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Neural Network Based Temperature Prediction

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Abstract: Hydroelectric power contributes around 20% to the world electricity supply and is considered as the most important, clean, emission free and an economical renewable energy source. India is endowed with economically exploitable and viable hydro potential assessed to be about 84,000 MW at 60% load factor. Hydro electric power plants operating all over the world has been built in the 20th century and are running at a higher plant-factor. This is achieved by minimizing the failures in plant and operating the plant continuously for a longer period at a higher load. However, continuous operation of old plants have constrained with the failures due to bearing overheating. The aim of this research is to model and simulate the dynamic variation of temperatures of bearing of a hydro electric generating unit.

Bearing heat exchanger system is a MIMO system with complex nonlinear characteristics, so it is difficult to model it using conventional modelling methods. Hence, in this research neural network (NN) technique has been used. Same approach is used to predict temperature rise in generator transformer in the plant. Temperature rise in transformers depend upon variety of parameters like ambient temperature, output current, type of core etc. Considering these parameters temperature rise estimation is a complicated procedure. This method avoids complication required for accurate estimation.

Keywords: Neural Network(NN), Winding temperature,Top oil Temperature, Bearing temperature, Hydro electricity, LM algorithm

I INTRODUCTION

HYDRO power contributes around 20% of worlds electricity generation[1].Hydro power produces no direct waste and will not contribute in emission of CO2, and various other green house gases compared to fossil fuel plants.It is a clean and emission free source of energy compared to others. As a renewable source of energy it has become a more economical resource compared to other renewable resourcesas far as the scarcity of fossil petroleum fuel deposits, environmental threats, climate chang due to green house gas emissions, and acid rains global warming, etc. are concerned. The global installed capacity of Hydro-electrical power generation is approximately 777GW with a production of 2998TWh/year [1]. It is around 88% of the renewable sources [2].

The deficit between electrical power generation and demand is met by thermal power generation.The present installed capacity is approximately **37,367.4 MW** which is 21.53% of total Electricity Generation in India. Kerala has 23 Hydro Electric Projects, two Diesel power plants and one Wind Farm. In order to obtain maximum capacity from existing power plants, minimizing their down times through various operations is very important. In that context predicting the availability of hydroelectric generating units for fault free operation is one of crucial factors for achieving this. Getting maximum possible share from hydro power plants will be a great savings to the national economy. Bearing oil temperature plays a vital role in continues operation of hydro power plants. Stability of bearing temperatures in turbine and generators are essential for their successful continues operations. All hydraulic and lubricating fluids have practical limits on the acceptable higher operating temperatures. The machine loses its stability and experiences conditional failures whenever the system’s fluid temperature violates this limits. Violations of the temperature limit could occur due to inadequate heat transfer rate, operating under higher ambient temperatures and

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longer duration of operation at higher mechanical loads. The power plant staff should closely monitor the bearing oil and metal temperatures in order to ensure a safe operation of the plant and the bearings life time [4].

Bearing overheating is one of the major problems for continues operations of hydropower plants. Monitoring the bearing temperature is an important task for continues running of a hydro electricity generating unit and maximizing the plant-factor. In this context, old hydro power plants continuous operations have been constrained with the failures due to the bearing temperatures rise. The temperature of a bearing depends on multiple variables such as temperatures of ambient air, cooling water and cooling water flow-rate, initial bearing temperatures, duration of operation and electrical load. Aim of this study is to minimize the failures of hydropower plants due bearing temperature variations and to improve the plant-factor. The bearing heat exchange system of a hydropower plant is multi-input (MI) and multi-output (MO) system with complex nonlinear characteristics. The heat transfer pattern is compel in nature and involves with large number of variables. Therefore, it is difficult to use conventional modelling methods to model a system of this nature. So that Neural Network (NN) method has been selected as the best where past input and output data is available, and the input characteristics can be mapped in order to develop a model. The aim of this research project is to model and simulate the dynamic variation of bearing (generator upper guide bearing UGB, generator Lower guide bearing LGB, turbine guide bearing TGB, thrust bearing THB) temperatures of a hydro electric generating unit.Typical acceptable bearing temperatures of a vertical hydroelectric turbine generator unit is shown in the table below.

Table 1:Bearing Metal/Oil Temperature limits

Bearing type	Metal Temperature (deg c)	Oil temperature (deg c)
Upper Guide Bearing	85	50
Lower Guide Bearing	85	65
Thrust Bearing	85	65
Turbine Bearing	70	70

Power transformers are the main components and constitute a large portion of capital investment. When a power transformer fails, an adverse effect occurs in the operation of transmission and distribution networks resulting in increase of the power system operation cost and decrease of reliability in electricity delivery. Temperature rise is one of the most crucial parameters that affect the transformer lifetime. Temperature rise can easily leads to the serious damages. This makes temperature estimation an important priority for engineers and companies. Power transformer outages have a considerable economic impact on the operation of an electrical network. Ageing of insulation mainly depend upon thermal load.Inorder to keep power transformers in long service it is worth to pay particular attention to its thermal behaviour.Top oil temperature prediction is an opportunity to diagnos its thermal behaviour.Through the comparison of measured value and predicted value operational problems can be detected.

A basic method for top oil temperature calculation from the IEEE/ANSI C57-115 standard [3] has been accepted for decades. however this model has a limitation of an accurately account due to an effect of variation in ambient temperature. some models investigated in[5],[6] in long term periods with varying load and ambient temperature. Results showed the deviation between measured and calculated as 2 K. However since an ANN presents a growing new technology as indicated by a wide range of applications, it has become an important tool in modern numerical calculations. Therefore there is also an interest for transformer top oil temperature prediction using NN.Several studies have been already presented using neural networks as a tool to improve accuracy of top oil temperature calculation[7][8][9].Neverthles these investigations are predicted only with short term periods and their application to transformer in the field was not tested.

II. NEURAL NETWORKS

Neural network or Artificial neural network(ANN) refers to an interconnecting group of artificial neurons that uses a mathematical model or a computational model designed to model some properties of biological neural network.In some practical term, neural network are non linear statistical data modelling tools.They can be used to model complex relationship between inputs and outputs to find pattern in the data.An attraction of neural network is that they are best suited to solve problems that are most difficult to solve by traditional computation methods. NNs imitate the function of human brain or biological nervous system made up of small units called neurons. The network is formed by connecting the neurons with each other by adjustable weights between neurons. Neural network can be trained or adjusted to get a desired output or target for a given input. Hence, when the input, output characteristics of a system; historical data is available we can train a NN to model the system.

The following formal definition was proposed by Hechi-Nielson [10][11][12] which describes the functionality of neural network."An artificial neural network is a parallel distributed information processing structure consisting of processing units (which can posses a local memory and can carry out localized information processing operations) interconnected via unidirectional signal channels called connections. Batch processing unit has a single output connection that branches ("fans out") into as many collateral connections as desired: each carries the same signal – the processing unit output signal. The processing unit output signal can be of any mathematical type desired[13]. The information processing that goes on within each processing unit can be defined arbitrarily with the restriction that it must be completely local: that is, it must depend only on the current values of the input signals arriving at the processing element via impinging connections and on values stored in the processing unit's local memory."

III FEED FORWARD ARCHITECTURE

Feed Forward Neural Networks are the most popular and most widely used models in many practical applications. They have been being applied successfully to solve some complex problem including non linear system identification and control, financial market analysis,signal modelling, power load forcasting etc.

Feed Forward Neural Networks are composed of many computing elements called neurons, working in parallel.The elements are connected by weights, which are allowed to be adapted through learning process. The weights on these connections encode the knowledge of network.An input- output represents raw information that is fed into a network connected to an output layer through one or more layers,which are called hidden layers(fig).Number of hidden layer are user design parameters. The general rule is to choose these parameters so that the best possible model with as few parameters as possible is obtained.

Every unit in the layer is connected with all units in the next layer.Each connections may have different strength or weight. Data enter at the inputs and pass through the network, layer by layer to the next until they arrive at the output. There is no feedback between the layers.No unit is linked between the same layer,back to the previous layer or skipping the layer. That is why they are called feed forward neural networks.

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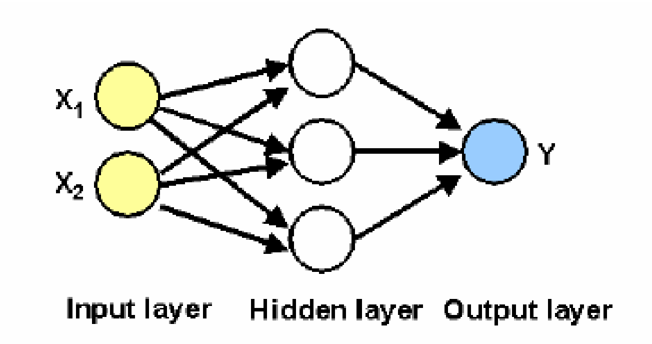

Fig 1: Feed Forward Neural Network

The behaviour of the output unit depends on the activity of the hidden units and the weigths between the hidden unit and output units.The outputs can be obtained from taking the linear combination of input signals and their weights,then transform them with an activation function.Each neuron starting from the hidden layer is usually transformed with a non linear (sigmoid or hyperolic tangent) activation function and the activation function in the output layer can be either a non linear (a non linear – non linear network) or linear (a non linear – linear network).The output of the network can be written in mathematical form as presented in (1)

$$Y = \sigma(\sum_i^n w_i x_i - \theta) \qquad (1)$$

Where 'Y' is the output, x_i is the input, w_i is the neuron weight and θ is the bias term (another neuron weight) and σ is the activation function.

The network weights are adjusted by training the network. The training process involves adjusting the weights till an aim is obtained.The aim involves minimising the sum of squares of differences between desired and the actual outputs. The network learning is carried out by repeatedly feeding the input – output pattern to the network. One complete entire training set is called an epoch. There are a number of such learning rules available for neural network models.The delta rule is one of the most commonly used learnng rule.It is also called the Least Mean Square (LMS) method.For a given input vector,an output vector is compared to a correct answer.If the difference is zero,no learning takes place, otherwise the weights are adjusted to reduce this difference. The change in weight 'w' from output 'u_i' to u_j is given by equation (2),where 'r' is the learning rate a_i represents the activation of u_i and e_j represents the difference between the expected output and the actual output of u_j[14].
If the set of input patterns form a linearly independent set then arbitarary associations can be learned using the delta rule.

$$\Delta w_{rj} = r * a_i * e_j \qquad (2)$$

VI TEMPERATURE PREDICTION

This section describes the approach and steps followed to develop a dynamic model to simulate hydro-electric power generating unit bearing temperature variation with time, electrical load, with the duration of operation and other environmental factors. 1) As the system consists of several heat exchangers, which has different inputs and output bearing temperature variables, first the inputs (which characterize the behaviour of the system) and outputs of the model are clearly identified. 2) Then the past historical data over a period is collected from past operation data records. 3) Then an artificial NN is formed to model the system by mapping the input to known outputs.The system is modelled using MATLAB neural network tool. 4) The simulated results are compared with past actual outputs and necessary adjustments are done to get the required accuracy. Input variables which affect to the characteristics of the system under investigation are listed out below:

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Electrical load in MW,MVAR,Unit voltage,Upper bearing oil temperature,Lower bearing oil temperature,Turbine bearing oil level,Cooling water inlet temperature,Cooling water outlet temperature,Cooling water pump amps,Turbine cooling water inlet pressure,Turbine cooling water outlet pressure. As a case study, a set of data records were obtained from the Lower periyar generating station, Kerala. It is a vertical shaft turbine generator unit which has an electrical power generating capacity of 180 MW.Station has three generating unit each producing 60 MW. The data set was extracted from eight channels of the DAQSTANDARD R8.11 data recorder, which contains bearing metal temperatures, cooling water flow rates and generator electrical load. The data set consists of 102 datas. The sampling period of data was 1 hour intervals. Input variables selected for predicting winding temperature of transformer are listed below:
Current per phase,Active power,Reactive power.As the first step of forcasting the datas required to forcast the temperature of bearings were determined. The number of input to neural network was considered as 12.All these datas were collected from the generating station and these datas were converted to an excel file.the input data consisted of 102 rows and 12 coloumns.the model was divided into sub models and temperatures of each bearings were predicted separately to improve the accuracy of the neural network.

The accuracy of prediction can be increased by providing normalised datas to the neural network..The whole data set was divided into sub sets to evaluate the networks.The best performance was obtained whEn maximum datas where provided for training.The next step was to determine the networks topology which means to identify the number of neurons in the hidden layer. Higher the number of hidden layers, and number of neurons in each layer the computing power (memory and processor speed) required is higher. Hence, a compromization between accuracy and computing power is needed. The network was trained using LM algorithm The neural network was trained and temperature variation of the four bearings were plotted..Similarly winding temperature of generator transformer was plotted and actual and predicted values were compared.

VII SIMULATION RESULTS

Temperature variation plot of the four bearings namely turbine guide bearing,lower guide bearing,upper guide bearing and thrust bearing is shown below.The variations are plotted with real value

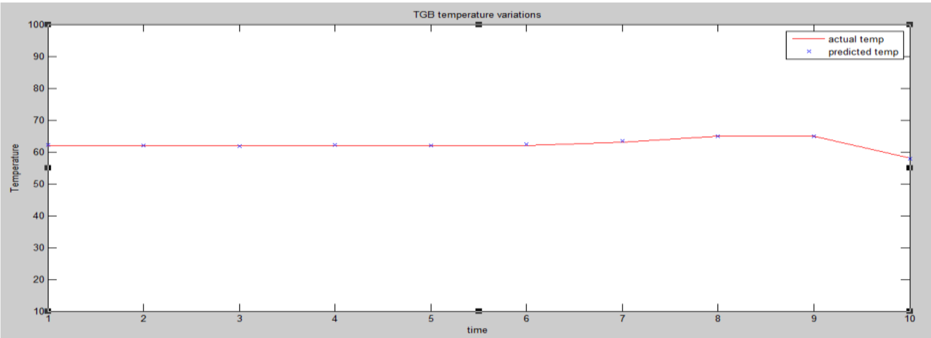

Fig 1 :Temperature variation plot of TGB

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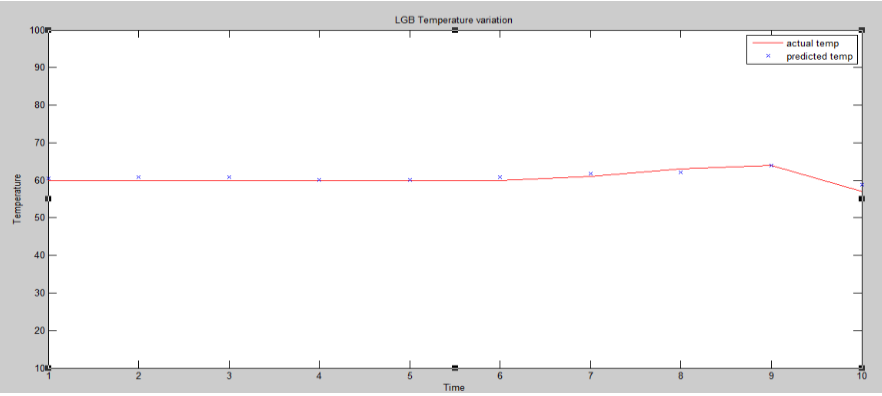

Fig 2 :Temperature variation plot of LGB

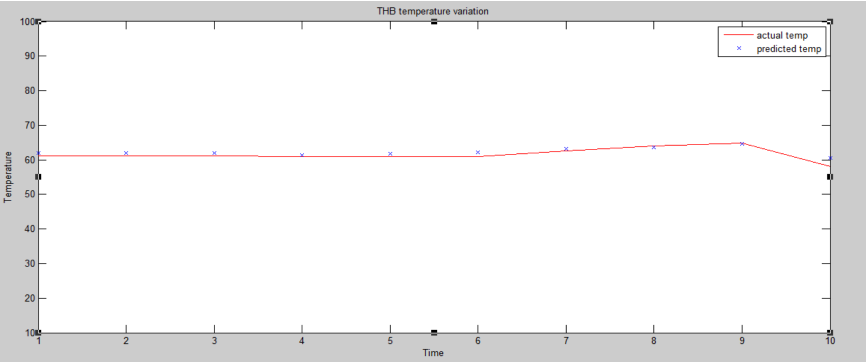

Fig 3 :Temperature variation plot of THB

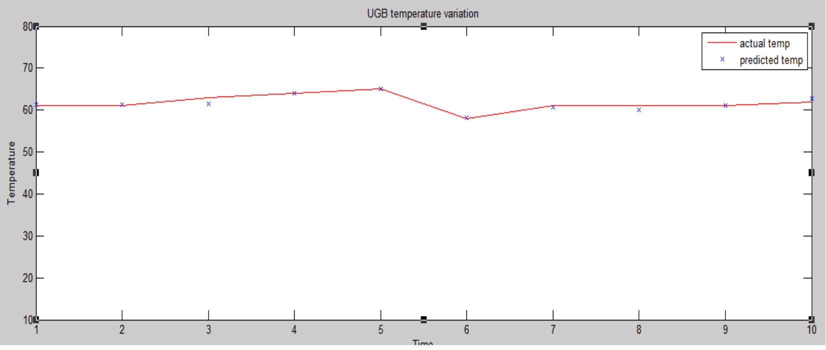

Fig 4 :Temperature variation plot of UGB

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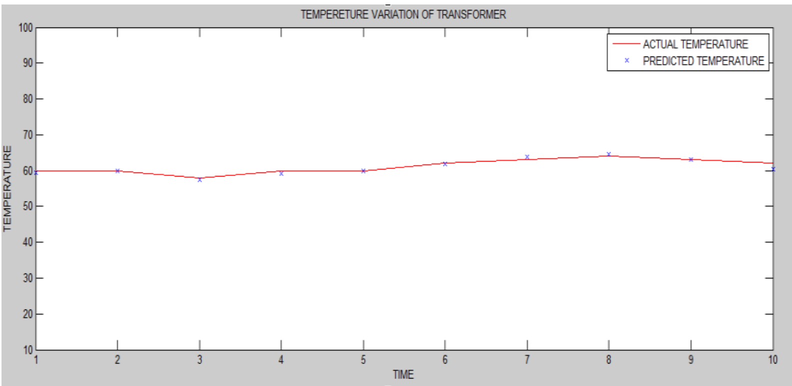

Fig 5 :Temperature variation plot of Transformer

Following table shows the mean squared error of bearing temperature when choosing different data sets.

Table 2:Error values with different data sets

Data sets	Training error	Validation error	Test error
90,5,5	$2.97214e^{-1}$	$3.29505e^{-1}$	$8.989e^{-1}$
80,10,10	$2.29514e^{-1}$	$2.47036e^{-0}$	$6.95509e^{-1}$
70,15,15	$6.58233e^{-1}$	$1.48207e^{-0}$	$1.50825e^{-0}$

Following table shows the mean squared error with real and normalised values

Table 3:Error values with real and normalised data sets

Data set	Training error	Validation error	Test error
90,5,5 (real)	$2.97214e^{-1}$	$3.29505e^{-1}$	$8.989e^{-1}$
90,5,5 (normalised)	$6.79138e^{-4}$	$8.9424e^{-4}$	$8.3308e^{-3}$

IX CONCLUSION

Continuous operation of old hydropower plants have constrained with the failures due to bearing overheating. The objective of this work was modelling and simulation of dynamic variation of temperatures of bearings (generator guide bearing, turbine guide bearing, thrust bearing) and winding temperature of generator transformer of a hydro electric generating unit. The temperature of a bearing is depends on multiple variables such as ambient air temperature, cooling water temperature, cooling water flow-rate, initial bearing temperatures, duration of operation and generating unit electrical load. As the problem under investigation was a multi-input (MI) and multi-output (MO) system, conventional first principles based model approach and sequential computer programs could not be applied. So that the neural network (NN) method was selected as the best where past input and output data is available, and the input characteristics can be mapped in order to develop a model. The NN's capability of parallel processing was used to develop a model the system. This was implemented in MATLAB environment. According to the simulation results, it demonstrates a reasonable (±2 °C) accuracy in temperature prediction.. Hence, this model can be used to predict the temperature variation characteristics of the system. Temperature increase in ambient air, or cooling water (due to reduced cooling water flow rate) would increase the temperature level of bearing metal and oil. Using this model, it is possible to predict the temperature increase for a given generator load profile for a given period. It will help to determine maximum safe load level, while maximizing the plant factor minimizing the sudden failures due to bearing overheating

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