J Electr Eng Technol Vol. 9, No. 2: 615-621, 2014
http://dx.doi.org/10.5370/JEET. 2014.9.2.615

ISSN(Print) 1975-0102
ISSN(Online)2093-7423

Improvement in Transformer Diagnosis by DGA using Fuzzy Logic

Nitin K. Dhote† and J. B. Helonde*

Abstract – Power transformer is one of the most important equipments in electrical power system. The detection of certain gases generated in transformer is the first indication of a malfunction that may lead to failure if not detected. Dissolved gas analysis (DGA) of transformer oil has been one of the most reliable techniques to detect the incipient faults. Many conventional DGA methods have been developed to interpret DGA results obtained from gas chromatography. Although these methods are widely used in the world, they sometimes fail to diagnose, especially when DGA results falls outside conventional method codes or when more than one fault exist in transformer. To overcome these limitations, fuzzy inference system (FIS) is proposed. 250 different cases are used to test the accuracy of various DGA methods in interpreting the transformer condition.

Keywords: DGA, Fault diagnosis, FIS, Ratio methods, Power transformer

1. Introduction

A transformer may function well externally with monitors, while some incipient deterioration may occur internally to cause fatal problems in later development. Nearly 80 % of faults result from incipient deteriorations. Therefore, faults should be identified and avoided at the earliest possible stage by some predictive maintenance technique. Dissolved Gas Analysis (DGA) is a reliable technique for detection of incipient faults in oil filled power transformer. It is similar to a blood test or a scanner examination of the human body; it can warn about an impending problem, give an early diagnosis and increase the chances of finding the appropriate cure. The working principle [1-3] is based on the dielectric breakdown of the some of the oil molecules or cellulose molecules of the insulation due to incipient faults. When there is any kind of fault, such as overheating or discharge inside the transformer, it will produce corresponding characteristic amount of gases in the transformer oil. These gases are detected at the per part million (ppm) level by Gas Chromatography [4-6]. It is a technique of separation, identification and quantification of mixtures of gases. The commonly collected and analyzed gases are Hydrogen (H_2), Methane (CH_4), Acetylene (C_2H_2), Ethylene (C_2H_4), Ethane (C_2H_6), Carbon Monoxide (CO) and Carbon Dioxide (CO_2). Through the analysis of the concentrations of dissolved gases, their gassing rates and the ratios of certain gases, the DGA methods can determine the fault type of the transformer. Even under normal transformer operational conditions, some of these gases may be formed inside. Therefore, it is necessary to build concentration norms from a sufficiently large sampling to assess the statistics.

† Corresponding Author: Dept. of Electrical Engineering, St. Vincent Pallotti College of Engineering & Technology, Nagpur, India. (nitindhote@yahoo. com)

* ITM College of Engineering, Nagpur, India. (j_b_helonde@ rediffmail.com)

Received: April 3, 2013; Accepted: July 29, 2013

2. DGA Methods

If an incipient fault is present in the transformer, concentration of gases dissolved in the oil significantly increases. A given gas volume may be generated over a long time period by a relatively insignificant fault or in a very short time period by a more severe fault. Once a suspicious gas presence is detected, it is important to be certain whether the fault that generated the gas is active by calculating the total dissolved combustible gases (TDCG) and rate of TDCG [7] which is given by Eq. (1) as follows:

$$R = \frac{(S_T - S_0).V.10^{-6}}{T} \quad (1)$$

Where, R is rate (litres/day)

S_o is the TDCG of First sample in ppm
S_T is the TDCG of Second sample in ppm
V is tank oil volume in litres
T is the time (days).

The rate of generation of TDCG greater than 2.8 liters / day indicates that the transformer has an active internal fault and requires additional inspection by DGA methods.

Incipient faults can be reliably identified by visual inspection [8] of the equipment after the fault has occurred in service:

(a) Partial Discharge (PD) - corona, possible X wax formation on paper insulation, sparking, inducing pinholes, small carbonized punctures in paper.
(b) Discharges of low energy (D1) - larger punctures in

paper, tracking or carbon particles in oil.

(c) Discharges of high energy (D2) - extensive carbonization of paper, metal fusion and possible tripping of the equipment.

(d) Thermal fault of low temperature (TL) - for TL< 300^0C, paper turns brown, for TL>300^0C, paper carbonizes.

(e) Thermal fault of high temperature (TH) - oil carbonization, metal coloration or metal fusion.

Many interpretative methods employ an array of ratios of certain key combustible gases as the fault type indicators. These five ratios are:

R 1 = C_2H_2 / C_2H_4
R 2 = CH_4 / H_2
R 3 = C_2H_4 / C_2H_6
R 4 = C_2H_6 / C_2H_2
R 5 = C_2H_2 / CH_4

Dornenburg [7] utilizes four ratios R1, R2, R4 and R5. This procedure requires significant levels of gases to be present for the diagnosis to be valid. The method gives fault after comparing these ratios to the limiting values.

IEEE / Modified Rogers method [7] utilizes three ratios R1, R2 and R3. Table 1 gives the values for three key gas ratios corresponding to suggested diagnosis.

IEC Standard 599 [9] also utilizes three ratios R1, R2 and R3. The coding rule and classification of faults by the IEC method are given in Tables 2 and 3.

Table 1 Fault diagnosis by IEEE method [7]

R1	R2	R3	Fault diagnosis
< 0.1	0.1 to 1.0	< 1.0	N
< 0.1	< 0.1	< 1.0	PD
0.1 to 3.0	0.1 to 1.0	>3.0	D2
< 0.1	0.1 to 1.0	1.0 to 3.0	Thermal overloading
< 0.1	>1.0	1.0 to 3.0	TL< 700 ^{0}C
< 0.1	>1.0	>3.0	TH > 700 ^{0}C

Table 2 Coding rule for IEC method [9]

Codes	Range of gas ratios		
	R1	R2	R3
0	<0.1	0.1 – 1	<1
1	0.1 – 3	<0.1	1 – 3
2	> 3	>1	>3

Table 3 Classification of faults by IEC method [9]

Fault Type	Characteristic Fault	R1	R2	R3
1	Normal ageing (N)	0	0	0
2	PD of low energy density	0	1	0
3	PD of high energy density	1	1	0
4	D1	1-2	0	1-2
5	D2	1	0	2
6	TL <150^0C	0	0	1
7	TL between 150^0C -300 ^{0}C	0	2	0
8	TL between 300^0C -700 ^{0}C	0	2	1
9	TH >700 ^{0}C	0	2	2

In new IEC 60599 publication [10], major gas ratios have been retained and three additional gas ratios have been introduced for specific diagnosis. These three ratios are

R 6 = C_2H_2 / H_2
R 7 = O_2 / N_2
R 8 = CO_2 / CO

If R6 > 3, it gives the possible contamination from the on load tap changer compartment. If R7 < 0.3, it gives abnormal oil heating or oxidation. If R8 < 3, it gives the possible paper involvement in the fault.

The Duval Triangle [11] method utilizes three % ratios of certain gases for DGA interpretation of transformers filled with mineral oil. The triangular coordinates corresponding to DGA results in ppm can be calculated by Eqs. (2-4) as follows:

$$\%C_2H_2 = \frac{100.x}{(x+y+z)} \quad (2)$$

$$\%C_2H_4 = \frac{100.y}{(x+y+z)} \quad (3)$$

$$\%CH_4 = \frac{100.z}{(x+y+z)} \quad (4)$$

Where x, y and z are concentration of C_2H_2, C_2H_4 and CH_4 in ppm resp. In addition to these three % ratios, Xiaohui Li *et al*., [12] utilizes fourth % ratio which is given by Eq. (5) as follows:

$$\%H_2 = \frac{100.H_2}{(H_2 + C_2H_6 + CO + CO_2)} \quad (5)$$

All these techniques are computationally straightforward. However, these methods in some cases provide erroneous diagnoses as well as no conclusion for the fault type.

To overcome these limitations, Fuzzy Inference System (FIS) is proposed.

3. Flow Chart of Proposed System

Flow chart of proposed system diagnosis is shown in Fig. 1. The input data include concentration of dissolved gases C_2H_2, C_2H_4, C_2H_6, CH_4, H_2, CO and CO_2 of the sample. Information such as tank oil volume, date of sampling and date of installation of transformer is asked for further inference.

In the first step, the system calculates TDCG and compares with the standard permissible limits [7]. For normal level of TDCG (< 720ppm), permissible limits for individual gases are checked. Normal level of TDCG and

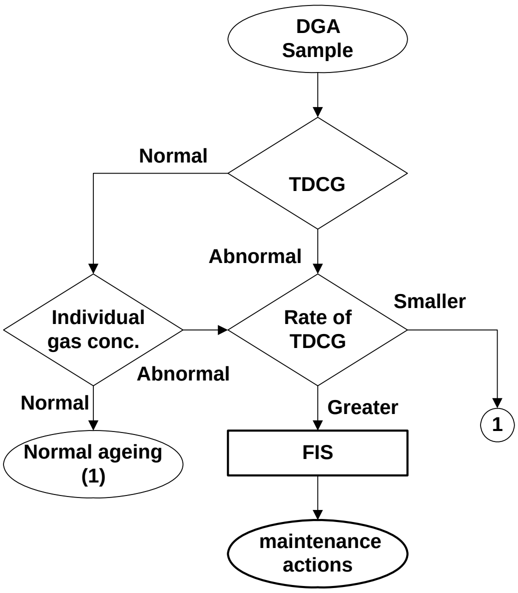

Fig. 1. Flow chart of proposed system diagnosis

individual gases indicates the satisfactory operation of a transformer. Once an abnormal level of TDCG or individual gas has been detected, the next step is to determine the rate of generation of TDCG (1) by analysis of the successive sample. For the normal rate of TDCG (less than 2.8 liters/day), further diagnosis is bypassed. For an abnormal rate of TDCG, the proposed FIS is adopted to diagnose the probable faults. In the last step, severity degrees are assigned to the diagnosed faults. On the basis of severity of faults, appropriate maintenance actions are suggested.

4. Fuzzy Inference System

Intelligent algorithms, e.g., Expert System [13], FIS [14], Artificial Neural Networks [15], Probabilistic Neural Networks [16], Evolving Neural Networks [17] and Artificial Neural FIS [18-19] have been used to interpret DGA results. These algorithms are not entirely satisfactory. These methods are mostly suitable for transformers with single fault. In case of multiple faults, only dominant fault is indicated by these methods. These methods based on specific set of codes defined for certain gas ratios. Further, no quantitative indication for severity of fault and maintenance suggestions is given by these methods.

The proposed Fuzzy diagnostic method is prepared using the MATLAB Fuzzy Logic Toolbox [20]. Sugeno type FIS [21-22] is used as a fuzzy inference method.

A typical rule in the zero order Sugeno fuzzy model has the form;

If input1 = x and input2= y, then output z = constant.

The output level z of each rule is weighted by firing strength w of the rule. For an AND rule, firing strength is given as

w = AND method [F1(x), F2(y)],

Where, F1(x) and F2(y) are the membership functions for input1 and input 2. The final output of the system is weighted average of all the rule output which is given by Eq. (6) as follows:

$$Z = \frac{\sum_{i=1}^{n} (w_i . z_i)}{\sum_{i=1}^{n} w_i} \tag{6}$$

where, Z is final output and n is the number of rules.

The FIS consists of 3 ratios R1, R2 and R3 as inputs. One of the major drawbacks of IEC method is that when gas ratio changes across coding boundary, the code changes sharply between 0, 1 and 2. In fact the gas ratio boundary should be fuzzy. Depending on the relative values of ratios in IEEE and IEC method, three fuzzy codes Low, Medium (Med) and High are selected. Due to uncertainty in measurements of gas concentrations by gas analyzers, the gas ratios would have a relative uncertainty of plus or minus 10% [23]. Hence, 10% of the boundary value of each ratio (Table 1) overlaps between two consecutive codes.

Membership function for code Low of ratio R1 is given by the linear declining function

$$\mu_{Low}(R1) = \begin{Bmatrix} 1 & \rightarrow R1 \le 0.09 \\ \frac{(0.11 - R1)}{(0.11 - 0.09)} & 0.09 \le R1 \le 0.11 \\ 0 & R1 \ge 0.11 \end{Bmatrix} \tag{7}$$

Membership function for code Med of ratio R1 is given by trapezoidal function

$$\mu_{Med}(R1) = \begin{Bmatrix} 0 & \rightarrow R1 \le 0.09 \\ \frac{(R1 - 0.09)}{(0.11 - 0.09)} & \rightarrow 0.09 \le R1 \le 0.11 \\ 1 & 0.11 \le R1 \le 2.7 \\ \frac{(3.3 - R1)}{(3.3 - 2.7)} & 2.7 \le R1 \le 3.3 \\ 0 & R1 \ge 3.3 \end{Bmatrix} \tag{8}$$

Membership function for code High of ratio R1 is given by linear increasing function

$$\mu_{High}(R1) = \begin{Bmatrix} 0 & \rightarrow R1 \le 2.7 \\ \frac{(R1 - 2.7)}{(3.3 - 2.7)} & \rightarrow 2.7 \le R1 \le 3.3 \\ 1 & R1 \ge 3.3 \end{Bmatrix} \tag{9}$$

The Membership function for ratio R1 is shown in Fig. 2.

The codes of the ratios R2 and R3 are also fuzzified as

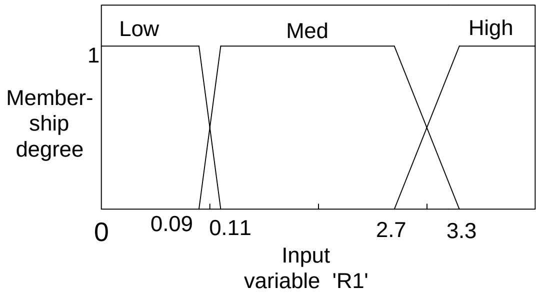

Fig. 2. Membership function for ratio R1

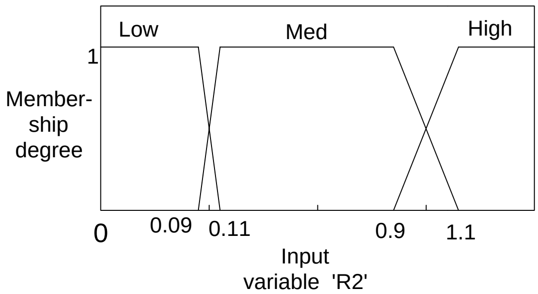

Fig. 3. Membership function for ratio R2

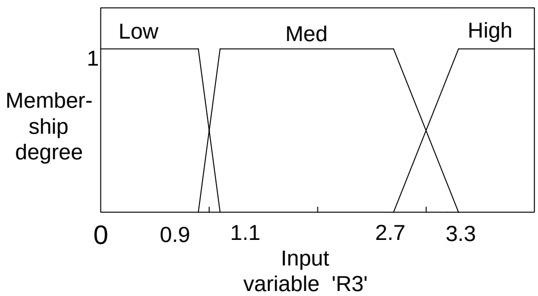

Fig. 4. Membership function for ratio R3

Low, Med and High variable depending on the range of ratios for these codes. Membership function for ratios R2 and R3 are shown in Figs. 3 and Fig. 4 resp.

The FIS comprises of single output which has 5 fault types as membership functions. Weight in the range of 0 to 1 is assigned to each fault type on the basis of severity of the fault. The five types of faults used in FIS are TL < 0.2 >, PD < 0.4 >, D1 < 0.6 >, TH < 0.8 > and D2 < 1.0 >.

The major drawback of the IEEE and IEC method is that a significant number of DGA results in- service fall outside the existing rules and cannot be diagnosed. Only 6 inference rules are suggested by the IEEE (Table 1) and 11 inference rules are suggested by the IEC (Table 3) out of the 27 (3x3x3) possible rules. To overcome this limitation, entire 27 rules are obtained as a result of extensive consultations with utility experts, existing literature, and approximately 1500 DGA case histories. Each rule consists of two components which are the antecedent (IF part) and the consequent (THEN part). The rules having a similar output are clubbed together and kept in order of increasing value of the weight of fault.

The fuzzy rules are given below:

Rule 1: IF R1 =Low AND R2=Low AND R3=Med, THEN Fault=TL.
Rule 2: IF R1 =Low AND R2=Med AND R3=Low, THEN Fault=TL.
Rule 3: IF R1 =Low AND R2=Med AND R3=Med, THEN Fault=TL.

FIS derives output from judging all the fuzzy rules by finding the weighted average of all 27 fuzzy rules output.

5. Case Studies, Results and Discussions

FIS is developed based on the proposed interpretative rules and diagnostic procedure of an overall system. To demonstrate the feasibility of the system in diagnostic, 250 DGA gas records supplied by the major power companies in India have been tested.

Accuracy is calculated in two different ways,

a) When considering only number of predictions, percentage accuracy is given by Eq. (10) as follows:

$$A_P = \frac{100.T_R}{T_P} \tag{10}$$

Where T_R is the number of correct predictions and T_P is the total number of the predictions,

b) When considering the total number of cases, percentage accuracy is given in Eq. (11) as follows :

$$A_C = \frac{100.T_R}{T_C} \tag{11}$$

Where Tc is the total number of cases.

Accuracy values of different methods for total 250 cases are compared and summarized in Table 4. Results from two case studies are presented here.

5. 1 Case study - I

A 35 MVA, 200KV /33KV transformer is in service for 11yrs. Tank oil volume is 32000 litres. Transformer had tracing on bushings and arcing in oil. DGA data obtained in

Table 4 Comparison of accuracy of different methods

Method	T_R	T_P	A_P	A_C
Doernenburg	85	123	69. 11	34
IEEE	103	157	65. 61	41. 2
IEC	174	195	89. 23	69. 6
Duval Triangle	218	250	87. 20	87. 2
Xiaohui Li et al.	223	250	89. 2	89. 2
Proposed Method	236	250	94. 40	94. 4

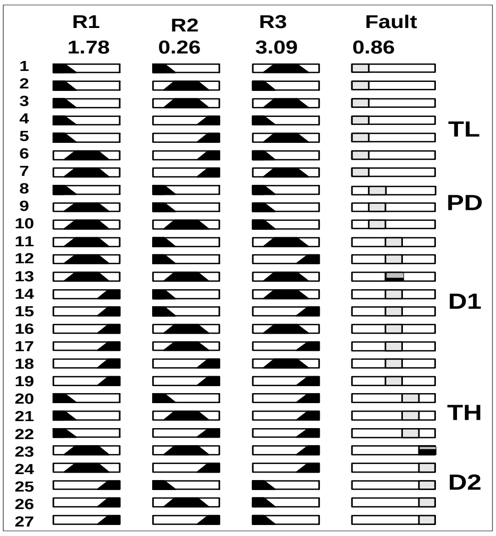

Fig. 5. Rule viewer for Case-I

ppm after the fault on 22/06/2011 is as follows:

C_2H_2-32 ; C_2H_4-15 ; CH_4-31; H_2-93; C_2H_6-15; CO-647; CO_2-3745.

Step 1: TDCG in ppm =833. TDCG is above normal (> 720 ppm).

Step 2: The transformer is sampled again on 25/06/2011 to determine rate of TDCG. Concentrations of dissolved gases in ppm are as follows:

C_2H_2-418; C_2H_4-235; CH_4-78; H_2-306; C_2H_6-76; CO-1317; CO_2-7458.

TDCG in ppm = 2430; Rate of TDCG =17.02 lit/ day, which is greater than normal level (2.8lit/ day).

Step 3: FIS is applied for fault diagnosis. The output of FIS is given by rule viewer which is shown in Fig. 5. Rule viewer shows R1=1.78(Med), R2= 0.26 (Med) and R3=3.09 which lies on the boundary of the fuzzy ratios Med and High. Dark dots of the fault column show that rules 13 and 23 are satisfied which indicate possible faults D1 and D2 resp. This result matches with the actual fault of the transformer. Weighted average of both the rules is given as 0.86. Weight of both the faults can be calculated as follows:

Weight of D1 = (1 - 0.86) / (1 - 0.6) = 0.35
Weight of D2 =1 - 0.35 = 0.65

The weights point towards the strong possibility of fault D2 and the relatively less possibility of fault D1.

Step 4: DGA interpretation by other methods is given as follows:

Dornerburg : Unidentifiable
IEEE : D2 IEC : D2
Duval triangle : D2 Xiaohui Li et al. : D2

The key feature of the proposed method is that it can diagnose multiple faults unlike conventional DGA methods.

Step 5: Severity of faults is very high. Maintenance actions suggested are as follows:

1. Retest oil daily.
2. Consider removal from service.

5. 2 Case study- II

A 25 MVA, 220KV /132KV transformer is in service for 15 yrs. Tank oil volume is 20000 liters. This transformer had an X - wax deposition. Traces of discharges were found on paper of high voltage cable. DGA data obtained in ppm after the fault on 18/03/2009 is as follows:

C_2H_2-15; C_2H_4-19; CH_4-172; H_2-1903; C_2H_6-14; CO-180; CO_2-635.

Step 1: TDCG in ppm =2303. TDCG is above normal (> 720 ppm).

Step 2: The transformer is sampled again on 21/03/2009 to determine rate of TDCG. Concentrations of dissolved gases in ppm are as follows:

C_2H_2-26 C_2H_4-23; CH_4-221; H_2-2257; C_2H_6-22; CO-220; CO_2- 821.

TDCG in ppm = 2769; Rate of TDCG = 3.10 lit / day, which is greater than normal level (2.8 lit / day).

Step 3: FIS is applied for fault diagnosis. The output of FIS is given by rule viewer which is shown in Fig. 4. Rule viewer shows R1 = 1.13 (Med), R2 = 0.0979 which lies on the boundary of the fuzzy ratios Low and Med and R3=1. 05 which lies on the boundary of the fuzzy ratios Low and Med. Dark dots in the fault column show that the rules 9, 10, 11 and 13 are satisfied which indicate possible faults PD and D1. This result matches with the actual fault of the transformer. Weighted average of both the rules is given as 0.529. Weight of both the faults can be calculated as follows:

Weight of PD = (0.6 - 0.529)/(0.6- 0.4) = 0.355
Weight of D1 = 1-0.355 = 0.645

The weights point towards the strong possibility of fault D1 and the relatively less possibility of fault PD.

Step 4: DGA interpretation by other methods is given as follows:

Dornerburg: Normal
IEEE: Unidentifiable IEC : Unidentifiable
Duval triangle: Mix of thermal and electrical fault
Xiaohui Li et al.: TL

Fault is unidentifiable by IEEE and IEC method. Dornerburg method gives normal condition of the transformer. The results given by Duval triangle and Xiaohui Li et al. Method do not matches with

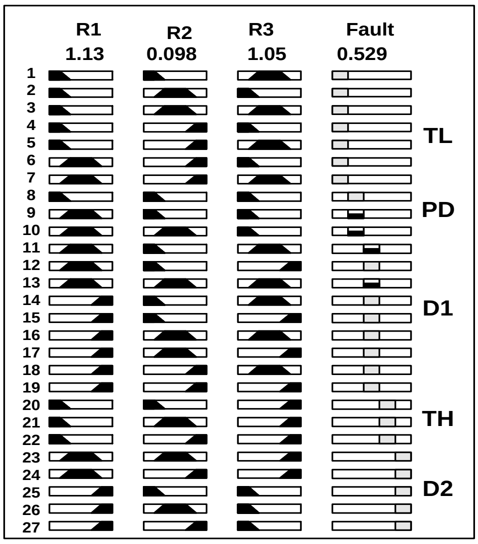

Fig. 6. Rule viewer for Case-II

the actual fault of the transformer.

Step 5: Severity of faults is Medium. Maintenance actions suggested are as follows:

1. Observe caution
2. Retest oil monthly.
3. Determine load dependence.

6. Conclusion

The proposed FIS is developed using 'MATLAB'. It can diagnose the incipient faults of the suspected transformers and suggest proper maintenance actions. The fuzzy three ratio method is proposed to diagnose multiple faults and faults that cannot be diagnosed by the conventional DGA methods. Accuracy values of fault diagnosis of different DGA methods are compared. An accuracy of the proposed method is better than other diagnostic methods.

References

[1] Hohlein I, Unusual Cases of Gasing in Transformers in Service *IEEE Electrical Insulation Magazine, Vol 22, No. 1*, 2006, pp. 22-25.

[2] Mayoux C, On the Degradation of Insulating Materials Withstanding Electrical Stress, *IEEE Transactions on Dielectrics and Electrical Insulation, Vol-7*, Oct 2000, pp 1-20.

[3] I. Fofana, J. Sabau, D. Bussieres and E. B. Robertson, The Mechanism of Gassing in Power Transformers, *IEEE conference on Dielectric Liquids, ICDL 2008*, June 2008, pp. 1-4.

[4] Arakelian, V. G., Effective Diagnostic for Oil Filled Equipments, *IEEE Electrical Insulation Magazine, Vol. 18, Issue 6*, 2002, pp. 26-38.

[5] Agah M, Lambertus G. R., Sacks R, Wise K, High Speed MEMS -Based Gas Chromatography, *Journal Of Micro Electromechanical Systems, Volume-15, Issue 5*, 2006, pp. 1371-1378.

[6] Duval M, New Techniques for Dissolved gas-in-Oil Analysis, *Electrical Insulation Magazine, IEEE, Volume 19, Issue 2*, 2003, pp. 6-15.

[7] IEEE Guide for Interpretation of Gases Generated in Oil Immersed Transformer *ANSI/IEEE, Standard C57. 104. TM 2008*, Feb 2009.

[8] M. Duval, A. dePablo, Interpretation of gas in Oil Analysis Using New IEC Publication 60599 and IEC TC10 Databases, *IEEE Electrical Insulation Magazine, Vol. 17, No. 2*, April 2001, pp. 31-41.

[9] M. Duval, Dissolved Gas Analysis: It can Save Your Transformer, *IEEE Electrical Insulation Magazine, Vol. 5, No. 6*, Dec 1989, pp. 22-27.

[10] Mineral Oil –Impregnated Electrical Equipment in Service Guide to the interpretation of Dissolved and Free Gases Analysis, *IEC Publication 60599*, 2007.

[11] M Duval, J. Dukaram, Improving the Reliability of the Transformer, Gas-in-Oil Diagnosis, *IEEE Electrical Insulation Magazine, Vol. 21, No. 4*, July / Aug 2005, pp. 21-27.

[12] Xiaohui Li, Hauren Wu and Danning Wu, DGA Interpretation Scheme Derived from Case Study, *IEEE Transactions on Power Delivery, Vol 26, No. 2*, April 2011, pp. 1292-1293.

[13] C. E. Lin, J. M. Ling, and C. L. Huang, An expert system for transformer fault diagnosis and maintenance using dissolved gas analysis, *IEEE Transactions on Power Delivery, vol. 8, no. 1*, 1993, pp. 231-238.

[14] Hong-Tzer Yang, Chiung- Chou Liao, Adaptive Fuzzy Diagnosis System for Dissolved Gas Analysis of Power Transformers, *IEEE Transactions on Power Delivery, Vol. 14, No. 4*, Oct 1999, pp. 1342-1350.

[15] Guardada J. L., J. L. Nareda, P. Moreno, C. R. Fuerte, A Comparative Study of Neural Network Efficiency in Power Transformers Diagnosis using Dissolved Gas Analysis, *IEEE Transactions on Power Delivery, Vol. 16, no. 4*, Oct 2001 pp. 643-647.

[16] Lin W. M., C. H. Lin, M. X, Tasy, Transformer – Fault Diagnosisby Integrating Field Data and Standard Codes with Training Enhancible Adaptive Pro-babilistic Network, *IEEGeneration Transmission Distribution, Vol. 152, No. 3*, 2005, pp. 335-341.

[17] Huang Y. C., Evolving Neural Nets for Fault Diagnosis of Power Transformer, *IEEE Transactions on Power Delivery, Vol. 18, No. 3*, April 1997, pp. 843-848.

[18] R. Naresh, V. Sharma, M. Vashisth, An Integrated Neural Fuzzy App. roach for Fault Diagnosis of Transformers, *IEEE Transactions on Power Delivery, Vol. 23, No. 4*, Oct 2008, pp. 2017-2024.

[19] Morais D. R., Rolim J. G., A Hybrid Tool for Detection of Incipient Faults in Transformers based on the Dissolved Gas Analysis of Insulating Oil, *IEEE Transactions on Power Delivery, Vol. 21, No. 2*,

April 2006, pp. 673-680.
[20] *Mathworks Ltd., Fuzzy Logic Toolbox, User's Guide*.
[21] D Driankov, H Hellendoorn, M Reinfrank, *An Introduction to Fuzzy Control* (Narosa Publishing House, Delhi. India. 2001)
[22] George J. Klir, Tina A. Folger, *Fuzzy Sets, Uncertainity and Information*(*PHI, elhi, India, 2008*).
[23] IEEE Guide for Dissolved Gas Analysis in Transformer Load Tap Changers, *IEEE Standard C57. 139-2010*.

Nitin K. Dhote He received Master degree in Electrical Engineering from Nagpur University in the year 2006. His research interests include Electrical power system, Electrical machines, Application of AI techniques in power sytem.

J. B. Helonde He received Ph. D degree in Electrical Engineering from Nagpur University in the year 2002. His research interests include Electrical power system, optimization techniques in power system, and electric drives.