Power Transformer Fault Diagnosis using DGA based on Three Gas Ratio and Fuzzy Logic

Nagesh Kalidas Bhosale, Chandra O. Reddy, Pankaj Bhakre

Abstract: For power system equipment with oil as insulating medium such as power transformer, *Dissolved Gas Analysis (DGA) of oil is very helpful method in order to detect faults below oil level. Early detection of fault conditions in a transformer is possible if analysis of gases is done which gets evolved in it. Analysis of the specific value of every gas helps in diagnosing faults. Faults which can be identified by this method include disturbances like presence of corona discharge, partial discharges, arcing and increase in temperature. If correct preventive actions are initiated early for the diagnosis of gases produced, failure to equipment will get prevented. Even though many methods are researched for fault identification and analysis in power transformers, DGA is much superior in comparison with other techniques as it gives more helpful data about the condition of the transformers in running condition. Different techniques, like key gases and their ratio, and their analyzing them graphically are mainly used to understand DGA samples. For a transformer having multiple faults, above methods fail to diagnose. IEC standards are in use for DGA from many years and valuable experience gained over theses years around the world is in use to diagnose internal faults on transformers. IEC three gas ratio technique suggested by IEC is mainly preferred, but in some conditions it can't correctly identify conditions like no suitable codes for diagnosis and multiple faults. The limitations of the traditional three gas ratio method are: with gas ratio is on the verge of crossing the coding boundary, there is a sharp change in the codes, but actually fuzzied boundary should be used. In this paper, codes "zero", "one", "two" are represented by fuzzy membership functions, then "AND" and "OR" conditions of three gas ratio method are coded into fuzzy logic based statements. MATLAB based scripts prove that the presented technique surely overcome the limitations of the traditional three gas ratio method, hence, it largely reduces the errors in diagnosis. In this paper, a method on the basis of fuzzy logic is explained which is able to identify many faults in oil insulated equipment. The presented diagnosis technique uses values of the ratios C_2H_4/C_2H_6, C_2H_2/C_2H_4 and CH_4/H_2 and the concentration of specific gases* namely methane (CH_4), hydrogen (H_2), acetylene (C_2H_2), carbon monoxide (CO), ethylene (C_2H_4), carbon dioxide (CO_2) and ethane (C_2H_6). *Values of these three ratios reflect various patterns of faults inside the transformer. Fuzzy three ratio technique can also quantitatively indicate the likelihood of identified fault with more accuracy as compared to conventional three ratio method. This tool will prove to be very useful to the engineers in DGA result interpretation.*

Index Terms: Dissolved Gas Analysis (DGA), Fuzzy Logic, Power Transformer, Three Gas Ratio.

I. INTRODUCTION

Electrical power sector is the backbone of every country for economic and industrial growth. Growth of any country is dependent on its facility to generate, transmit and utilize the electrical power. Presently with the advances in science and technology for analysis purpose, various new tolls are available and it is possible to locate early the cause of disturbance or fault in the power system and its components. Transmission and distribution of an electrical power has very important role of power transformers. Complete loss of transformer can lead to loss of electrical power and reliability over a longer duration and need costly repairs. Early location of faults in power equipment can achieve major economic and safety objectives in electrical power systems. Different oil cooled and insulated components are used in power sector and their protection and operational safety are major concerns. In the current economic climate, an increased awareness is placed on the reliability of the existing electric power supply. Often, the overloading increases the stress on the transformer. The resultant thermal, electrical and mechanical stress must be conditioned and monitored from reliability and safety point of view. Scheduled monitoring and testing of oil in a transformer is a part of preventative maintenance program. With a preventive approach, the efficiency and life of the transformer can be improved. An internal fault in transformer must be detected early, to prevent further damage and ageing of the transformer. Transformer oil is a composition of hydrocarbons and faults are can not be prevented inevitable if appropriate care is avoided. Transformer oil degrades because of different reasons like ageing, increase in voltage, surrounding conditions, overheating and various other factors. During oil degradation, a number of hydrocarbons such as acetylene, methane, ethylene, ethane and others are generated. Also a number of gases like hydrogen, carbon dioxide and carbon monoxide are produced. These evolved gases under enclosed condition can lead to an explosion. Generation and concentration of these gases is dependent on the oil condition and therefore,

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Retrieval Number: A1380058119/19©BEIESP
DOI: 10.35940/ijrte.A1380.078219
Journal Website: www.ijrte.org

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Published By:
Blue Eyes Intelligence Engineering
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it is very important to monitor presence and value of these harmful gases in the transformer under running condition.

Contamination and ageing of transformer oil and various insulating materials can been monitored by various methods like Factor of dissipation, Voltage to Breakdown of oil and other dielectric materials, capacitance, loss angle, Polymerization Degree etc.

DGA is most generally used technique to identify the internal faults in oil insulated transformers and electrical components. Several diagnosis methods, like Key Gas, Rogers Ratio, Dorenburg's Ratio, International Electric Committee (IEC) and Duval's Triangle methods are available to identify the various type faults generally occurring in running condition like corona loss, sparking, partial discharges and temperature rise etc. The DGA results inform about the transformer condition and warning about faults occurring, monitoring the fault development rate, confirmation of the presence of faults, scheduling repairs and condition monitoring during overload. In conventional method, the interpretation of fault diagnosis results in power transformer depends on the human expertize. Sometimes a large inconsistency and inaccuracy is observed regarding conclusion of result by different human experts. So Artificial Intelligence (AI) techniques used for DGA like Artificial Neural Network (AAN), Fuzzy Interface System (FIS), Genetic Algorithm (GA), Self Organizing Map (SOM) and Discrete Wavelet Network (WNs) etc. increases the diagnosis accuracy. This paper proposes an efficient method to correctly diagnose different faults on a transformer with the help of fuzzy logic in coordination with the conventional IEC three gas ratio method.

II. TRADITIONAL THREE GAS RATIO APPROACH

Transformer during fault produces gases due to insulating oil degradation or by some other insulating/dielectric material, for example paper or cellulose material. When partial or full discharge or excess heating takes place, oil in circulation near fault decomposes in some gases. These gases dissolve in oil. Different fault types are therefore reflected by the different compositions of the gases-in-oil.

In this method the concentration and gassing rates of the key hydrocarbon gases is monitored. The key gases analyzed are, hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), carbon monoxide (CO), and carbon dioxide (CO_2). The concentrations are expressed in ppm. Normal concentration during operation of these gases with reference to IEC 60599 is as shown in Table I.

Table I. Dissolved gas compositions [3]

Gas	Concentration (ppm)
H_2	60-150
CH_4	40-110
C_2H_6	50-90
C_2H_4	60-280
C_2H_2	3-50
CO	540-900
CO_2	5100-13000

Table II. IEC codes [3]

Defined ranges of the ratio	Codes of different ratios of gases		
	$C_2H_2/$ C_2H_4	$CH_4/$ H_2	$C_2H_4/$ C_2H_6
< 0.1	0	1	0
0.1-1	1	0	0
1-3	1	2	1
> 3	2	2	2

Table III. Fault classification of faults by IEC three gas ratio codes [3]

SN	Fault type	$C_2H_2/$ C_2H_4	$CH_4/$ H_2	$C_2H_4/$ C_2H_6
1	No fault	0	0	0
2	Partial discharges of low energy density	0	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

IEC standards are in use for DGA from many years and valuable experience gained over theses years around the world is in use to diagnose internal faults on transformers. Initial conclusions were focused on certain gas components like H_2 and CH_4 for findings about oil discharges. "Guide for Interpretation of the Analysis of Gases in Transformer and Other Oil Filled Electrical Equipment in Service" is the guide for standard techniques of DGA provided in year 1978 by IEC. Respective gases under consideration to calculate shown ratio of gases and their referred limits is as shown in Table II. Codes like 0, 1 and 2 are given with respect to ratio value calculated for two gases each and respective fault is characterized as given in Table III.

- *Diagnosing steps for Conventional Three Ratio Method*

Step1: Get DGA sample report for sampled oil of transformer, take a note of concentration values for various gases such as like hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), carbon monoxide (CO), and carbon dioxide (CO_2) in parts per million.

Step 2: Calculate given three ratios of gases r_1 = Acetylene (C_2H_2) / Ethylene (C_2H_4), r_2 = Methane (CH_4) / Hydrogen (H_2), and r_3 = Ethylene (C_2H_4) / Ethane (C_2H_6).

Step 3: With reference to Table II, every ratio is identified with a classified code 0, 1, or 2.

Step 4: For traditional logic used in diagnosis by IEC rules, statements with the use of "AND" and "OR" logic are formed to make decision by referring Table III, and then respective type of fault amongst these nine faults given in Table III is obtained.

Step 5: In case of any no-decision condition, the term 'Not diagnosable (No Result)' is used.

Step 6: A result window shows gas content (ppm), corresponding IEC code and decision regarding fault by conventional IEC three gas ratio method.

- *Limitations of the traditional three gas ratio method*

IEC 599 calculates three ratios of gases, C_2H_2 / C_2H_4, CH_4 / H_2 and C_2H_4 / C_2H_6, where each ratio is provided with a classified code of zero, or one or two. In all there are total twenty-seven possible combinations or types of fault, whereas IEC 599 defined only possible eleven conditions whereas remaining sixteen combinations lead to no decision diagnosis. The codes used consider only two conditions of whether "True" or "False" for identification of fault. This is always not working, because boundaries between separating these codes need to be non-linear or fuzzy. This can be done with the help of much more accurate methods of analysis like fuzzy logic based diagnostic method given and implemented as given below [3].

III. FUZZY LOGIC BASED THREE GAS RATIO METHOD

Through the use of fuzzy logic with IEC three gas ratio method; the paper presents fuzzy three gas ratio method. To overcome disadvantage of sharp change at boundary condition, this fuzzifies the coding boundary.

- *The fuzzification of the three-ratios*

As shown in Table II, r_1, r_2 and r_3 are the ratios of gases observed during DGA and are coded with zero, one, and two to represent various ratio ranges.

With reference to Table III, certain codes for three ratios of gases represent specific type of fault. For example, with the diagnosis of transformer with fault number eight, where r_1, r_2, and r_3 are 0, 2 and 1 respectively. For conventional IEC based analysis, the logical 'AND' and 'OR' operations are applied. For instance: $r_1 = 0$ *AND* $r_2 = 2$ *AND* $r_3 = 1$, from the traditional logic condition, it is either one (true) or zero (false). The method has the disadvantage of the traditional IEC method that with the ratio of gas changing across coded boundary, code changes suddenly between 0, 1, and 2.

In fuzzy logic based method, codes used in IEC (0, 1 and 2) are replaced with fuzzy codes ZERO, ONE, TWO for each ratio of gas and represented with fuzzy vector [μ_{ZERO} (r), μ_{ONE} (r), μ_{TWO} (r)]. Here μ_{ZERO} (r), μ_{ONE} (r) and μ_{TWO} (r) represent the membership function for fuzzy set ZERO, ONE and TWO.

In the following part, r_1 is taken as an example to explain how to transfer IEC codes 0, 1, 2 into fuzzy set ZERO, ONE, and TWO.

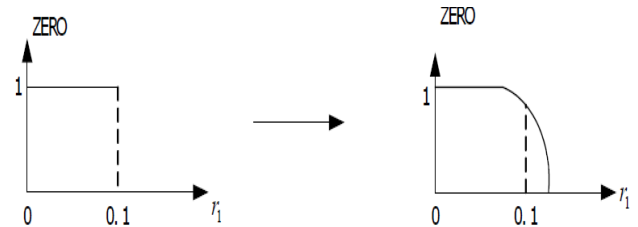Figure 1, 2, and 3 shows representation of fuzzification method for code 0, 1 and 2 with ratio r_1.

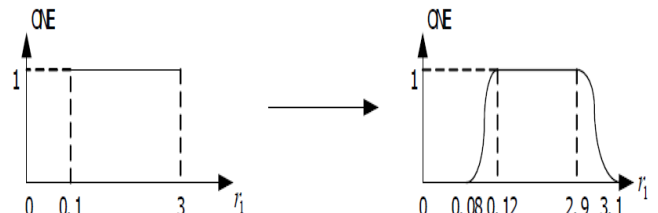**Fig.1. Fuzzification method for code 0 with ratio r_1 [3]**

Fig. 2. Fuzzification method for code 1 with ratio r_1 [3]
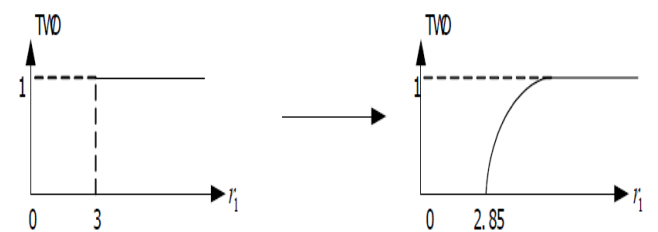

Fig. 3. Fuzzification method for code 2 with ratio r_1 [3]

Similarly, representation of fuzzification method for code 0, 1 and 2 with ratio r_2 and r_3 can be shown.

- *Steps for fuzzy three gas ratio method*

Step1: Get DGA sample report for sampled oil of transformer, take a note of concentration values for various gases such as like hydrogen (H_2), methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), carbon monoxide (CO), and carbon dioxide (CO_2) in parts per million.

Step 2: Calculate given three ratios of gases r_1 = Acetylene (C_2H_2) / Ethylene (C_2H_4), r_2 = Methane (CH_4) / Hydrogen (H_2), and r_3 = Ethylene (C_2H_4) / Ethane (C_2H_6).

Step 3: Every gas ratio is represented by fuzzy based membership functions.

Step 4: In conventional logic "AND" and "OR" statements are in use for the traditional IEC based diagnosis method, replacing "AND" with "minimum", "OR" with "maximum", the diagnosis vector based on fuzzy logic Fuzzy$_i$ with i = 1, 2, …,9 representing i^{th} fault as give in Table III is identified by the below equations [3]:

$Fuzzy_1$ = minimum [μ_{ZERO} (r_1), μ_{ZERO} (r_2), μ_{ZERO} (r_3)]

$Fuzzy_2$ = minimum [μ_{ZERO} (r_1), μ_{ONE} (r_2), μ_{ZERO} (r_3)]

$Fuzzy_3$ = minimum [μ_{ONE} (r_1), μ_{ONE} (r_2), μ_{ZERO} (r_3)]

$Fuzzy_4$ = maximum (minimum [μ_{ONE}(r_1), μ_{ZERO}(r_2), μ_{ONE}(r_3)]
minimum [μ_{TWO} (r_1), μ_{ZERO} (r_2), μ_{ONE} (r_3)]
minimum [μ_{TWO} (r_1), μ_{ZERO} (r_2), μ_{TWO} (r_3)])

$Fuzzy_5$ = minimum [μ_{ONE} (r_1), μ_{ZERO} (r_2), μ_{TWO} (r_3)]

$Fuzzy_6$ = minimum [μ_{ZERO} (r_1), μ_{ZERO} (r_2), μ_{ONE} (r_3)]

$Fuzzy_7$ = minimum [μ_{ZERO} (r_1), μ_{TWO} (r_2), μ_{ZERO} (r_3)]

$Fuzzy_8$ = minimum [μ_{ZERO} (r_1), μ_{TWO} (r_2), μ_{ONE} (r_3)]

$Fuzzy_9$ = minimum [μ_{ZERO} (r_1), μ_{TWO} (r_2), μ_{TWO} (r_3)]

Step 5: Type of Fault among the nine listed fault types is identified.

Step 6: Result is displayed in graphical type windows with content of gases in ppm, and fuzzy logic based three gas ratio method's diagnosis [3].

IV. RESULS AND DISCUSSION

To validate the performance of fuzzy logic based three gas ratio method presented in the paper, DGA result of 18 oil samples with type of fault occurring is already known are considered [3]. MATLAB scripts are programmed according to the steps mentioned in chapter V and results are analyzed below.Fuzzy Inference System (FIS) is a tool of presenting the diagram from provided inputs to an output based on fuzzy logic. The method involves all of the portions related to membership functions, logical operators and if-then statements. Here a Mamdani FIS is used as shown in fig. 4, with three inputs, one output and eleven rules, with the aid of MATLAB's Fuzzy Logic Toolbox R2017a. A Rule viewer with eleven rules is shown in fig. 5.
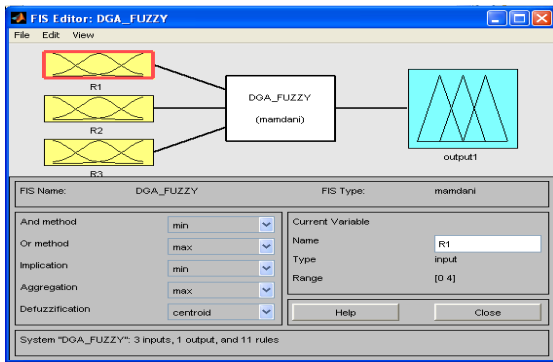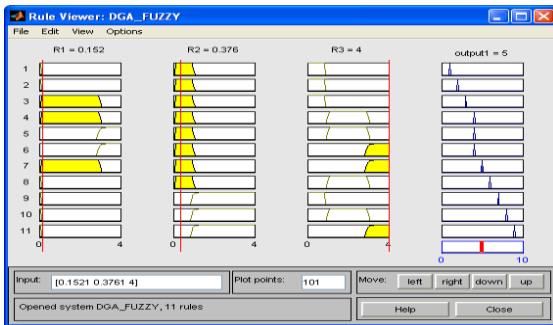

Fig. 4. FIS editor for fuzzy three ratio method

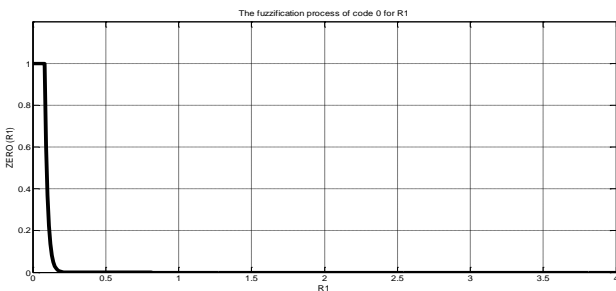**Fig. 5. Rule viewer for fuzzy three ratio method**

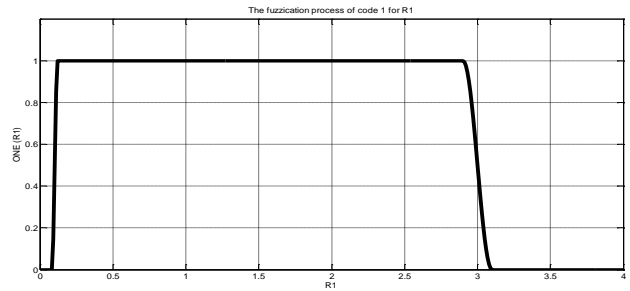**Fig. 6. Fuzzification method for code 0 with ratio r_1**

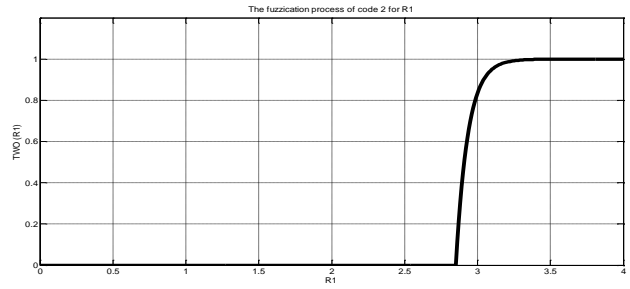**Fig. 7. Fuzzification method for code 1 with ratio r_1**
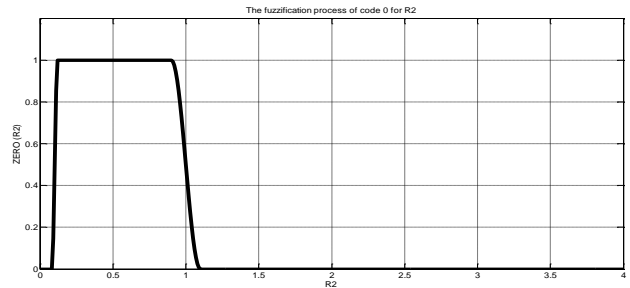

Fig. 8. Fuzzification method for code 2 with ratio r_1

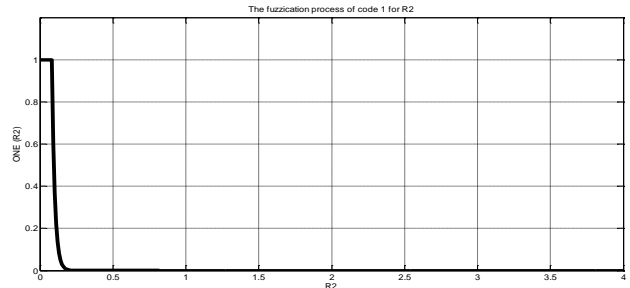**Fig. 9. Fuzzification method for code 0 with ratio r_2**

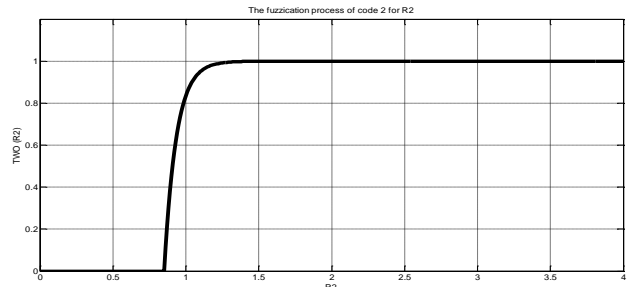**Fig. 10. Fuzzification method for code 1 with ratio r_2**

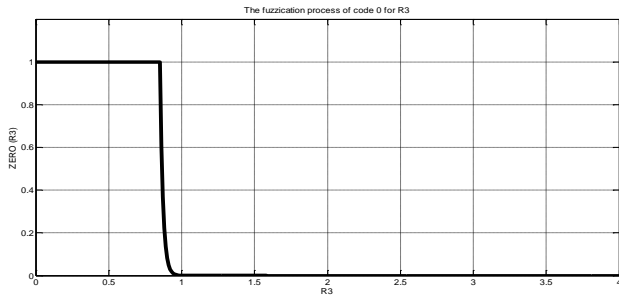**Fig. 11. Fuzzification method for code 2 with ratio r_2**

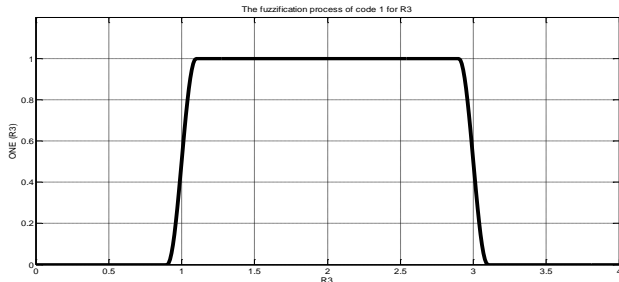**Fig. 12. Fuzzification method for code 0 with ratio r₃**

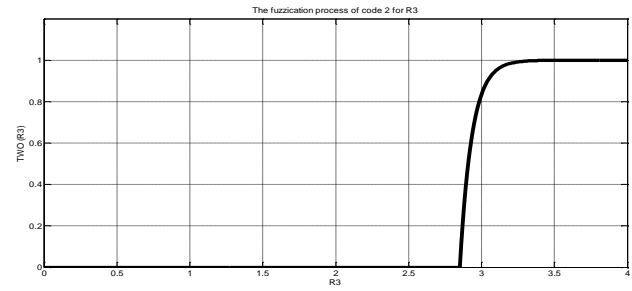**Fig. 14. Fuzzification method for code 2 with ratio r₃**

Fig. 13. Fuzzification method for code 1 with ratio r₃

Results of MATLAB programming or m-scripts are presented in Table IV. It is observed that, in these eighteen test results, IEC three gas ratio method is having five 'No Diagnosis' and failed to accurately diagnose one case with many faults at a time and one of the diagnostic result is not matching with occurring fault type from the result table. But, with proposed fuzzy logic based method, it can do the correct diagnosis of four out of these five 'No Diagnosis' samples as compared to IEC three gas ratio method, and it can accurately diagnose a case many faults occurring. For selected samples, IEC based three gas ratio method accuracy is around 67 %, and proposed fuzzy logic based three gas ratio method accuracy is around 89 %. Hence it is easy to conclude that proposed fuzzy logic based method is efficient and more accurate.

Table IV. DGA samples and diagnosis results by IEC and fuzzy three gas ratio methods

S.N.	Hydrogen H_2	Methane CH_4	Ethane C_2H_6	Ethylene C_2H_4	Acetylene C_2H_2	Actual Type of Fault	IEC Three Gas Ratio Method	Fuzzy Based Three Ratio Method
01	200	700	250	740	1	8,9	8	8,9
02	300	490	180	360	95	8	No Diagnosis	8
03	56	61	75	32	31	3	No Diagnosis	3
04	33	26	6	5.3	0.2	1	1	1,2
05	176	205.9	47.7	75.7	68.7	4	No Diagnosis	8
06	70.4	69.5	28.9	241.2	10.4	9	No Diagnosis	9
07	162	35	5.6	30	44	5	5	5
08	345	112.25	27.5	51.5	58.75	4	4	4
09	181	262	210	528	0	8	8	8
10	172.9	334.1	172.9	812.5	37.7	9	9	9
11	1678	652.9	80.7	1005.9	419.1	5	5	5
12	206	198.9	74	612.7	15.1	9	No Decision	9
13	180	175	75	50	4	7	1	3,4
14	34.45	21.92	3.19	44.96	19.62	5	5	5
15	51.2	37.6	5.1	52.8	51.6	5	5	5
16	106	24	4	28	37	5	5	5
17	27	90	42	63	0.2	8	8	8
18	138.8	52.2	6.77	62.8	9.55	5	5	5

V. CONCLUSION

The traditional IEC based three gas ratio method is applied for various oil samples in the paper with the help MATLAB based software programming, and is tested to diagnose different types of faults commonly occurring in the transformer. Fuzzy Logic based three gas ratio method is more informative towards the transformer incipient faults providing reliable information to the maintenance engineer and at the same time maintaining integrity of the original method. Fuzzy membership functions represent more accurate relation between the type of fault and DGA samples as reflected in the output results. Also with the method, more than one fault at a time can be identified, which is not correctly diagnosed by the traditional method.

The paper also presents diagnosis of faults in a transformer using fuzzy logic based three gas ratio. This concept can remove the limitations of traditional IEC based three gas ratio method like: no diagnosis and not able to diagnose many faults occurring at a time. Also the method is not required to waste time in "learning" and its coding is simplified with modern day software applications. Programming results with DGA analysis of oil samples for a power transformer, shows that the method is working properly and error percentage of the presented method is much less than that of the traditional IEC based method.

REFERENCES

1. M. Duval, "Interpretation of Gas-in-Oil Analysis using New IEC Publication 60599 and IEC TC 10 Databases", *IEEE Electrical Insulation Magazine*, vol. 17, no. 2, pp. 31-41, 2001.
2. CS Chang, CW Lim, and Q Su, "Fuzzy-Neural approach for Dissolved Gas Analysis of Power Transformer Incipient Faults," *Australasian Universities Power Engineering Conference (AUPEC 2004)*, Brisbane, Australia, Sept. 2004.
3. Hongzhong Ma, Zheng Li, P. Ju, Jingdong Han, and Limin Zhang, "Diagnosis of Power Transformer Faults Based on Fuzzy Three-Ratio Method," *The 7th International Power Engineering Conference (IPEC)*, Singapore, Nov. 2005.
4. R. Naresh, Veena Sharma and Manisha Vashisth, "An Integrated Neural Fuzzy Approach for Fault Diagnosis of Transformers," *IEEE Transactions on Power Delivery*, vol. 23, no. 4, pp. 2017–2024, Oct. 2008.
5. ZH. H. Peng, B. Song, "Research on Transformer Fault Diagnosis Expert System Based on DGA Database", *2009 Second International Conference on Information and Computing Science*, Manchester, UK, May 2009.
6. Kanika Shrivastava and Ashish Choubey, "Data Mining Approach with IEC Based Dissolved Gas Analysis for Fault Diagnosis of Power Transformer", *International Journal of Engineering Research and Technology (IJERT)*, vol. 2, Issue 3, pp. 1-11, March 2013.
7. Charles Q. Su, " A New Fuzzy Logic Method for Transformer Incipient Fault Diagnosis", *2016 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE)*, Vancouver, BC, Canada, pp. 324-327, July 2016.
8. Athira K. Anil and Archana R., "A Review of Dissolved Gas Analysis and transformer health Condition", *International Journal of Advanced Research and Innovative Ideas in Education IJARIIE-ISSN(O)-2395-4396*, vol. 2, Issue 4, pp. 189-195, 2017.
9. M. Noori, R. Effatnejad, P. Hajihosseini, "Using Dissolved Gas Analysis Results to Detect and Isolate the Internal Faults of Power Transformers by Applying a Fuzzy Logic Method", *IET Generation Transmission and Distribution*, vol. 11, no. 10, pp. 2721-2729, July 2017.
10. MATLAB R2017a Documentation.

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