Monitoring Power Transformer Using Fuzzy Logic

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Abstract :

In this work fuzzy logic is applied to Roger's IEC-599; as it is the most popular method, which dissolved gases in the insulating oil are analyses through gas chromatography and ratios ($R_l=CH_4/H_2$, $R_2=C_2H_2/C_2H_4$, $R_3=C_2H_2/CH_4$, $R_4=C_2H_6/C_2H_2$, and $R_5=C_2H_4/C_2H_6$) are calculated for the purpose of detecting of two different kinds of incipient faults: electrical and -thermal faults, whereby each type of failure can be subdivided into different categories , So in this work construct an expert system that measures the level of dissolved gases and suggests weather the power transformer is normal or faulty, and if it was faulty what might be responsible for the accumulation of these gases. The system developed show that the obtained results are satisfactory.

Key word: Power transformer, Roger, s IEC-599, Dissolved Gas, Fuzzy logic

مراقبة محولات الطاقة باستخدام المنطق الضبابي

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الخلاصة:

تم في هذا البحث تطبيق المنطق الضبابي على طريقة روجر IEC-599 لأنها الطريقة الأكثر شهرة في مراقبة حالة عوازل محولات الطاقة والتي يتم فيها تحليل الغازات الذائبة في الدهن بواسطة مقياس درجات التلون وتحسب النسب / ($R_l=CH_4/H_2$, $R_2=C_2H_2/C_2H_4$, $R_3=C_2H_2/CH_4$, $R_4=C_2H_6\ C_2H_2$ $R_5=C_2H_4/C_2H_6$) و كشف نوعين من الأعطال الابتدائية: أعطال كهربائية وحرارية ويمكن تقسيم كل نوع إلى عدة حقول، ومن ثم بناء نظام خبير من اجل قياس مستوى الغازات المتحللة واقتراح ما إذا كانت محولة الطاقة صالحة أم عاطلة ، وإذا كانت عاطلة فما هو سبب تولد هذه الغازات وقد بين هذا النظام إن النتائج المستحصلة كانت مقنعة.

1. Introduction

It is to every body's knowledge how an important role electricity power is playing in our everyday life that includes both of the residential and the commercial sectors The dependence on electric power is growing at a great rate, all people and every society take it for granted that when a light switch is flicked a light will be turned on, and so the residential use is increasing as time goes on. In addition to this residential demand for electricity, both the industrial sector and commercial sector do need an enormous electricity supplies every day.

This dependence on electricity presents an excellent opportunity for electric power utilities to establish a successful and growing business with many customers throughout the world.

Among many other things, the reliability of a power system depends on a trouble-free functioning of power transformers. Consequently, their Maintenance and particularly their preventive maintenance can lead to huge savings, besides achieving uninterrupted power supply to customers.

Even in normal operation a power transformer is subjected to huge internal stresses that often in time do have an effect on the performance and reliability of the transformer through the steady breakdown of its insulating materials. These insulating materials include paper and oil and after being subjected to a variety of stressful conditions that occur in a transformer, they have been found to deteriorate which would result in generation of gases which are often combustible.

The insulation system of a power transformer consists mostly of hydrocarbon oil and paper. Many of these power transformers within electric utilities around the world are approaching the end of their designed life. Therefore insulation degradation is a major concern for these aged transformers, several factors, especially electrical and thermal stresses age the transformer md subject them to incipient faults [1]. The presence of faults such as arcing, sparking, partial discharges and overheating in power transformers results in chemical decomposition of the insulating materials [2].

The paper insulation in the power transformer provides the dielectric strength and dielectric spacing for the power transformer windings. The ageing of paper depends on operating temperature, moisture, oxygen, acidity levels of insulating oil and the type of paper used. Mineral oil in the transformer provides cooling for the transformer [3]. During this period of time in which the power transformer is gradually aging, which is called an incipient fault, the electrical properties of the insulation alter adversely and incipient-like behavior commences. Incipient faults may convey non-periodic, asymmetric and sporadic arcing current, which are random in magnitude and could involve sporadic bursts as it is well known that an initial incipient fault does not draw sufficient current from the line to operate the protective devices. As the fault becomes more severe, it is important to detect it before catastrophic failure does happen [3]. Several gases are formed during transformer faults. These are: H_2, 0_2, N_2, $IC0_2$, CH_4, C_2H_6, C_2H_4, C_2H_2 and C_2H_S. These gases are either entirely or partially dissolved in the mineral oil [1, 3]; this is due to the differences in solubility of gases in the insulating oil. These dissolved gases can be analyzed by Gas Chromatography [4] Chromatography is a separation method from which compounds of a complex - mixture can be identified and possibly quantified. In gas chromatography, for material to be detected, it has to be sufficiently volatile to pass through a Gas chromatography column at a temperature that may be as high as 300-400°C under helium gas flow. Solvent extraction is a common way of separating extractable compounds from a mixture, followed by injection of the solution in to the Gas Chromatography [5].

2. Fault Types

There are many types of power transformer faults that could be sub-divided into smaller groups, but the main types of faults are:-

1. Arcing

Arcing is the most severe of all fault types. Large amounts of hydrogen and acetylene are produced, with minor quantities of methane and ethylene. Arcing occurs through high current and high temperature conditions. Carbon dioxide and carbon monoxide may also be formed if the fault involved cellulose. In some instances, the oil may become carbonized [6].

2. Corona

Corona is a low-energy electrical fault. Low-energy electrical discharges produce hydrogen and methane, with small quantities of ethane and ethylene Comparable amounts of carbon monoxide and dioxide may result from discharge in cellulose [7].

3. Partial Discharges (PD)

Partial discharges occur where an electric field surrounding a conductor exceeds the dielectric strength of the conductor insulation. They occur in items of electrical plant as a result of temporary over voltage, incipient weaknesses in the insulation introduced during manufacturing and aging of plant. different classes of PD source of defect type exist - Bad Contact (BC) caused by sparking, e.g. sparking occurring between the threads of loose nuts and - Protrusion (PRO)- caused by fixed, sharp metallic protrusions existing on windings, e.g. due to poor manufacture or as a result of winding vibration over a substantial period of time [8].

4. Sparking

Sparking occurs as an intermittent high voltage flashover without high current, increased levels of methane and ethane are detected without concurrent increases in acetylene, ethylene or hydrogen [7].

5. Overheating

The decomposition products as a result of overheating may include ethylene and methane, together with smaller quantities of hydrogen and ethane. Traces of acetylene may be formed if the fault is severe or involves electrical contacts.

Large quantities of carbon dioxide and carbon monoxide are evolved from overheated cellulose. Hydrocarbon gases, such as methane and ethylene, will be formed if the fault involved an oil-impregnated structure [7].

3. Fault Gases

The causes of fault gases can be divided into three categories; corona or partial discharge, thermal heating, and arcing. These three categories differ in the intensity of energy that is dissipated per unit time per unit *volume* by the fault.

The most severe intensity of energy dissipation occurs with arcing, less with heating, and least with corona. The amount of each individual gas is dependent on the temperature in the neighborhood of the stressed: point and gases are generated in the following order with an increase of temperature: H2 then CH4 then C2H6 then C2H4 then C2H2.

Acetylene is generated at low' temperature and its amount steadily increases, acetylene is generated at a very high temperature and also steadily increases its amount. Fault gases that can be found within a unit are shown in **Table (1),** [9].

Table (1) Fault Gases

Hydrocarbons& hydrogen		Carbon oxides		Non-fault gases	
Methane	CH4	Carbon monoxide	CO	Nitrogen	N2
Ethane	C2H6	Carbon dioxide	CO2	Oxygen	O2
Ethylene	C2H4				
Acetylene	C2H2				
Hydrogen	H2				

These gases will accumulate in the insulating oil, as a result of various faults. Their distribution will be affected by the nature of the insulating materials involved in the fault and the nature of the fault itself, major fault gases are categorized in **Table (2)** by the type of material s involved and the type of fault present as follows:

Table (2) Fault Types

Corona		Pyrolysis				Arcing
Oil	Cellulose	Oil		Cellulose		H2,
H2	H2,	Low	High	Low	High	C2H2,
	CO,	temperature	temperature	temperature	temperature	CH4,
	C02	CH4, C2H6	C2H4, $H2_f$ CH4,	C02, CO	CO, C02	C2H6, C2H4

Mineral oil insulating fluids are composed essentially of saturated Hydrocarbons called paraffin, whose general molecular formula is (CnH2n+2) with (n) in the range of 20 to 40. The cellulosic insulation material is a polymeric substance whose general -molecular formula is $[C_{12}H_{14}0_4\ (0H)_6]$ n with (n) in the range of 300 to 750 [6].

4. Ratio Methods of Fault Gas Detection

Ratio methods use the standard ratios of dissolved gas concentrations as the basis of fault diagnosis. Historically five ratios (listed in **Table 3**) have used [7]. The concentrations of gases such as Methane, Ethane, Ethylene, are extracted through gas analysis namely dissolved gas analysis *ZGA)* in a part per million part (PPM), that is a part of the gas being measured in a million parts of the insulating oil, then the ratios (to be used for diagnosing the incipient faults of a power transformer) are calculated in accordance with the method in use.

Table (3) Ratio definition of ratio methods

Abbreviation	Ratio
R_1	CH_4/H_2
R_2	C_2H_2/C_2H_4
R_3	C_2H_2/CH_4
R_4	C_2H_6/C_2H_2
R_5	C_2H_4/C_2H_6

Each method uses some ratios that may not be used by another method; the Doernenburg’s method uses four ratios (R_1, R_2, R_3, and R_4) whereas the Roger’s method uses only three ratios (R1, R2, and R5), however, both of the methods mentioned earlier use the ratios in a similar fashion, that is to say For the Roger's method If R2, Rl, and R5 are in a preset ranges, then the fault of the power transformer being examined is a certain fault (preset the method itself)

4.1. Doernenburg's Method

The first attempt was made in late 1960s at the Central Electricity Generating Board (CEGB) [8]. Doernenburg was one of the first members of the engineering community to publish a technique that diagnosed faults in power transformers using dissolved gas-in-oil analysis (DGA) results obtained through gas chromatography. In 1970 Domenburg was able to differentiate between thermal and electrical faults using four ratios and six gases [9, 10]. The six gases are H_2, CH_4, CO, C_2H_2, C_2H_4 and C_2H_6. The four ratios and their diagnosis values are shown in **Table (4).** The method has many validation tests before reaching the final decision and it often fails to do so. The most important validation test is the LI limit test, which sets up a critical level for each gas. In order to apply the method, at least one gas for each of the ratios must exceed the corresponding LI norm. The revised LI norms are listed in **Table (5).**

Table (4) Dornenburg's ratio method [7]

Fault	R_l	R_2	R_3	R_4
Thermal Decomposition	>1	<0.75	<0.3	>0.4
Corona (low intensity PD)	<1	Not Significant	<0.3	>0.4
Arcing(high intensity PD)	>0.1 and <1	>0.75	>0.3	<0.4

R_l= Methane / Hydrogen
R_2= Acetylene/ Ethylene
R_3= Acetylene/ Methane
R_4= Ethane/ Acetylene

Table (5) Doernenburg's LI limit

Gas	H_2	CH_4	CO	C_2H_2	C_2H_2	C_2H_6
LI limit (ppm)	100	120	350	35	50	65

The results of these equations are used in straight forward decision statements to determine what fault is occurring if one is diagnosable.

An example of this structure is illustrated below.

IF $R_1 > 1.0$ And $R_2 < 0.75$ And $R_3 < 0.3$ And $R_4 > 0.4$Then Fault is Thermal Decomposition [11].

It should be noted that when data generates ratios that completely fit into the Pre-mentioned intervals, Doernenburg's method returns a diagnosis with 100% Confidence. However, data obtained from gas chromatography rarely fits neatly into all ratio intervals which lead to the need for adjustable interval Boundaries (implementation of fuzzy logic), or a revised technique which is where Rogers' research is often more assertive and accurate.

4.2. Roger's Ratio Method

The Rogers' ratio method follows the Doer nenburg's method and its improvements have led it to be one of the first significantly accurate methods resigned for dissolved gas analysis. Similar to the Doer nenburg's approach, it considers ratios of gases that have been dissolved into the insulating oil. And by examining these ratios one can often accurately determine the fault type and severity **Figure (1).**

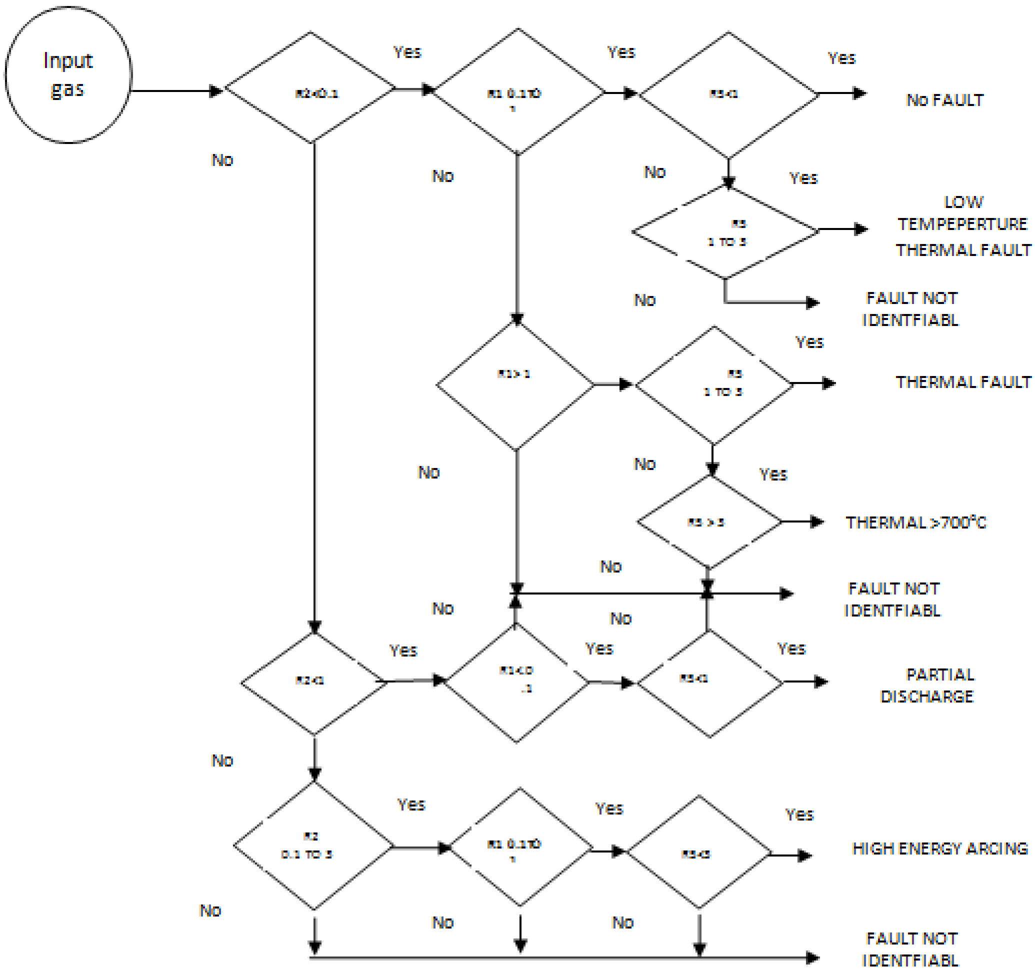

Fig.(1) the Roger's Ratio Method Flow Chart

5. General Fuzzy Systems

A fuzzy system is a static nonlinear mapping between inputs and outputs It is assumed that the fuzzy system has inputs ui belonging to Ui where i= 1, 2....n and outputs Yj belonging to Y j where j= 1, 2 m as shown in **Figure (2),** the inputs and outputs are crisp values that is, they are real numbers, not FUZZY sets, the inference mechanism uses the fuzzy rules in the rule base to produce fuzzy conclusions (the implied fuzzy sets), and the defuzzification block converts these fuzzy conclusions into crisp outputs [12].

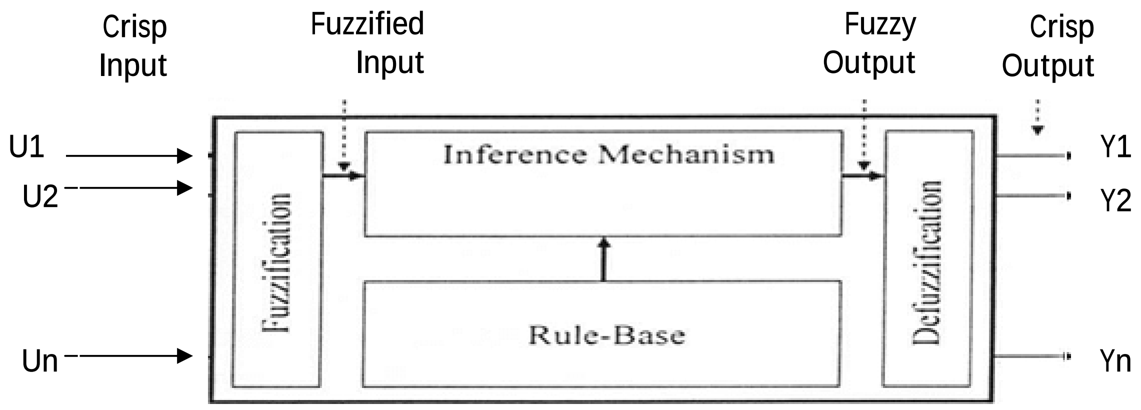

Fig. (2) Fuzzy System

Universes Of Discourse

The ordinary crisp sets Ui and Yj are called the universes of discourse for ui *And* yj respectively, in other words they are their domains. In practical *appli*cations, most often the universes of discourse are simply the set of real numbers or some interval or subset of real numbers [13].

Linguistic Variables

They are constant symbolic descriptions of what are in general time varying quantities. To specify rules for the rule base, the expert will use a linguistic description hence linguistic expressions are needed for the inputs *and out*puts and the characteristics of the inputs and outputs [14].

Linguistic Rules

The mapping of the inputs to the outputs for a *fuzzy* system is in part characterized by a set of condition —► action rules, or (If- Then) form.

If premise Then consequent.

Usually, the inputs of the fuzzy system are associated with the premise and the outputs are associated with the consequent which would then mean: - If input then output [15].

Membership Function

Let Ui denote a universe of discourse and Ai denote a specific linguistic value for a linguistic variable ui, the function associated with Ai that maps Ui to (0, 1) is called a membership function.
This membership function describes the certainty that an element of Ui denoted ui may be classified linguistically as Ai .Membership functions are subjectively specified in a heuristic manner from experience or intuition. Clearly many choices for the shape of the membership function are possible (Triangular, trapezoidal, bell shape....etc.) and these will each provide a Different meaning for the linguistic values that they quantify, **Figures (3and 4)** for a graphical illustration of a variety of membership functions [16] **.**

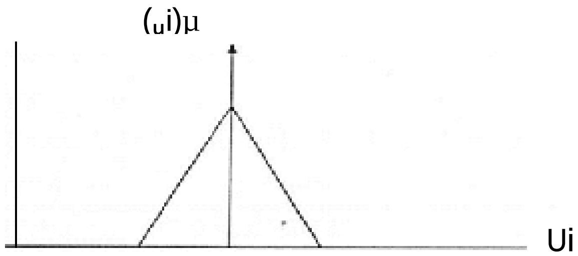

Fig. (3) Triangular membership function

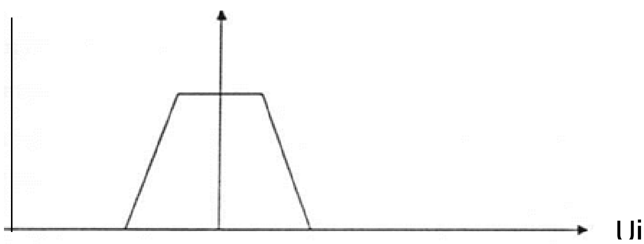

Fig. (4) Trapezoidal membership function

Fuzzification

Fuzzy sets are used to quantify the information in the rule base and the inference mechanism operates on fuzzy sets. Fuzzification is the transformation or converting the system's numeric inputs into fuzzy sets so that they can be used in the fuzzy system.

Inference mechanism

The inference mechanism has two basic tasks:-

1. Determining the extent to which each rule is relevant to the current situation as characterized by the inputs ui, i=l, 2, 3, ...n 2 Drawing conclusions using the current inputs ui and the information in the rule base (the inference step).

Defuzzification

Defuzzification is driving a value off a fuzzy set. A number of defuzzification strategies exist. Each provides a means of choosing a single output based on the implied fuzzy sets, a typical defuzzification technique for the implied fuzzy sets is the center of gravity (COG) which is given by:-

$$Ucrisp = \frac{\sum i\ bi \int \mu(\mathrm{i})}{\sum i \int \mu(\mathrm{i})}$$

Where

bi is the center of the membership function

∫μ (i): is the area under the membership function μ (i) U crisp the numerical output

This technique is also called composite moments (centroid) which means calculating the mean of the fuzzy region. It is the most widely used method of defuzzification for reasons like:-

1. Defuzzified values tend to move smoothly.
2. Easy to calculate.
3. Itcan be applied to both fuzzy and singleton output set geometries.

6. Fuzzy monitoring system

In this work the fuzzy inference approach achieves the diagnostic results by *assu*ming a multi-dimensional space pattern and trapezoidal fuzzy subsets have re;ˉ. assigned to each of the dimensions used, then the rules of the method concerned were applied as the rule base, the method of implication used is the minimum and the method of aggregation used is the maximum to ensure the I best and the most reliable solution out of the available data (DGA readings).

For the Roger's method as an example the inference approach achieves the diagnostic results by assuming a three dimensional space pattern of (i, j, k) and three trapezoidal fuzzy subsets were assigned to each of the three ratios (Low, Medium, High) **Figure (5),** then the rules of Roger's method based on 1EC_599 were applied as the rule base.

The general form of a rule is

Rijk: IF $R_2=S_i$ and $R_1=S_j$ and $R_5=S_k$ Then fault is Fij_k with certainty Cij_k

Where: S_i, S_J, S_k are fuzzy subsets belonging to L, M, H

Rijk is the fuzzy if then rule

Cijk is the certainty ranging from above zero to 100%

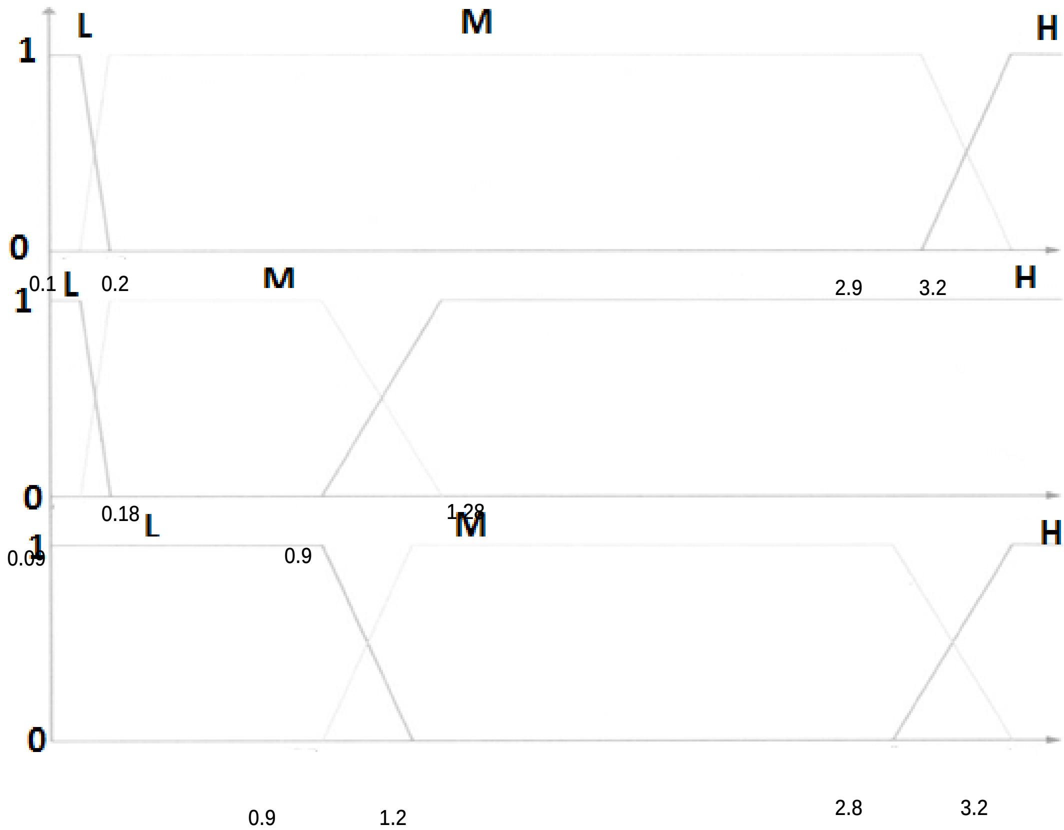

Fig (5) Fuzzy Relations Based on Roger's Method IEC 599

49 real data samples were collected through literature survey, using the internet to collect papers that involve real DGA readings out of real power t:ransformers which are in use in power distributing companies throughout the world, every' DGA reading or sample collected has its own real fault the fault discovered after an inspection by human experts on real ground. (Efforts were made to collect samples from AL-Dora Refinery Company and other electricity distributing stations but unfortunately they all failed as it turned out that they do not use the method of Dissolved Gas Analysis DGA in maintaining their power *transformers* in *Iraq yet).*

7nese forty nine real samples have been used and applied to the analysis of the developed expert system to try to work out or diagnose a fault that matches the actual fault which was recorded through the collection of data.

The new developed expert system programming has been constructed and executed using MATLAB-7 software (as most of the programming involves numerical manipulation of input values of which MATLAB-7 has proven to be effective and efficient, it was chosen to be the tool of implementation) as shown in program(1) .

Table (6) presents the real data samples that were collected in order to apply them to the new developed expert system; the numbers under each gas column -present the concentrations in part of this gas per million parts of the insulating oil in the power transformer, and the faults under the actual fault column are the real faults recorded on ground by human experts.

Program (1) Dissolved Gas Analysis (DGA) Method Based on IEC 599

Fuzzy Relations IEC599

IF R_1>=0 & R_1<0.09

R_1_L=l;

R_1_M=0;

R_1_H=0;

Else if R_l>=0.09 & R_1 <0.18

R_1_L=2-R_1/0.09;

R_1-M= R_1/0.09-1;

R_1-H=0;

Else if R_1>=0.18 &R_1<0.9

R_1-L=0;

And the same for (R_2, R_5)

% Rules (IEC-599)

F_0= [R_2-L R_1-M R_5-L];

F_1= [R_2-L R_1-L R_5-L];

F_2= [R_2-M R_1-L R_5-L];

F_3 = [R_2-M R_1-M R_5-M];

F_4 = [R-M R_1-M R_5-H];

F_5 = [R_2-L R_1-M R_5-M];

F_6= [R_2-L R_1- H R_5-L];

F_7= [R_2-L R_1- H R_5-M];

F_8= [R_2-L R_1-H R_5- H];

Table (6) Data samples in PPM

Sample	H2	CH4	C2H6	C2H4	C2H2	CO	Actual fault
1	6	23	4	7	0	392	OH
2	6	14	3	3	0	217	OH
3	495	1775	276	2438	2	293	OH
4	80	619	326	2480	0	268	OH
5	21	24	23	98	0	159	OH
6	231	3997	1726	5584	0	0	OH
7	127	24	0	32	81	0	ARCING
8	54	0	0	4	0	106	ARCING
9	246	43	0	21	53	218	ARCING
10	9474	4066	353	6552	12997	553	ARCING
11	507	1053	297	1440	17	22	OH
12	416	695	74	867	0	200	OH

Sample	H2	CH4	C2H6	C2H4	C2H2	CO	Actual fault
13	47	12	0	8	0	115	ARCING
14	441	207	43	224	261	161	ARCING
15	234	25	162	10.1	0.8	230	PD
16	235	25	165	10	1	231	PD
17	225	23	115	7.4	0.4	220	PD
18	239	25	149	10.9	0.76	225	PD
19	911	104	231	153	363	82	ARCING
20	16	19	162	69	2	159	NORMAL
21	0	58	11	137	5	250	OH
22	0	67	12	150	4.8	178	OH
23	160	53	28	6	0	190	NORMAL
24	2	13	44	37	2	2	OH
25	4	70	61	164	<1	198	OH
26	608	603	200	200	36	606	OH
27	48	43	3	75	81		ARCING
28	318	337	57	583	641		ARCING
29	338	32	1	32	50		PD
30	114	1417	296	2096	0		OH
31	2	4	3	4	0		NORMAL
32	21	34	5	47	62		ARCING
33	37	75	126	5	0		OH
34	59	339	42	392	1		OH
35	13	10	14	13	0		NORMAL
36	800	1393	304	2817	3000		ARCING
37	1360	2554	1332	561	0	554	OH
38	22	40	36	6	1	194	OH
39	1770	3630	1070	8480	78	832	OH
40	86	30	10	35	29	134	DHE
41	34	39	9	40	9	48	DHE
42	24	33	65	2	0	50	NORMAL
43	5	107	106	5	0	74	NORMAL
44	36	35	58	4	0	55	NORMAL
45	30	32	63	3	0	50	NORMAL
46	97	95	44	164	0	0	OH
47	9	65	7	7	0	0	OH
48	28	26	23	3	0	101	OH
49	64	19	11	82	0	459	OH

Table (7) show few points to be noted:

* The faults have been diagnosed for each sample through this method which uses the newly developed expert system

** Certainty means here how much the expert system is sure or certain that this result is the right or correct result (in a percentage manner)

*** ND not diagnosable. The expert system was not able to make a decision as what fault that might have resulted from the concentrations of gases in this sample, or it has named a fault but the certainty was zero

OH =Over Heat
PD =Partial Discharge
PDLE = Partial Discharge Low Energy
DLE =Discharge Low Energy
DHE =Discharge High Energy
ND = Not Diagnosable

We compute result of certainty by using the formula:-

FDGA=[min(F0) ;min(F_1);min(F_2);min(F_3);min(F_4);min(F_5);min(F_6);min(F_7);min(F_8);
%Certainty Percentage of Fault (IEC-599)
CDGA=100*[FDGA];
[Certainty, Fault]=max (CDGA);

Table (7) Results of IEC-599 Method

Sample	Actual Fault	Correct	Certainty	Incorrect	ND
1	OH	OH 300-700	100		
2	OH	OH 150-300	66.67		
3	OH	*OH >700*	100		
4	OH	*OH >700*	100		
5	OH	*OH >700*	63.91		
6	OH	*OH >700*	100		
7	ARCING	DHE	100		
8	ARCING				ND
9	ARCING	DHE	94.22		
10	ARCING	DHE	100		
11	OH	*OH >700*	100		
12	OH	*OH >700*	100		
13	ARCING				ND
14	ARCING	DHE	100		

Sample	Actual Fault	Correct	Certainty	Incorrect	ND
15	PD	PDLE	81.29		
16	PD	PDLE	81.8		
17	PD	PDLE	86.42		
18	PD	PDLE	83.77		
19	ARCING	PDHE	73.16		
20	NORMAL			OH 150-300	
21	OH	*OH >700*			
22	OH	*OH >700*	100		
23	NORMAL	NORMAL	100		
24	OH	OH 150-300	100		
25	OH	OH 300-700	100		
26	OH			DLE	
27	ARCING	DHE	100		
28	ARCING	DHE	57.96		
29	PD	DHE	5.19		
30	OH	*OH >700*	100		
31	NORMAL			OH 300-700	
32	ARCING				ND
33	OH	OH 150-300	100		
34	OH	*OH >700*	100		
35	NORMAL	NORMAL	90.48		
36	ARCING	DHE	100		
37	OH	OH 150-300	100		
38	OH	OH 150-300	33.33		
39	OH	*OH >700*	100		
40	DHE	DHE	100		
41	DHE	DHE	34.98		
42	NORMAL			OH 150-300	
43	NORMAL			OH 150-300	
44	NORMAL	NORMAL	80.99		
45	NORMAL	NORMAL	56.14		
46	OH	*OH >700*	20.89		
47	OH	150-300	66.67		
48	OH			NORMAL	
49	OH				ND

7. Discussion

The important advantage of an expert system as far as fault diagnosis of an equipment is concerned is really manipulating a problem in such a way that an expert engineer would do when having to solve such a problem, bearing in mind that this expert system is really acting as a decision support system and not a decision making system.

There are many ways that a good quality expert system can be achieved; using artificial neural networks (ANN) is one of them as this kind of an expert system has the ability to learn from examples, there by adding more knowledge and useful expertise to the expert system which would definitely raise its quality.

Another way is to use fuzzy logic and make use of its ability in dealing with uncertain data and offer more freedom in solving problems that contribute to more uncertainty and imprecise information.

Incorporating fuzzy logic has made it easier to tackle the problem of incipient fault diagnosis of a power transformer by loosening up the constrictions or limitations set by a certain method such as the Roger's IEC_599 or the revision draft IEC_599r, and so giving more freedom in dealing with tolerance of data (due to a human error and/or device error) or even an uncertain or poor data.

The system can still return a correct result that would definitely reduce the amount of an engineer's workload. This is by shortening the way towards solving a problem, a decision that is 75% correct is really shortening the time needed to solve a problem by 75%, and in turn one can solve or have decisions made for three different problems instead of one as far as time consumption is concerned, which is a lot better to start with rather than a decision that is 25% correct or even less some times.

In this newly developed expert system this reduction of an engineer's workload has successfully reached more than 83.67%, besides giving diagnosis in a much shorter period of time thereby decreasing the failure time or the down time which in turn means increasing the overall power system reliability as this feature is one of the major concerns of any power distributing company or utility.

8. Conclusions

Three points can be concluded from this paper

1- A power transformer incipient fault diagnosis expert system has been improving the conventional methods that use dissolved gas analysis (DGA).

2- Using fuzzy logic can enhance and has indeed enhanced the ability of the proposed expert system to diagnose more power transformers correctly, even those that had poor or uncertain data; this is made possible by loosening the boundaries to allow for even more tolerance without breaking the rules set by those methods involved in the diagnosis.

3- Several programs were initiated, improved, and upgraded using the Mat lab software to apply the adopted fuzzy diagnosis system. Efforts have been made to find the right type of the membership function and the coordination of that membership function in order to use it for the fuzzy subsets, and software programs are modified accordingly.

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