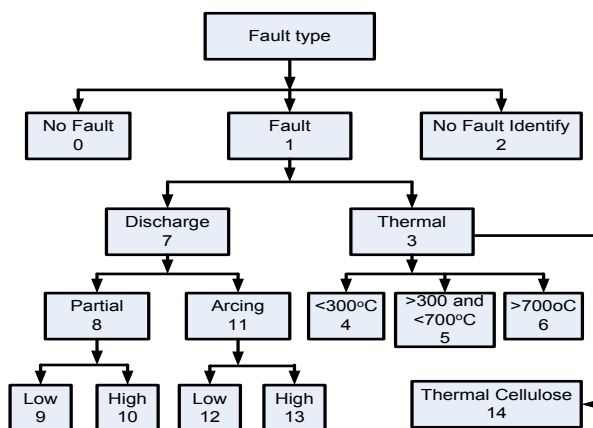


Fig. 3: Decision fault tree

| | | |
|----------------------------------|-------------------|--------------------|
| Name of station | | 66/11kV DOMIAT |
| Sample Date | | 18.5.2010 |
| Age of transformer | 10 | |
| Methane | 1081 | |
| Hydrogyne | 269 | |
| Acetyline | 25 | |
| Ethylene | 1725 | |
| Ethane | 347 | |
| Co2 | 1808 | |
| Co | 269 | |
| Nitrogyne | 84008 | |
| Oxygene | 1151 | |
| Fault from Dornenberg method | THERMAL FAULT | |
| Fault from Rogers ratio method | THERMAL >700 | |
| Fault from Duval triangle method | THERMAL FAULT>700 | |
| Fault from key gases method | THERMAL OIL | |
| Main cause | | HIGH THERMAL FAULT |

(a)

| | | |
|----------------------------------|-------------------|--------------------|
| Name of station | | 66/11kV DOMIAT |
| Sample Date | | 18.5.2010 |
| Age of transformer | 15 | |
| Methane | 1081 | |
| Hydrogyne | 269 | |
| Acetyline | 25 | |
| Ethylene | 1725 | |
| Ethane | 347 | |
| Co2 | 1808 | |
| Co | 269 | |
| Nitrogyne | 84008 | |
| Oxygene | 1151 | |
| Fault from Dornenberg method | NO FAULT | |
| Fault from Rogers ratio method | THERMAL >700 | |
| Fault from Duval triangle method | THERMAL FAULT>700 | |
| Fault from key gases method | THERMAL OIL | |
| Main cause | | HIGH THERMAL FAULT |

(b)

Fig. 4: The effect of age of the transformer on the result by Dornenberg method.

| | | |
|----------------------------------|-----------------------|--------------------|
| Name of station | | 66/11kV |
| Sample Date | | 05.06.2011 |
| Age of transformer | 5 | |
| Methane | 492 | |
| Hydrogyne | 360 | |
| Acetyline | 1 | |
| Ethylene | 305 | |
| Ethane | 54 | |
| Co2 | - | |
| Co | 580 | |
| Nitrogyne | - | |
| Oxygene | - | |
| Fault from Dornenberg method | NO FAULT | |
| Fault from Rogers ratio method | THERMAL >700 | |
| Fault from Duval triangle method | 1 | |
| Fault from key gases method | 300<THERMAL FAULT<700 | |
| Main cause | | HIGH THERMAL FAULT |

Fig. 5: The final report

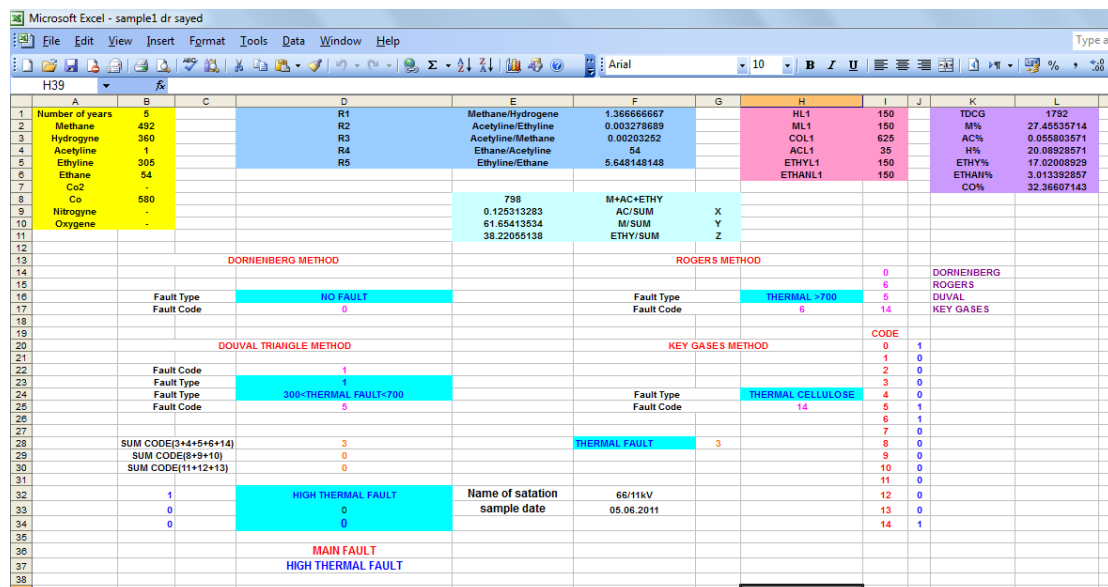


Fig. 6: The excel sheet that use to give the main cause of transform fault.

Table 5: Comparison between the laboratory results and proposed method results for some real oil transformer cases

| Transformer | 66/11kV | 66/11kV | 66/11kV | 220/500kV | 220/500kV | Talkha |
|---|----------------------|--------------------------|----------------|--------------------|----------------------|-------------------|
| Date | 5.06.2011 | 2.05.2010 | 10.08.2010 | 27.07.2010 | 11.07.2011 | 13.04.2011 |
| Methane CH ₄ | 30 | 13 | 13 | 7 | 3 | 10 |
| Hydrogen H ₂ | 30 | 17 | 62 | 9 | 62 | 10 |
| Acetylene C ₂ H ₂ | 0.0001 | 22 | 18 | 0.0001 | 0.0001 | 0.0001 |
| Ethylene C ₂ H ₄ | 20 | 15 | 36 | 8 | 3 | 1 |
| Ethane C ₂ H ₆ | 578 | 19 | 60 | 49 | 1 | 8 |
| Carbon dioxide CO ₂ | 5518 | 1993 | 7238 | 3320 | 2556 | 12797 |
| Carbon mono-oxide Co | 564 | 165 | 171 | 2021 | 470 | 798 |
| Nitrogen N ₂ | 108606 | 85128 | 42812 | 68020 | 76857 | 81682 |
| Oxygen O ₂ | 4986 | 12603 | 10120 | 12531 | 9318 | 3247 |
| LABORATORY RESULTS | Thermal 300-700 °C | Discharge of high energy | Thermal >700°C | Thermal >700°C | Thermal 300-700 °C | Thermal <300°C |
| EXPERTISE METHPD | Medium thermal fault | High arcing discharge | thermal fault | High thermal fault | Medium thermal fault | Low thermal fault |

V. Validation of the Proposed Technique

As in Table 6, the comparison between the results from the software code based on expertise method and the results from other methods in literatures is illustrated.

Table 6 explains the reliability and validation of the proposed expertise method for detecting the incipient faults in transformer based on DGA.

VI. Conclusions

The results from different cases under study reveal that the proposed technique is reliable to use as a diagnostic tools to detect the fault in transformer in its early stage. The conclusions from the real cases explain that the nature of the insulating materials involved in the fault and the nature of the fault itself affect on distribution of dissolved gases. Based on The results from the software code and the lab results, the software code is reliable to produce the transformer fault based on the gas concentrations.

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Table 6: Comparison between the expertise method results and results in literatures

| case | Sample 2 in [3] | Example 1 in [19] | Example 2 in [19] | Case III in [20] |
|-------------------------------|-----------------------|-----------------------|-----------------------|------------------------------|
| H ₂ | 59 | 64 | 206 | 127 |
| CH ₄ | 93 | 19 | 42 | 24 |
| C ₂ H ₂ | 1 | 0.001 | 221 | 81 |
| C ₂ H ₄ | 6 | 82 | 82 | 32 |
| C ₂ H ₆ | 89 | 11 | 16 | 0.0001 |
| CO | 736 | 459 | 334 | 0.0001 |
| CO ₂ | 1519 | - | 3432 | 2024 |
| result | Thermal decomposition | High thermal fault | Arcing Discharge | Arcing not involve cellulose |
| Expertise Meth. | Low thermal fault | Thermal fault > 700°C | High arcing discharge | High arcing discharge |