Modeling of Transformer DGA using IEC & Fuzzy Based Three Gas Ratio Method

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Abstract— Monitoring of incipient faults taking place in the transformers is very helpful to avoid the accidents, shut downs or financial loss associated with it. Dissolve gas analysis is the method which is widely used for this purpose. The DGA is carried out on the insulting oil of transformer. Various diagnosis methods are available for DGA as per different standards. And with the aid of Artificial intelligence techniques the accuracy of diagnosis can be improved. This paper presents a survey that has been done to collect the DGA samples. An Intelligent fuzzy based analysis is done using MATLAB. Validation of the software model is found to be satisfactory in comparison with IEC standard & actual survey report

Keywords—dga, IEC three ratio method,Fuzzy based three ratio method.

I. INTRODUCTION

Transformer plays vital role in Power industry .Operation of transformers free from faults is important for safety and economy. Most of power transformers used in industries is oil filled, and primary insulation used in it is Kraft paper, wood, porcelain and mineral oil. A failure occurs in the transformer when the insulation system becomes weak to extent that it can no longer act as an insulator to the high voltage to which it is subjected.

The various factors involves in degradation of insulation are overvoltage, overheating, ageing, environmental conditions etc. Due to this electrical & thermal stresses certain gases are produced. Hydrogen (H_2), methane (CH_4), acetylene (C_2H_2), ethylene (C_2H_4) and ethane (C_2H_6) are the gases produced due to oil decomposition, whereas carbon monoxide (CO) and carbon dioxide (CO_2) are the gases produced due to paper decomposition.

Dissolve gas Analysis is a very efficient method for monitoring the gases in early stage which helps to identify the incipient faults developing in transformer. Concentrations, gas ratios & gassings rates of various gases are useful in concluding the type of fault present or developing in the transformer. In order to carry out DGA, Oil Sample from transformer are taken and sent to laboratory for analysis with the help of gas chromatography. Oil samples can be taken without de-energizing the transformer. With the advent of technology some transformer monitoring devices are developed which enables the maintenance person to take the corrective decisions with the help of real time readings of various parameters associated with transformer. In classical method the interpretation of the result to diagnosis the fault in power transformer depends upon the experience of human experts. Some time a high degree of deviations and vagueness have absorbed regarding interpretation of result by different human experts.

This paper presents various processes involved with gas generation related with faults, various DGA Diagnosis methods. Further this project presents an effective method for accurate diagnosis of various faults in transformer with the help of Fuzzy logic in coordination with the conventional IEC three ratio method.

II. TRANSFORMER FAULTS AND GASES ASSOCIATED WITH IT ASE OF USE

Gases are generated in insulating oil due to breaking of chemical bonds present in hydrocarbon molecules. The energy required for breaking the chemical bonds is obtained from the energy present in transformer faults.

Four basic types of faults in the transformer are:

a) Arcing or high current break down.
b) Low energy sparking or partial discharges.
c) Localized overheating or hot spots and,
d) General overheating due to inadequate cooling or sustained overloading

Above listed faults are responsible for thermal degradation of oil or combination with paper insulation. Different amount of gases are evaluated like hydrocarbons, hydrogen, carbon, oxides as per the fault type.

TABLE I. TRANSFORMER FAULTS & ITS ASSOCIATED GASES

Type of Fault	Gases Evaluated
Heavy current arcing	Hydrogen and Acetylene
Arcing involving paper insulation	oxide of carbon
Partial discharge	hydrogen and lower order hydrocarbons
Localized heating or hot spot	methane and ethane
Prolonged overloading or impaired heat transfer	Carbon monoxide and Carbon dioxide

III. METHODS OF DISSOLVE GAS ANALYSIS

Various methods of diagnosis available are listed below.

A. Key Gas method

In this method the concentration and gassing rates of the key hydrocarbon gases are monitored. The concentrations are expressed in ppm (parts per million). The normal operating concentration of these key gases according to IEC 60599

B. Total Dissolved Combustible Gases (TDCG)

It is the sum of concentrations of all the combustible gases. It indicates the insulation deterioration. The typical limits are defined for the diagnosis of the faults in transformer insulation.

C. Duval Triangle

The Triangle is graphical method of representation and is used to visualize the different cases and facilitate their comparison .

D. Ratio method

This method is the most widely used method for the fault interpretation. In this method ratios of gas concentrations are used for the interpretation purpose. Roger ratio method, Dorrenburg ratio method, and IEC ratio methods are used by the utilities.

1) IEC Three Gas Ratio Method-

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IEC Three ratio is the most commonly used Industry standard method. The ratios of certain gases are used for diagnostic techniques. These techniques were standardized by IEC in 1978 in "Guide for Interpretation of the Analysis of Gases in Transformer and Other Oil Filled Electrical Equipment in Service" .The individual gases used to determine each ratio and its assigned limits are shown in Tables 3. Codes are then allocated according to the value obtained for each ratio and the corresponding fault characterized.

TABLE II. CODING FOR GAS RATIOS

Sharply defined ranges of the gas ratio	**Codes of different gas ratios**		
	R1	R2	R3
	C2H2/C2H4	CH4/H2	C2H4/C2H6
<0.1	0	1	0
0.1-1	1	0	0
1-3	1	2	1
>3	2	2	2

TABLE III. GAS RATIOS & ITS ASSIGNED LIMITS.

No.	Fault type	C2H2/C2H4	CH4/H2	C2H4/C2H6
1	No fault	0	0	0
2	Partial discharges of low energy density	0 (but not significant)	1	0
3	Partial discharges of high energy density	1	1	0
4	Discharges of low energy density	1 or 2	0	1 or 2
5	Discharges of high energy density	1	0	2
6	Thermal fault of low temperature <150˚C	0	0	1
7	Thermal fault of low temperature 150˚-300 ˚C	0	2	0
8	Thermal fault of medium temperature 300 ˚-700˚C	0	2	1
9	Thermal fault of high temperature >700 ˚C	0	2	2

This method is generally based on the empirical experience and sometimes fails to give accurate diagnosis of faults. Sometimes the results do not match with existing codes; also in case of multiple faults confusion is created in ratios between different gases due to mixing of gases which leads toward unsuccessful diagnosis.

IV. ARTIFICIAL INTELLIGENCE TECHNIQUES FOR DGA

Fault interpretation from DGA is relayed on the human expertise & past experience. To improve the interpretation accuracy of DGA, Artificial intelligence techniques are applied. This technique makes use of collection of data including DGA results, past fault and some standard methods used for diagnosis.

Various AI techniques used for DGA are Artificial Neural Network (AAN), Fuzzy Interface System (FIS), Genetic Algorithm (GA),Bayesian Network (BN), Self Organizing Map (SOM), Extended Relation Function (ERF) and Discrete Wavelet Network (WNs) etc which improves the accuracy of diagnosis of DGA.

A. Fuzzy Three Ratio Method

Through the combination of fuzzy logic and IEC Three Ratio method, this paper puts forward Fuzzy Three Ratio Method. It fuzzifies the coding boundary, thus overcomes the drawbacks of coding boundary sharp changing.

Fuzzification of The Three Ratios

According to Table2, three gas ratios, R1 = Acetylene (C_2H_2) / Ethylene (C_2H_4), R2 = Methane (CH_4) /

Hydrogen (H_2), and R3 = Ethylene (C_2H_4) / Ethane (C_2H_6); can be coded as 0, 1, and 2 for different ranges of ratios.

In this method, IEC codes 0, 1, 2 are replaced by fuzzy sets ZERO, ONE, TWO, each gas ratio can be represented by a fuzzy vector [μ_{ZERO} (R), μ_{ONE} (R), μ_{TWO} (R)], where μ_{ZERO} (R), μ_{ONE} (R), μ_{TWO} (R)are the membership function of the fuzzy set ZERO, ONE, TWO.

In the following, R1 is taken as an example to explain how to transfer IEC codes 0, 1, 2 into fuzzy set ZERO, ONE, and TWO.

a) The membership function of fuzzy set ZERO is:

$$\mu_{ZERO}(R1) = \begin{cases} 1 & R1 \le 0.08 \\ e^{-50(R1-0.08)} & R1 > 0.08 \end{cases} \quad (1)$$

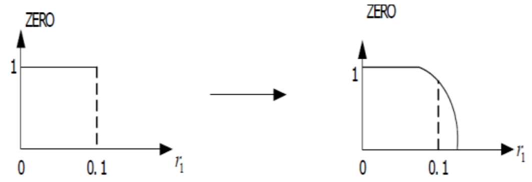


Fig.1 The fuzzification process of code 0 for R1

b) The membership function of fuzzy set ONE is

$$\mu_{ONE}(R1) = \begin{cases} 0 & R1 \le 0.08 \\ 0.5 + 0.5\sin(25\Pi(R1-0.1)) & R1 \in (0.08, 0.12) \\ 1 & R1 \in (0.12, 2.9) \\ 0.5 - 0.5\sin(5\Pi(R1-3)) & R1 \in (2.9, 3.1) \\ 0 & R1 > 3.1 \end{cases} \quad (2)$$

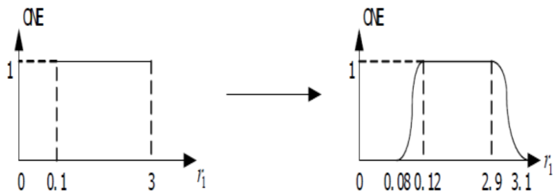
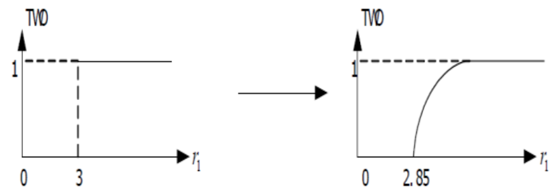


Fig. 2 The fuzzification process of code 1 for R1

c) The membership function of fuzzy set TWO is

$$\mu_{TWO}(R1) = \begin{cases} 0 & R1 \le 2.85 \\ e^{-12(R1-2.85)} & R1 > 2.85 \end{cases} \quad (3)$$



Fie.3 The fuzzification process of code 2 for R1

Figure 1,2,3 are the representation of fuzzification process of code 0, 1 and 2 for R1.

Similarly, the three fuzzy membership functions for R2 can be obtained as follows:

The membership function of fuzzy set ZERO is:

$$\mu_{ZERO}(R2) = \begin{cases} 0 & R2 \le 0.08 \\ 0.5 + 0.5\sin(25\Pi(R2-0.1)) & R2 \in (0.08, 0.12) \\ 1 & R2 \in (0.12, 0.9) \\ 0.5 - 0.5\sin(5\Pi(R2-1)) & R2 \in (0.9, 1.1) \\ 0 & R2 > 1.1 \end{cases} \quad (4)$$

The membership function of fuzzy set ONE is:

$$\mu_{ONE}(R2) = \begin{cases} 1 & R2 \le 0.08 \\ e\text{-}50(R2-0.08) & R2 > 0.08 \end{cases} \quad (5)$$

The membership function of fuzzy set TWO is:

$$\mu_{TWO}(R2) = \begin{cases} 0 & R2 \le 0.85 \\ e\text{-}12(R2-0.85) & R2 > 0.85 \end{cases} \quad (6)$$

Similarly, the three fuzzy membership functions for R3 can be obtained as follows:

The membership function of fuzzy set ZERO is:

$$\mu_{ZERO}(R3) = \begin{cases} 1 & R3 \le 0.85 \\ e\text{-}50(R3-0.08) & R3 > 0.85 \end{cases} \quad (7)$$

The membership function of fuzzy set ONE is:

$$\mu_{ONE}(R3) = \begin{cases} 0 & R3 \le 0.9 \\ 0.5 + 0.5\sin(25\Pi(R3-1)) & R3 \in (0.9, 1.1) \\ 1 & R3 \in (1.1, 2.9) \\ 0.5 - 0.5\sin(5\Pi(R3-3)) & R3 \in (2.9, 3.1) \\ 0 & R3 > 3.1 \end{cases} \quad (8)$$

The membership function of fuzzy set TWO is:

$$\mu_{TWO}(R3) = \begin{cases} 0 & R3 \le 2.85 \\ e\text{-}12(R3-2.85) & R3 > 2.85 \end{cases} \quad (9)$$

B. The Diagnosing Steps Involved in Fuzzy Three ratio Method-

Step1: From the DGA report input values of gas concentrations of key gases from oil sample in ppm.

Step 2: Calculate three ratios R1 = Acetylene (C_2H_2) / Ethylene (C_2H_4), R2 = Methane (CH_4) / Hydrogen (H_2), and R3 = Ethylene (C_2H_4) / Ethane (C_2H_6).

Step 3: Calculate the three fuzzy membership functions of each ratio based on equations listed in above section.

Step 4: As for the conventional logic "AND" and "OR" used in the conventional IEC diagnosis, replace "AND" by "min", "OR" by "max", the fuzzy diagnosing vector F(i) where i = 1,2,…,9 represent i^{th} fault in Table.3 is determined by the following equations:

$$F(1) = \min[\mu_{ZERO}(R1), \mu_{ZERO}(R2), \mu_{ZERO}(R3)]$$

$F(2) = \min[\ \mu_{ZERO}(R1), \mu_{ONE}(R2), \mu_{ZERO}(R3)\ ]$

$F(3) = \min[\ \mu_{ONE}(R1), \mu_{ONE}(R2), \mu_{ZERO}(R3)\ ]$

$F(4) = \max(\ \min[\ \mu_{ONE}(R1), \mu_{ZERO}(R2), \mu_{ONE}(R3)\ ]$
$\quad \min[\ \mu_{TWO}(R1), \mu_{ZERO}(R2), \mu_{ONE}(R3)\ ]$
$\quad \min[\ \mu_{TWO}(R1), \mu_{ZERO}(R2), \mu_{TWO}(R3)\ ]\ )$

$F(5) = \min[\ \mu_{ONE}(R1), \mu_{ZERO}(R2), \mu_{TWO}(R3)\ ]$

$F(6) = \min[\ \mu_{ZERO}(R1), \mu_{ZERO}(R2), \mu_{ONE}(R3)\ ]$

$F(7) = \min[\ \mu_{ZERO}(R1), \mu_{TWO}(R2), \mu_{ZERO}(R3)\ ]$

$F(8) = \min[\ \mu_{ZERO}(R1), \mu_{TWO}(R2), \mu_{ONE}(R3)\ ]$

$F(9) = \min[\ \mu_{ZERO}(R1), \mu_{TWO}(R2), \mu_{TWO}(R3)\ ]$

Step 5: Fault type out of the 9 listed faults is determined.

Step 6: Results are displayed in graph window for gas content in ppm, and Fuzzy Three Ratio Method decision.

V. RESULTS AND ALANLYSIS

DGA results of 18 different oil samples are taken, and these values are applied to MATLAB Scripts that are programmed separately for Conventional IEC Three Ratio Method and Fuzzy Three Ratio Method and results are presented below.

From these 18 samples 3 results give no diagnosis, 2 results Fails to diagnose correct fault and 1 result fails to diagnose multiple faults using IEC Three Ratio Method, Hence provides 66.67 % accuracy. Whereas Fuzzy Three Ratio Method provides 1 fault which fails correct diagnosis, and one fault in which wrong multiple faults out of the 18 results hence provides 88.89 % Accuracy Therefore it shows that this proposed method is more appropriate.

TABLE IV . COMPARATIVE ANALYSIS OF RESULTS OF IEC THREE RATIO & FUZZY THREE RATIO METHOD WITH ACTUAL FAULTS RECORDED.

Sr no.	Hydrogen (H2)	Methane (CH4)	Ethane (C2H6)	Ethylene (C2H4)	Acetylene (C2H2)	Actual fault Type	BY IEC Three Ratio	By Fuzzy based Three
1	154	149.71	113.94	76	6.08	7	1	3,4
2	9340	995	60	60	7	3	N	3
3	305	100	33	161	541	4	4	4
4	183	259	209	531	0	8	8	8
5	134	134	157	45	0	4	7	4
6	94	76	43	61	3.7	6	6	6
7	69.9	70	29.03	139.9	9.98	9	9	9
8	298	498	179.6	358	94	8	N	8
9	1599	651	81.2	998.9	421	5	5	5
10	346	114	29	49.9	60	4	4	4
11	57	58	74	29	31	3	N	3
12	54.6	38.2	4.98	54.8	49.4	5	5	5
13	173	341	169	814	41	9	9	9
14	35.01	19.98	3.4	45	20	5	5	5
15	114	36	8.4	24.2	43	4	4	4
16	33.9	25.98	6.1	5.4	0.2	1	1	1,2
17	198	703	249	745	2	8,9	8	8,9
18	1270	3450	520	1390	8	8	8	8

CONCLUSION

This paper proposes transformer fault diagnose method which is an improvement of IEC three ratio Method with the help of Fuzzy logic. This method proves its accuracy by diagnosing the correct fault or multiple faults which conventional IEC method fails to diagnose. The programming associated with this fuzzy logic is comparatively simple and easy for modification.

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