A Comparative Analysis of DGA Methods for the Incipient Fault Diagnosis in Power Transformer Using ANN Approach

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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: Artificial Neural Network (ANN), Dissolved Gas Analysis (DGA), Doernenburg Ratios Method, IEC ratio method, Rogers ratio method

1. Introduction

Transformers are the electrical equipment used for bulk amount of transfer of power from one voltage level to another. Power transformers plays most crucial role in the power system. Transformer under continuous operation confront 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 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].

Though DGA provides best interpretation of incipient faults, it inconclusive during complex classification. When the value of gas ratio is near the threshold, it gives wrong diagnosis. To overcome this problem ANN method has been used for, since the hidden relationships between the fault types and dissolved gases can be recognized by ANN through training process.

In this paper ANN approach is applied to the DGA methods and result obtained are compared with the results of conventional DGA methods.

2. 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,

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the most used are the Key Gas methods, Doernenburg 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].

i) Doernenburg Ratios Method

This method formulates four gas ratios using dissolved gases of transformer oil as plotted in Table 1. Taking these gas ratios ranges, it diagnosis the three types of fault conditions (i) Thermal decomposition , (ii) Corona and (iii) Arcing as shown in table 2. The limitation of this method is that, it can interpret only three faults and it is very complex.

In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily [2], [5]. The discussion can be made in several sub-chapters.

Table 1. Gas Ratios For Dorenenberg Ratios Method

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

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

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

ii) Rogers Ratio Method

Rogers ratio method diagnosis the faults by considering the ranges of four gas ratios, CH4/H2, C2H6/CH4, C2H4/C2H6 and C2H2/C2H4[2]. The gas ratios are used to determine incipient failures. Each combination of diagnosis code indicates a certain condition of the power transformer. Table 3 shows codes for gas ratios used in this method while table 4 shows the shows the Fault diagnosis according to Rogers ratio method

Table 3. Codes for Rogers gas ratios

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
C2H4/C2H6 (k)	<1.0	0
	>=1.0,<3.0	1
	>=3.0	2
C2H2/C2H4 **(l)**	<0.5	0
	>=0.5,<3.0	1
	>=3.0	2

Table 4. 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 <150^0C
1-2	1	0	0	Overheating 150^0C -200^0C
0	1	0	0	Overheating 200^0C -300^0C
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)

ii) IEC Ratio Method

The Rogers method fails to indicates all temperature range of decomposition[3]. 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.

Table 5. Codes for IEC gas ratios

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 6. The Fault diagnosis according to IEC ratio method.

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 <150^0C
0	2	0	Thermal fault 150^0C -300^0C
0	2	1	Thermal fault 300^0C -700^0C
0	2	2	Thermal fault >700^0C

ii) Duval triangle

The Duval triangle method considers the three gases (i) methane (CH4), (ii) ethylene (C2H4), and (iii) acetylene (C2H2). Percentages of the total (CH4 + C2H4 + C2H2) gas are considered. The percentage of each gas are plotted on a triangular chart which has been subdivided into different fault zones as shown in Figure 1. The fault zone in which the point is located indicates the type of fault which is produced .

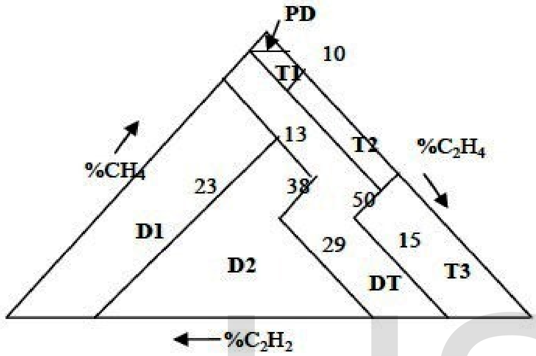

Figure 1 Duval triangle

3. 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. When the value of gas ratio is near the threshold, it gives wrong diagnosis or remains inconclusive. 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. 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.
In this paper, an Artificial Neural Network approach is used to overcome the above drawback of ratio methods.

4. 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. It's 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.

5. APPLICATION OF ANN TO DGA

In this paper MATLAB software is used to construct ANN models. MLP neural networks are created separately for Rogers ratio method and IEC ratio method. The Multilayer Layer Perceptron (MLP) neural network, is generated by using command *newelm*. Function *tansig* and *purelin* are used as transfer function. Figure 2 shows the Artificial Neural Network with five hidden layers. For the development of the neural network 200 sample datasets are used. 150 datasets are used for training purpose and 50 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 3. By using this panel the method to which ANN is applied is selected. The fault type window displays the type of fault.

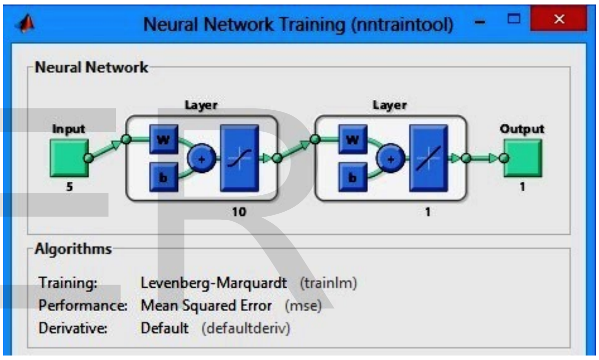

Figure 2 Artificial Neural Network

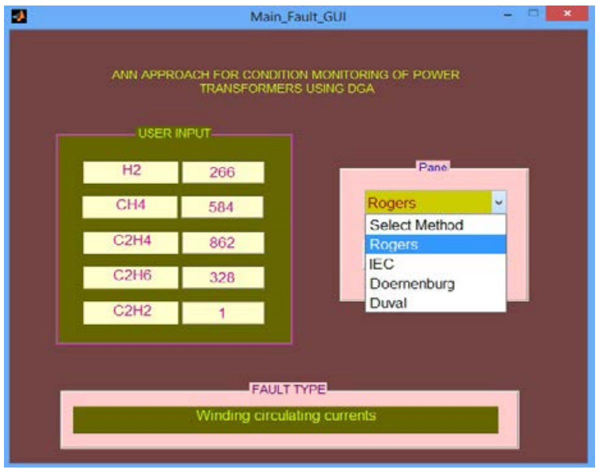

Figure 3. GUI panel

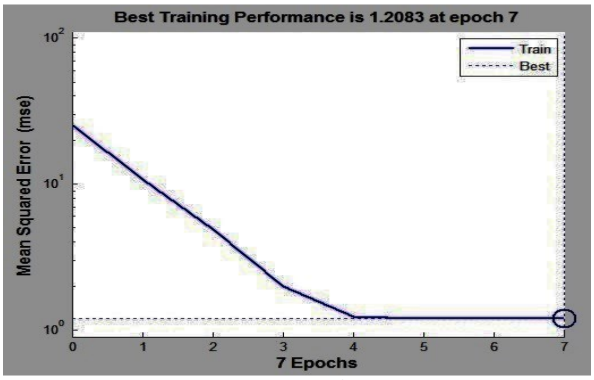

Figure 4. Training Performance

In figure 4 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.

6. Result And Discussion

Effectiveness of ANN fault analysis is demonstrated by testing dissolved gas analysis results of various transformers. In this paper, data sets of three transformers are tested using Doernenburg ratio method, Rogers ratio method and ICE ratio methods shown in table 8, 9 and 10. The ANN is applied to this methods. 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 7.

From table no 11, Out of 19 datasets Rogers ratio method inconclusive at 14 condition, while IEC ratio method 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. It can be seen that the DGA method using ANN depicts improvement in performance than the single DGA methods.

Table 7. Code assigned to faults

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 8 :20kV Alephata Make: BHEL 220/33KV 50 MVA, Year Of Manuf. :2003 D.O.C. 18/7/2003

Sr. no.	H2	CH4	C2H6	C2H4	C2H2	CO
1	41	2	0.001	0.001	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 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
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 10. 132kV Sanaswadi Make: DANKE 33/22KV 12.5 MVA, Year Of Manuf.: 2000 D.O.C. 6/9/03

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

7. 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. Doernenburg Ratio method, Rogers Ratio method and IEC ratio methods. The experimental results shows 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 appear to be a promising approach to monitoring and diagnosis faults in power transformer.

Table XI. Results without ANN and with ANN

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

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