

Study of Different Techniques for Load Forecasting - A Review

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Abstract— This paper focuses on various approaches to load forecasting, which is essential for developing power supply method to improve the reliability of the power line and provide optimal load scheduling for many developing countries where the demand can be increased day by day. Load forecast is extremely important in electric energy generation, transmission, distribution and markets. Electricity suppliers use forecasting models for prediction of load demand of the consumers to increase or decrease the power generated and to minimize the operating cost of producing electricity. This paper shows study of different methods for load forecasting such as wavelet method, ANN method and fuzzy logic method.

Key words: Load Forecasting, Wavelet, Neural Networks (NN), Fuzzy Logic (FL)

I. INTRODUCTION

Load forecasting refers to the prediction of the load in large power system. It is a technique used by power or energy-providing companies to predict the power or energy needed to meet the demand and supply equilibrium. The need for accurate load forecasts will increase in future because of the several changes occurring in the structure of the utility industry due to deregulation and competition. The accuracy of forecasting is of great significance for the operational and managerial loading of a utility company. Load forecasting helps electric utility to make important decisions including decisions on purchasing and generating electric power, and also in prediction of next day, week or year's load.

Load forecasts can be divided into following categories: Very short term load forecasting, forecasting horizon ranging from a few minutes ahead to a few hours ahead. Time period for short term load forecasting is one day to one month. Medium term load forecasting, which forecasts within period of one month to one year. Long term forecasting with a time period of more than one year. Short-term load forecasting is used to estimate load flows and to make decisions that can prevent overloading. Load flows are also based on the results of the short term load forecasting. There are varieties of methods, which include the so-called similar day approach, various regression models, time series, wavelet method, neural networks, expert systems, fuzzy logic, and statistical learning algorithms etc., are used for short-term forecasting. For medium and long term forecasting there are two methods: so-called end use and econometric approach [12]. The historical load and weather data, different class of customers, age of the appliances in the area and their characteristics, forecasts of the economic and demographic data, the appliance sales data, and other factors are taken into account for medium- and long-term forecasts. For short-term load forecasting several factors should be considered like time factors, data of weather, and data of possible customer's classes. Wavelet method is powerful tool which is used for load forecasting. Wavelet method individually and its combination with other

technique (Wavelet Neural Network method) are efficient for short term load forecasting and the result has come in the form of forecasting error. Error should be minimum for good forecasting [5]. Use of pre-processed data through wavelet technique not only improves the performance of the forecasting models but at the same time takes lesser time for training. Wavelet approaches are always much superior than non-wavelet approaches [6]. Neural network method also used for load forecasting with minimum error. In ANN method historical load data taken as input and forecasted day is taken as output of ANN. The outputs of an artificial neural network are linear or nonlinear mathematical function of its input values. Load prediction period may be two week or one month. Sometimes load is divided into two distinct pattern: weekday and weekend day-pattern and backpropagation learning algorithm used to train ANNs for forecasting [1]. Another method based on appropriate training data selection is used in ANN for efficient approach for load forecasting and minimum forecasting error is possible [7].

Combination of Artificial Neural Network (ANN) method and Fuzzy Logic method is also used for short term load forecasting, ANN method is found to be more efficient than Fuzzy Logic method [8]. Artificial Neural Network (ANN)-based short-term load forecasting technique that considers electricity price is one of the main characteristics of the system load, demonstrating the importance of considering price when predicting load in present day electricity markets [4]. Properly designed fuzzy logic systems can be very robust when used for forecasting. Due to robustness, fuzzy rules is combined with neural network to train ANN and have a better load demand forecasting. Neuro-fuzzy interference system ANFIS, combines intelligibility of fuzzy rules and self-learning algorithms of neural networks. By using Neuro-Fuzzy approach best performance in prediction of load forecasts is obtained [11]. Several techniques used for very short term load forecasting such as Fuzzy Logic (FL), Neural Network (NN), and Auto-regressive model (AR). FL and NN based forecasters give better response in comparison to AR based forecaster [3].

II. WAVELET METHOD

In 1982, Jean Morlet, a French Geophysical Engineer, first introduced the idea of wavelet transform as a new mathematical tool for seismic signal analysis. Wavelet is the extend concept of Fourier Transform. Fourier Transform gives frequency signal information but wavelet provides time-frequency representation of any signal. It uses the Fourier Transform in the form of Short Time Fourier Transform, in which signal is multiplied by window function and then Fourier Transform of signal is taken. Output depends on window's size. Narrow window provides good time resolution and poor frequency resolution. Wide window provides good Frequency resolution and poor time

resolution. It is used in load forecasting for smoothing the non-linear load signal.

Wavelet is a powerful tool that can be effectively utilized for the prediction of short-term loads. The valuable information is not easily available from raw signal or original signal. To accurately capture load features at multiple frequencies, wavelet technique is used to decompose the loads into several frequency components. Wavelet transform can be divided into two categories i.e. continuous wavelets transform (CWT) and discrete wavelet transforms (DWT). DWT algorithm is capable of producing coefficients of fine scales for capturing high frequency information, and coefficients of coarse scales for capturing low frequency information. Wavelet processing has two stages: decomposition and reconstruction. Wavelet decomposition provides a signal to breakdown into many lower resolution components, known as the wavelet decomposition tree. Wavelet decomposition tree can yield a signal to get valuable information. The decomposition can continue only until the individual details consist of a single sample or pixel. Wavelet Decomposition is shown in Fig. 1. The decomposition is implemented by using multichannel filter bank: one, two, three, and four channels.

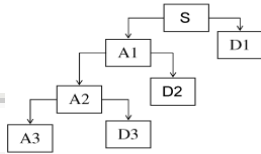


Fig. 1: Wavelet Decomposition.

Where S is original signal and A, D are coefficient vectors. Wavelet decomposed components can be assembled back into the original signal without loss of information. This process is called reconstruction or synthesis. The signal is reconstructed by combining its wavelet coefficients as shown in Fig. 2. Up sampling is the process of lengthening a signal component by inserting zeros between samples. The down sampling of the signal components is performed during the decomposition. There are two types of filters to decompose or reconstruct the signal. The low and high-pass decomposition filters (L and H), together with their associated reconstruction filters (L and H), form a system.

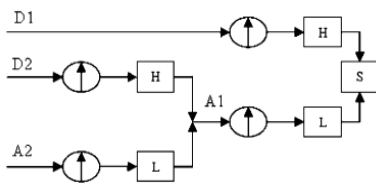


Fig. 2: Wavelet Reconstruction

Where H is High Pass Filter and L is Low Pass Filter.

Wavelet can be integrated with the neural network for load forecasting. Wavelet decomposition techniques have been integrated successfully with neural networks showing more accurate and acceptable results as compared to conventional methods [6].

A wavelet decomposition based load forecast approach was proposed for 24-h and 168-h ahead short-term load forecasting by Pandey et al. in [6]. Wavelet decomposition approach was compared with various load forecasting approaches. Process of Forecasting was completed in three steps (Wavelet decomposition, smoothing and reconstruction, predicting the load).

Historical load data was divided into low and high frequencies. Historical load data was smoothed by deleting high frequency components and fed as input to proposed model for prediction of load. They found that Wavelet approach was much superior to non-wavelet approaches. The results were compared in the form of mean absolute percentage error (MAPE). Minimum MAPE was found.

Chen et al. [5] a similar day-based wavelet neural network method to forecast tomorrow's load. Proposed method combined similar day selection, wavelet decomposition, and neural networks to forecast next day load. Similar day based load data was taken as input and applied it to the wavelet. Wavelet decomposed input load data into low and high frequencies. Nonlinear load data was smoothed by wavelet.

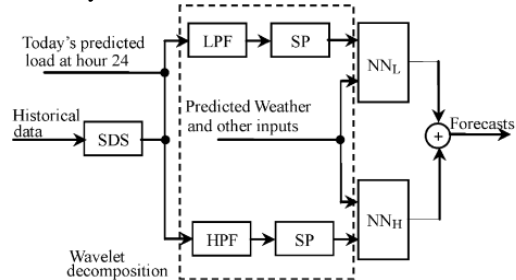


Fig. 3: Overall Forecasting process of Wavelet Neural Network.

Separate Neural networks (NN_L and NN_H) were used to predict the two components of tomorrow's load. Output of High Frequency network and Low Frequency network was added up and output came into the form of forecasted load. Forecasted load and actual load was compared and minimum error was found. Author found that this method gives accurate prediction of load. Overall forecast process is shown in Fig. 3.

Paper [9] proposed a model developed through Neural-Wavelet for prediction of short-term load forecasting.

Discrete wavelet transform was used for load forecasting. Wavelet transform was divided into three steps. In the first step, input time series raw data was pre-processed using wavelet decomposition. Then each decomposed scale was put into one neural network as its input and the respective neural network was taken in their allocated scale for training or for prediction in the second step. In the third step, the decomposed scales at the output of the neural network were recombined to obtain the required prediction.

III. ARTIFICIAL NEURAL NETWORK TECHNIQUE [ANN]

The first artificial neuron was found in 1943 by Neurophysiologist Warren McCulloch and the logician Walter Pitts. But the technology that time did not allow them to do too much.

Neural networks are essentially non-linear circuits that have the demonstrated capability to do non-linear curve fitting. Neural network is information processing model inspired by biological nervous systems (such as our brain), in which large number of highly interconnected elements working together to perform a particular task. Feedback paths are sometimes used in ANN method. One of the major features of the neural network is its learning capability.

They can also adjust weights to improve the performance for a given task. Feed forward ANN model is shown in Fig. 4.

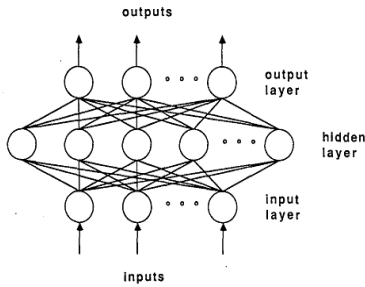


Fig. 4 Feed forward ANN model.

Main elements of ANN are: Input layer, Hidden layer and output layer. Speech processing, image recognition, machine vision, robotic control, etc. are the various fields where neural networks are better suited for achieving human-like performance. Processing elements in an ANN are also known as neurons. Each neuron can have multiple inputs, while there can be only one output. A neural network consists of four main parts:

- Processing units
- Weighted interconnections between the various processing units.
- An activation rule which acts on the set of input signals at a unit to produce a new output signal, or activation.
- Optionally, a learning rule that specifies how to adjust the weights for a given input/output pair.

Previous historical load data work as input variables and forecasting day is output of ANN model.

IV. TRAINING OF ANN

ANN training basically used for determining the network parameters such as weights and others, that allow achieving the desired objective, based on available training sets. Here Back-propagation is used as training method which is an iterative procedure that has three steps during each iteration:

- Forward: The outputs are calculated for given inputs.
- Backward: The errors at the output layer are propagated backwards toward the input layer, with the partial derivatives of the performance with respect to the weights and biases are calculated in each layer.
- Weight adjustment: A nonlinear numeric optimization algorithm is used to find the weights that minimize the error based on the gradient.

V. MATHEMATICAL MODEL OF ANN

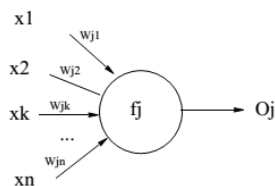


Fig. 5 Mathematical model of ANN

The output of the given model is

$$O_j = f_j \sum (w_{jk} x_k)$$

O_j = output of neuron
 w_{jk} = adjustable weight
 x_k = input of neuron

The error function used in the back-propagation training process can be given as

$$E = 0.5 \sum_p \sum_j (t_{pj} - o_{pj})^2$$

Where t_{pj} and O_{pj} are the target output and the actual output j for input pattern p , respectively. [1], [4].

Chen et al. [4] developed a three layer fully connected feed forward neural network and the back propagation algorithm was used as the training method. They also proposed a mathematical models namely, additive models and multiplicative models. An additive model that takes the form of predicting load as the function of four components:

$$L = L_n + L_w + L_s + L_r$$

where L is the total load, L_n shows the “normal” part of the load, which is a set of standardized load shapes for each “type” of day that has been identified as occurring throughout the year, L_w is the weather sensitive part of the load, L_s is a special event component that create a substantial deviation from the usual load pattern, and L_r shows that completely random term, i.e. noise.

A multiplicative model presented by Chen may be of the form,

$$L = L_n * F_w * F_s * F_r$$

Where L_n is the normal (base) load and the correction factors F_w , F_s , and F_r are positive numbers that can increase or decrease the overall load. These corrections are based on current weather (F_w), special events (F_s), and random fluctuation (F_r). Multi-layer feed-forward ANN was taken for STLF. The maximum absolute percentage error is minimum. They also observed that the relationship between electricity price and load was complex and dynamic.

Backpropagation method is another technique in ANN method which is used for load forecasting. In backpropagation method several activation functions of neuron such as sigmoid function, linear function, bipolar function, unipolar function etc are used for load forecasting. Weights are updated on the basis of error at the output neuron.

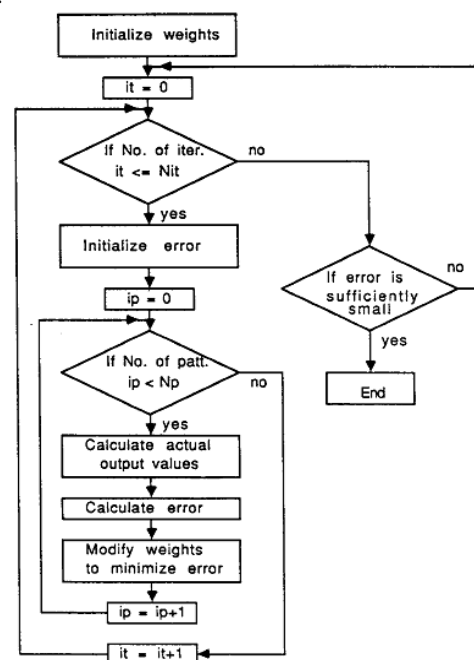


Fig. 6: Flowchart of Backpropagation algorithm.

Lee et al. [1], gives a nonlinear load model and several structures of ANN for short-term load forecasting were tested. Past loads data were taken as inputs of the ANN and the output of the ANN is the load forecast for a given day. The load pattern divided into two ways: weekday and weekend day-pattern and author have attempted to apply the back propagation learning algorithm to train ANNs for forecasting. Fig. 6 shows flow chart of back propagation algorithm. The results were compared in terms of forecasting error. They also proposed dynamic and static approaches. The back propagation algorithm is found to be robust in estimating the weights in nonlinear equation. They concluded that Dynamic approach was much better than static approach.

Combination of ANN with several techniques is also used for effective forecasting. Similar day based wavelet neural Network model was presented by Chen et al. in [5], in which similar days load data is used as input of ANN for next day load forecast. Forecasting of load obtained by added up output of to neural networks i.e. High Frequency network (NN_H) and Low Frequency Network (NN_L). This method concluded that it gives accurate prediction for very short term load forecasting.

Badri et al. [8] compared ANN method and fuzzy logic method for short term load forecasting. Each hour load amount and corresponding temperature was taken as input for both ANN and Fuzzy logic. They found that ANN method gives more accurate result in comparison to fuzzy logic method. There was minimum forecasting error in ANN method.

The disadvantages of ANN are that the training process is very time-consuming and there is no assurance of convergence.

IV. FUZZY LOGIC METHOD

Fuzzy Set Theory was formulated by Professor Lofti Zadeh at the University of California in 1965. Fuzzy logic is amongst number of techniques for mapping inputs to outputs (i.e. curve fitting). Fuzzy set extends concept of crisp set. It takes membership value in between interval (0,1) Among the advantages of fuzzy logic are the absence of a need for a mathematical model mapping inputs to outputs and the absence of a need for precise (or even noise free) inputs. With such generic conditioning rules, properly designed fuzzy logic systems can be very robust when used for forecasting.

Flow chart of fuzzy logic methodology for forecasting is shown in fig. 7.

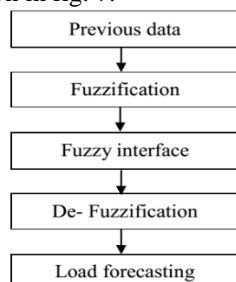


Fig. 7: Flow chart of Fuzzy Logic system for Load Forecasting.

In order to process the input to get the output reasoning there are six steps involved in the creation of a rule based fuzzy system:

- 1) Identify the inputs and their ranges and name them.
- 2) Identify the outputs and their ranges and name them.
- 3) Create the degree of fuzzy membership function for each input and output.
- 4) Construct the rule-base for system.
- 5) Decide how the action will be executed by assigning
- 6) strengths to the rules.
- 7) Combine the rules and defuzzify the output.

For forecasting of any load, Fuzzy Logic system completes its task based on three steps:

- 1) Fuzzification
- 2) Fuzzy inference system
- 3) Fuzzy rule base
- 4) Defuzzification

Fuzzy rule sends information to fuzzy inference system. Fuzzy rules are prepared on the basis of historical load data. The inference schemes are based on the compositional rule of inference, and the result is derived from a set of fuzzy rules and given inputs. Fuzzy logic models, called fuzzy inference systems, consist of a number of conditional "if - then" rules.

Fuzzification is the process of decomposing a system input and/or output into one or more fuzzy sets. Many types of curves can be used, but triangular or trapezoidal shaped membership functions are the most common because they are easier to represent in embedded controllers. Defuzzification is inverse transformation which maps the output from the fuzzy domain back into the crisp domain [13].

Manoj and Shah [10] proposed fuzzy logic approach for short term load forecasting. Time, forecasted temperature and similar previous day load were taken as input data.

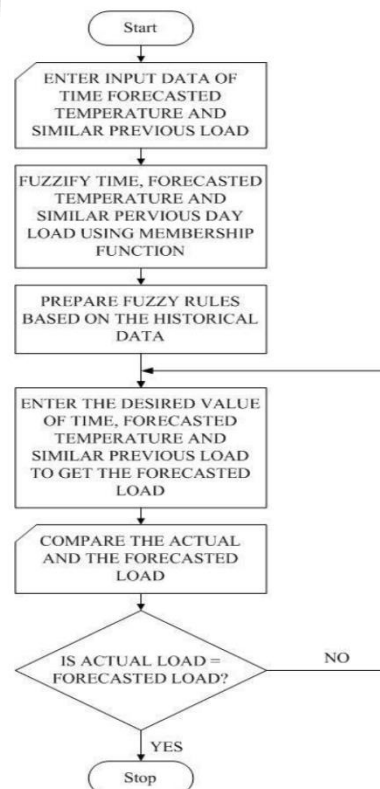


Fig. 8: Fuzzy Logic methodology for STL.

Flow chart of fuzzy logic methodology for short term load forecast is shown in fig. 8. The input data was forecast using membership function and Fuzzy rules were prepared on the basis of historical load data, in which forecasted load was compared with actual load and the result was compared in terms of percentage error. This method is easy to understand and gives minimum forecasting error.

To train ANN, Fuzzy rules is combined with neural network and has a better load demand forecasting. The training patterns for the ANN models were collected from the historical load data. In paper [11], Fuzzy rules are combined with neural network and have a better load demand forecasting. The training patterns for the ANN models were collected from the historical load data. An adaptive neuro-fuzzy interference system ANFIS was proposed for load forecasting. Fuzzification and Defuzzification of input data was done and then this data was used by neural network to obtain the forecasted output. Work of Neuro-Fuzzy model was divided into three steps:

- 1) Classification of training data using Fuzzy set.
- 2) Training of the neural network for each hour of each day for which the load is to be forecasted using the training data of that particular class to which that hour belongs.
- 3) Hourly load data has been forecasted using trained neural network.

Neuro-Fuzzy systems gives better predicted output of any load data.

Combination of Fuzzy logic with Expert Systems gives more accurate and efficient forecasting. Kim et al. [2] used a two-step approach in forecasting load for Korea Electric Power Corporation. First, an ANN is trained to obtain an initial load prediction, and then a fuzzy expert system modifies the forecast to accommodate temperature changes and holidays. Overall process of ANN and Fuzzy Expert System is shown in Fig. 9.

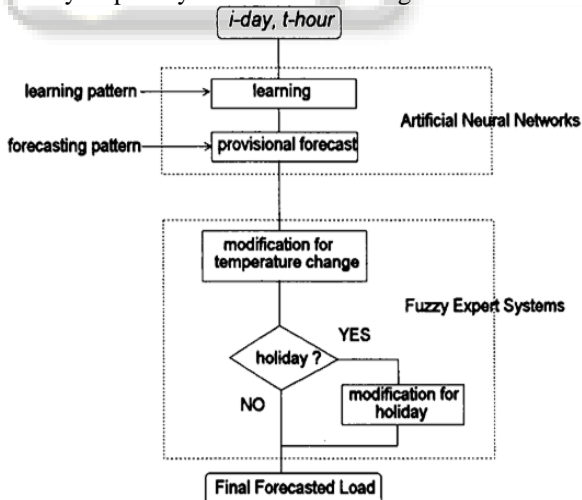


Fig. 9: Overall Forecasting process using ANN with Fuzzy Logic Expert Systems.

Liu et al [3] compared three techniques of short term load forecasting such as Fuzzy Logic (FL), Neural Networks (NN), and Auto-regressive model (AR). Performances of these techniques were evaluated on the basis of simulation study. Fuzzy logic-based forecaster worked in two stages, that is, training and on-line forecasting. Triangular fuzzy membership function was used for forecasting. Forecasted load was compared with actual

load by these techniques individually, and results were compared in terms of forecasting error. They concluded that the performances of FL-based and NN-based forecaster were much superior to the one of AR-based forecaster. FL-based and NN-based forecaster and combination of both were suitable for efficient forecasting.

Additional benefits of fuzzy logic include its simplicity and flexibility. Fuzzy logic can handle problems with imprecise and incomplete data, and it can model nonlinear functions of arbitrary complexity.

V. FORECASTING MODEL ACCURACY

Error is defined as the difference between the actual value and the forecasted value for the corresponding period.

$$\varepsilon_t = A_t - F_t$$

Where, ε_t is the error for the period T, A_t is the actual value for the period T, F_t is the forecasted value for the period T. Following are the errors calculated for load forecasting:

A. Mean Absolute Error:

$$MAE = \frac{\sum_{t=1}^N |\varepsilon_t|}{N}$$

B. Mean Absolute Percentage Error:

$$MAPE = \frac{\sum_{t=1}^N \left| \frac{\varepsilon_t}{A_t} \right|}{N}$$

C. Percentage Mean Absolute Deviation:

$$PMAD = \frac{\sum_{t=1}^N |\varepsilon_t - \bar{\varepsilon}|}{\sum_{t=1}^N |A_t|}$$

D. Root Mean Squared Error:

$$RMSE = \sqrt{\frac{\sum_{t=1}^N \varepsilon_t^2}{N}}$$

Where N represents the number of observations used for analysis.

VI. CONCLUSION

In this paper, study of different methods of load forecasting has been done. After surveying all these approaches, we can observe a clear trend towards new, stochastic, and dynamic forecasting techniques. On the basis of surveys performed, this paper presents the basic idea of load forecasting, and describes the factors influencing the behavior of load in different methods used for forecasting. Methods such as WAVELET, NEURAL NETWORK, and FUZZY LOGIC are reviewed. The hybrid methods which comprises of different methods to overcome the shortcomings of different separate methods to accurately forecast the load in power markets. Hybrid methods give efficient and effective load forecasting result.

REFERENCES

- [1] K. Y. Lee, Y. T. Cha and J. H. Park, "Short Term Load Forecasting using an Artificial Neural Network," IEEE

- Transactions on Power Systems, Vol. 7, No. 1, February 1992.
- [2] Kwang-Ho Kim, Jong-Keun Park, Kab-Ju Hwang, Sung-Hak Kim, "Implementation of Hybrid Short-term Load Forecasting System Using Artificial Neural Networks and Fuzzy Expert Systems," IEEE Transactions on Power Systems, Vol. 10, No. 3, August 1995.
- [3] K. Liu, S. Subbarayan, R. R. Shoults, M.T. Manry, C. Kwan, F. L. Lewis, J. Naccarino, "Comparison of Very Short-Term Load Forecasting Techniques," IEEE Transactions on Power Systems, Vol. 11, No.2, May 1996.
- [4] Hong Chen, Claudio A. Canizares, and Ajit Singh, "ANN-Based Short-Term Load Forecasting in Electricity Markets," Proceedings of the IEEE Power Engineering Society Transmission and Distribution Conference, 2:411-415, 2001.
- [5] Ying Chen, Peter B. Luh, Fellow, Che Guan, Yige Zhao, Laurent D. Michel, Matthew A. Coolbeth, Peter B. Friedland, and Stephen J. Rourke, "Short-Term Load Forecasting: Similar Day-Based Wavelet Neural Networks," IEEE Transactions on Power Systems, Vol. 25, NO.1, February 2010.
- [6] Ajay Shekhar Pandey, Devender Singh and Sunil Kumar Sinha, "Intelligent Hybrid Wavelet Models for Short-Term Load Forecasting," IEEE Transactions on Power Systems, Vol. 25, No. 3, August 2010.
- [7] Yuhang Yang, Yao Meng, Yingju Xia, Yingliang Lu, and Hao Yu, "An Efficient Approach for Short Term Load Forecasting," International Multi Conference Of Engineers and Computer Scientists 2011 Vol.I.
- [8] A. Badri, Z. Ameli, A. Motie Birjandi, "Application of Artificial Neural Networks and Fuzzy logic Methods for Short Term Load Forecasting," Sci Verse Science Direct Energy Procedia 14 (2012).
- [9] D. K. Chaturvedi, Sinha Anand Premdayal, "Neural-Wavelet Based Hybrid Model for Short-Term Load Forecasting," Vol.3, No.2, 2013- National Conference on Emerging Trends in Electrical, Instrumentation & Communication Engineering.
- [10] Patel Parth Manoj, M.E. Student, Ashish Pravinchandra Shah, "Fuzzy Logic Methodology for Short Term Load Forecasting," International Journal of Research in Engineering and Technology, Volume: 03, Issue: 04, Apr-2014.
- [11] Suhas B. Karwade, Dr. M. S. Ali, "Review Paper on Load Forecasting Using Neuro Fuzzy System," IOSR Journal of Electrical and Electronics Engineering, Volume 10, Issue 3 Ver. II (May - Jun. 2015), www.iosrjournals.org
- [12] Ms. Ranjana V. Wasu, "An Approach to Electricity Load Forecasting and Techniques: A Review," ISSN: 0975 - 6779, Nov 13 TO Oct 14, Volume - 03, Issue 01.
- [13] Marcelo Godoy Simoes Colorado School of Mines Engineering Division 1610 Illinois Street Golden, Colorado 80401-1887 USA, "Introduction to Fuzzy Control," inside.mines.edu/msimoes/documents/Intro_Fuzzy_Logic.pdf.