Short-Term Load Forecasting for a Captive Power Plant Using Artificial Neural Network

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ABSTRACT

The irregularity of the Indian grid system increases with the increase in the power demand. The quality of power supplied by the power grid is also poor due to continuous variation in frequency and voltage. To overcome this problem of power deficit, captive power plants installed capacity has grown at a faster rate. Here, short-term load forecasting of Yara Fertilizers India Private limited installed at Babrala, Uttar Pradesh is performed using multi-layer feed-forward neural network in MATLAB. The algorithm used is a Levenberg Marquardt algorithm. However, the training and results from ANN are very fast and accurate. Inputs given to the neural network are time, ambient air temperature from the compressor, cool air temperature at the compressor, and IGV opening. The need, benefits, and growth of CPP in India and use of ANN for short-term load forecasting of CPP has been explained in detail in the paper.

KEYWORDS

Artificial Intelligence, Back Propagation Algorithm, Combined Cycle Power Plant, Gas Turbine, Heat Recovery Steam Generator, Inlet Guide Vane, Levenberg-Marquardt Back-Propagation, Yara Fertilizers Limited

1. INTRODUCTION

Electricity has now become a part of everyone's life. In India, demand is increasing day by day and also facing problems such as power quality issue, lack of latest technology, losses etc. Stress on existing energy resources has also increased drastically due to increase in electricity demand and thus, leads to shortage of power. Now-a-days demand of CPP is increasing day by day due to its various advantages such as high efficiency, low environmental impact, low investment cost, simple operation and many more.

The load demand prediction and generation of CPP must be accurate. Electrical load Prediction is the process of future load prediction in the blocks of hours, days, weeks, months or for a year. It is mainly done in order to prognosticate the power consumption of electrical utilities and help them to plan their future decisions related to Generation, Transmission and Distribution system. Electrical load prediction also helps in managing demand and supply of electricity at every moment which is managed by utilities. Load forecasting is used for power supply planning, transmission & distribution

DOI: 10.4018/IJIRR.289613

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planning, demand side management, maintenance and financial planning. So accurate load prediction is very essential for the effective working of the power system otherwise it may leads to the equipment's failure and supply loss (Jaswal, 2013).

An author (Alam et al., 2013; Oak & Patil, 2016) presented case study of the captive power plant in Maharashtra and Bangladesh respectively. A study by (David et al., 2004) has shown that the scenario of captive power plants in India can be broadly assigned to (a) manage the backup power system, (b) checks the quality of the supply, (c) ensures the benefits of co-generation process of industries, and (d) also generate electricity at lower costs than the high industrial tariffs. In view of designing the Captive power generation from coolant jet author (Pooja et al., 2018) suggested some guidelines for executing the captive hydro power plant at low head of coolant jet for developers.

There are various factors which affect load forecasting such as weather variables (temperature, rain, wind and humidity), holidays, festivals, economic growth and new load demand (Gupta et al., 2013). The two main classification of load forecasting techniques are parametric and non-parametric. Examples of parametric technique are auto regressive moving average (ARMA), linear regression, general exponential technique and stochastic time series techniques. These techniques are also known as statistical or traditional techniques. The main limitations of traditional methods are its capability to cover up the changes due to environment. However, this can be resolved by using non-parametric techniques. This method is also known as modern techniques as it uses artificial intelligence. Modern techniques include Neuro-Fuzzy Method, Artificial Neural network (ANN) method, Genetic algorithm (GA), Fuzzy logic method, and Particle swarm optimization (PSO). Among these methods of artificial intelligence based technique called artificial neural network is appeared to be most appropriate and has received attention of many researchers (Bello & Harrison, 2015; Hippert, Pedreira, & Souza, 2001; Karthikeyan et al., 2019). ANN has the capacity to make decisions for uncertain environment, to solve complex problems, image recognition, and prediction capability. Thus ANN has emerged as a useful techniques as compared to the other traditional techniques. (Abiodun et al., 2018; Araque et al., 2017).

In hybrid networks, stochastic learning techniques like genetic algorithm (GA), particle swarm optimization (PSO) are applied in combination with the artificial neural network for short term load forecasting. An author (Baliyan et al., 2015) has discussed about the various applications of several stochastic learning techniques with the artificial neural network for short term load forecasting. In the paper (He, 2017) author proposes an architecture of deep neural network for load forecasting of an hourly load of North China city. Deep neural network architecture is also used by other various authors for load forecasting (Graziani & Xibilia, 2020; Li et al., 2019; Sun et al., 2019).

In the present work ANN is used for short term load prediction of Captive Power Plant, Yara Fertilizers India Private limited installed at Babrala, Uttar Pradesh, India. The MATLAB tool box is used to train and predict the load using ANN. Section 2 describes about the Captive Power Plant component, section 5 explains the ANN technology which is used to predict the load demand of CPP. Results of proposed methodology are illustrated in section 6 and further conclusions are discussed.

2. CAPTIVE POWER PLANT

There are two types of power generation entities in India such as Generation Non-Utilities or Captive Power Plants (CPPs) and Generation Utilities. Captive Power Plant (CPP) is a power plant which is set up by any person in order to generate electricity for his own use. It is set up by any association of persons or co-operative society for their own consumption of electricity (Electricity Act, 2003) (Ministry of Power, 2003). After the introduction of the Electricity Act 2003, surplus power from captive plants, after meeting self-requirements, could be sold to third parties. (Tirthankar, 2010).

Yara fertilizer India Private limited, Babrala (captive Power plant) consist of two gas turbines units, two waste heat recovery boilers, steam and turbo pump, auxiliary electrical and mechanical

Table 1. Gas turbine specifications

1.	Type	Impulse turbine
2.	Speed	5178 rpm
3.	Air inlet temperature	45 degree Celsius
4.	Exhaust temperature of flue gases	516 degree Celsius
5.	Exhaust pressure of flue gases	756 mm Hg

equipment's. The main plant block consists of two modules, each of 1 GTGs (Gas Turbine Generator) placed on each side and 1 HRSG (Heat Recovery Steam Generator).

3. GAS TURBINE

A rotating device in which the action of a fluid is used to produce work is called a Turbine. These fluids may be: helium, steam, air, wind, water and gas etc. Major components of gas turbine are air intake filter with evaporative cooler, the shaft driven compressor and the combustion chamber. A gas turbine mainly consist of a compressor which is used to extract air from the environment .In compressor air got compressed and then passes to the combustor. In combustor, fuel is added to the compressed air in order to increase its temperature. That hot air is then given to the turbine to extract power from the flow to hot air and get expanded. These Gas turbines are capable of attaining full load within 10 to 15 minutes. The operating speed of gas turbine is 5178 rpm and other specifications are mentioned in table 1.

4. WORKING OF COMBINED CYCLE POWER PLANT

Here CPP is a combined cycle power plant which mainly consists of both the gas turbine and steam turbine to produce electricity. Atmospheric air is taken as the input for the compressor where air is compressed and then the air moves to the combustion chambers where it is ignited and that high temperature air moves to the gas turbine which drives a generator and hence electricity is produced.

Heat recovery steam generator (HRSG) captures the exhaust from the gas turbine which is further used to produce steam and that steam is used to drive the steam turbine in order to produce further additional electricity. This whole system increases the overall efficiency. So from Figure 1, cool air temperature to the compressor is the air going into the compressor and ambient air temperature from the compressor is air coming out of the compressor and IGV is Inlet Guide Vane controls the air flow to the compressor, in which air is allowed to flow at the proper angle.

5. IMPLEMENTATION OF ANN FOR CAPTIVE POWER PLANT

ANN is mainly composed of highly connected structure in order to process the information. Multi-layer feed forward neural network is used for load forecasting as it can approximate nonlinear function with high accuracy. Selection of input and output data is very important for prediction (Bello et al., 2015). Input is given to the input layer, which is then given to the hidden layer where the information is processed and output from the hidden layer is finally given to the final layer which is called output layer. The ANN is a huge parallel implementation whose processing speed is very high and due which ANN has a great potential in the field of research (Hippert, Pedreira, & Souza, 2001). Now-a-days ANNs is used for various applications such as natural language processing, image recognition, and many more.

Figure 1. Combined cycle power plant

An ANN model made use of the Levenberg- Marquadt Back-Propagation two layer feed forward ANN model with the help of MALTAB which showed a high degree of accuracy in future load forecasting (Atlas et al., 1991). The most common algorithm is back propagation algorithm as it is fast, simple and easy to program. Back propagation algorithm is very flexible as well. AI can be extensively applied to in petroleum exploration and industrial production (Abiodun et al., 2018) and business (Araque et al., 2017) setting for optimization. Since ANN model resembles to the functioning of human brain due to which its applications are increasing globally (Liu et al., 2017).

Figure 2 shows the block diagram of the overall model of feed-forward neural network which is trained by Levenberg-Marquardt Back Propagation algorithm. Data which is taken from Yara Fertilizers of six months and that data are used for training, validation and testing. For training 70% data is used, 15% for validation and 15% for testing. For prediction, data is imported into Neural Network Toolbox of the MATLAB and prediction procedure is carried out to predict the load for the month of March 2020 and the network is trained with the past six month's data. From the, Figure 2 inputs given to the model are time, ambient air temperature from the compressor, cool air temperature at the compressor and the IGV opening from which forecasted load is obtained.

Two variables X and Y are created in the workspace of the MATLAB which are input and target data respectively. Both input and Target data is imported in the neural network toolbox. This is a feed-forward network with two layer structure in which sigmoid activation function is used in hidden layer and linear activation function in output layers. This network is trained with Levenberg-Marquardt

Figure 2. Block diagram of ANN structure

Figure 3. Neural Network Model

back-propagation algorithm. There is no specific approach to calculate the number of hidden layer nodes and the numbers of neurons are taken as 10.

6. TRAINING AND TESTING RESULTS

After training the network we have obtained the following results:

6.1 Regression Plot

Figure 4 shows the plot of regression, which mainly comprises of four plots as shown below. The regression plot is mainly the plot between set target and the output obtained from the network. In Figure 4, the first plot is the plot of the data which was set for Training, the second plot is the plot of data which was set for Validation, the third plot is the plot of the data which was set for testing and the forth plot is the overall plot of the network. From all the plots we can see that value of R is coming as 1, which shows the accurate and reasonable good fit of data. So, the relationship between output obtained after training the network and the target is linear and accurate.

6.2 The Performance Plot

Performance plot is the plot between the number of epochs and Mean Squared Error (MSE). It mainly shows the performance of the network by showing Validation error, Train error and Test error. From the given plot, we can see that the result is reasonable as the final mean square error is extremely small. From the figure 5, at 6th iteration the best validation performance of 0.00013282 is achieved.

6.3 Error Histogram

The figure 6 shows the plot of the error histogram in which Blue bars, Green Bar and Red bar represents Training data, Validation data and Testing data respectively. From the figure 6, it can be seen that most of the error fall between -0.02179 and 0.01845 .

6.4 Training State Plot

The Figure 7 shows the training state plot which mainly consists of three plots. The first plot is a plot between gradient and number of Epochs. The value of a gradient is obtained as 0.00062898 at 11 epochs. The second plot of Figure 7 is the plot between learning rate (μ) and the number of epochs and it can also be seen that with the increase in epochs μ decreases and becomes constant. It shows that with the increase in training process error of the network reduces. The value of μ is coming

Figure 4. Regression Plot

Figure 5. Performance plot

as $1e-05$ at 11 epochs. The third plot of Figure 7 performs a validation check which is coming as 6 at 11 epochs.

6.5 Comparison Between the Predicted Load and Actual Load

The Figure 8 shows the plot between Predicted Load in Megawatt (Output) after the training of the network and the actual load for the month of March 2020. The graph mainly consist of the two plots. The Red line plot shows the predicted load and the blue line plot shows the Actual load (Target) which is given for training as a target to the neural network.

Figure 6. Error Histogram

Figure 7. Training state plot

From the Figure 8 it can be seen that both plots of the actual load and predicted load are almost overlapping which shows that there is very less deviation between the predicted load and the actual load. Thus, an output after training is accurate. Table 2 shows the comparison between the Absolute percentage error of the actual load and the predicted load.

Figure 8. Forecast results for the month of March

Table 2. Comparison between the Actual load and Predicted load

S No.	Date	Load in Megawatts		Absolute Percentage error (%)
		Actual load	Predicted load	
1.	01-03-2020	21.221	20.906	1.484%
2.	02-03-2020	21.299	20.785	2.413%
3.	03-03-2020	21.328	20.710	2.897%
4.	04-03-2020	21.295	20.761	2.507%
5.	05-03-2020	21.104	20.655	2.127%
6.	06-03-2020	20.992	20.661	1.576%
7.	07-03-2020	20.900	20.629	1.29%
8.	08-03-2020	20.785	20.763	0.105%
9.	09-03-2020	20.708	21.001	1.414%
10.	10-03-2020	20.757	21.004	1.189%
11.	11-03-2020	20.643	21.031	1.879%
12.	12-03-2020	20.661	21.205	2.632%
13.	13-03-2020	20.628	21.185	2.700%
14.	14-03-2020	20.763	21.125	1.743%
15.	15-03-2020	21.000	21.106	0.505%

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Table 2. Continued

S No.	Date		Load in Megawatts		Absolute Percentage error (%)
			Actual load	Predicted load	
16.	16-03-2020		21.007	21.169	0.771%
17.	17-03-2020		21.032	21.155	0.58%
18.	18-03-2020		21.204	21.097	0.504%
19.	19-03-2020		21.184	21.179	0.024%
20.	20-03-2020		21.130	21.204	0.350%
21.	21-03-2020		21.106	21.182	0.374%
22.	22-03-2020		21.170	21.130	0.188%
23.	23-03-2020		21.157	21.108	0.231%
24.	24-03-2020		21.098	21.170	0.341%
25.	25-03-2020		21.179	21.112	0.316%
26.	26-03-2020		21.204	21.105	0.466%
27.	27-03-2020		21.184	20.906	1.312%
28.	28-03-2020		21.130	20.785	1.632%
29.	29-03-2020		21.106	20.701	1.918%
30.	30-03-2020		21.175	20.761	1.955%
31.	31-03-2020	21.106		21.122	0.075%

7. CONCLUSION

The load forecasting by ANN is suitable because of its various advantages. Moreover, the ANN is used for load forecasting because utilization of power output of CPP is fixed. The data was collected for all the 24 hours. The patterns include the features like load (MW), date, time, ambient air temperature from the compressor, cool air temperature at the compressor and IGV opening. The designed network is trained with supervised algorithm (Back propagation algorithm). Implementation of this network is showing reasonably good results with the Mean absolute Percentage Error (MAPE) of 1.210% which is very less. The error will be less by the use of large data set with very less variation. The result from the ANN model reflects good prediction performance with a least error. Thus, short term load forecasting using ANN is an effective method for load forecasting.

ACKNOWLEDGMENT

My sincere gratitude goes to Yara Fertilizers, India Private Limited for providing required data and their contributions are sincerely appreciated and gratefully acknowledged.

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