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Developing Artificial Neural Network (ANN) Model for Fault Diagnosis of Power Transformer Using Dissolved Gas Analysis (DGA)

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Abstract— Power transformer is one of the major apparatus in the power system. Power transformer breakdown or damage may interrupt power transmission and distribution operation. Hence, to manage the life of transformers and to reduce failures some measures are being adopted. Dissolved Gas Analysis (DGA) is a reliable and commonly practiced technique for the detection of incipient fault condition within power transformer. This paper presents the application of Artificial Neural Network (ANN) for detecting the incipient faults in power transformer by using dissolved gas analysis technique. Using historical transformer failure data, ANN model was developed to classify seven types of transformer condition based on the percentage of three hydrocarbon gases. The method of DGA used is Duval triangle, while data collected from different utilities was used in training and testing processes. The proposed ANN algorithm has been tested by many real time fault samples and the results are compared with conventional Duval triangle method. The test results indicate that the proposed ANN yields a very satisfactory result where it can make a very reliable classification of transformer condition with respect to combustible gas generated.

Index Terms— Artificial Neural Network (ANN), Dissolved Gas Analysis (DGA), Duval triangle, Power Transformer.

1 Introduction

POWER transformers play an important role in both the transmission and distribution of electrical power. Transformers in continuous operation are subjected to electrical and thermal stresses. These cause the degradation of the insulating materials which then leads to the formation of several gases [1]. Hydrocarbons and carbon oxides are formed and dissolve in transformer oil due to decomposition of the electrical insulator. The carbon hydrogen and carbon-carbon bonds of the insulating oil break and this leads to formation of active hydrogen and hydrocarbons atoms. These atoms combine with each other to form gases such as Hydrogen (H_2), Carbon Monoxide (CO), Methane (CH_4), Carbon Dioxide (CO_2), Ethylene (C_2H_4), Ethane (C_2H_6) and Acetylene (C_2H_2) [2]. These gases tend to stay dissolved and can serve as the indicators of the type and severity of fault. The concentrations of the gases, total concentrations of the combustible gases, the relative proportions of gases and generation rates are used to estimate the condition of the transformer and the incipient faults present [1].

Dissolved Gas Analysis (DGA) is a core method for monitoring and diagnosing a transformer. But, in some cases, DGA fails to give diagnosis and interpret the fault. This normally happens when a transformer has more than one fault or when the gases concentrations are near the threshold. In multiple fault condition, gases from different faults are mixed up resulting in confusing ratio between different gas components. To deal with this problem, ANN technique has been used since the relationships between the fault types and dissolved gases can be recognized by Artificial Neural Network through a training process [1].

2 Dissolved Gas Analysis (DGA)

Transformers are highly reliable and efficient equipment used for bulk transfer of power from one voltage level to another and are always under the influence of electrical, mechanical, thermal and environmental stresses which cause the degradation of insulation quality leading to major breakdown of the power system itself. To avoid this, it is necessary to monitor the health of transformers [3]. When thermal or electrical stresses are higher than the normal permissible value, affects the insulating oil and cellulose material which leads to the formation of certain combustible gases, referred as fault gases, inside the transformer. The most significant fault gases produced by oil decomposition are H_2 (Hydrogen), C_2H_6 (Ethane), C_2H_4 (Ethylene) and C_2H_2 (Acetylene) as well as Carbon monoxide (CO) and Carbon dioxide (CO_2) which are produced from decomposition of insulated paper (Cellulose) [4].

Dissolved Gas Analysis is a well known and effective diagnostic technique for power transformer fault detection. The Gas Chromatograph (GC) is the most practical method used to identify combustible gases by analyzing the quality and quantity of gases dissolved in transformer oil [5].

3 DGA Methods

There are various methods of DGA used by organizations and

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utilities to access the condition of a transformer. Mostly used DGA methods are Key gas method, Doernenberg's ratio method, Roger's ratio method, IEC ratio method and Duval triangle method. The DGA method considered in this paper is Duval triangle method.

3.1 Key Gas Method

Decomposition of gases in oil and paper insulation of transformers caused by faults depends on temperature of faults. Various faults produce certain gases and the percent of these gases can be used to detect fault types, such as overheated oil and cellulose, corona in oil and arcing in oil. Table 1 shows the diagnostic interpretations by various key gas concentrations [6].

TABLE 1
INTERPRETATION OF FAULT BY KEY GAS METHOD

Gas Detected	Interpretation
Oxygen (O_2)	Transformer seal fault
Carbon Monoxide (CO) and Carbon Dioxide (CO_2)	Cellulose decomposition
Hydrogen (H_2)	Electric discharge (corona effect, low partial discharge)
Acetylene (C_2H_2)	Electric fault (arc, spark)
Ethylene (C_2H_4)	Thermal fault (local overheating)
Ethane (C_2H_6)	Secondary indicator of thermal fault
Methane(CH_4)	Secondary indicator of an arc or serious overheating

3.2 Doernenberg's Ratio Method

This method utilizes five individual gases or four gas ratios that are $R_1=CH_4/H_2$, $R_2=C_2H_2/C_2H_4$, $R_3=C_2H_6/C_2H_2$ and $R_4=C_2H_2/CH_4$. By using these gas ratios it detects the existence of three types of faults i.e. thermal fault, corona discharge and arcing as given in table 2. This method is based on thermal degradation principles.

TABLE 2
FAULT DIAGNOSIS ACCORDING TO DOERNENBERG'S RATIO METHOD

Diagnosis	R_1	R_2	R_3	R_4
Thermal decomposition	> 1.0	< 0.75	> 0.4	< 0.3
Corona (low intensity PD)	<0.1	Not significant	> 0.4	< 0.3
Arcing(High intensity PD)	0.1-1	> 0.75	<0.4	> 0.3

3.3 Roger's Ratio Method

This 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. A simple coding scheme based on ranges of gas ratios is used for the diagnosis of fault. Four conditions are detectable, i.e. normal ageing, partial discharge, thermal fault and electrical fault of various degrees of severity. Table 3 shows codes for gas ratios and table 4 shows the fault diagnosis by this method [5].

TABLE 3
CODES FOR ROGERS GAS RATIOS

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

TABLE 4
FAULT DIAGNOSIS ACCORDING TO ROGER'S 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)

3.4 IEC Ratio Method

IEC ratio method is originated from Roger's ratio method, except that the ratio C_2H_6/CH_4 is eliminated since it only indicated a limited temperature range of decomposition. In this method three gas ratios are used to interpret the faults [5].By using the gas ratios it detects the existence of four types of fault conditions, i.e. normal ageing, partial discharge, electrical faults and severity. Table 5 and 6 show the codes for different gas ratios depending on the range of gas ratios and their interpretation.

TABLE 5
IEC RATIO CODES

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
IEC FAULT DIAGNOSIS TABLE

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

3.5 Duval Triangle Method

This method uses values of only three gases CH_4, C_2H_4 and C_2H_2. The concentrations (in ppm) of these gases are expressed as a percentage of the total (CH_4+C_2H_4+C_2H_2) and plotted as a point (%CH_4, %C_2H_4, %C_2H_2) in a triangular coordinate system on a triangular chart which has been subdivided into different fault zones as shown in figure 1. Each zone is related to a certain type of individual fault as shown in table 7 [5]. An intermediate zone DT has been attributed to the mixtures of electrical and thermal faults in the transformer.

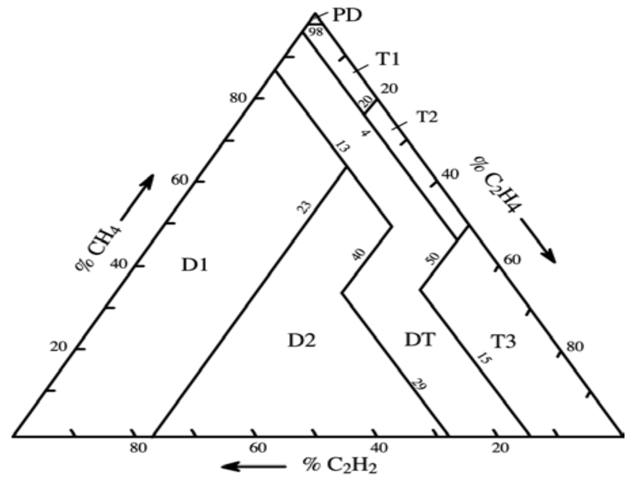

Fig. 1. Duval Triangle

TABLE 7
FAULT TYPE AND CORRESPONDING CODE USED IN ANALYSIS

Fault Type	Zone	Code
Partial discharge	PD	F1
Low energy discharge	D1	F2
High energy discharge	D2	F3
Thermal faults, T <300 °C	T1	F4
Thermal faults, 300 <T< 700 ºC	T2	F5
Thermal faults, T > 700 ºC	T3	F6
Mixture of electrical and thermal faults	DT	F7

4 ARTIFICIAL NEURAL NETWORK (ANN)

The concept of ANN is basically introduced from the subject of biology where neural network play an important role in human brain. Neural Network is just a web of inter connected neurons. In the neural network, the most basic information processing unit is the neuron. They are organized in three or more layers, such as the input layer, one or several hidden layers and single output layer [7]. ANN method can be used to recognize the hidden relationships between the dissolved gases and the fault types through training process. These hidden relationships may not be recognized by DGA methods. ANN approach is automatically capable of handling highly nonlinear input output relationships, acquiring experiences from training data, automatically adjust the network parameters, connection weights and bias terms of neural network, to create the best model. This feature will enable ANN to overcome some limitations of conventional DGA method [7].

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5 Implementation Of Ann To Duval Triangle

5.1 Data Collection

Data for various gases generated from transformer oil are collected from utilities. This sample data consists of the concentration of combustible gas generated in every sample of transformer oil. The oil sample had undergone through many tests to determine types and values of combustible gases generated. The developed network was created using 350 data samples.

5.2 Neural Network Configuration

In this paper, MATLAB is used to construct ANN model. Multilayer perceptron (MLP), a network organized in layers, was created. The transfer function used is *tansig*. The training algorithm used is *trainlm* and the training method used is Levenberg-Marquardt algorithm as it is the fastest training algorithm compared to others.

The developed neural network consists of single input layer, five hidden layers and single output layer. The input layer is made up of 3 neurons to which three gas concentrations are given as input. The output layer is made up of 7 neurons which give seven transformer faults conditions as the output. Five hidden layers consist of 2,4,6,8 and 10 neurons respectively. Figure 2 shows the ANN model with one input layer, five hidden layers and one output layer.

Fig. 2. Artificial Neural Network

5.3 Neural Network Training and Testing

The collected data samples are divided into two data sets: training data set (300 samples) and testing data set (50 samples). The training data set have been evaluated using conventional duval triangle method. In training stage, three gas concentrations are given to the input layer and the corresponding outputs are given to the output layer as targeted output. In testing stage, we feed the neural network model with the set of data that has not been shown to the network before and the final outputs are compared with the conventional duval triangle outputs.

A Graphical User Interface (GUI) is a window that enables a user to perform interactive tasks with the developed network. The values of fault gases are given as input to the network by using GUI and the window displays the type of fault as shown in the figure 3.

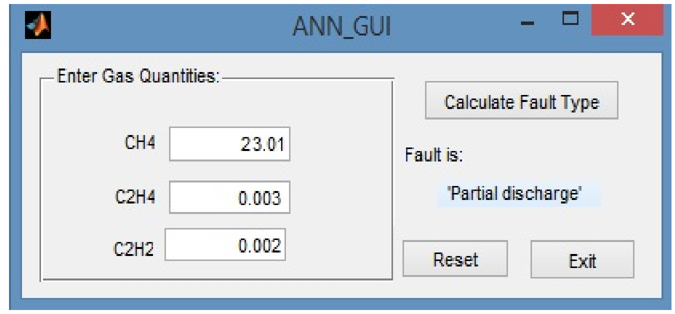

Fig. 3. GUI window

6 Result And Discussion

The performance of the developed neural network in training and testing stages are discussed below.

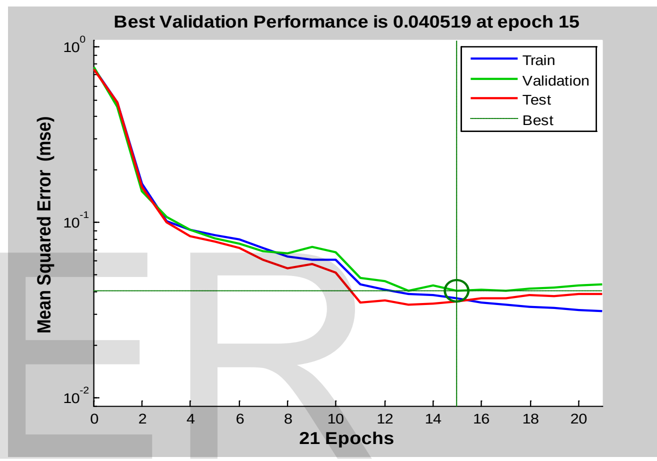

Fig. 4. Performance of Training Stage

Figure 4 shows the performance of the network during training stage. The graph shows that the test set error and the validation set error have similar characteristics. Early stopping was employed to the network to improve generalization.

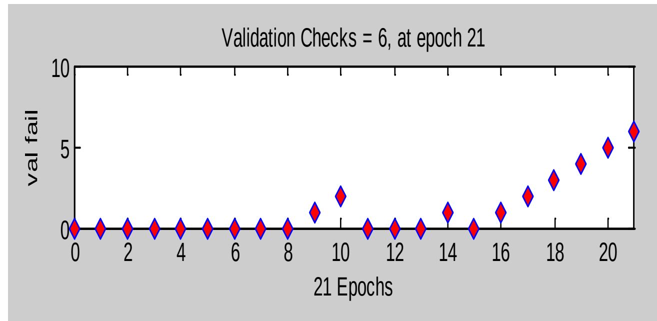

Fig. 5. Validation in Training Stage

Figure 5 shows validation check performance by validation set. Once the validation error starts to increase, the network stops the training process even though the goal is not yet reached. The network has the capability to generalize well. It will stop the training process at the optimum generalization capability. After training and testing the network best network was selected.

DGA method using Artificial Neural Network provides better accuracy in fault diagnosis as compared to conventional DGA method. Some of the diagnosis results based on Duval triangle with and without the application of ANN are displayed in table 8.

Neural network model was tested against 50 data samples and the results were compared with conventional duval triangle results. Table 9 shows the accuracy of the network.

TABLE 8
GAS CONCENTRATION VALUES AND PREDICTED FAULT TYPES

Sr. no.	CH_4	C_2H_4	C_2H_2	Duval triangle output	Duval triangle with ANN output
1	48.19	0.05	0.05	F1	F1
2	3.69	BDL	BDL	F1	F1
3	2	<1	0.5	F2	F2
4	BDL	BDL	19	F2	F2
5	5	34	24.4	F3	F3
6	4	30	19.9	F3	F3
7	<1	29	18.8	F3	F3
8	2	<1	<0.5	F4	F4
9	40	6	<0.5	F4	F4
10	70	21	0.5	F5	F5
11	2	<1	<0.5	F5	F5
12	5	18	3.5	F6	F6
13	11	30	4	F6	F6
14	4	30	13.1	F7	no prediction
15	3	19	5.5	F7	F6
Where, BDL – Below Detection Level					

The developed ANN model for prediction of incipient faults in power transformer is a three layer feed-forward back-propagation neural network with configuration [1,5,1]. Table 10 shows the properties of the developed network for detection of incipient fault in power transformer.

TABLE 9
DIAGNOSIS RESULTS

Method of DGA	Number of DGA samples Used	Number of DGA samples correctly Classified	% Diagnosis Accuracy
Duval Triangle	50	36	72 %

7 CONCLUSION

A model of multilayer feed forward back-propagation artificial neural network is successfully developed to predict incipient fault in power transformer using three dissolved gases concentration based on Duval triangle.

TABLE 10
PROPERTIES OF DEVELOPED NETWORK FOR DETECTION OF INCIPIENT FAULT

ANN properties	Properties
Network configuration	[1,5,1]
Transfer function	tansig
Learning rate	0.60
Momentum constant	0.60
Regression coefficient, R	0.83509
Epochs	21
Training Algorithm	Levenberg-Marquardt

The proposed ANN network has been trained by using 300 data samples and is tested by 50 data samples. The results of ANN model were compared with the results of conventional duval triangle method. After comparison, it is found that the proposed ANN model provides diagnosis for 36 samples similar to the conventional duval triangle method. The diagnosis accuracy is found to be 72%.

The proposed ANN model is found to be suitable for the prediction of incipient faults of power transformer. Further, the ANN model can be developed to handle the faults where conventional duval triangle method fails to give diagnosis.

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