Artificial Neural Network Approach to Dissolved Gas Analysis for Interpretation of Fault in Power Transformer

Pravin S. Khade, Girish K. Mahajan, Ajit P. Chaudhari

Abstract— Power transformer is most crucial equipment in the power system. Monitoring the behavior of transformer is necessary to avoid catastrophic failures, costly outages. Dissolved Gas Analysis (DGA) is a widely used technique to estimate the condition of oil-immersed transformers. The change of combustible gases in the insulating oil is a trustworthy diagnostic tool which can be used as indicator of undesirable events occurring inside the transformer. The main drawback of the ratio methods is that they fail to cover all ranges of data. To improve the diagnosis accuracy of the conventional dissolved gas analysis (DGA) an Artificial Neural Network is applied to conventional Rogers Ratio Method. The selected ANN approach to DGA design yields a very satisfactory result where it can make a reliable classification of transformer condition with respect to combustible gas generated.

Index Terms— Dissolved Gas Analysi DGA, Artificial Neural Network (ANN), power transformer, Multilayer Layer Perceptron (MLP).

1 Introduction

POWER transformers play an important role in electrical power system. The reliability and stability of the overall power system depends on the working condition of Transformer. When the Transformer is under constant operation is subject to thermal and electrical stresses, which cause the degradation of insulation quality and failure of transformer leading to major breakdown of the power system. To avoid power system failure, it is very much important to periodically monitor the health of transformers to keep them in satisfactory working condition [1-10].
The faults occur in transformer is classified into two types, one is an internal incipient faults and other is an internal short circuit faults[1]. The majority of fault occurs in power transformer is incipient faults it will effect on transformer & reduces life span of transformer. In service, transformers are subject to electrical and thermal stresses, causing the degradation of the insulating materials which degradation then leading to the formation of several gases. Thus, based on the formation of the gases for that temperature, using on dissolved gas analysis (DGA) the fault in transformer can be predicted[1][2].

The qualitative and quantitative analysis of dissolved gases in transformer oil may be of great importance in order to assess fault condition and further operating reliability of power transformers [3][10]. In some cases, conventional fault detection methods, such as Roger's, fail to give diagnosis.

This normally happens for those transformers which have more than one fault. In multiple fault condition, gases from different faults are mixed up resulting in confusing ratio between different gas components[1][3]. These methods do not involve any mathematical formulation and the interpretation is based on heuristic method which may vary based on experience of the analyst, results in unreliable analysis [4]. To overcome the drawback, Artificial Neural Network is applied to Rogers Ratio Ratio Method to analyze incipient fault in transformer.

2 Dissolved Gas Analysis

Transformer that is under constant operation is subject to thermal and electrical stresses. Excessive stresses will result in degradation of electrical insulator such as mineral oils. The carbon-hydrogen and carbon-carbon bonds of the insulating oil will break and this will lead to formation of active hydrogen and hydrocarbons atoms. These atoms will combine with each other to form gases such as Hydrogen (H2), Carbon Monoxide (CO), Methane (CH4), Carbon Dioxide (CO2), Ethylene (C2H4), Ethane (C2H6) and Acetylene (C2H2). These gases can be detected by using gas chromatography. Types of incipient fault that may be involved in a transformer is determined by monitoring and analyzing the concentration, generation rate, ratio and total concentrations of combustible gases in insulation oil[3][4]. Because the resulting fault gases dissolve in the oil, the technique of DGA was developed to detect in the early stage defects on the surface of the solid insulation. Dissolved gas analysis is probably the most used tool for detecting faults in electrical equipment in service [4][5]. Following DGA techniques are mostly used.

(a)RogersRatioMethod
(b) The IEC

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(c) Duval's Triangle Method
(d) Key gas method

In this paper the ANN approach is applied to the Rogers Ratio Method.

2.1 Rogers Ratio Method

It is one method most commonly used for diagnosis of the transformer incipient faults [1][10].

The Roger's method utilizes four ratios, CH_4/H_2, C_2H_6/CH_4, C_2H_4/C_2H_6 and C_2H_2/C_2H_4.The ranges of each ratio are specified into different codes to determine the fault type[6]. Each combination of diagnosis code indicates a certain condition of the power transformer.

Table 1.
Codes for Rogers gas ratios

Ratio Code	Range	Code
CH_4/H_2 (i)	<=0.1	5
	>0.1,<1.0	0
	>=1.0,<3.0	1
	>=3.0	2
C_2H_6/CH_4 (j)	<1.0	0
	>=1.0	1
C_2H_4/C_2H_6 (k)	<1.0	0
	>=1.0,<3.0	1
	>=3.0	2
C_2H_2/C_2H_4 (l)	<0.5	0
	>=0.5,<3.0	1
	>=3.0	2

Table 2.
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)

2.2 Stage Limitations of DGA

Rogers Ratio Method provides best interpretation of incipient faults, the drawback of the ratio methods is the "no decision" problem associated with some cases which lies out of the specified codes. It fails during complex classification[1][10] Since DGA are based on empirical evidence rather than scientific facts, it is not completely objective or accurate[7]. When the value of gas ratio is near the threshold, it gives wrong diagnosis or remains inconclusive.

3. Artificial Neural Network

It replicates the human brain system to process the information and to take the decision. ANN approach is automatically capable of handling highly nonlinear input output relationships, acquiring experiences which are unknown to human experts from training data and also to generalize solutions for a new set of data.[8][10] ANN learns by examples in other words, self learning, self studying and self adaption. It can be trained with known example of a problem to acquire knowledge and experience[9][10]. Training and learning ability of ANN gives best fit data and provides the best interpretation under the given circumstance. These features of ANN helps to overcome the drawbacks of Rogers Ratio Method.

4 .ANN approach to Rogers Ratio Method

4.1 Data Collection and Preparation

Data of combustible gas generated from transformer oil due to the incipient fault is obtained from the substations in Maharashtra. The data consist of the values of combustible gas generated in every sample of transformer oil taken.

4.2 ANN model

In this paper ANN model is constructed using MATLAB software. MLP neural networks are created for Rogers ratio method. The Multilayer Layer Perceptron (MLP) neural network, is generated by using command newff. Function tansig and purelin are used as transfer function. Figure 1 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.

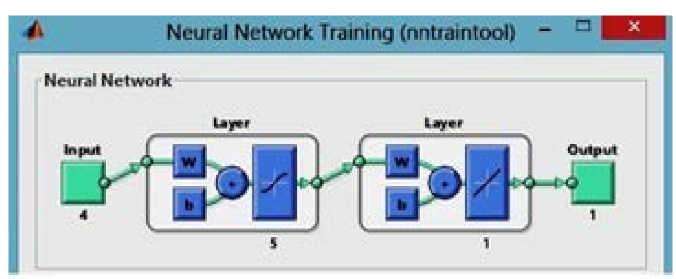

Fig1 Artificial Neural Network

4.3 Graphic User Interface

The Graphic User Interface (GUI) is created to interact with MLP. 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 2. By using this panel the method to which ANN is applied is selected. The fault type window displays the type of fault.

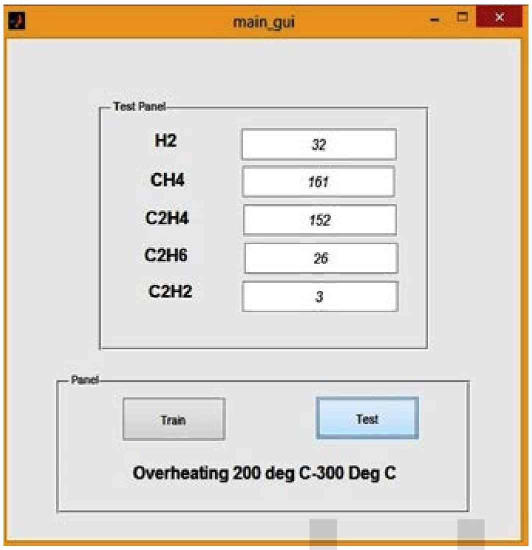

Fig2. Graphic user interface

4.3.1 Training Stage

The network is fed with data consist of three ratios of gases and transformer conditions as the targeted output. Training stage plays most vital role in designing ANN. Data for training stage is divided into three subsets, training set, validation set and testing set. Training set is used to compute gradient

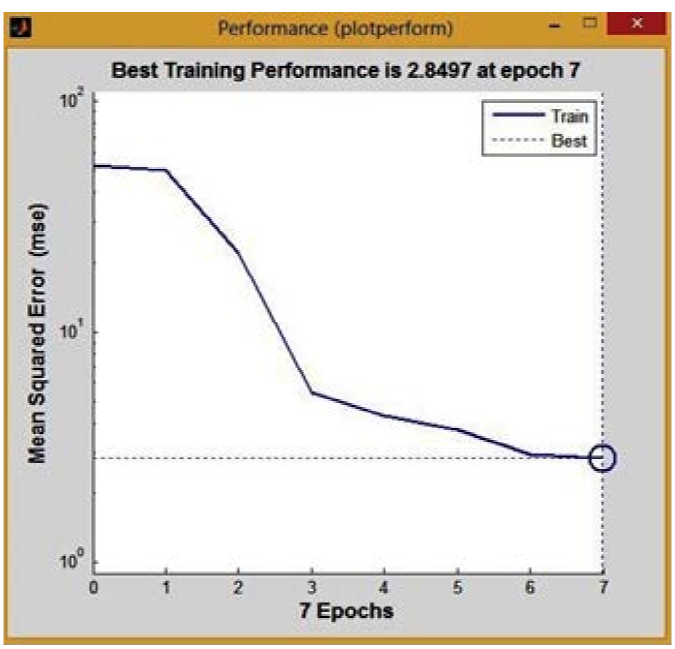

Fig 3. Training performance

and update network's biases and weight while validation set is used to monitor the condition of the training stage[4][10]. In figure 3 shows the Training Performance. 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.

4.3.2 Testing Stage

During testing stage, new data set is used to evaluate the trained network's performance. At the testing stage, network

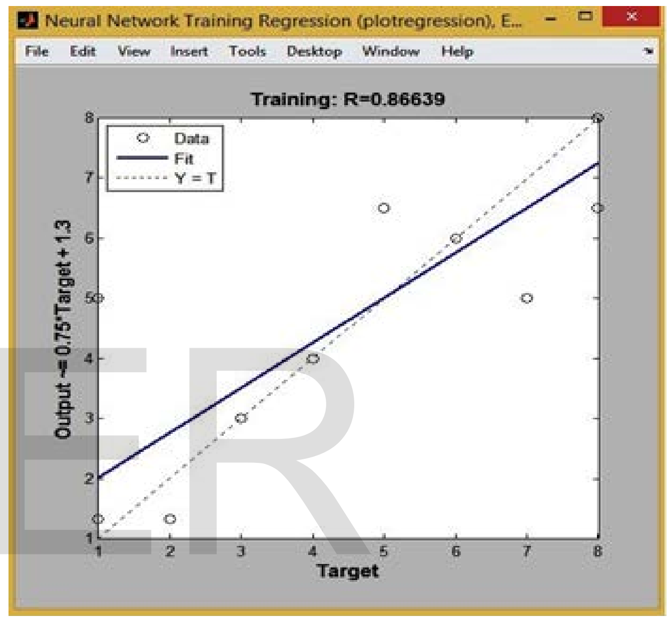

Fig 4. Regression Plot

is evaluated by using linear regression analysis. Figure 4. shows the Regression plot. Regression coefficient, R is computed, to analyze correlation between network outputs and targeted output [7]. A well trained network results in values of R close to 1, showing strong correlation between network output and targeted output[8][9][10]. The performance of the developed network is evaluated based on value of R. The best network is chosen based on closest value to 1.

5. 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, Rogers ratio method shown in table 3,4 and 5. these tables shows the comparison between conventional Rogers ratio method and with ANN approach to the Rogers ratio method. It is observed that out of 19 datasets Rogers ratio method inconclusive at 11 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.

Table 3.
Rogers Ratio Method with Ann Approach 20kv Alephata Make: Bhel 220/33kv 50 Mva, Year of Manuf.:2003 D.O.C. 18/7/2003.

Sr. No.	Year	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	Rogers Ratio Method	Rogers Ratio Method With ANN
1	2006	32	161	26	152	3	No prediction	Overheating 200 deg C-300 Deg C
2	2007	40	165	30	160	5	No prediction	Overheating 200 deg C-300 Deg C
3	2008	135	188	72	195	0.001	Core and tank circulating currents, overheated joints	General conductor overheating
4	2009	179	191	82	210	0.001	No prediction	General conductor overheating
5	2009	169	234	82	274	5	No prediction	General conductor overheating
6	2010	199	205	85	225	0.001	Core and tank circulating currents, overheated joints	General conductor overheating
7	2011	201	226	90	230	0.001	Winding circulating currents	General conductor overheating

Table 4.

Rogers Ratio Method with ANN approach 132kV Kamthadi Make: Atlanta 33/22KV 10 MVA, Year of Manuf.:2005 D.O.C. 16/10/2005.

Sr. No.	Year	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	Rogers Ratio Method	Rogers ratio Method with ANN
1	2006	329	49	54	370	5	No prediction	Winding circulating currents
2	2007	154	328	401	978	8	Winding circulating currents	Core and tank circulating currents, overheated joints
3	2008	28	85	132	684	0.001	No prediction	Slight overheating <150 degree celcious
4	2009	36	47	82	415	0.001	No prediction	Slight overheating <150 degree celcious
5	2010	15	20	70	320	0.001	No prediction	Slight overheating <150 degree celcious
6	2011	14	21	72	325	0.001	No prediction	Slight overheating <150 degree celcious

Table 5.
Rogers Ratio Method with ANN approach 132kV Sanaswadi Make: DANKE 33/22KV 12.5 MVA, Year of Manuf.: 2000 D.O.C. 06/09/2003

Sr. No.	Year	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	Rogers Ratio Method	Rogers ratio Method with ANN
1	2006	76	9	30	50	0.001	No prediction	Overheating 200 deg C-300 Deg C
2	2007	0.001	0.001	0.001	0.001	0.001	No prediction	Thermal decomposition
3	2008	3	28	38	48	0.001	General conductor overheating	General conductor overheating
4	2009	5	30	35	52	0.001	General conductor overheating	General conductor overheating
5	2010	6	28	24	35	0.001	General conductor overheating	General conductor overheating
6	2011	9	33	27	37	0.001	General conductor overheating	General conductor overheating

6. CONCLUSION

The overall system of multilayer feed forward back-propagation artificial neural network is successfully developed to interpret incipient fault in power transformer. This proposed ANN algorithm applied to Rogers Ratio Method has been tested by many real fault samples, and its results are compared with conventional Rogers Ratio method. The experimental result shows that diagnosis accuracy of DGA methods using ANN is higher than conventional DGA methods for fault detection of transformer. Hence, the interpretation of incipient fault of power transformer can be successfully done by using developed network of artificial neural network.
ANN approach has capability of automatically acquiring experiences from training data and the experiences. It provides remedy on drawback of these DGA ratio methods. These methods overcome the complexities and appear to be a promising approach to predict and classify incipient fault of power transformer.

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