ANN Based Age Estimation of In-Service Transformer Oil Samples

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Abstract— The mineral oil or the transformer oil, the main ingredient of power transformer acts as an insulating and cooling agent. Some of the important oil characteristics like viscosity, specific gravity, flash point, oxidation stability, total acid number, breakdown voltage, dissipation factor, volume resistivity and dielectric constant are indicative of its insulating property that deteriorates during in- service period with respect to time. Some of the properties show correlation with service aging of the oil. 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 an ANN (Artificial Neural Network) model for estimating the age of in service transformer oil samples. The model uses the six properties as inputs and age as target. The most popular ANN architecture for such non linear problem is a multi layer feedforward network employing back propagation algorithm which is simulated for estimating the age of unknown samples of transformer oil.

Keywords— *ANN, Power Transformer, Regression, Performance, Backpropagation Algorithm*

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I. INTRODUCTION

Power transformer is one of the most important and expensive equipment in electrical network. The transformer oil, the main ingredient of power transformer acts as an insulating and cooling agent. The transformer oil is subjected to the degradation because of the ageing, high temperature and other chemical reactions which results in the deterioration of its insulating property. 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. There are several characteristics which can be measured to assess the present condition of the oil. The main oil characteristics are divided into the physical, chemical and electrical characteristics. Some of the important characteristics of the oil are viscosity, specific gravity, flash point, oxidation stability, total acid number, breakdown voltage, dissipation factor, volume resistivity and dielectric constant. The rate of aging is normally a function of temperature and moisture. Oil will age rapidly at high temperatures whereby the moisture acts as a catalyst for its aging.

II. PROPERTIES OF TRANSFORMER OIL

The main oil characteristics are divided into the physical, chemical and electrical characteristics which are described here.

A. *Physical Properties*

Different physical properties of transformer oil are described as follows.

1) *Moisture Content*

Moisture or water content in transformer oil is highly undesirable as it adversely affects the dielectric properties of the oil. Water content in oil is measured in ppm (parts per million). Water content in oil is allowed up to 50 ppm as recommended by IS – 335(1993). The accurate measurement of water content at such low levels requires very sophisticated instrument like Coulometric Karl Fisher Titrator.

2) *Interfacial Tension (IFT)*

Interfacial tension is exactly useful for determining the presence of polar contaminants and oil decay products. A good new oil sample generally exhibits high interfacial tension of about 0.04 N/m at 29.5 ^{0}C.

3) *Flash Point*

It is the temperature at which oil gives so much vapour that mixes with air, forms an ignitable mixture and gives momentary flash. For a good transformer oil flash point should be of higher value of about 145 ^{0}C.

4) *Viscosity*

The oil must be mobile to transfer the heat in a better manner from the core to the transformer radiators where heat is dissipated. So viscosity of the transformer oil should be very less. The prescribed value of viscosity is 22 kg/m^3 at 20^0 C.

5) *Pour Point*

Pour Point should be low for good transformer oil, which say at -6 degree centigrade starts just flowing, so pour point should be low so that oil can start flowing even at low temperatures.

B. *Electrical Properties*

Different electrical properties of transformer oil are described as follows.

1) *Electrical Breakdown Voltage (BDV)*

Break down voltage is measured by observing at what voltage, sparking starts between two electrodes immersed in the oil, separated by a specific gap. For measuring BDV of transformer oil, portable BDV measuring kit is generally available at site. In this kit, oil is kept in a pot in which one pair of electrodes are fixed with a gap of 2.5 mm (in some kit it is 4 mm) between them as shown in Fig1.

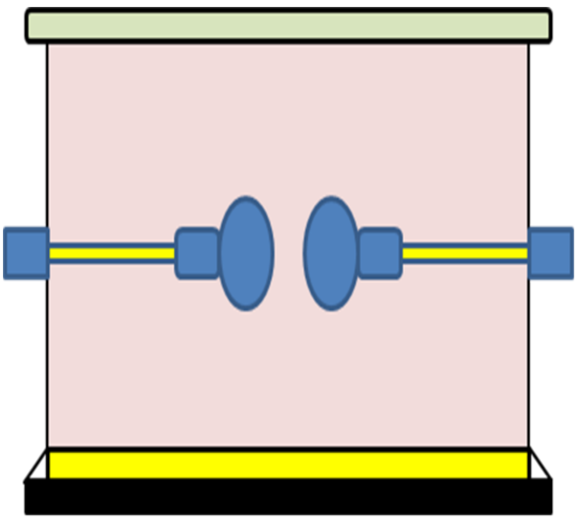

Fig. 1 A 2.5 mm Gap Electrodes in BDV Tester

Slowly rising voltage, at a rate of 2 KV/s is applied between the electrodes and observe the voltage at which sparking starts between the electrodes. The breakdown voltage of transformer oil at which this can safely be used is 30 KV/cm.

2) *Resistivity*

This is a measure of dc resistance between two opposite sides of one cm^3 block of oil. Its unit is taken as ohm-cm at specific temperature. With increase in temperature the resistivity of oil decreases rapidly. Lower resistivity of transformer oil indicates the presence of moisture and conductive contaminating agents. Minimum standard specific resistance of transformer oil at 90°C is 35x10^{12} ohm – cm and at 27°C it is 1500x10^{12} ohm – cm.

3) *Dielectric Dissipation Factor (Tan Delta)*

Dielectric dissipation factor is also known as loss factor or tan delta of transformer oil. When any insulating materials is placed between live part and grounded part of an electrical equipment, leakage current will flow. High value of tan δ is an indication of presence of contaminants in transformer oil. Therefore, it is desirable to have a small tan δ value.

C. *Chemical Properties*

Different chemical properties of transformer oil are described as follows.

1) *Neutralization Value*

It is the measure to determine the free organic and inorganic acids present in the oil expressed in terms of milligrams of KOH required to neutralize the total free acids in one gram of oil. Oxidation in the transformer oil is due to reaction between the hydrocarbons present in the oil and air. For good transformer oil total acidity should be low.

2) *Corrosive Sulphur*

Crude petroleum contains sulphur compounds. Most of this is removed at the time of refining process. Presence of corrosive sulphur results in pitting and black deposit on the surface of the bare copper which hinders the heat dissipation ability.

III. DEVELOPEMET OF ANN MODEL

In this paper, the author envisages to simulate the age estimation of transformer oil samples of different transformers using ANN with back propagation (BP) learning algorithm of neural network tool of MATLAB/SIMULINK. The data for the proposed work has 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. A total of 710 data set were retrieved from literature [2] and arranged in tabular form. Out of the 710 data sets 700 data sets were used for training the neural network and remaining 10 data sets were kept for testing purpose. Test data is shown in TABLE I.

TABLE I
TABLAE 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.	0.021	44.95	40.60	139.71	0.0290	2.01	2591
2.	0.012	55.29	19.31	145.64	0.0272	1.043	2310
3.	0.014	48.69	34.07	140.31	0.0290	2.24	2294
4.	0.023	75.80	21.92	143.49	0.0285	1.07	2244
5.	0.003	75.80	15.21	141.93	0.0304	4.30	897
6.	0.006	64073	16.61	149.53	0.0289	1.80	1446
7.	0.027	64.62	16.42	147.50	0.0278	0.89	1958
8.	0.012	50.91	26.37	142.63	0.0287	1.39	2005
9.	0.027	63.35	16.24	147.17	0.0275	0.89	2155
10.	0.023	47.81	21.92	143.49	0.0285	1.07	2243

The desired ANN model with back propagation (BP) learning algorithm 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. 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. The training continued for 184 iterations with training functions logsig in hidden layer and purelin in output layer respectively. Regression value of 0.9999 (close to1) indicates that target and output are nearly the same and hence training has been good.

Fig.1 sows the performance plots in which performance for all three types of plots, namely training plot (blue), testing plot (red) and validation plot (green) has been good as they closely follow one another and mean square error is gradually decreasing till the best performance is achieved at epoch number 178 where MSE is 175.8955.

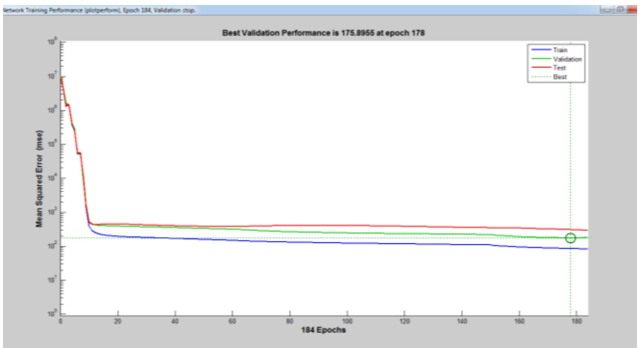

Fig. 2 Performance Plots

Now, after the network has been trained, its training plots for target and output generated by ANN are plotted in Fig. 2 The two plots, target (blue colour) and network output (red colour) are almost superimposed which means the values are nearly equal.

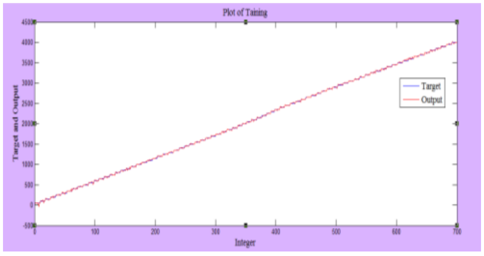

Fig. 3 Training Plot (Target and Output)

IV. SIMULATION RESULTS

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. The formulae for the three error indices are

Error = Output by ANN – Actual Output

Percentage Error = (Error / Actual Output) x 100

Mean Absolute Percentage Error (MAPE) = Σ | % Error | / No. of samples

Actual values, network output and error indices have been tabulated in TABLE II and graphs between actual age and age predicted by the network have been plotted in Fig. 3.

TABLE II
TABLE FOR ACTUAL AGE, AGE PREDICTED BY ANN, ERROR AND % ERROR

S. No.	Actual Age (Days)	Age Predicted by ANN	Error	% Error
1.	2591	2567.983	23.02	0.88
2.	2310	2299.142	10.86	0.47
3.	2294	2292.323	1.68	0.07
4.	2244	2258.205	-14.20	-0.63
5.	897	896.1074	0.89	0.09
6.	1446	1442.382	3.62	0.25
7.	1958	1963.316	-5.32	-0.27
8.	2005	2013.588	-8.59	-0.42
9.	2155	2142.475	12.53	0.58
10.	2243	2258.205	-15.2	-0.67
Mean Absolute Percentage Error (MAPE)= 0.4397				

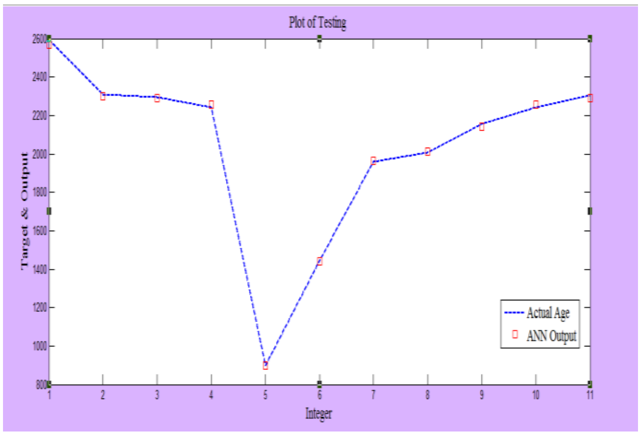

Fig. 3 Plot for Actual Age and Age Predicted by ANN Model

In this figure blue curve is for actual age while red squares indicate ANN output. The difference between the two values is very small as the two plots almost coincide.

V. CONCLUSIONS

In this paper ANN model based on backpropagation algorithm has been developed for predicting age of in-service transformer oil samples. It has been observed that model has yielded very good results with very small errors. The model 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 ANN model is expected to solve non-linear problems because of its 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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