Development of ANN and AFIS Models for Age Prediction of in-Service Transformer Oil samples

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Abstract

Power transformer is one of the most important and expensive equipment in electrical network. The transformer oil is a very important component of power transformers. It has twin functions of cooling as well as insulation. The oil properties like viscosity, specific gravity, flash point, oxidation stability, total acid number, breakdown voltage, dissipation factor, volume resistivity and dielectric constant suffer a change with respect to time. Hence it is necessary that the oil condition be monitored regularly to predict, if possible, the remaining lifetime of the transformer oil, from time to time. Six properties such as moisture content, resistivity, tan delta, interfacial tension and flash point have been considered. The data for the six properties with respect to age, in days, has been taken from literature, whereby samples of ten working power transformers of 16 to 20 MVA installed at different substations in Punjab, India have been considered. This paper aims at developing ANN and ANFIS models for predicting the age of in-service transformer oil samples. Both the the models use the six properties as inputs and age as target. ANN (Artificial Neural Network) model uses a multi-layer feedforward network employing back propagation algorithm, and ANFIS (Adaptive Neuro Fuzzy Inference System) model is based on Sugeno model. The two models have been simulated for estimating the age of unknown transformer oil samples taken from generator transformers of Anpara Thermal Power Project in state of U.P. India. A comparative analysis of the two models has been made whereby ANFIS model has been found to yield better results than ANN model.

Keywords: ANN, ANFIS, Power Transformer, Regression, Performance, Backpropagation Algorithm

I. INTRODUCTION

Power transformer is one of the most important constituent of electrical power system. The transformer oil, a very important ingredient of power transformers, acts as a heat transfer fluid and also serves the purpose of electrical insulation. Its insulating property is subjected to the degradation because of the ageing, high temperature, electrical stress and other chemical reactions. Hence it is necessary that the oil condition be monitored regularly. This will help to predict, if possible, the in-service period or remaining lifetime of the transformer oil, from time to time.

There are several characteristics which can be measured to assess the present condition of the oil. The main oil characteristics are broadly classified as physical, chemical and electrical characteristics; some of these are viscosity, specific gravity, flash point, oxidation stability, total acid number, breakdown voltage, dissipation factor, volume resistivity and dielectric constant. There exists a co-relation among some of the oil properties and suffer a change in their values with respect to time [2]. This variation of oil properties with respect to time has been utilised to develop the two models as said earlier

The training data for the proposed work have been obtained from literature, whereby ten working transforms of 16 to 20 MVA, 66/11 KV installed at different substations in the state of Punjab, India have been considered. The six properties of transformer oil such as breakdown voltage (BDV), moisture, resistivity, tan delta, interfacial tension and flash point have been considered as inputs and age as target. Test data have been taken from generator transformers of 250 MVA, 15.75kV/400kV from Anpara Thermal Power Project in state of U. P., India.

II. "ANN" AND "ANFIS" METHODS

It is known that classical models need linear data for their processing, therefore models like ANN and ANFIS that are based on soft computing techniques, play an important role for solving these kinds of non-linear problems.

Neural networks exhibit characteristics such as mapping capabilities or pattern association, generalization, robustness, fault tolerance, parallel and high speed processing. Neural networks can be trained with known examples of a problem to acquire knowledge about it. Once trained successfully, the network can be put to effective use in solving unknown or untrained instances of the problem. ANN model which uses multilayer feed forward network is based on back propagation (BP) learning algorithm of neural network. Backpropagation gives very good answers when presented with inputs never seen before. This property of generalization makes it possible to train a network on giving set of input-target pairs and get good output.

ANFIS stands for Adaptive Neural Fuzzy Inference System. Using a given input/output data set, the toolbox function ANFIS constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using either a backpropagation algorithm alone, or in combination with a least squares type of method. This allows the fuzzy systems to learn from the data they are modelling. These techniques provide a method for the fuzzy modeling procedure to learn information about a data set, in order to compute the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data. This learning method works similarly to that of neural networks.

III. DEVELOPMENT OF ANN MODEL

The proposed ANN model uses "Levenburg-Marquardt (trainlm) algorithm which is independent of learning rate, hence by simply changing the number of neurons in hidden layer, training and testing error could be reduced. A total of 700 data sets obtained from literature [2] were arranged in tabular form and used for training the neural network. The model uses a simple two layer network, one hidden layer and one output layer. Input layer comprises of six neurons, one for the each input, while the output layer has a single neuron for a single output, the age of oil sample.

It has been found that network architecture that uses 20 neurons in hidden layer gave the best performance with a regression of 0.999 and mean square error (MSE) of 83.0 (data is non –normalized, so error looks large) . The training continued for 184 iterations with training functions logsig in hidden layer and purelin in output layer respectively.

The model has been applied for the data obtained from Anpara Thermal Power Project, India. This data has been depicted in TABLE I.

Table - 1
Table for Testing Data

S. No.	*Tan δ (at 90^{0}C)*	*BDV (KV/cm.)*	*Moisture (ppm)*	*Flash Point (^{0}C)*	*IFT (N/m) (at 27^{0}C)*	*Resistivity (Ω-cm)x10^{12}*	*Age (days)*
1.	*0.026*	*56.8*	*16.7*	*152*	*0.03*	*1.25*	*604*
2.	*0.0058*	*64.8*	*16*	*147*	*0.031*	*3.4*	*1153*
3.	*0.0065*	*51.6*	*17.4*	*145*	*0.031*	*4.08*	*1933*
4.	*0.021*	*50.2*	*20*	*144*	*0.029*	*1.2*	*1934*
5.	*0.025*	*48.2*	*19*	*146*	*0.026*	*0.88*	*2258*
6.	*0.007*	*48.8*	*20*	*142*	*0.03*	*3.2*	*2306*
7.	*0.026*	*47.8*	*19.6*	*145*	*0.026*	*0.88*	*2407*
8.	*0.0317*	*59.2*	*16.6*	*145*	*0.027*	*0.86*	*2406*

IV. DEVELOPMENT OF "ANFIS" MODEL

Adaptive Neuro-Fuzzy Inference System (ANFIS) model, a hybrid of ANN and Fuzzy Logic techniques, is attempted to improve upon the performance of the previous ANN model. In Fuzzy tool box of MATLAB, ANFIS model uses SUGENO model. First of all in FIS editor window a new FIS is created with the six input variables and one output variable, the same FIS is set for training.

The data had been kept separate in the form of training data and testing data. Now the data, in the ANFIS model is loaded from the variable sheets which are in the form of Excel worksheet. First, a number of 700 training data pairs are loaded for training the FIS. This FIS has been generated using the grid partition and the same has been further edited to change number and types of membership functions assigned to each of the input and one output variable. Two membership functions of "gaussmf" type are assigned to each input variable while a "linear" type MF is assigned to output variable. Now after the FIS has been generated and MFs are defined, ANFIS model structure has been created as shown in Fig.1.

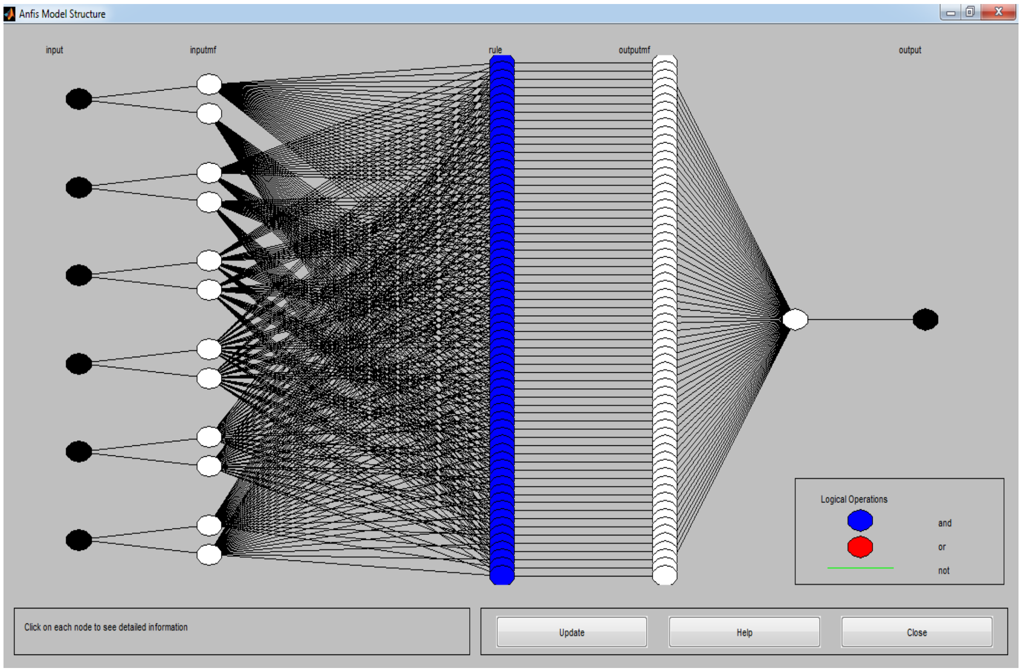

Fig. 1: Proposed ANFIS Model Structure

After generating the FIS it has been trained using hybrid optimization method. When training is started, the number of epochs are set equal to 10, but training has been completed in just two epochs with 64 fuzzy rules and an error of 10.0586. The complete information about training appears on command window of MATLAB after the training has been completed.

A total of 472 parameters, 448 linear and 24 nonlinear, have been used for training of proposed ANFIS model. For a number of 700 training data pairs, 161 nodes are required and 64 fuzzy rules have been fired. The logical operations that apply on these rules are AND, OR and NOT. Output obtained from these rules has been in fuzzified form which was then defuzzified to give a single crisp output value.

V. Simulation Results and Comparative Analysis of the Two Models

The age predicted by the model has been compared with actual age of the oil samples in terms of the error indices like error, percentage error and mean absolute percentage error. Actual data and network output of ANFIS model have been depicted in Fig.2.

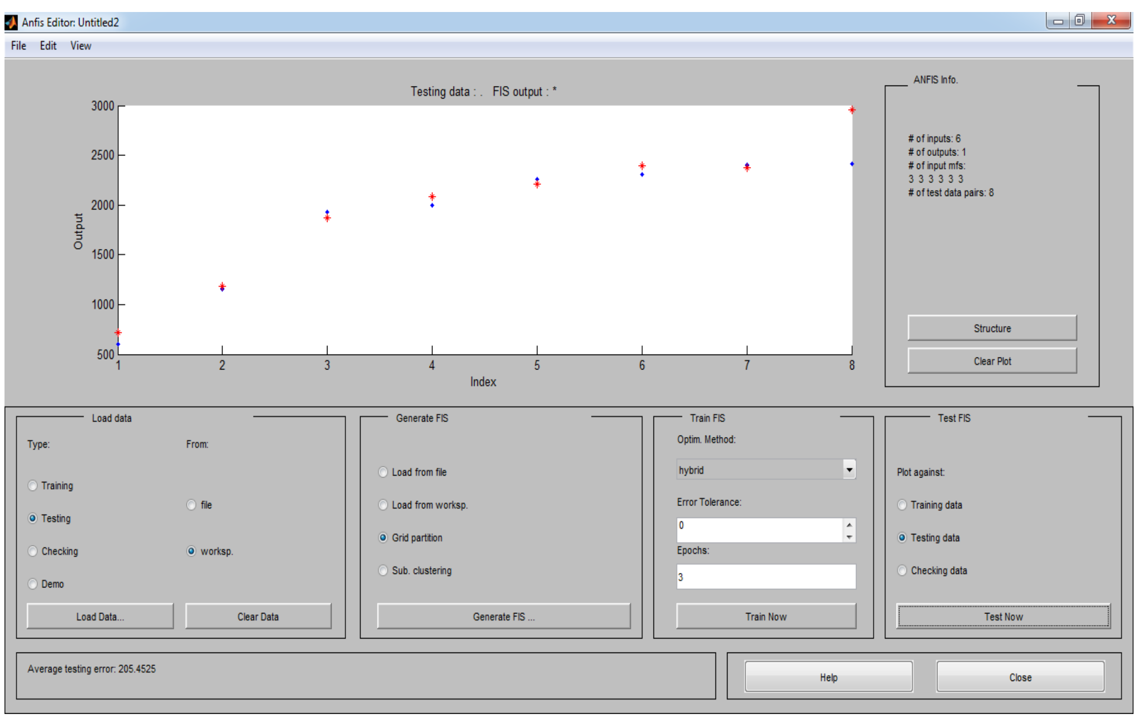

Fig. 2: Actual Age and Age Predicted by ANFIS Model

It is clear from Fig. 2 that age predicted by the ANFIS model have errors that are not significant for most of the results, but for sample number 1, 3 and 8 the errors are comparatively large. The results as mentioned in the TABLE II have also been plotted in Fig.3 by using MATLAB software.

Table - 2
Table Of Comparison For "ANN" And "ANFIS" Results

Oil Sample	*Actual Age (Days)*	*Age Predicted by ANN (Days)*	*Age Predicted by ANFIS(Days)*	*% Error (ANN Model)*	*% Error (ANFIS Model)*
1.	*604*	*741.87*	*680.73*	*-22.83*	*-12.70*
2.	*1153*	*1175.82*	*1203.77*	*-1.98*	*-4.10*
3.	*1933*	*1659.28*	*1743.46*	*14.16*	*9.81*
4.	*1934*	*2104.46*	*2017.30*	*-8.81*	*-4.30*
5.	*2258*	*2382.22*	*2327.75*	*-5.50*	*-3.08*
6.	*2306*	*2186.38*	*2329.06*	*5.19*	*1.00*
7.	*2407*	*2436.94*	*2468.50*	*-1.24*	*-2.55*
8.	*2406*	*3122.65*	*2853.65*	*-29.78*	*-18.60*
MAPE of ANN Model: 11.18 *MAPE of ANFIS Model: 7.01*					

The results of this comparison have also been plotted in Fig. 3 as shown hereunder.

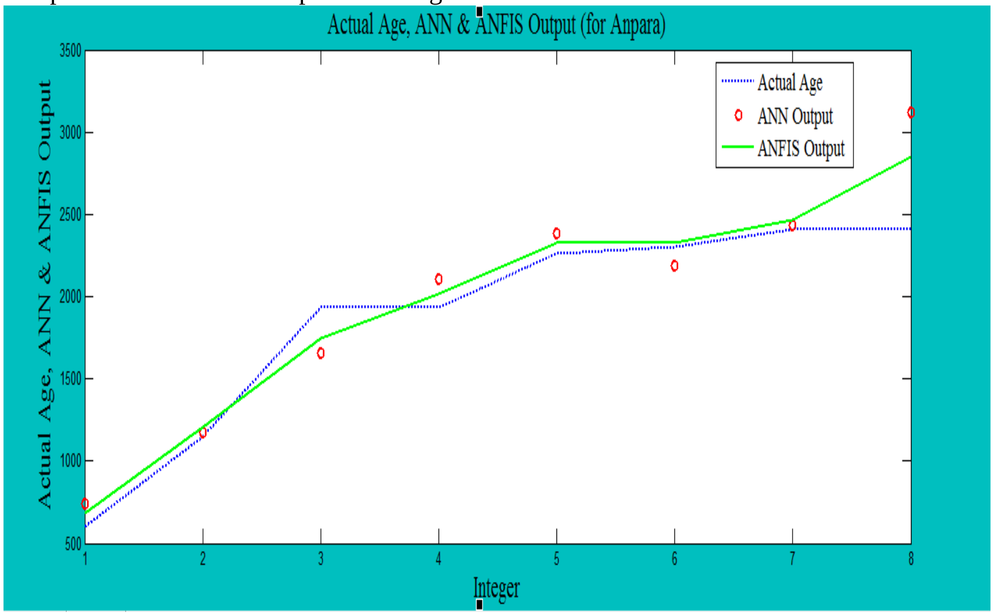

Fig. 3: Plot for Actual Age, Age Predicted by "ANN" and "ANFIS" Models

VI. CONCLUSIONS

In this paper ANN and ANFIS models using "nntool" and "fuzzy tool" of MATLAB software (2010b) have been developed. The models have been tested for the unknown data and the results of simulation were obtained in terms of predicted age, error, %error and mean absolute percentage error (MAPE). The results have been presented both, in tabular form and also in graphical form. A comparison between the two developed models has been made in terms of predicted age, error, %error and mean absolute percentage error (MAPE).

It has been found that there has been a significant improvement in ANFIS output values over those of ANN model. In this case MAPE improved from 11.18 to 7.01 i.e. by 4.17 points, and also regression improved from 0.925 to 0.971. This means errors in predicted values by the second model have reduced. The models can be extended to varied types oil samples provided the size of training data is large enough to accommodate oil samples of various types of operating conditions. The proposed models are expected to solve non-linear problems because of flexibility in handling nonlinear systems. Useful results of the study may be implemented in order to design an efficient and cost effective mechanism for health and age monitoring of any insulation system.

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