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POWER SYSTEM PLANNING USING ANN WITH FUZZY LOGIC AND WAVELET ANALYSIS

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Abstract
The electricity load required for the forthcoming years are predetermined by means of power system planning. Accuracy is the crucial factor that must be taken care of in the power system planning. Electricity is generally volatile, that is it changes and hence appropriate estimation must be done without leading to overestimation or underestimation. The aim of the project is to do appropriate power estimation with the help of the economic factors. The 9 input factors used are GDP, industry, imports, CO2 emission, exports, services, manufacturing, population, per capita consumption. The proposed methodology is done by means of Neural Network concept and Wavelet Analysis. Regression Analysis is also performed and the comparisons are done using Fuzzy Logic. The nonlinear model, Artificial Neural Network and the Wavelet Analysis are found to be more accurate and effective.

Keywords:
Power System Planning, Artificial Neural Networks, Regression Analysis, Fuzzy Logic, Wavelet Analysis

1. INTRODUCTION

The estimation of future electricity demand starts with Power system development. The consumption in India increases by ten percentages annually from the year 2000. This is due to the increase in industries and commercial sectors. It is the primary prerequisite for achieving the planning at optimum level and processing of power systems. The key factor of social and economic development of the country is the electrical energy. Hence the development of the country is linked with consumption of electricity. Due to the population growth, higher per capita consumption, and rapid development of industrial & commercial sectors, higher Gross Domestic Product (GDP) growth and structural changes in the economy of the country, the demand increases immensely.

Furthermore policies associated with the energy sectors in the world energy markets will be an important role in the future patterns of energy supply and demand. Load forecasting in an accurate way is very vital for the reliable and economical processing of the power planning system. Modelling and prediction of electricity usage occupies an important role in developed as well as developing countries for decision makers and associated organizations.

The underestimation of the demand would result in immense outages that are devastating to socio-economy, whereas the overestimation would pave a way for unused idle capacity would result in wastage of financial resources. Hence, it would be preferable to design power system planning with improved accuracy in order to not leading to costly mischievous.

Several methodologies are being proposed to perform accurate estimation. Artificial intelligence techniques are based on conventional approaches. The mathematical combination of the previous values of the variables and current values of other variables are computed to predict the future values are also based on conventional approaches. Traditional methodologies like Regression Analysis are used to make future estimations based on the relationship between the load and other economic factors. The advantage is that the relationships between input and output factors are feasible to comprehend. Auto Regressive Integrated Moving Average (ARIMA) time-series analysis models based on Box-Jenkins method to design the forecasting model for the prediction of power system were also one of the methodology implemented.

Artificial neural networks is an important soft-computing technology which is extensively studied and applied on research areas on for different types of ANN like multilayer perceptron network, radial basis function, recurrent network, feedback network, and unsupervised Kohonen self-organizing network. On comparative analysis, especially the multilayer perceptron network with a back propagation training algorithm is found to perform better in forecasting problems and also other applications which solve the problem of minimum accuracy and data over fitting.

2. RELATED WORK

The economic factors influencing for the 2012–2020 period will be driven by the similar variables as was the period for the 2000–2011 period, or for any period of years. There are several traditional techniques for future prediction which involves expert forecasts. Regression analysis is one of the most popular methodologies, which are a statistical technique to analyze quantitative data to predict model and make future decisions [1].

The input variables are chosen based on the correlation between the electricity demand and associated parameters such as economic variables for demand forecasting scenario. The several government policies and decisions associated with the energy sector development will play crucial roles in the future related estimations of energy production and consumption [2].

Regression Analysis which is a technique used for analysing the numerical data based on the logic for determining the dependent variable with the help of the combination of the independent variables. Linear regression under the regression analysis where the observational data are modelled by a least squares function. Least squares are linear combination of the model parameters. The relationship with the economic factors is considered and performed using support vector regression [3].

Load forecasting effectively is the primary tool for the power system planning. Importance of load forecasting has turned to be of immense importance in higher growth rate countries like KSA.

Owing to this importance, for the short term load forecasting, swarm optimization is being proposed for the prediction [4]. Hybrid technologies involving both support vector regression with chaotic sequence and genetic algorithm for the estimation of load forecasting aims to increase the forecasting performance with better accuracy and to overcome premature convergence [5]. A new hybrid short term load forecaster with the help of economic indices to overcome the impact of economic dynamics involving economic recession on patterns involving load demand [6].

Wavelet Analysis plays a vital role in forecasting apart from image compression purposes. The prediction of Wi-MAX BS Signal by means of the statistical methodologies is performed in the wavelet domain by using Auto Regressive Fractionally Integrated Moving Average [7]. A wavelet-based prediction is implemented and data on crude oil is applied to forecasts over different forecasting horizons. The results obtained are compared with results from estimated markets for oil and the relative performance of this technique is applied and investigated [8].

3. PROPOSED METHODOLOGY

3.1 DATA COLLECTION

The input variables in the dataset are chosen based on the higher correlation coefficient values with electricity demand. Data set is of size 35 × 9. The 9 related parameters chosen based on the higher correlation values are: GDP, Industry, Imports, CO_2 Emission, Exports, Services, Manufacturing, Population, Per capita consumption. The Fig.1 gives the content present in the dataset.

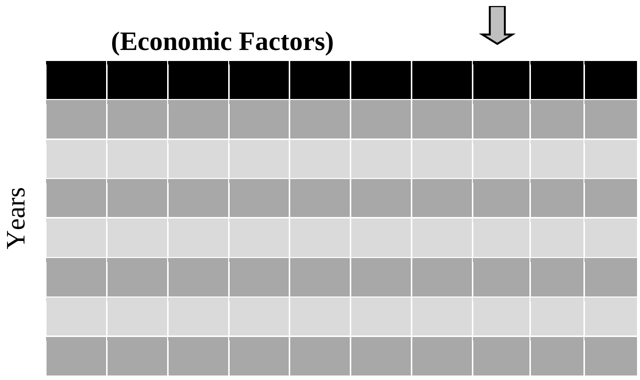

Fig.1. Rows and Columns in the Dataset

3.2 REGRESSION ANALYSIS

Multiple Linear Regression (MLR) is a methodology for predetermined forecasting by means of analysis of numeric data. It predicts the values of a dependent (output) variable based on the computations on one or more independent (input) variables. By means of the following equation, the output variable can be determined by means of the values of the input variables.

$$z = a_1x_1 + b_1x_2 + d_1x_3 + e_1 \tag{1}$$

where,

z represents the predicted electricity consumption;

a_1, b_1, d_1 values indicates regression coefficient.

For instance, the x values indicates the independent (input) variables that is the economic factors like imports, exports, population, GDP, industry, manufacturing. The input parameters are expected to give a best fit of the data. The error term e represents unexplained variation in the dependent variable and considered as a random variable. Typically, the best fit is evaluated using the minimum error rate. Several models are developed with different combination of input variables. Inspite of the model being linear, they are extensively used for prediction.

3.3 ARTIFICIAL NEURAL NETWORK

In machine learning and cognitive science, Artificial Neural Networks (ANNs) are influenced by biological neural networks that are the central nervous systems of animals. They are made to determine the approximate functions that are dependent on a series of inputs. Artificial neural networks are generally depicted as systems of interconnected neurons, which is communicated between each other. The connections are given numeric weights that can be assigned based on experience, making neural nets adaptive to series of input.

A neuron usually receives many simultaneous inputs. Each input has its own relative weight, which paves the input, the need to process with the element's summation function. Weights are adaptive coefficients that compute the impact of the input as registered by the artificial neuron. Let (i_1, i_2,..., i_n) and (w_1, w_2,..., w_n) be the inputs and weights respectively. The total input signal is calculated as the dot product, $(i_1 * w_1) + (i_2 * w_2) +\ldots+ (i_n * w_n)$; hence a single number is obtained. The input and weighting coefficients can be calculated and brought together in many different ways before passing on to the transfer function. Among the total 9 input factors, the different combination of input variables: imports, exports, industry, manufacturing, GDP etc., are taken as training sets. Electricity consumption for the years to be calculated is taken as testing set. ANN is processed using input layer, hidden layer and one output layer. In the hidden layer, training is done using delta rule for associating with appropriate weights. The activation function $g(x)$ used is the sigmoid function. For a neuron i with activation function g(x), the delta rule is given by,

$$\Delta w_{ij} = \alpha(t_i\text{-}y_i)g'h_ix_j \tag{2}$$

$$g(x) = 1/(1 + e^x) \tag{3}$$

where,

α is a small constant called learning rate

$g(x)$ is the neuron's activation function

t_i is the target output

h_i is the weighted sum of the neuron's inputs

y_i is the actual output and x_j is the j^{th} input

The combination of input variables with minimum error rate is chosen by calculating the actual and predicted values. With the best topology of combination of input variables, the prediction is done for forthcoming years.

3.4 PERFORMANCE EVALUATION

In order to evaluate the pre-estimation capability, we calculate the forecasted accuracy by calculating the following statistical parameters. The evaluation measures are the Mean Absolute Percentage Error (*MAPE*), Root Mean Square Error (*RMSE*), Mean Bias Error (*MBE*) is given by the Eq.(4) to Eq.(6).

$$MAPE = \left(\frac{1}{n} \sum_{i=0}^{n} \left| \frac{(P_i - A_i)}{A_i} \right| \right) \times 100 \quad (4)$$

$$RMSE = \sqrt{\frac{\sum_{i=0}^{n} (A_i - P_i)}{n}} \quad (5)$$

$$MBE = \frac{1}{n} \sum_{i=0}^{n} (P_i - A_i) \quad (6)$$

where, P_i is the predicted value and A_i is the value, n is the total number of predictions.

MAPE and *RMSE* are used to determine the residual errors, which gives the difference between the predicted and actual values. *MBE* indicates whether the predicted data are over estimated or under estimated.

3.5 FUZZY LOGIC

Fuzzy logic also called as Fuzzy Interface systems works on user given rules and thresholds. It is simpler and provides flexibility to the developer on setting conditional rules. Based on the error rates obtained from MLR, ANN and Wavelet Analysis, the comparisons are done based on the conditional statements setting thresholds using Fuzzy Logic.

3.6 WAVELET ANALYSIS

A wavelet series is a representation of a square-integrable which is simple or complex by a certain orthonormal series which is generated by a wavelet. Wavelet transformation is one of the most commonly used time-frequency transformations. Wavelet analysis has its huge uses in image processing. On the other hand, it is also used for forecasting purposes. It has two types: discrete wavelets and continuous wavelets. Wavelet is chosen for prediction.

The Fourier transform can be depicted as a representation of a function which is the sum of sinusoidal waves. These sinusoids are found to be well localized in the frequency, but not in time. This is a consequence of periodicity. For the representation of the frequency behaviour of in time, the signal must be observed by functions which are localized both in time and frequency where as Wavelet analysis attempts to overcome these problems by the process of decomposing a time series into time/frequency space simultaneously. As a result it gives information on both the amplitude of any periodic signals within the series, and also how the amplitude varies with time.

By considering the known electricity consumption for the past years, wave packet, of finite duration and with a specific frequency can be generated. This wavelet has the advantage of incorporating a wave of a certain period of years given, as well as being finite in extent.

Considering the total width of this wavelet is about 10 years that is from the year 2005 to 2015, we can determine the number which gives us a measure of the projection of this wave packet on our data during the required period, i.e. how much [amplitude] does our 10-year period resemble a Sine wave of this width [frequency]. By sliding this wavelet along our time series, one can then construct a new time series that is of the projection amplitude versus time for the forthcoming years from 2016 to 2030. The wave is defined as the product of complex exponential wave and Gaussian envelope:

$$\psi_0(\eta) = \pi^{-\frac{1}{4}} e^{iw_0 n} e^{\frac{-\eta^2}{2}} \quad (7)$$

where,

ψ_0 is the wavelet value at non- dimensional time, η.

w_0 is the wave number.

This is the basic wavelet function, where as the need is to change the overall size as well as slide the entire wavelet along in time period. Hence the scaled wavelets are needed which is given by,

$$\psi\left[\frac{(n'-n)\delta t}{s}\right] = \left(\frac{\delta t}{s}\right)^{1/2} \psi_0\left[\frac{(n'-n)\delta t}{s}\right] \quad (8)$$

where

s is the dilation parameter used to change the scale

n is the translation parameter used to slide in time

$s^{-1/2}$ is a factor for the normalization to keep the total energy of the scaled wavelet constant.

$$W_n(s) = \sum_{n=0}^{N-1} x'_n \psi^* \left[\frac{(n'-n)\delta t}{s}\right] \quad (9)$$

For the given time series X with values of x_n, at time index n. Each value is separated in time by dt which is a constant time interval. The wavelet transform $W_n(s)$ is given as the inner product (or convolution) of the wavelet function with the original time series.

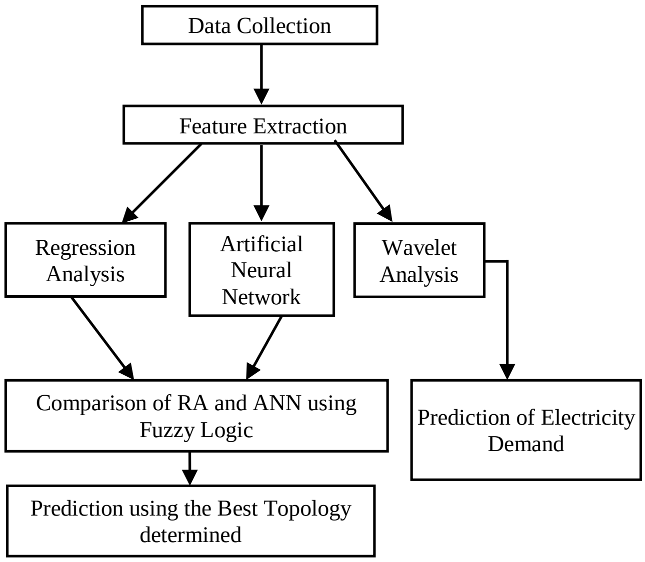

Fig.2. Framework of the Proposed System

The above integral can be evaluated for several values of the scale s, as well as all values of n between the start and end period. A two-dimensional picture of the variability can then be representing by plotting the wavelet amplitude and phase. Finally, the varying of the scale of the wavelet is done by changing its width. The wavelet analysis uses a wavelet of the exact same shape, only the scaling of the size is done up or down with the size of the window, by which the prediction of electricity demand for the forth coming years can be done. The Fig.2 gives the Overall Framework.

4. RESULT ANALYSIS

Multiple Linear Regressions gives the linear relationship between the electricity demand and the economic factors are implemented successfully from the year 2005 to 2010. It is implemented with different input variables in each model. The combination of input variables with minimum MAPE is chosen and the corresponding predicted value is compared with the actual value in the following graph with *X* axis representing Years and in *Y* axis representing the Electricity Consumption in BkWh. The Fig.5 gives the Comparison of Actual and Predicted values using MLR.

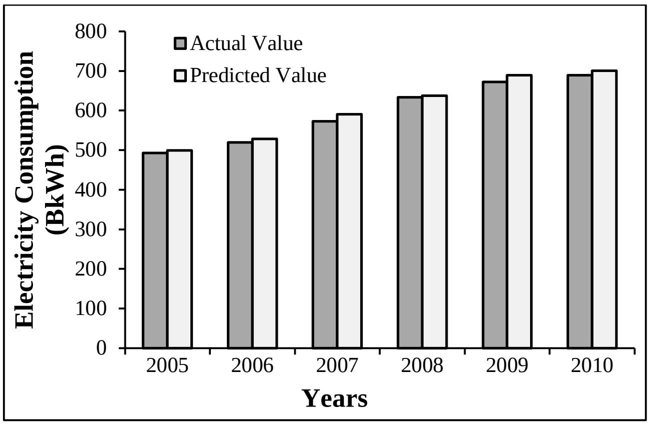

Fig.3. Comparison of Actual and Predicted values in MLR

ANN which gives the non linear relationship between the electricity demand and the economic factors are implemented successfully from the year 2005 to 2010. The input is given as different input variables. The combination of input variables with minimum MAPE is chosen and the corresponding predicted value is compared with the actual value in the following graph with X axis representing the Years and in Y axis representing the Electricity Consumption in BkWh. The Fig.4 gives the Comparison of Actual and Predicted values in ANN.

Fuzzy logic is implemented in graph form comparing the performance of MLR and ANN based on the three error rates: MAPE, RMSE and MBE. Wavelet is represented and by sliding this wavelet of width 10 years from 2005 to 2015, the wavelet representing the electricity forecasting that is of the projection amplitude versus time for the forthcoming years from 2016 to 2030 is obtained. The following graph depicts the difference in actual and predicted values for instance from the year 2011 to 2015 determined using Wavelet Analysis with X axis representing the Years and in Y axis representing the Electricity Consumption in BkWh. The Fig.5 gives the Comparison of Actual and Predicted values in Wavelet Analysis.

Wavelet results are obtained with input as electricity consumption of width 10 years from 2005 to 2015, the prediction are obtained for the electricity forecasting that is of the projection on time series for the forthcoming years from 2016 to 2030 is obtained.

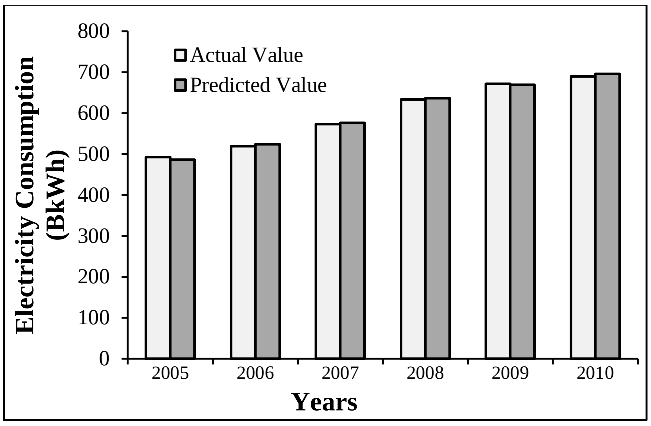

Fig.4. Comparison of Actual and Predicted values in ANN

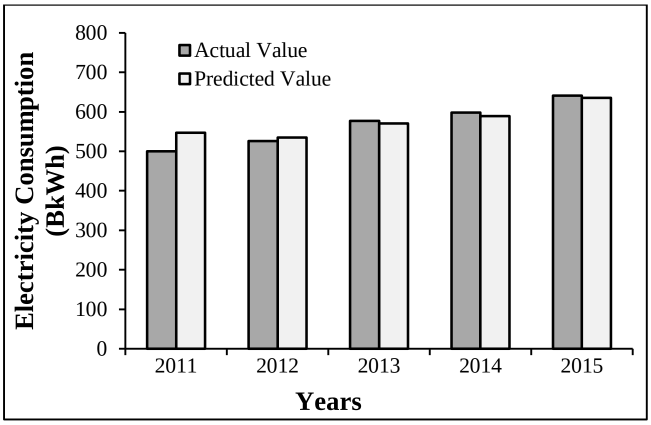

Fig.5. Comparison of Actual and Predicted values in Wavelet Analysis

5. CONCLUSION

The electrical energy sector is linked with the development of the country. Hence accurate forecasting of electricity for the upcoming years is an important task. The forecasting is done successfully using MLR and ANN. ANN gives a better accuracy compared to MLR. The comparison on performance based on error rates are implemented by Fuzzy Logic. Another methodology for forecasting, Wavelet Analysis is effectively applied for the prediction. Hence the accuracy of long term forecasting have vital effects on power system planning to construct new power generation plants and transmission facilities to meet the requirements of the power demand in the future. Future enhancement can be done by performing prediction using Advanced ANN on ensemble basis using least squares and K Nearest Neighbour non-parametric method.

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