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Incipient Fault Diagnosis in Power Transformer based on Dissolved Gas Analysis by Artificial Neural Network

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ABSTRACT: Assessment of power transformer conditions plays crucial role to prevent incipient fault failures, to achieve reliability, efficiency and to enhance the transformer life period. Dissolved Gas Analysis (DGA) is useful for diagnostic analysis of incipient in power transformers. In this paper a novel method Artificial Neural Network (ANN) is applied to DGA for the interpretation incipient faults in power transformers. Fault interpretation can found to be a problem of multi-class classification. This paper presents ANN approach to DGA for interpretation of incipient faults in power transformers. ANN automatically tune the network parameters, connection weights and bias terms of the neural networks, to achieve the best model based on the proposed evolutionary algorithm, which provides the solution for complex classification problems. The proposed ANN algorithm applied to DGA has been tested by many real fault samples, and its results are compared with conventional DGA methods i.e. Doernenburg Ratios Method, Rogers Ratio method and IEC ratio methods. The result indicates that the proposed approach has remarkable diagnosis accuracy, and with it multiple incipient faults can be classified effectively**.**

KEYWORDS: Dissolved Gas Analysis (DGA), Artificial Neural Network (ANN)

I. INTRODUCTION

Transformers are the electrical equipment used for bulk amount of transfer of power from one voltage level to another. Power transformer plays most crucial role in the power system. Transformer under continuous operation confronts electrical and thermal stresses. These stresses will result in degradation of electrical insulation oils. Any fault in the power transformer may lead to the power supply interruption. To avoid the major power failure, it is very much important to monitor the health of transformers periodically. There are several diagnostic techniques are available in monitoring insulation condition of oil filled power such as dissolved gas analysis (DGA), partial discharge (PD), and moisture analysis in transformer oil [1][3] are used. Among these methods, DGA is a fast and economical method for detecting an incipient fault by utility engineers [3]. Dissolved Gas Analysis is one of the reliable and proven techniques to detect incipient fault in transformer [8]. Dissolved Gas Analysis can be used to assess current equipment condition, give advance warning of developing faults and determine the improper use of equipment in order to provide convenient scheduling of repairs[2][6].

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II. LITERATURE SURVEY

There are so many fault detection technique are available for transformer some are costly, some are cheap, some having limitation, some are useful in specific conditions only. So, in this chapter different fault detection technique available for smooth working of transformer are discussed.

A) Winding Resistance Method
B)Tan Delta Method
C) Partial Discharge Method
D) Low Voltage Impulse Method
E) Frequency Response Analysis

Like a blood test or a scanner examination of the human body DGA can warn about an impendent problem, give an early diagnosis, and increase the chances of finding the appropriate cure. Power transformers are always under the influence of electrical, mechanical, thermal and environmental stresses which cause the degradation of the insulating materials. The degradation then leading to the formation of several gases. These gases tend to stay dissolved. According to the temperature reached in the area, the product of the oil decomposition change. There is a correlation between type of the gases found and these temperatures.

III. DISSOLVED GAS ANALYSIS: A DIAGNOSTIC METHODS

The decomposition of electrical insulation materials, as a result of faults the power transformer causes development of gases in oil. The gases developed 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). As incipient faults causes gases dissolve in the oil, the technique of DGA was developed to detect in the early stage defects on insulation. The Gas Chromatography (GC) is the most practical method used for the identification of combustible gases. [1] GC gives a qualitative as well as quantitative analysis of dissolved gases in transformer oil.

Among the available DGA techniques, the most used are the Key Gas methods, Dorenenberg ratio, IEC ratio, Rogers' ratio, Duval's Triangle method. The advantage of using ratio methods is that, they overcome the issue of volume of oil in the transformer [3].

A) Dorenenberg Ratios Method

This method formulates four gas ratios using dissolved gases of transformer oil as plotted in Table I. Taking these gas ratios ranges, it diagnosis the three types of fault conditions (i) Thermal decomposition , (ii) Corona and (iii) Arcing. The limitation of this method is that, it can interpret only three faults and it is very complex.

Ratio 1 (RI)	CH4/H2
Ratio2 (R2)	C2H2/C2H4
Ratio3 (R3)	C2H6/ C2H2
Ratio4 (R4)	C2H2/CH4

Table.1 Gas Ratios for Dorenenberg Ratios Method

Diagnosis	R1	R2	R3	R4
Thermal decomposition	> 1.0	< 0.75	> 0.4	< 0.3
Corona (low intensity PD)	<0.1	Not significan t	> 0.4	< 0.3
Arcing (High intensity PD)	0.1-1	> 0.75	<0.4	> 0.3

Table.2 Fault diagnosis according to Dorenenberg' ratio method.

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B) Rogers Ratio Method

[2-6] Rogers' ratio method diagnosis faults by considering the ranges of four gas ratios, CH_4/H_2, C_2H_6/CH_4, C_2H_4/C_2H_6 and C_2H_2/C_2H_4.

Ratio Code	Range	code
CH4/H2 (i)	*<=0.1*	*5*
	>0.1,<1.0	*0*
	>=1.0,<3.0	*1*
	>=3.0	*2*
C2H6/CH4 (j)	<1.0	0
	>=1.0	1
	<1.0	0
C2H4/C2H6 (k)	>=1.0,<3.0	1
	>=3.0	2
	<0.5	0
C2H2/C2H4 **(l)**	>=0.5,<3.0	1
	>=3.0	2

Table.3 Codes for Rogers' gas ratios

The gas ratios are used to determine incipient failures. Each combination of diagnosis code indicates a certain condition of the power transformer. Table I shows codes for gas ratios used in this method while table II shows the shows the Fault diagnosis according to Rogers ratio method.

i	j	k	l	Diagnosis
0	0	0	0	Normal deterioration
5	0	0	0	Partial discharge
1-2	0	0	0	Slight overheating <150^{0}C
1-2	1	0	0	Overheating 150^{0}C -200^{0}C
0	1	0	0	Overheating 200^{0}C -300^{0}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)

Table.4: the Fault diagnosis according to Rogers' ratio method.

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C) IEC Ratio Method

The Rogers method fails to indicate all temperature range of decomposition [3-7]. IEC ratio method derived from the Rogers method by eliminating C2H6/CH4 ratio. Three gas ratios CH4/H2, C2H4/C2H6 and C2H2/C2H4 are used to interpret the faults.

Ratio Code	Range	Code
l	<0.1	0
	0.1-1.0	1
	1.0-3.0	1
	>3.0	2
i	<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.5:Codes for IEC gas ratios

l	i	k	Characteristic fault
0	0	0	Normal ageing
0	1	0	Partial discharge of low energy density
1	1	0	Partial discharge of high energy density
1-2	0	1-2	Discharge of low energy (Continuous sparking)
1	0	2	Discharge of high energy (Arc with power flow through)
0	0	1	Thermal fault <150^{0}C
0	2	0	Thermal fault 150^{0}C -300^{0}C
0	2	1	Thermal fault 300^{0}C -700^{0}C
0	2	2	Thermal fault >700^{0}C

Table.6: Fault diagnosis according to IEC ratio method.

D) Duval triangle

The Duval triangle method considering the concentrations (ppm) of methane (CH4), ethylene (C2H4), and acetylene (C2H2) are expressed as percentages of the total (CH4 + C2H4 + C2H2) gas. The evaluating based on a work point in a triangular coordinate system on a triangular chart which has been subdivided into fault zones. The fault zone in which the point is located designates the likely fault type which produced that combination of gas concentrations

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IV. LIMITATIONS OF DGA

Fault interpretation can found to be a problem of multi-class classification. Though DGA provides best interpretation of incipient faults, it fails during complex classification. [1-5] DGA methods have several disadvantages.

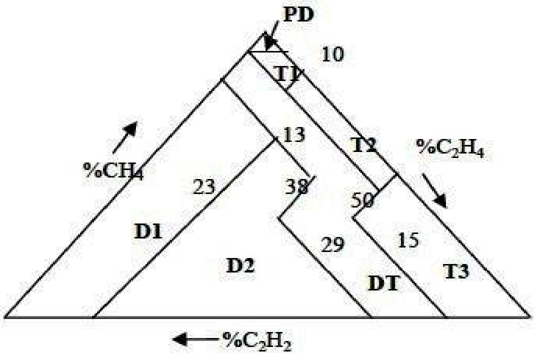

Figure.1 Duval triangle

They do not always yield an analytical result and are not always correct. It requires other information such as the concentrations of the dissolved gases, their generation rates, specific gas ratios, and the total combustible gases in the oil to determine the types of fault. The DGA methods cannot provide a completely objective and accurate results [6] for all faults since the number of possible code combinations exceeds that of fault types.
In this paper, an Artificial Neural Network approach is used to overcome the above drawback of ratio methods.

V. ARTIFICIAL NEURAL NETWORK

The term neural network derive its origin from human brain, which consist of massively, parallel connection of large numbers of neurons.[3-8] Artificial Neural Networks attempt to model the structure of the human brain and are based on self-learning. Its structure is highly parallel, resulting in the ability to self-organize to represent information and rapidly solve problems in real time.

In this paper a novel method Artificial Neural Network is applied to DGA for the interpretation incipient faults in power transformers. Fault interpretation can found to be a problem of multi-class classification. ANN automatically tune the network parameters, connection weights and bias terms of the neural networks, to achieve the best model based on the proposed evolutionary algorithm, which provides the solution for complex classification problems, since the hidden relationships between the fault types and dissolved gases can be recognized by ANN through training process.

VI. APPLICATION OF ANN TO DGA

In this paper MATLAB software is used to construct ANN models. MLP neural networks are created separately for Rogers's ratio method and IEC ratio method. The Multilayer Layer Perceptron (MLP) neural network is generated by using command *newff*. Function *tansig* and *purelin* are used as transfer function, while for training command *trainlm* used. For the development of the neural network 350 sample datasets are used. 220 datasets are used for training purpose and 130 datasets are used for testing purpose.

To interact with MLP network the GUI is created using MATLAB. It provides the interfacing of user with network. Values of gases produced due to the faults are given as network input by using GUI as shown in figure 1.

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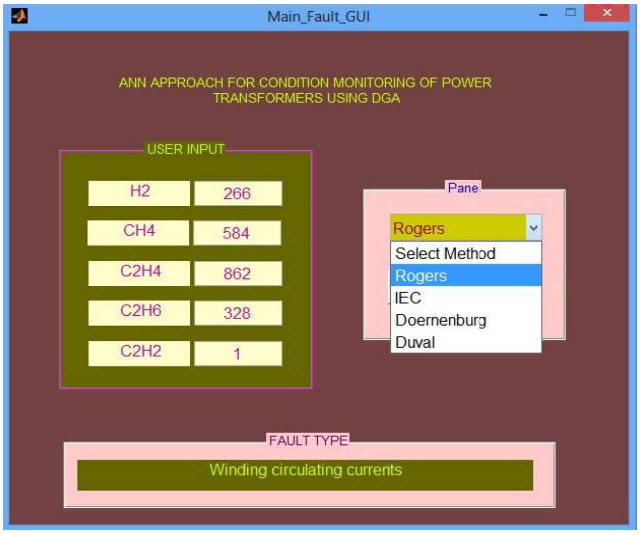

Figure.2 GUI panel

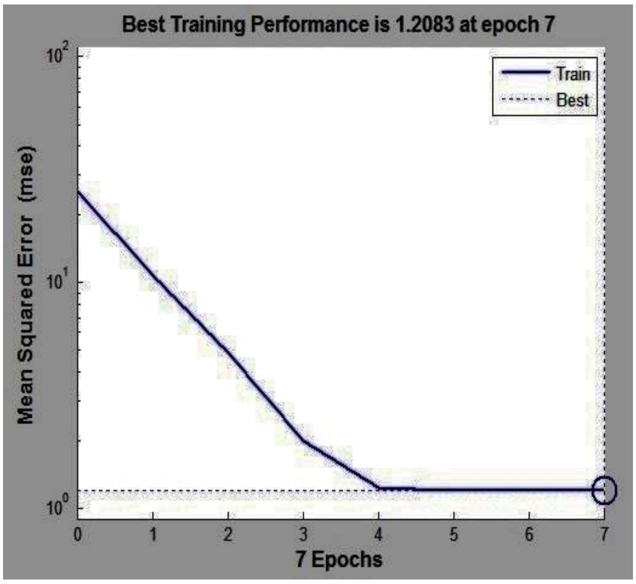

Figure.3 Training Performance

In figure 3 the errors are plotted with respect to training epochs. The error dropped until it fell beneath the error goal (the black line). At this point training is stopped. It shows the training performance of MLP network, it gives graphical analysis of neural network. Here best training performance is obtained at 7th epoch.

VII. Result And Discussion

Effectiveness of ANN fault analysis is demonstrated by testing dissolved gas analysis results of various transformers. Sample datasets are tested for the Dorenenberg ratio method, Rogers's ratio as well as for IEC ratio method MLP. Rogers' ratio method and IEC ratio methods without ANN are compared with Rogers ratio method and IEC ratio methods with ANN. In this paper, data sets of three transformers are tested using Rogers ratio method and ICE ratio methods shown in table VI, VII and VIII. For the purpose of common fault analysis all faults are categorized into eight fault code. Code F1 to F8 is assigned to these faults as shown in table V.

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From table no VI, VII, VIII, Out of 19 datasets Rogers ratio method fails to predict the fault at 14 condition, while IEC ratio method fails at 7 condition, but when these methods are trained by means of Multilayer Layer Perceptron (MLP) neural network separately, it is found that performance of these ratio method get improved. In table no VI at Sr. No 1, both Rogers and IEC method fails to predict the condition while using this methods using ANN predicts the normal aging of transformer. It can be seen that the DGA method using ANN depicts improvement in performance than the single DGA methods.

Code	Fault
F1	Normal Ageing
F2	Arcing
F3	Partial discharge
F4	Thermal fault <150
F5	Thermal fault 150-300
F6	Thermal fault 300-700
F7	Thermal fault >700
F8	No Prediction

Table.7 Code assigned to faults

Sr. no.	H2	CH4	C2H6	C2H 4	C2H2	CO
1	41	2	0.001	0.00 1	0.001	13
2	32	161	26	152	3	186
3	135	188	72	195	0.001	519
4	179	191	82	210	0.001	415
5	169	234	82	274	5	483
6	199	205	85	225	0.001	425
7	201	226	90	230	0.001	430

Table.8 **:**20kV Alephata Make: BHEL 220/33KV

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Vol. 6, Issue 1, January 2017

50 MVA, Year Of Manuf. :2003 D.O.C. 18/7/2003

Sr. no.	H2	CH4	C2H6	C2H4	C2H2	CO
8	329	49	54	370	5	126
9	154	328	401	978	8	290
10	28	85	132	684	0.001	114
11	36	47	82	415	0.001	142
12	15	20	70	320	0.001	152
13	14	21	72	325	0.001	162

Table.9 132kV Kamthadi Make: Atlanta 33/22KV
10 MVA, Year Of Manuf.:2005 D.O.C. 16/10/05

Sr. no.	H2	CH4	C2H6	C2H4	C2H2	CO
14	76	9	30	50	0.001	31
15	0	0	0.001	0.001	0.001	33
16	3	28	38	48	0.001	51
17	5	30	35	52	0.001	42
18	6	28	24	35	0.001	58
19	9	33	27	37	0.001	66

Table.10 132kV Sanaswadi Make: DANKE 33/22KV
12.5 MVA, Year Of Manuf.: 2000 D.O.C. 6/9/03

VIII. CONCLUSION

This paper presents the ANN approach for the systematic interpretation of incipient faults for power transformers. The multilayer Layer neural network is developed and implemented for dissolved gas analysis in power transformer.
This proposed ANN algorithm applied to DGA has been tested by many real fault samples, and its results are compared with conventional DGA methods i.e. Dorenenberg Ratio method, Rogers Ratio method and IEC ratio methods. The experimental results show that diagnosis accuracy of DGA methods using ANN is higher than conventional DGA methods for fault detection of transformer. ANN approach provides remedy on drawback of these DGA ratio methods. This method overcome the complexities and appears to be a promising approach to monitoring and diagnosis faults in power transformer.

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Sr. No.	Doernenburg Ratio	Doernenburg with ANN	Rogers RAtio	Rogers With ANN	IEC Ratio	IEC With ANN
1	F1	F1	F8	F1	F8	F1
2	F5	F5	F8	F5	F8	F5
3	F5	F5	F5	F5	F5	F5
4	F5	F5	F8	F4	F8	F5
5	F3	F3	F8	F5	F5	F5
6	F5	F5	F6	F6	F6	F6
7	F5	F5	F6	F6	F8	F6
8	F8	F1	F8	F2	F8	F2
9	F5	F5	F6	F6	F6	F6
10	F8	F5	F8	F4	F6	F6
11	F5	F5	F8	F4	F7	F7
12	F8	F3	F8	F4	F7	F7
13	F8	F5	F8	F4	F7	F7
14	F1	F1	F8	F6	F8	F6
15	F1	F1	F8	F1	F8	F1
16	F1	F1	F8	F6	F6	F6
17	F5	F5	F8	F6	F6	F6
18	F1	F1	F8	F6	F6	F6
19	F1	F1	F5	F6	F6	F6

Table.11 Results without ANN and with ANN

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