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Health Assessment of an Oil Filled Transformer using Artificial Neural Network

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Abstract— Transformers are widely used equipment in power system. Reliability is one of the major requirements of today's power system. Any fault in power transformer will lead to serious problem and continuity of power supply is affected. In order to avoid catastrophic failure and reduce outage rates fault detection in its initial stage is required. Incipient faults lead to thermal and electrical stresses on transformer leading to decomposition of oil and insulation. This decomposition will generate gases due to decomposition. Thus based on this gas concentration a Dissolved gas Analysis (DGA) is used. In this paper various DGA techniques are reviewed. Then an ANN approach is applied to these conventional methods. After applying ANN approach to conventional methods accuracy was compared to conventional methods namely Rogers's ratio and Dornenberg methods.

Key words: Rogers Ratio, Artificial Neural Network, Dissolved Gas Analysis

I. Introduction

For Modern power system reliability is one of the basic requirements. Modern power system should be reliable and should have less outage period in case of fault. Transformers are widely used in power system. Faults in power system can lead to longer outage and thus hamper reliability of the system.

Transformer protection has gained utmost importance in modern protection scheme. Reliability of power system can be improved if the incipient faults are detected in early stage and removed before they develop in some serious faults.[1] Incipient fault develops thermal and electrical stresses on oil as well as insulation. Due to this stresses insulation as well as oil decompose and generate certain gases. Analyzing these gases will give us idea about the health of the transformer as well as the type of material involved.[1] Predicting transformer health based on gases concentration is not easy as it depends on various transformer parameters like loading, oil volume, construction type etc.

A diagnostic technique named dissolved gas analysis is widely used. This technique has certain, methods that can be used to predict the condition of the transformer. Various methods are Rogers ratio, Dornenberg, key gas etc. Rogers's ratio basically takes in account three gas ratios to detect the fault same way Dornenberg method uses four ratios. Key gas method uses concentration of individual key gas to determine the fault. So basically these methods can be classified as ratio methods, based on individual gas concentration and graphical methods. Thus various methods have been developed to monitor transformer health but there are limitations of each that can affect the accuracies of each.

These methods basically based on data association experience and ability of the analyst for reliable diagnosis. Thus results may vary from person to person and thus these methods are not that reliable. Thus search for a reliable tool to detect the fault using DGA is still a topic of interest for many. Thus next step is the use of artificial intelligence techniques.

Neural network is extensively used where pattern recognition is required. They are adaptive and quite capable of handling nonlinear relationship. Using this ANN approach for fault detection in oil filled transformer can be reduced to association process of inputs and outputs. The initial steps for incipient fault detection using ANN includes defining input\output pattern, ANN training and configuration [1] and finally testing network using known and unknown data.

II. Gas Analysis Techniques

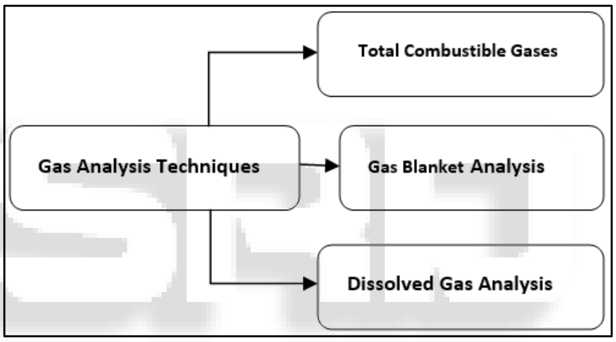


Fig. 1: Classification of Gas Analysis Techniques

The above three are the basic methods to perform gas analysis of transformer oil. First TCG it takes into account the sum of all combustible gases that are dissolved in oil. GBA is analysis of gas blanket that is formed between oil surface and top conservator tank. DGA is most commonly used method for oil analysis based on proportion of all the dissolved gases. It is most widely used technique and it is further classified into various methods they are as follows:

A. *Rogers Ratio Method*

It is a ratio method. It was the first method to be developed for fault diagnosis based on gas ratio. This utilizes mainly three gas ratio namely C_2H_2/C_2H_4, CH_4/H_2, C_2H_4/C_2H_6. Based on these ratios a refined code for detection is created. The flow chart for Rogers's ratio method is shown in fig

This method has certain limitations:

- It requires certain combinations of ratios to detect fault.
- It has high no of outputs as "NO PREDICTION".
- Unable to determine multiple faults and give precise location of fault.
- Stray gassing severely affects its diagnosis capability.

Based on flowchart a MATLAB program was made and tested with data collected from various electrical utilities. It predicted 34 cases accurately.

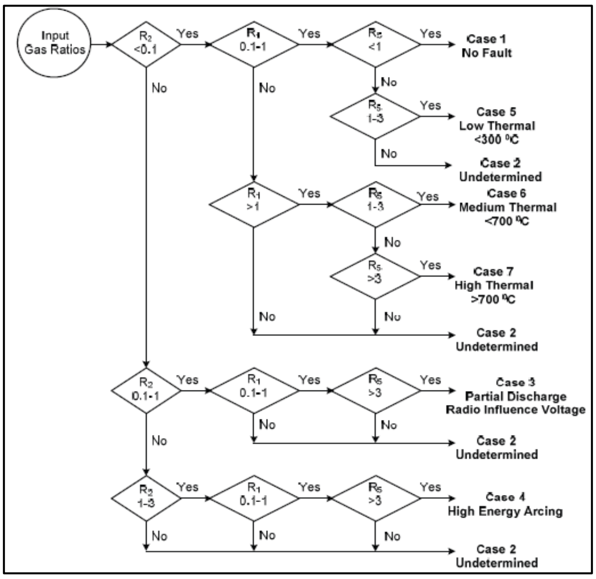


Fig. 2: Flowchart of Rogers's Ratio Method [7]

B. *Dornenberg Method*

It is also one of the ratio methods. But it is different from Rogers's method as it utilizes four gas ratios namely R1=CH4/H2, R2=C2H2/C2H4 R3=C2H2/CH4, R4=C2H6/C2H4. It also requires three conditions to be satisfied to make diagnosis. They are as follows:

- If at least one key gas concentration (H2,CH4,C2
- H2, C2H4) has exceeded twice it normal value.
- C2H6 and CO should have their concentration high Er than normal valve.
- Ratio should be verified.

This method is slightly better as compared to Rogers but has Many "Undetermined "cases due to above mentioned condition ion. The flowchart of this method is shown In Fig3

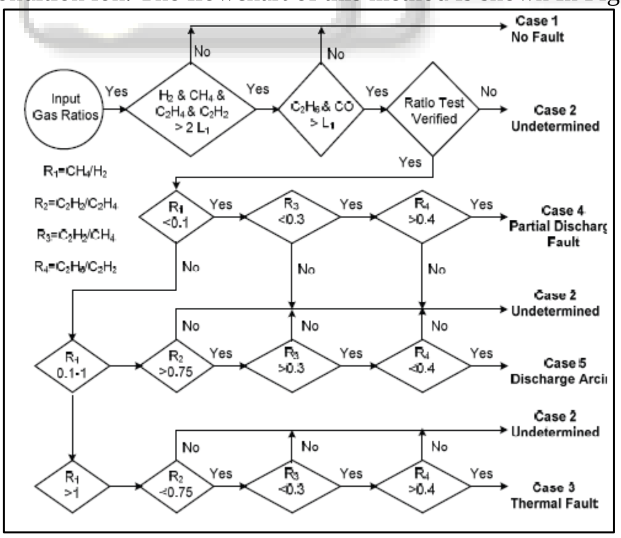


Fig. 3: Flowchart of Dornenberg Method [7]

Based on flowchart MATLAB program is coded and tested with 50 samples this method gave 32 correct predictions.

C. *Key Gas Method*

It is a method that makes diagnosis based on proportion of individual gases. It takes in to account four key gases to detect four types of fault. Total dissolved combustible gases are calculated and percentage of each gas is calculated.

TDCG=H2+CO+CH4+C2H2+C2H6

Key gas Percentage = [(key gas)/TDCG]*100

The main types of fault and key gas responsible for it are shown in table below:

Sr. No.	Key Gas	Fault Type
1	Overheated oil	Ethylene(C2H4)
2	Overheated cellulose	Carbon monoxide(CO)
3	Corona	Hydrogen(H2)
4	Arcing in oil	Acetylene(C2H2)

Table 1:

This method has its limitations as it is affected by stray gassing. Moreover the safe limit of each gas has no standard thus it affects the accuracy as it vary from operator to operator.

III. ARTIFICIAL NEURAL NETWORK

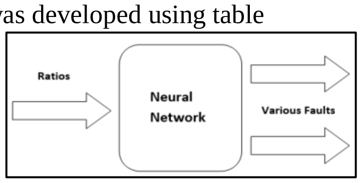
ANNs are tools particularly adapted to help specialist in maintenance in terms of the activities of classification, diagnosis and decision making, prediction etc. With the powerful learning ability, excellent generalization capability and infinite non-linear approximation characteristic, Neural Network (NN) has become a valid method for fault diagnosis (Yu Xu, et al, 2010). The highly non-linear mapping capability of the neurons of ANN-based fault diagnosis provides comparable and often superior performance over fuzzy system solutions. Stating that one drawback of fuzzy system is that it is bonded with conventional DGA methods, and cannot learn directly from data samples.

Application of ANN makes it possible to reduce considerably the laboratory experiment time while networks learn how to predict properties of insulation for duration longer than those of the test, thus, constituting a tool making more economical, the tests of high voltage in general. The researcher further explained that ANN method is more accurately used for DGA as it has hidden layers which have the ability to learn the relationship between the DGA result and fault type through training. ANNs have the ability to model linear and non-linear systems without the need to make assumptions implicitly as in most habitual statistical approaches. ANNs can be classified as feed-forward and feedback (recurrent) networks. In the former network, no loops are formed by the network connections, while one or more loops may exist in the latter. The most commonly used family of feed-forward networks is multi-layer NN.

Thus owing to the above mentioned capabilities and speciality ANN approach has been applied to conventional DGA methods and accuracy has been compared with that of conventional methods.

IV. NEURAL NETWORK ARCHITECTURE

ANN for fault diagnosis and classification based on DGA result using Rogers redefined ratio code is modelled in Mat Lab. It was developed using table



As shown in the above block diagram Ratios are given as an input to the network and we will get output as diagnosed fault in the transformer. Each fault has been given a specific code from 0 to 6 as shown in table below

FAULT	ASSIGNED CODE
No fault	0
High Thermal Fault	1
Low Thermal Fault	2
Medium Thermal fault	3
High Energy Arcing	4
Low Energy Arcing	5
Partial Discharge	6

Table 2:

A. Network Design Procedure

The ANN model for diagnosing fault conditions in transformer maintenance in this paper is designed using MATLAB toolbox. Design process involves the following steps

1) Data Collection

Data collected for this design are concentration of key gases such as H2, CH4, C2H4, C2H4, and C2H6 in part per million (ppm) obtained from DGA.

2) Network Creation

This requires choosing the number of hidden layers and their associated number of neurons.

3) Network Configuration

This specifies the number of input and output layers neuron based on the number of input and the needed output categories, and also initializes the network adjustable parameter (weights and bias).

4) Network Training

The weights and bias are adjusted such that the outputs are approximately equal to the target or known output of the network.

5) Network Testing

The performance of the network developed is tested using a part of the input data randomly selected by the application software.

B. Created Network

A network is created using ANN toolbox in MATLAB. Network with various configuration were created and one with best performance is selected. The selected network is shown below.

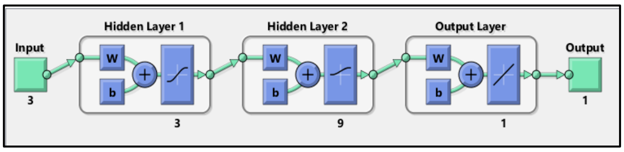


Fig. 4: Created ANN

The created network has two hidden layers having 3 and 9 neurons respectively. Inputs given are three ratios and there will be one output that is fault type.

During the training process which involves, training, validation and testing, the proposed network tries to match its outputs with targets. This goes for several iterations as the weights are adjusted to reduce the error between the output and the target to develop a linear relationship between inputs and outputs. Click on Regression button to view the relationship between target and output in figure5 and then on Performance tab to view network performance in figure 6. The closer the value, R is to 1 the more linear the relationship. The similarity between the test curve and the validation curve reveals that the network is well trained. Had there been a significant increase of validation curve before the test curve, over fitting could be assumed. Training and retraining continues until the network is able to generalize. As shown in figure 4, the proposed network topology has three inputs, two hidden layer with transig logsig and purlin transfer function in each and one output.

Performance plot of Created network is shown in fig 5

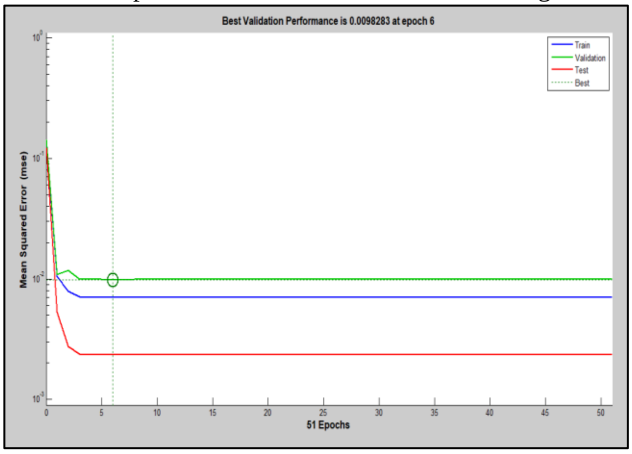


Fig. 5: Performance Plot

Regression plot of the network is shown in fig 6. Total of 700 data samples of DGA were collected from various electrical utilities. Total of 650 samples were used for training purpose and 50 were used to test the network. The network has a regression coefficient 0.9345 which shows close linear relation between output and input. The output of the network is shown in table 3 in results section.

Here back propagation algorithm has been used as training algorithm. It is based on the principle of weight updating based on the error in the output of network. Here output of network is fed back to network and error is calculated and based on that weights are updated to get output closer to target.

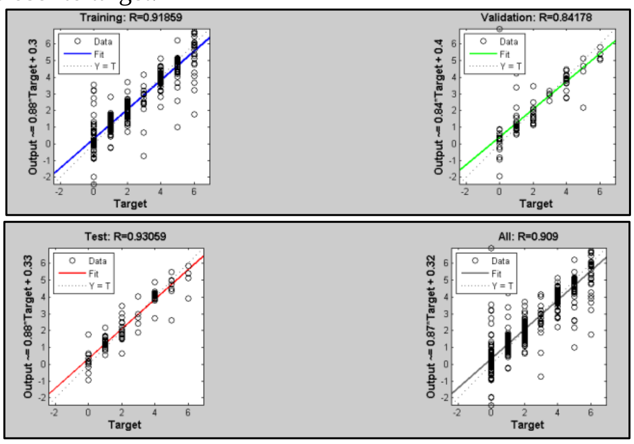


Fig. 6: Regression Plot

The above regression plot gives the idea about the relation between the input and out in all the three stages. Overall regression coefficient is 0.909.

C. ANN approach to Dornenberg Method

Now a neural network based Dornenberg model is created in which input is four gas ratios and the output is four transformer faults. The created network is as follows:

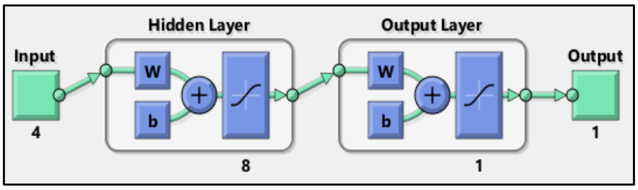


Fig. 7:

The regression plot for the network created is as follows

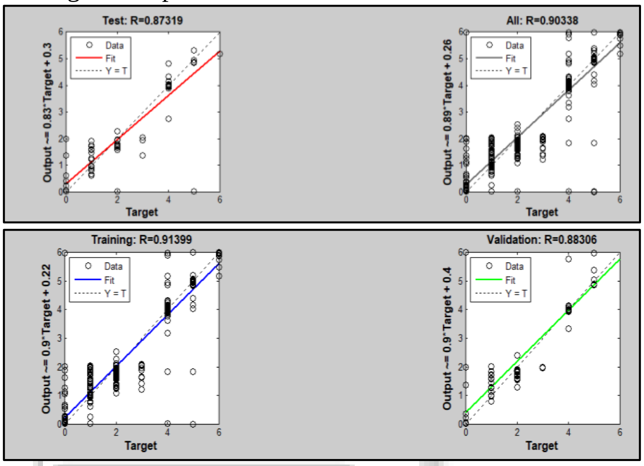


Fig. 8:

This ANN was trained using 600 samples and then tested with 48 samples and it predicted 46 correctly.

V. RESULTS & DISCUSSION

Created network was tested for 48 data and its results were compared with the results of conventional methods. Accuracies of all three methods are compared and shown in table. As from the results it can be seen that network successfully diagnosed 45 faults condition from total of 48 cases used for its testing.

Method	Correct Predictions	Accuracy
Rogers Ratio	34	68%
Dornenberg	32	64%
ANN(Dornenberg)	46	96%
ANN(RogersMethod)	45	95%

Table 3:

VI. CONCLUSION

As we can see from the results and comparison table above conventional methods have limited accuracies and have certain limitations. When ANN approach is used for these purpose accuracies has improved significantly. Thus convention methods can be improved by application of ANN

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