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Fuzzy Decision on Transformer Fault Diagnosis using Dissolved Gas Analysis and IEC Ratio Codes

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Abstract— This paper emphasizes on the use of fuzzy approach in dealing with the incipient fault conditions of power transformer. DGA (Dissolved Gas in Oil Analysis) cannot provide better fault diagnosis results when multiple faults are involved. The boundary values specified by the ratio methods are of limited concern .Considering the limitations of convergence of the conventional neural networks in the local minima, fuzzy logic may take care of the uncertainties in fault conditions. Fuzzy decision is used to deal with various incipient fault conditions including the normal condition with major faults as per the IEC Ratio codes. The comparative of the fuzzy system, conventional IEC method of fault diagnosis and Roger's ratio diagnosis of some oil samples of transformer and data from research paper are presented. Rule based fuzzy decision on various faults is made using IEC Ratio codes.
Index Terms— Fuzzy Logic, Dissolved Gas Analysis, Incipient fault, Power Transformer.

1 INTRODUCTION

Power transformer is an important and costly equipment of the transmission and distribution system and its well being is crucial from reliability point of view. Thermal and, electrical stresses are the main causes of incipient faults leading towards deterioration of insulation or failure of the equipment [1]. Fault related gases are H2, CH4, C2H6, C2H4, C2H2, CO and CO2. There is a correlation between the generation of gases and the temperature given by Hallstead's thermodynamic model. Through the analysis of the concentration of dissolved gases, their gassing rates, and the ratios of certain gases, the DGA method can determine the type of fault. An ANSI/IEEE standard and IEC publication 599 describes three DGA approaches: 1) key gas method; 2) Roger's ratio method; and 3) the Dorneneburgs ratio method [2] .All three methods are computationally straightforward. However, these methods, in some cases, provide erroneous diagnoses as well as no conclusion for the fault type. The key gas method based on the determination of the key gas provides the basis for qualitative determination of fault types from the gases those are typical or predominant at various temperatures. Now, if the fault is very severe, then all of the gas concentrations will be high, yet insufficient to register a fault when using the values specified in IEEE standard

Also, the gas ratios obtained for the particular transformer sample, may not fall within ANSI/IEEE-specified ranges, . leading to the failure of the ratio methods for transformer diagnosis. Several artificial intelligence methods like neural networks, fuzzy logic, and genetic algorithms etc.are available to overcome the drawbacks of the conventional methods. Improvement in IEC table for transformer failure diagnosis with knowledge extraction from neural networks and a new rule table is proposed[4].To deal with the uncertaintities in occurrence of the faults and the borderline and multiple faults, fuzzy logic may be an excellent tool. IEC codes define the gas ratios with the crisp boundaries of 0, 1 and 2. However, in practice these boundaries are non crisp or fuzzy.

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2 DISSOLVED GAS IN OIL ANALYSIS

In the normal operation of transformer, the released gases are Hydrogen (H2), methane (CH4), ethylene (C2H4), acetylene (C2H2), ethane (C2H6) and so on. When there is an abnormal situation such as a fault, some specific gases are produced more than in the normal operation and the amount of them in the transformer oil increases. The increase in the amount of gases results in saturation of the transformer oil and no more gas can be dissolved in oil. Therefore, when the oil is saturated, the gas is released from the oil. The amount of dissolved gas is related to the temperature of the oil. These gases are produced by polarization, corona and arcing. Severity of the fault depends upon the released energy during the fault. The largest and lowest amount of the released energy is associated with the arcing and corona respectively.

2.1 Polarization

In oil, the released gases at low temperature are CH4 and, C2H6 and at high temperature are C2H2, CH4, C2H4 and H2. In cellulose, the generated gases at low and high temperatures are CO and CO2 respectively.

2.2 Corona

In this discharge, the produced gas in oil is H2 and the released gases in cellulose are H2, CO and CO2.

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2.3Arcing

In this case, the released gases are C2, H2, C2H6, CH4, C2H, and H2. The produced gas also can be classified into three groups: Hydrogen and hydrocarbons: H2, CH4, C2H4 and C2H2, Carbon oxides: CO, CO2, Non-faulty gases: O2 and N2. [5]. Apart from the DGA (Dissolved Gas in Oil Analysis), other conventional methods such as Rogers Ratio, Dorneneburgs Ratio and IEC Ratio methods can also be used for fault diagnosis of transformer, however the ratio methods have some drawbacks of ratio ranges specified in dealing with the faults.IEC Ratio codes are preferred as the basis for further diagnosis using the fuzzy approach.

A combination of neural network and fuzzy logic is proposed for enhancing diagnosis accuracy using feature selection and subtractive clustering [6].

3 IEC Ratio Codes and Diagnosis of Faults

Gases are evolved due to degradation of oil and solid insulation like cellulose and paper used for windings in a transformer. Due to discharge and overheating, the oil around the fault will decompose into specific gases and gets dissolved in the oil. The composition of the dissolved gases and the ratio of gases are as specified by IEC 599 extended codes. Three gas ratios such as, C2H2/C2H4, CH4/H2, C2H4/C2H6 are used with the assigned codes 0, 1 or 2. The ratio CO2/CO is not considered due to less possibility of occurrence of cellulose degradation. From the ratio limits specified in the table of IEC fault description, the inference can be drawn for the existence of a fault. Fuzzy neural diagnosis system designed in mat lab environment with ANFIS (Adaptive Neuro fuzzy inference system) is proposed by CS Chang et.al using 10 fuzzy rules and ANFIS [7].

TABLE 1
IEC RATIO CODES

Ratio Code	Range	Code
i	<0.1	0
	0.1-1.0	1
	1.0-3.0	1
	>3.0	2
j	<0.1	1
	0.1-1.0	0
	1.0-3.0	2
	>3.0	2
k	<0.1	0
	0.1-1.0	0
	1.0-3.0	1
	>3.0	2

TABLE 2
FAULT DESCRIPTION AS PER IEC

Fault Type	Fault Description	$\frac{C_2H_2}{C_2H_4}$	$\frac{CH_4}{H_2}$	$\frac{C_2H_4}{C_2H_6}$
HEDA_4	High Energy Discharge and Arcing	2	0 or 2	X
HEDA_3		1	0 or 2	X
HEDA_2	Low Energy Discharge	2	1	X
HEDA_1		1	1	X
LED	Partial Discharge	0	1	X
Normal	Normal Aging Condition	0	0	0
OH_T1	Low Temperature Overheating, T<150	0	0	1 or 2
OH_T2	Thermal Fault (Overheating) , 150<T<300	0	2	0
OH_T3	Thermal Fault (Overheating) , 300<T<700	0	2	1
OH_T4	High Temperature Overheating, T>700	0	2	2

TABLE 3
ROGER'S RATIO CODES

Ratio code	Range	Code
i	<=0.1	5
	>0.1,<1.0	0
	>=1.0,<3.0	1
	>=3.0	2
j	<1.0	0
	>=1.0	1
k	<1.0	0
	>=1.0,<3.0	1
	>=3.0	2
l	<0.5	0
	>=0.5,<3.0	1
	>=3.0	2

TABLE 4
FAULT CLASSIFICATION BASED ON ROGER'S RATIO CODES

I	J	K	L	Diagnosis
0	0	0	0	Normal deterioration
5	0	0	0	Partial discharge
1-2	0	0	0	Slight overheating<1500C
1-2	1	0	0	Overheating 1500-2000C
0	1	0	0	Overheating 2000-3000 C
0	0	1	0	General conductor overheating
1	0	1	0	Winding circulating currents
1	0	2	0	Core and tank circulating currents, overheated joints
0	0	0	1	Flashover without power follow through
0	0	1-2	1-2	Arc with power follow through
0	0	2	2	Continuous sparking to floating potential
5	0	0	1-2	Partial discharge with tracking(note CO)

4 FAULT DIAGNOSIS USING ROGERS RATIO

Many conventional and ratio methods are available for fault diagnosis of transformer. Rogers ratio method specifies four gas ratios with their limits. The gas ratios and Roger's ratio codes are shown in Tables 3 and 4. This method uses four gas ratios, C_2H_2/C_2H_4, CH_4/H_2, C_2H_4/C_2H_6, and C_2H_6/CH_4 [2]. The comparative study on transformer fault diagnosis using key gas method, Roger's ratio and Dorneneburgs ratio is presented by authors [3] and the Roger's ratio diagnosis is shown in table no.5.

5 FUZZY DIAGNOSIS RULES FOR IEC RATIO CODES

Fuzzy logic involves three successive processes like Fuzzification, Inference and defuzification. Fuzzification converts crisp gas ratios into fuzzy input membership. Fuzzy inference system is responsible for drawing conclusions from the knowledge based fuzzy rules of if-then linguistic statements. Defuzzification converts fuzzy output back to crisp output [8].The fuzzy system to be built is shown in fig.1. In Fuzzy diagnosis crisp values like code0, code1 and code2 of gas ratio C_2H_2/C_2H_4 is represented by Gaussian Bell fuzzy membership function shown in fig.2.The same follows for other two gas ratios CH_4/H_2 and C_2H_4/C_2H_6.The fault description as per IEC is shown in table 2. The set of fuzzy inputs with their membership function is a prime part of analysis. A fuzzy rule set is used to form judgment on fuzzy inputs derived from 3 gas ratios as per IEC.The fuzzy rules for the 10 conditions as per IEC table are shown below. The 10 fuzzy rules including the normal condition maps the fault types and is shown in rule viewer.

Membership function plots for different codes and FIS output for HEDA_4 is shown in fig.4. For other 9 conditions the results are obtained. The membership Values assigned to various faults ranges from 0.1 to 1, which determines the type of fault.

If [(C_2H_2/C_2H_4 is code2)] and [(CH_4/H_2 is not code1)] then [fault is HEDA_4]
If [(C_2H_2/C_2H_4 is code1)] and [(CH_4/H_2 is not code1)] then [fault is HEDA_3]
If [(C_2H_2/C_2H_4 is code2)] and [(CH_4/H_2 is code1)] then [fault is HEDA_2]
If [(C_2H_2/C_2H_4 is code1)] and [(CH_4/H_2 is code1)] then [fault is HEDA_1]
If [(C_2H_2/C_2H_4 is code0)] and [(CH_4/H_2 is code1)] then [fault is LED]
If [(C_2H_2/C_2H_4 is code0)] and [(CH_4/H_2 is code0)] and [(C_2H_4/C_2H_6 is code 0)] then [fault is Normal ageing]
If [(C_2H_2/C_2H_4 is code0)] and [(CH_4/H_2 is code0)] and [(C_2H_4/C_2H_6 is not code 0)] then [fault is OH_T1]

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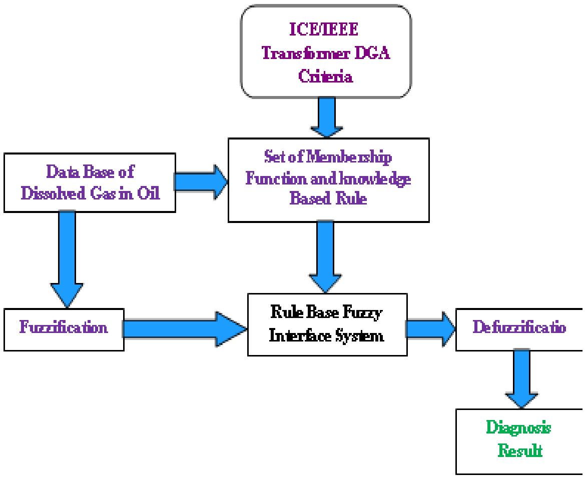

Fig. 1. Fuzzy diagnosis system

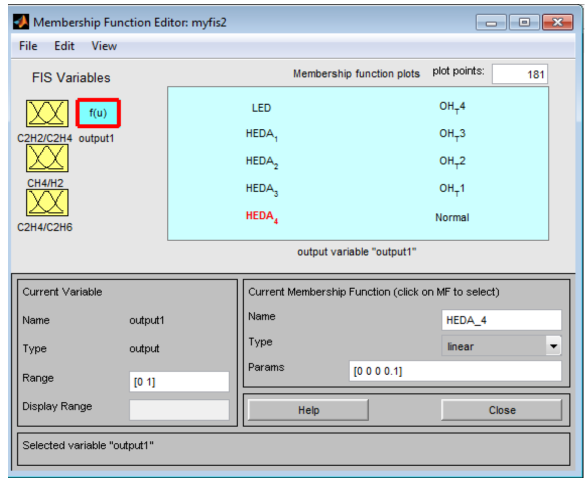

Fig. 2.Membership Functions for Gas Ratio

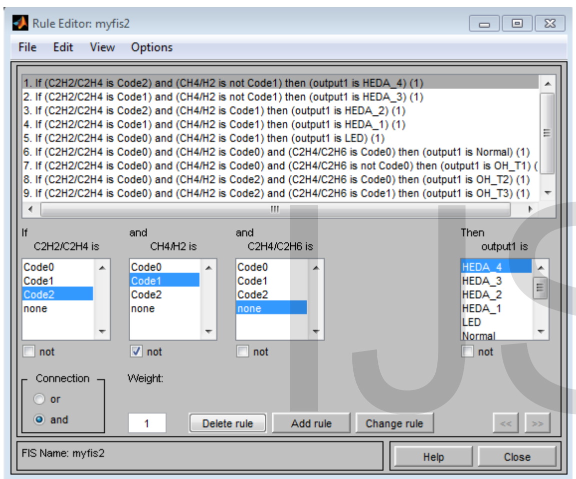

Fig. 3 . Fuzzy Diagnosis Rules

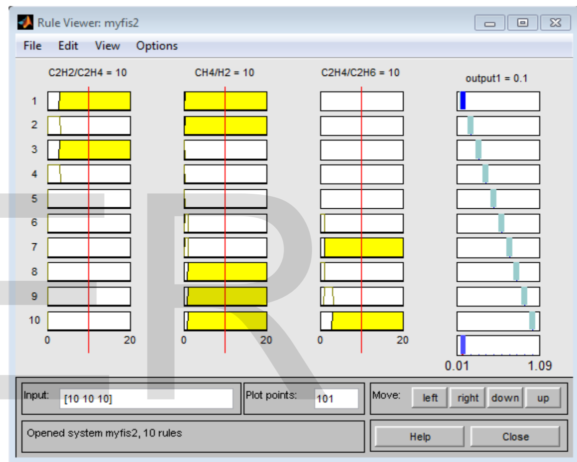

Fig. 4. FIS Output Window

If [(C2H2/C2H4 is code0)] and [(CH4/H2 is code2)] and [(C2H4/C2H6 is code 0)] then [fault is OH_T2]
If [(C2H2/C2H4 is code0)] and [(CH4/H2 is code2)] and [(C2H4/C2H6 is code 1)] then [fault is OH_T3]
If [(C2H2/C2H4 is code0)] and [(CH4/H2 is code2)] and [(C2H4/C2H6 is code 2)] then [fault is OH_T4].

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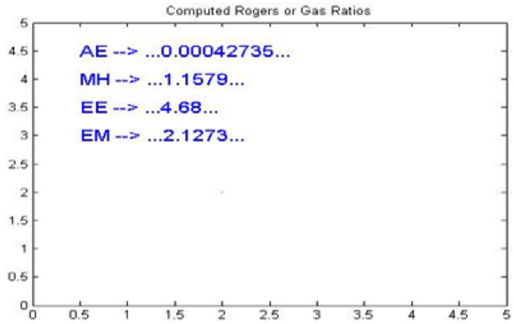


Fig. 5.

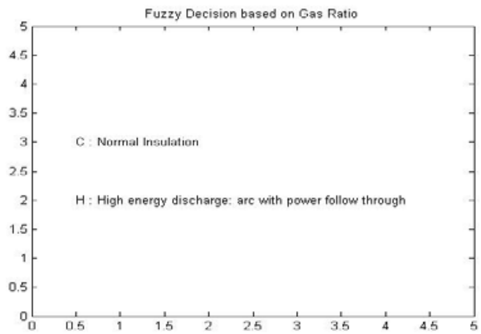
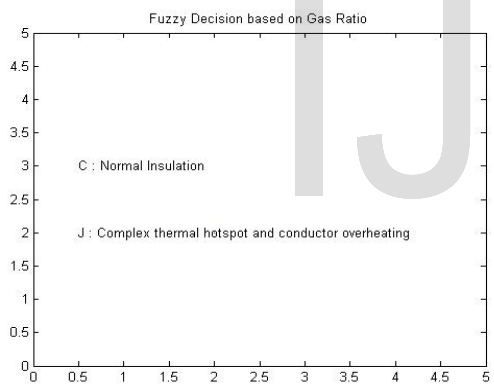


Fig. 6



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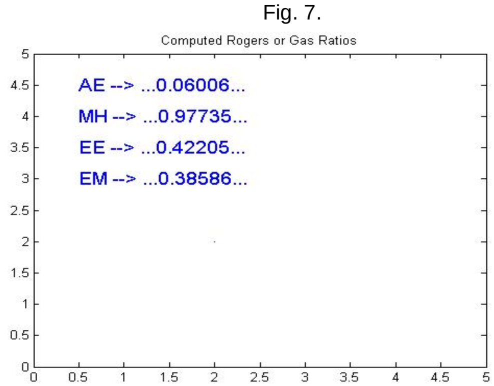

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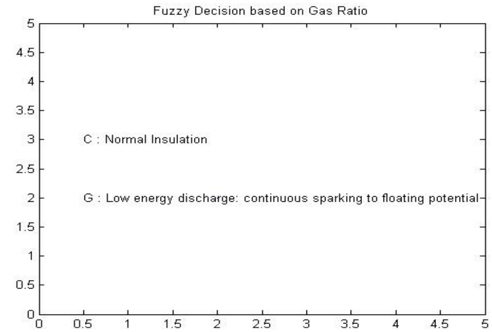

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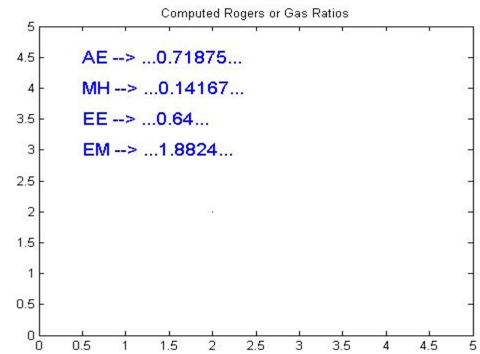

Fig. 10.

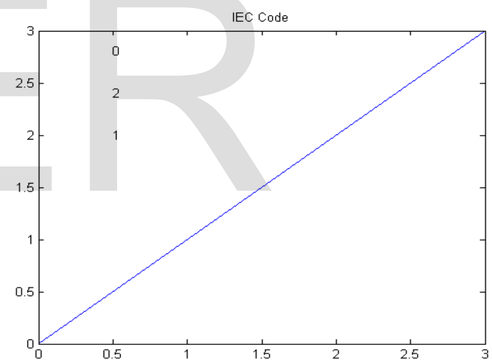

Fig. 11.

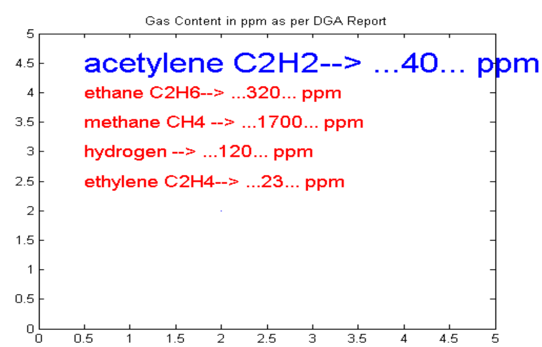

Fig. 12.

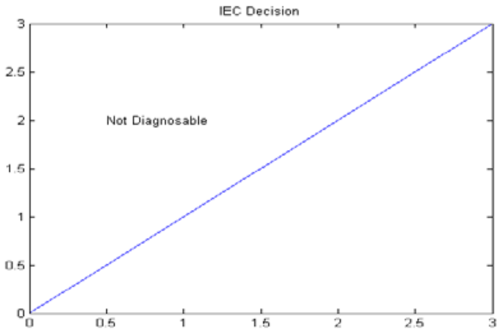

Fig. 13.

Results & discussion

Simulation codes were developed in mat lab for all the methods. Using the IEC Ratio codes as the basis of fault diagnosis, four sample cases of transformer. DGA data were analyzed using the fuzzy decision system making use of some paper cases presented by authors[4]. The results of different cases analyzed pertaining to the oil samples are shown in table no.5. The gas ratios of sample cases used in IEC ratio, Roger's ratio and fuzzy decision system are presented as shown in fig. 5 – 13. The comparative regarding the type of fault by each method is also presented. It was verified that, the present approach provides the accurate results as compared to the IEC and DGA, Roger's ratio diagnosis and the paper cases. The ratio as per IEC fails to diagnose the faults falling within the boundary values in most of the cases. The Roger's ratio method also fails in some cases. In case of paper case 2, correct fuzzy decision was made regarding the presence of High energy discharge and arc with power follow through. IEC method totally failed on case30, which has a critical insulation failure. Hence in most of the sample cases, the proposed fuzzy decision approach provides better diagnosis, which correlates with the actual fault.

Conclusion

IEC fault diagnosis codes are used for DGA (Dissolved Gas in Oil Analysis).It is used to analyze the oil samples of transformers. The fuzzy decision making match with the actual faults. Comparison of 3 methods namely IEC DGA, Roger's ratio and fuzzy decision is presented. It is proved that, fuzzy decision has better prediction abilities as mentioned in table5.

TABLE 5
DIAGNOSIS RESULTS

		Fuzzy Results- Sample paper cases		
	Paper Case1	Paper Case2	Paper Case3	Case 30
carbon_monoxide	0			264
methane	999	110	17	632
carbon_dioxide	0			2419
ethylene	1599	50	23	1591
ethane	234	160	32	140
acetylene	31	0.1	4	0
hydrogen	796	95	120	4325
IEC Code	220	020	011	210
Result IEC	9 thermal fault temp > 700	7 thermal tmp 150 to 300	3 partial discharge with high energy density	Non Diagnosable
Result Fuzzy	H : High energy discharge: arc with power follow through	H : High energy discharge: arc with power follow through	G : Low energy discharge: continuous sparking to floating potential	**A : No Fault: normal deterioration**
	C : Normal Insulation	C : Normal Insulation	C : Normal Insulation	**A : Critical Insulation Failure**
Actual as per paper	thermal fault temp > 700	thermal fault temp 200 to 300	thermal fault temp < 150	

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