

# Review on Power Transformer Internal Fault Diagnosis

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## Abstract

Power Transformers have emerged as an integrated part of a power system. Any fault in the transformer can cause a severe outage, which therefore necessitates continuous monitoring and diagnostics of its operation. The faults in Windings, OLTC, Core, Terminals and Fluid are 88% of the total faults in the Power Transformer. The renewed thrust in smart power system networks along with the development of advanced methods in the monitoring and diagnostics has resulted in major impetus to research in the related domain. Artificial neural network (ANN) is powerful tool for the problem with small sampling and high dimension. ANN is applied to establish the power transformers faults classification. All configurations are evaluated using real-world training and testing data of Power Transformer from Tamil Nadu State Transmission Utility. The test parameters like winding parameters of voltage, current, winding resistance, etc., have been used in this Project for Power transformers faults detection. A multilayer feed forward neural network with a back propagation learning Algorithm is implemented. The performance of proposed ANN models, which in turn gives the performance of windings, Core, OLTC and Joints. RBF classifier is trained with the training samples. Finally, the trained classifier identifies the normal state and the fault types of transformers. The test results indicate that the ANN approach can significantly improve the diagnosis accuracies for internal power transformer fault classification.

## 1 Introduction

Power system stability depends on the reliable operation of various individual components within the network. Power transformer is one of the necessary and significant units in the transmission and distribution levels of a power system. However, it is subjected to many different types of faults which may cause interruptions in power supply; consequently result in serious economic losses as well as social impacts. Several fault diagnosis methods only could able to detect all the faults mentioned in Figure 1. As a result, effective fault diagnosis approaches are warrant to detect and

analyze the power transformer internal faults, and eliminate the associated impacts to the lowest possible level. Faults in a transformer can be categorized as internal and external faults. External faults include asymmetric fault, line to-ground fault, line-line fault, etc, while the internal faults include winding defects and winding insulation failures resulting in turn-to-turn fault or ground fault. The insulation degradation may happen because of several reasons including magnetizing inrush current, lightning strikes, prolonged overload, failure of cooling mechanism, etc.

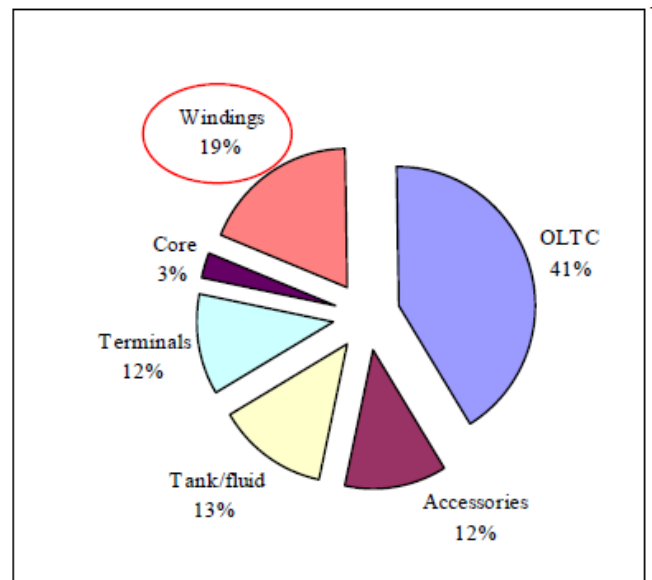


Figure 1

The test parameters like fault gas content in Transformer oil, winding parameters of voltage, current, winding resistance, etc., have been used in this paper for Power transformers faults detection. For repairing and reconditioning of the failed Power Transformer, diagnosing the fault in short duration is must so as to carryout the repairs immediately. Delay in repairing the Power Transformer / Replacement will cause delay in power restoration. Hence with the field data, identification and location of Internal Faults with ANN technique is essential for fault diagnosis.

In the past years, various fault diagnosis techniques have been proposed. From the available fault detection methods, we could not able to locate the internal fault at pinpoint. The various methods of fault diagnosis of Power Transformer are

1. Set pair analysis method is applied to design emulation model and implement fault diagnosis by fuzzy inference system [8].
2. Fault tree analysis method of expert grading is used to perform the probability of fault estimation based on fuzzy set theory [5].
3. Dissolved gas-in-oil analysis (DGA) is an important method to find the hidden or incipient insulation faults of oil-immersed Power Transformer calculating the correlation function of feature matter element models and standard ones. [9]
4. Based on the electrical and magnetic equivalent circuits, simple analytical models of three- and five-legged transformers are developed for the analysis of winding inter-turn fault using ANSYS Parametric Design Language (APDL) [2].
5. Transformer Fault Analysis based on fuzzy c-means (FCM) and quantum-inspired particle swarm optimization (QPSO) which can automatically configure network structure.[4]
6. Transformer winding fault classification based on Transfer Function Analysis by support vector Machine [10].
7. Power Transformer fault diagnosis based on Dissolved Gas Analysis by Artificial Neural Network [6].
8. Sweep Frequency Response Analysis to find the physical change inside the transformer [1].
9. Fault Diagnosis of Power Transformers using Auto associative Neural Networks based on the results of dissolved gas analysis [7].
10. Transformer Fault Diagnosis Based on Principal Component Analysis of dissolved gas content.[3]

This paper deals an artificial intelligence technique for the purpose of developing more accurate diagnostic tools based on Power transformer test parameters.

## 2. Internal Faults in the Transformer

The internal faults in the Power Transformer are due to winding defects and winding insulation failures resulting in turn-to-turn fault or ground fault. The insulation degradation may happen because of several reasons including magnetizing inrush current, lightning strikes, prolonged overload, failure of cooling mechanism, etc.

The internal faults in the Power Transformer are classified as below.

1. Core Fault
2. LV Ratio Link Fault
3. R – Phase winding Fault
4. Y – Phase winding Fault
5. B – Phase winding Fault
6. OLTC Fault

## 3. Comparative Study on Internal Fault Diagnosis Methods.

In 2006, Su, Hong – Sheng S; Mi, Gen – Suo have developed set pair analysis applied to design emulation model and implement fault diagnosis by fuzzy inference system [8]. In 2007 Tong Wu , Guangyu Tu, Z Q Bo and A Klimek have developed fault tree analysis method based on fuzzy set theory. The method of expert grading is used to perform the probability of fault estimation without the requirement for corresponding statistics information.[5]

In 2009, Peng, Li ; Lü, Fang-Cheng C. ; Li, Ning-Yuan ; Huang, Hua-Ping ; Xie, Qing have developed Dissolved gas-in-oil analysis (DGA) is an important method to find the hidden or incipient insulation faults of oil-immersed power transformer. By building the cloud matter element models of transformer fault diagnosis and calculating the correlation function of feature matter element models and standard ones, fault modes of transformer are identified. [9]

In 2010, R. S. Bhide, M. S. S. Srinivas, A. Banerjee and R. Somakumar have developed Analysis of Winding Inter-turn Fault in Transformer. , A simple analytical models of three- and five-legged transformers are developed based on their electrical and magnetic equivalent circuits, which can be easily implemented in the analysis of winding inter-turn fault. Various results obtained from the analytical models are validated with the help of Finite Element (FE) modeling using ANSYS Parametric Design Language (APDL) [2]. Ke Meng, Zhao Yang Dong, Dian Hui Wang, , and Kit Po Wong, have developed Self-Adaptive RBF Neural Network Classifier for Transformer Fault Analysis and this method is able to generate RBF neural network models based on fuzzy c-means (FCM) and quantum-inspired particle swarm optimization (QPSO), which can automatically configure network structure and obtain model parameters[4].

In 2012, Bigdeli, Mehdi ; Vakilian, Mehdi ; Rahimpour, Ebrahim have developed Transformer winding fault classification based on Transfer Function Analysis by support vector Machine. The required data for training and testing of SVM are obtained by measurement on two groups of transformers namely under intact condition and under different fault conditions (axial displacement, radial deformation, disc space variation and short circuit of winding) [10]. Souahlia Seifeddine, Bacha Khmais and Chaari Abdelkader have developed Power Transformer fault diagnosis based on Dissolved Gas Analysis by Artificial Neural Network. ANN is applied to establish the power transformers faults classification and to choose the most appropriate gas signature between the DGA traditional methods and a novel extension method [6].

Recently during 2013, Nishant Prakash , Mathura and Himanshu have developed Expert system for Sweep Frequency Response Analysis of Power Transformer. Changes in frequency response as measured by SFRA techniques may indicate a physical change inside the transformer[1]. D.Jeba Sundari Newlin and A. Venkatasami have developed Intelligent Fault Diagnosis Of Power Transformers Using Auto associative Neural Networks. In this method a set of Auto associative neural networks or auto encoders are trained for each transformer fault, such that each auto encoders becomes tuned with a particular fault mode based on the results of dissolved gas analysis[7].

From the above papers we get a clear picture of several fault diagnosis methods only could able to detect all the faults of the Power Transformer. The dynamic behaviour of Power Transformer was simulated using MATLAB. Accurate simulations are required to investigate the faults in the Transformer for the reliability of the power system stability.

## 4. Proposed Neural Network model of Transformer fault diagnosis

Radial Basis Function neural network (RBFNN) is a kind of three-layer forward neural network, the cryptic layer activation function of which is a set of radial symmetrical kernel function. When the input sample transmits to the cryptic cell space, this set of kernel function forms a set of "Base" of input sample. Accordingly, such neural network is called RBFNN.

RBFNN consists of input layer, cryptic layer and output layer as shown in Fig.2. Therefore, the node number of each layer is respectively I, H and O. The weight value from input layer to cryptic layer is 1, which means that the input vectors are sent to each cryptic mode without any change and the weight value from cryptic layer to output layer is adjustable.

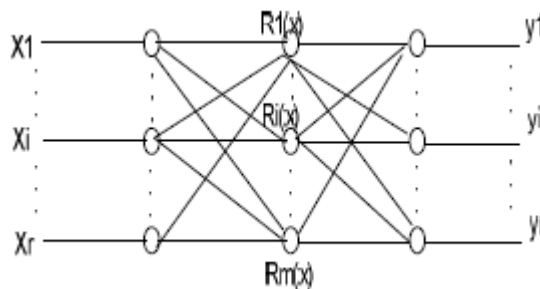


Fig . 2 Structure of RBF Neural Network

Because of numerous factors causing transformer fault and data measured on the spot about 160 of sample data collected can't be used for decision and instruction directly. To acquire reasonable data, improve the train efficiency of n0eural network, look for principal components, the sample data need to be preprocessed in order to cancel redundancy composition within sample data, Simplification network, shorten training time.

This method of fault diagnosis employs Test Results from different types of testing procedures like Core balance Test, Spill Current Test, HV and LV Winding Resistance Test, Magnetising Current Test, and Turns Ratio Test, calculations for training and testing in the failed and healthy 110/11 KV Power Transformer from Tamil Nadu State Transmission Utility.

### 4.1 Network Construction :

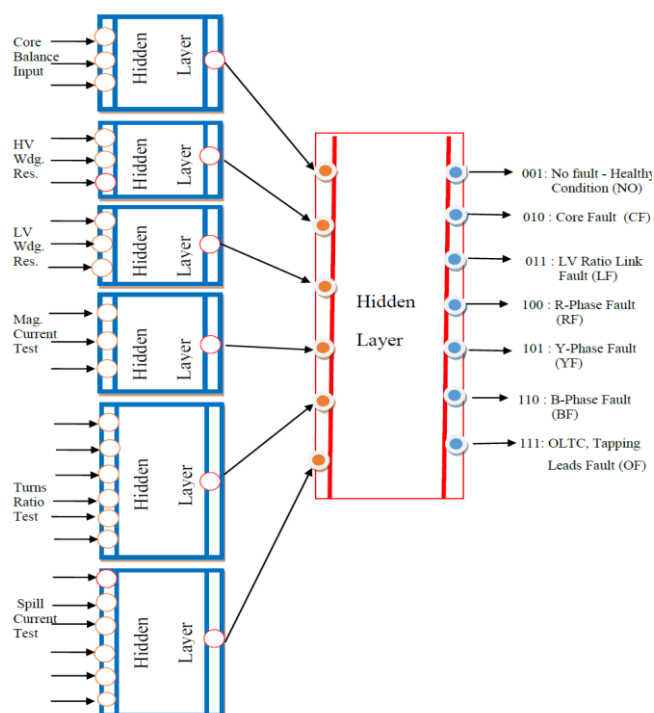


Fig. 3 ANN Configuration for Fault Networks

Six type of networks are constructed for Core Balance Test, HV Winding Resistance Test, LV Winding Resistance Test, Magnetising Current Test, Turns Ratio Test and Spill Current Test. Finally these six networks are combined to form seventh network in which its output indicate the nature of fault inside the Power Transformer like Core Fault, Winding Fault, OLTC and Joints Fault and No Fault & Healthy for healthy Transformer Test data.

a. Sample Data for Core Balance Test

$V_{RN} = [117 \ 116 \ 116 \ 0 \ 232 \ 6 \ 112 \ 230 \ \dots \ 118.3];$   
 $V_{YN} = [233 \ 231 \ 235 \ 229 \ 2 \ 235.3 \ 235 \ 228 \ \dots \ 236.7];$   
 $V_{BN} = [115 \ 113 \ 115 \ 229 \ 236 \ 232 \ 118 \ 225 \ \dots \ 117.3];$

b. Sample Data for HV Winding Resistance Test

$R_{RY} = [1.975 \ 1.987 \ 1.613 \ 2.08 \ 2.98 \ \dots \ 2.586];$   
 $R_{YB} = [1.953 \ 1.984 \ 1.657 \ 2.097 \ 0.54 \ \dots \ 0.446];$   
 $R_{BR} = [1.899 \ 1.884 \ 1.721 \ 2.096 \ 2.88 \ \dots \ 2.986];$

c. Sample Data for LV Winding Resistance Test

$R_{rn} = [19.371 \ 18.998 \ 18.85 \ 0 \ 21.80 \ \dots \ 22.985];$   
 $R_{yn} = [21.032 \ 19.902 \ 0 \ 20.2 \ 20.9 \ \dots \ 23.52];$   
 $R_{bn} = [19.718 \ 18.877 \ 33.4 \ 21.34 \ 23.2 \ \dots \ 24.253];$

d. Sample Data for Magnetising Current Test

$I_R = [7.14 \ 8.69 \ 8.89 \ 9.51 \ 8.92 \ \dots \ 8.6];$   
 $I_Y = [6.92 \ 8.94 \ 8.5 \ 0.42 \ 7.73 \ \dots \ 9.5];$   
 $I_B = [8.31 \ 9.19 \ 0.7 \ 7.58 \ 0.35 \ \dots \ 0.67];$

e. Sample Data for Turns Ratio Test

$V_{ry} = [41.6 \ 39.6 \ 42.6 \ 41.1 \ 40.2 \ \dots \ 0];$   
 $V_{yb} = [42.0 \ 38.4 \ 42.5 \ 40.5 \ 39.8 \ \dots \ 0];$   
 $V_{br} = [41.52 \ 39.78 \ 41.84 \ 39.98 \ 0 \ \dots \ 39.7];$   
 $V_m = [21.5 \ 20.9 \ 21.8 \ 22.0 \ 21.97 \ \dots \ 9.8];$   
 $V_{yn} = [21.2 \ 20.9 \ 20.32 \ 18.99 \ 2.35 \ \dots \ 21.8];$   
 $V_{bn} = [22.9 \ 24.2 \ 28.9 \ 22 \ 21 \ \dots \ 21.9];$

f. Sample Data for Spill Current Test

$I_R = [4.2 \ 3.9 \ 3.8 \ 4.4 \ 4.2 \ \dots \ 3.6];$   
 $I_Y = [4.2 \ 4.1 \ 3.5 \ 3.4 \ 4.3 \ \dots \ 3.7];$   
 $I_B = [4.6 \ 4.4 \ 3.9 \ 3.8 \ 4.2 \ \dots \ 4.1];$   
 $I_r = [41.7 \ 42.3 \ 39.8 \ 39.98 \ 40.38 \ \dots \ 41.6];$   
 $I_y = [39.8 \ 41.2 \ 4.02 \ 0 \ 42.3 \ 4.3 \ \dots \ 36.3];$   
 $I_b = [40.9 \ 42.2 \ 13.2 \ 43.4 \ 37.3 \ \dots \ 0];$

The data is divided into two data sets: the training data set (160 samples) and the testing data set (30 samples). The training data sets have to be evaluated using various test methods and the corresponding judgments related to seven classes have been provided, normal unit (70 samples), Core Fault (5 samples), LV Ratio Link Fault (10 samples), R – Phase Fault (25 samples), Y – Phase Fault (10 samples), B – Phase Fault (15 samples) and OLTC, Tapping Leads Fault (25 samples).

The Characteristics of winding Parameters of Power Transformer of with 110/11 KV class is used in this study.

The ANN faults classification is performed using Test Parameters and the proposed Test method as Test signature.

An ANN-based power transformer fault diagnostic system includes input features, network topology, fault outputs as well as training patterns. In the current study, we used Seven Neural Network for transformers test classification.

- Six types of Network are used for Core Balance Test, HV Winding Resistance Test, LV Winding Resistance Test, Magnetising Current Test, Turns Ratio Test and Spill Current Test.
- The Input to Six Networks were the actual Test Data measured at the field. The output of these Network will be either 1 or 0 for Healthy and Defect respectively.
- The Seventh Network is formed from the outputs of Six Networks. The Seventh Network gives the nature of fault inside the Power Transformer. It has Seven Outputs as below:
  - ❖ 001 : No fault - Healthy condition(NO) ;
  - ❖ 010 : Core Fault (CF) ;
  - ❖ 011 : LV Ratio Link Fault (LF) ;
  - ❖ 100 : R-Phase Fault (RF) ;
  - ❖ 101 : Y-Phase Fault (YF) ;
  - ❖ 110 : B-Phase Fault (BF) ;
  - ❖ 111: OLTC, Tapping Leads Fault (OF).

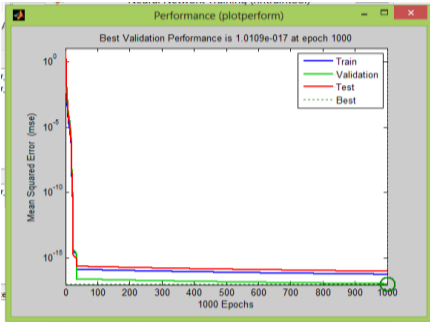
## 5. Results and Discussions

From the literature reviews, several fault diagnosis methods are required to detect all the faults of the Power Transformer. The dynamic behaviour of Power Transformer was simulated using MATLAB. Accurate simulations are required to investigate the faults in the Transformer for the reliability of the power system stability. From the Sweep Frequency Response Analysis (SFRA), core & winding deformation and movement of windings can be detected. In the other method the inter turn failure of the winding can be detected by Finite Element (FE) modelling using ANSYS Parametric Design Language (APDL). In Dissolved Gas Analysis (DGA) method, from the presence of different gases, the moisture, energy discharge and thermal faults in the Transformer can be detected. But in none of the method, we could able to point out the fault location at pinpoint. This drawback is over come by this fault diagnosis method using ANN.

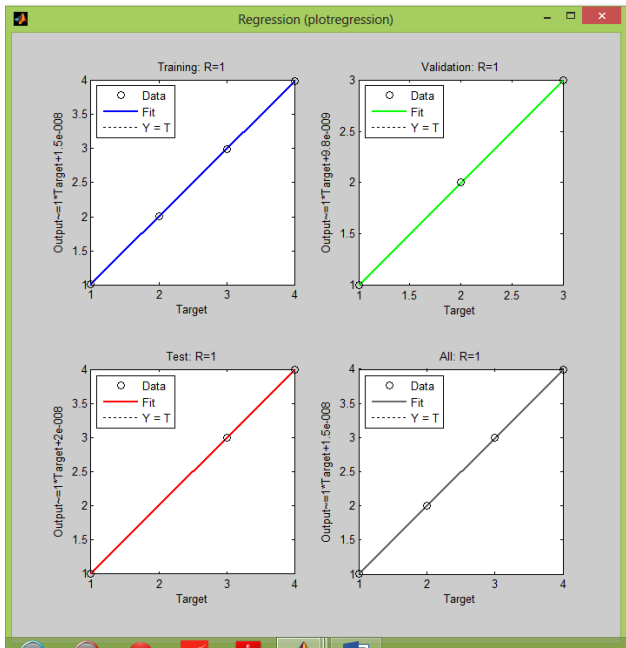
After configuration of seven Networks and their exportation in MATLAB workspace, the work space is saved with the assigned parameters and networks. The Power Transformer Fault Network was trained and the performance

plot is shown in Fig 4. The Regression Plot is as shown in Fig.5.

The Simulation of Network will give the Fault No. as assigned with respect to the specific fault directly in the MATLAB Network / Data Manager.



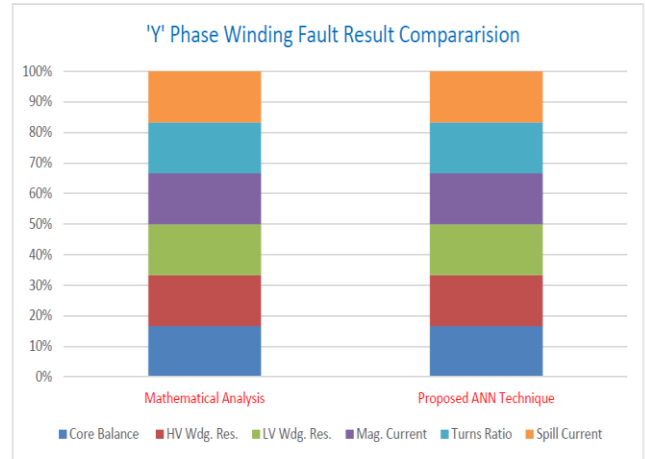
**Fig. 4 Performance Plot for Power Transformer Fault Network Training**



**Fig.5 Regression Plot for Power Transformer Fault Network Training**

The Neural Network with Feed Forward Back Propagation algorithm is used to recognize and classify complex fault patterns without much knowledge about the process and the accuracy of the ANN for faults diagnosis is comparable to conventional methods due to their great facilities for study. The experimental data from Tamil Nadu state Transmission Utility are used to illustrate the performance of proposed ANN Networks which in turn gives the performance of windings, Core, OLTC and Joints of the Power Transformer.

The Test Result of a Power Transformer with ‘Y’ Phase winding Fault is simulated in Proposed Artificial Neural Network and the same is compared with the mathematical Analysis of Fault Diagnosis and which shows exactly the same result with each method as shown in Fig.6.



**Fig. 6. Comparison of ‘Y’ Phase winding Fault Result using Proposed ANN Technique and Mathematical Analysis.**

The Power Transformer Fault Diagnosis can also be done through MATLAB Program after importing the Seven Networks in the work space after necessary training. The Power Transformer Fault can be identified directly from the Network simulation and iterations.

## 6. Conclusions

The primary objective of the work outlined in this proposal was to provide a reliable internal fault diagnosis of the Power Transformer and the objective has been met. The secondary objective was to have less time consumption when comparing to other fault diagnosis method and this objective has also been met. The third objective was the fault diagnosis to be economical when comparing with the other methods and this objective has also been met.

In this paper, the effectiveness of artificial neural network has been analyzed with Feed Forward Back propagation algorithm for the automation of decision on the power transformers state. The effectiveness of ANN diagnosis has been analyzed with RBF NN. The real data sets are used to investigate its feasibility in forecasting the internal faults in the power transformer. The accuracy of the RBF for faults diagnosis is comparable to conventional methods due to their great facilities for study. This method can be applied to any Power Transformer to find the internal fault.

We can conclude from the above mentioned studies that the prominent way of internal fault detection of Power

Transformer can be performed simply by uploading the Test Parameters effectively by simulation of RBF Neural Network.

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