POWER TRANSFORMER FAULTS IDENTIFICATION USING FUZZY BASED DISSOLVED GAS ANALYSIS METHOD

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Abstract: *Power system reliability depends on the consistency of electrical equipment. Power transformer is one of the most important equipment in electrical power system due to its cost and failure consequence. Dissolved Gas Analysis (DGA) is a sensitive and reliable technique for the detection of incipient fault condition of transformer by monitoring and quantifying the presence of certain key gases like hydrogen, methane, ethane, ethylene and acetylene in its oil. This paper proposes the Fuzzy Roger system for detection of faults from Hydrocarbon gas data collected from Dissolved Gas Analysis of power transformers. The gas ratios and relative proportions of gases are used to diagnose the fault. Fuzzy Roger based diagnosis system is insensitive to errors in the oil sampling, storage and testing processes. Output of Fuzzy Rogers method is compared with conventional method. The computational efficiency, reliability and success rate of proposed method is presented. Result shows that Fuzzy Rogers method is found to be more reliable and efficient for transformer fault diagnosis.*

Key words: *Hydrocarbon Gases, Dissolved Gas Analysis (DGA), Power Transformers and Fuzzy Rogers Ratio*

1. Introduction

Power transformers are essential devices in a transmission and distribution system and their conditions have a direct influence on safety and reliability of the power system. Depending upon the usage of the equipment and environmental conditions faults are developed. Thermal and electrical faults developed in oil filled power transformers are always associated with the formation of gases dissolved in the oil including methane (CH_4), ethane ($C\ H_6$), ethylene (C_2H_4), acetylene (C_2H_2), carbon monoxide (CO) and carbon dioxide (CO_2) [1]. Using Dissolved Gas Analysis (DGA), it is possible to diagnose faults such as partial discharge, overheating and arcing [2]-[4]. Over several decades of the industrial practice in the testing and monitoring oil filled transformers, DGA has gained worldwide acceptance as a diagnostic method for the detection of incipient faults [5],[6].

Transformer is identified as the most efficient electrical equipment with its smooth working of the electromagnetic circuit, dielectric system, mechanical structure, cooling system, bushing, OLTC, oil preservation system, protection and monitoring system [7]. Removal of heat is the main problem in high capacity transformers. Mineral oils are used for insulation and cooling of transformers. The oil is the mixture of many different Hydrocarbon molecules which decompose under high thermal and electrical stress within the transformer during the period of service [8],[9]. The critical changes are the breaking of Carbon-Hydrogen and Carbon-Carbon bonds; as a result of which different gases are formed due to the presence of individual Hydrocarbon and the distribution of energy and the temperature in the neighbourhood of the fault.

The causes of fault gases differ mainly in the intensity of energy dissipated. The most severe intensity of energy dissipation occurs at arcing, less with Heating and least with Corona. The identity of the gases being generated by a particular unit can be very useful information in any preventive maintenance program. There are several techniques in detecting those fault gases and DGA was recognized as the most informative method [10], [11]. This method involves sampling of the oil to measure the concentration of the dissolved gases. The most important aspect of fault gases analysis is the correct diagnosis of the fault from the detected gases. Currently there are several methods developed to do the interpretation of the fault type from the dissolved gases data [12]-[14]. In this work evaluation of transformer faults is carried out by the analysis of separate combustible Hydrocarbon gases using Fuzzy system.

2. Dissolved Gas Analysis (DGA)

The fault gases found in a unit are Hydrocarbons like Hydrogen H_2, Methane

CH_4, Ethane C_2H_6, Ethylene C_2H_4, Acetylene C_2H_2 and carbon oxides such as CO, CO_2 in addition to no-fault gases like N_2 and O_2 .The majority of gases that are found to indicate the faults are more soluble in Oil. At a pressure of 760 mm Hg and 25^o C temperature, the solubility of gases in Transformer oil is found and it is shown in Table 1.

Gas	Solubility in % by volume
H_2	7 %
N_2	8.6 %
CO	9.0 %
O_2	16 %
CH_4	30 %
CO_2	120 %
C_2H_6	280 %
C_2H_4	280 %
C_2H_2	400 %

Table 1: Solubility of gases

Over a temperature range of 80 degree centigrade, some gases increase its solubility upto 79 %. By extracting the dissolved gases in the oil they are identified and quantitatively determined by Dissolved Gas Analysis (DGA) method. Data from DGA detects the gases in the oil phase giving the earliest possible detection of an incipient fault. Thermal and Electrical faults that develop in oil filled power transformers are always associated with the evolution of gases dissolved in the oil.

The decomposition of mineral oil (from 150^o C to 500^o C) produces relatively large quantities of the low molecular weight gases such as H_2, CH_4 and trace quantities of the higher molecular weight gases Ethylene (C_2H_4) and Ethane (C_2H_6). As the fault temperature in mineral oil increases to modest temperatures, the Hydrogen concentration exceeds that of Methane, but now the temperatures are accompanied by significant quantities of higher molecular weight gases first Ethane and then Ethylene. At high level of thermal fault range, increasing quantities Hydrogen and Ethylene and traces of Acetylene (C_2H_2) is produced. The presence of Acetylene suggests a high temperature fault, perhaps an arc has occurred in the oil in a Transformer, and the presence of Methane suggests that it is a lower energy electrical or thermal fault.

A Low Intensity discharge produces Hydrogen with decreasing quantities of Methane and trace quantities of Acetylene. As the intensity of discharge increases, the Acetylene, and Ethylene concentrations rise significantly. High Intensity Arcing is produced when the quantity of Acetylene becomes pronounced as the intensity of electrical discharge reaches arcing. Dissolved gas analysis (DGA) technique is simple, inexpensive and widely used to interpret gases dissolved due to the deterioration of the oil of power transformers. In this paper the fuzzy system approach is combined with DGA to separate the fault according to the gas contents in the insulation oil of transformers.

3. Rogers Ratio Method

Rogers Ratio is a straight forward method and it is useful for completely oil filled (conservator type) transformers. It is also permits continuous monitoring of insulation deterioration in spite of any oil handling activity that includes degasification. In this method the total volume of evolved gas is used as an indicator of the magnitude of incipient faults. To determine the volume in gallons, the following equation called Total Dissolved Gases Combustible in insulating oil (TDGCv) is used.

$$TDGCv = \frac{FG(V)}{1000000} \quad (1)$$

Where, FG (Fault Gases) is the sum of H_2, CH_4, C_2H_6, C_2H_4, C_2H_2 and CO and V is the volume of oil in transformer.

In the thermal degradation principle an array of ratios of certain key combustible gasses are used as the fault indicators. In this paper the ratios used is as follows.

Ratio-1 (R1) = C_2H_2/C_2H_4
Ratio-2 (R2) = CH_4/H_2
Ratio-3 (R3) = C_2H_4/C_2H_6

The Rogers method does not depend on specific gas concentration of gases for the diagnosis. It uses the concentrations of separate gases and the total concentration of all combustible gases. Table 2 shows the normal limits of individual gases.

Key gas	Concentration Limits
Hydrogen(H_2)	100
Methane(CH_4)	120
Carbon Monoxide(CO)	350
Acetylene(C_2H_2)	1
Ethylene(C_2H_4)	50
Ethane(C_2H_6)	65

Table-2: Limit concentrations of dissolved gas

In this paper three ratios are used and it is based on the thermal degradation principle. Table 3 gives the values for the three key gas ratios corresponding to suggested diagnoses. These ratios according to Rogers are applicable to both gases taken from the gas space and gases extracted from the oil. The fault types are given in table 3.

Case	R1 C2H2/ C2H4	R2 CH4/ H2	R3 C2H4/ C2H6	Suggested faults for diagnosis
0	<0.1	>0.1 to <1.0	<1.0	Unit normal
1	<0.1	<0.1	<1.0	Potential discharge
2	0.1 to 3.0	0.1 to 1.0	>3.0	Arcing high energy discharge
3	<0.1	>0.1 to <1.0	1.0 to 3.0	Low temperature thermal
4	<0.1	>1.0	1.0 to 3.0	Thermal<700deg
5	<0.1	>1.0	>3.0	Thermal>700deg

Table-3: Rogers Ratio for key gases

Fuzzy Rogers Ratio system uses the ratios of fault gases to determine transformer conditions. The ratios are identified as the input parameters while the interpretation results based on the different combination of ratios are identified as the output parameter and it is listed in table 4.

Fault code	Fault Type	Ranges of Gas ratio		
		C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6
0	No fault	<0.1	0.1-1.0	<1.0
1	Low energy partial discharges	<0.1	<0.1	<1.0
2	High energy partial discharges	0.1-3	<0.1	<1.0
3	Low energy discharges	>0.1	0.1-1.0	>1.0
4	High energy discharges	0.1-3	0.1-1.0	>3.0
5	Low temperature fault 150°C	<0.1	0.1-1.0	1.0-3.0
6	Low temperature fault 150-300°C	<0.1	>0.1	<1.0
7	Medium temperature fault 300-700°C	<0.1	>0.1	1.0-3.0
8	High temperature fault>700°C	<0.1	>0.1	>3.0

Table-4: Fault type with its Gas ratio

4. Experimental Results

The fuzzy logic analysis involves three successive processes, namely: Fuzzification, fuzzy inference, and defuzzification. Fuzzification converts a crisp gas ratio into a fuzzy input membership. A chosen fuzzy inference system (FIS) is responsible for drawing conclusions from the knowledge based fuzzy rule set of if-then linguistic statements. Defuzzification then converts the fuzzy output values back into crisp output actions. In this paper Fuzzy Rogers system uses 5 numbers fault gases like Acetylene, Ethylene, Methane, Hydrogen and Ethane to determine transformer conditions. The gas values are fuzzified using the following linguistic variables and membership functions as shown in figure 1.

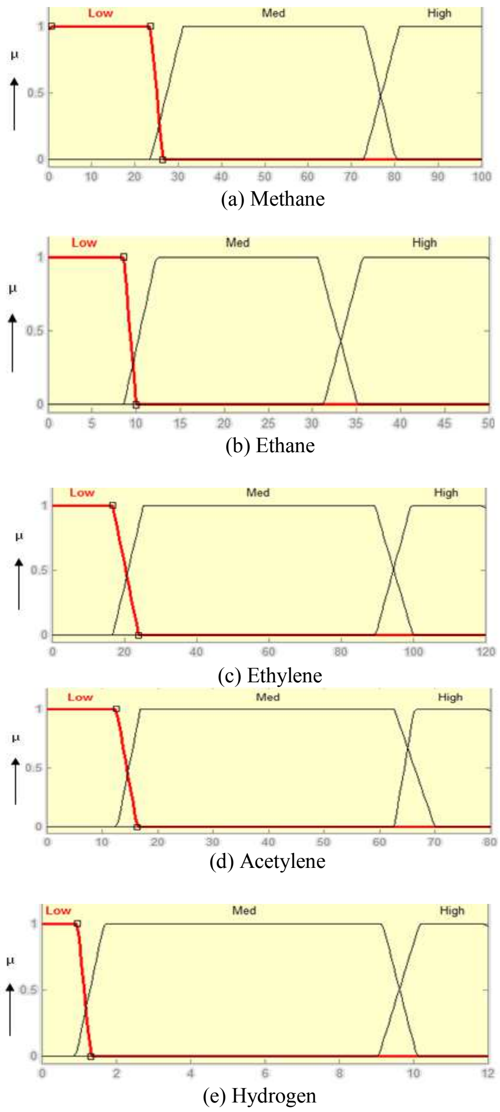
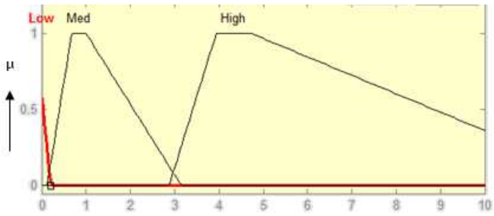
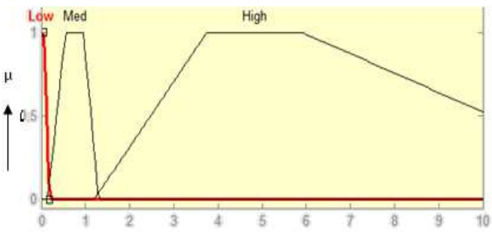


Figure 1: Membership functions for Different Gases

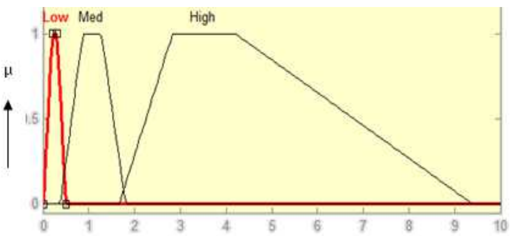
The set of fuzzy inputs (3 gas ratios) with their respective membership functions form the premise part of a fuzzy logic analysis. A fuzzy rule set (linguistic if-then statements) is then used to form the type of fault based on the fuzzy inputs derived from the 3 gas ratios. Three gas input ratios are given as the input to Fuzzy Roger system as shown in figure 2. Figure 3 gives the output of Fuzzy Roger system.



(a) Input variable for Ratio-1(R1) = C_2H_2/C_2H_4



(b) Input variable for Ratio-2 (R2) = CH_4/H_2



(c) Input variable for Ratio-3 (R3)=C_2H_4/C_2H_6

Figure 2: Input variables for three ratios of Fuzzy Roger Method

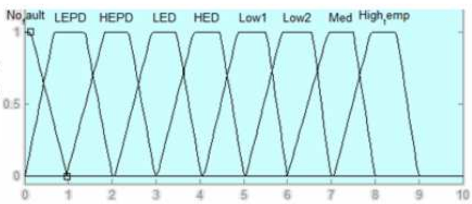


Figure 3: Output of Fuzzy Roger Method

The developed Fuzzy Rogers system output for input ratios R1=1.06, R2=1.16 and R3=1.77 is shown in figure 4.

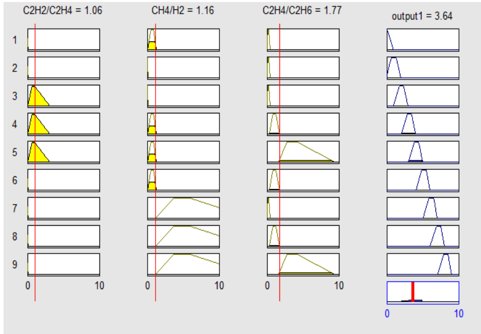


Figure 4: Sample test output for R1=1.06, R2=1.16 and R3=1.77

The test results of DGA for data collected from Electricity board of Tamilnadu state for 16MVA, 110/11kV Transformer is shown in table 5 for some random samples. The remark predicts the suspected occurrence of thermal fault.

Samples	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO_2
I	46	168	37	286	2	840
II	64	224	49	376	2	1164
III	38	219	52	377	1	1340
IV	29	189	75	353	2	1454
V	14	67	42	111	0	1223
VI	22	94	43	138	3	1823
VII	25	96	50	158	6	1964

Table-5: Hydrocarbon gases from DGA data of 16MVA, 110/11kV Transformer

Out of the 551 samples collected from various transformers located at different substations, 329 samples are no fault data and 137 are recommended for resampling by the electricity board test Lab. These 137 samples were tested with Rogers Ratio and Fuzzy Rogers Ratio System and the results are compared in table 6.

Description	Conventional Rogers Ratio Method	Fuzzy Rogers Ratio Method
Samples taken	137	137
Consistent	83	95
Inconsistent	54	42
Success	64	87
Failure	19	8
% of Success	80	91
Efficiency	77	92

Table-6: Comparison of Results

5. Conclusion

This paper investigates the efficiency and consistency of Fuzzy Rogers method for transformer fault diagnosis. The proposed Fuzzy Roger based diagnosis system is insensitive to errors in the oil sampling, storage and testing processes. The real Dissolved Gas Analysis data from power transformer is given as input to the Rogers Ratio method and to Fuzzy Rogers system. It has been found that the success rate in determining the types of fault by Fuzzy Rogers system increases by 11% compared to conventional Rogers Ratio method. The computational efficiency, reliability and success rate of Fuzzy Rogers method reveals that it is more reliable and an efficient tool for diagnosing incipient faults in oil filled power transformers.

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