# Short term load forecasting using fuzzy logic

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***Abstract* – Load forecasting is essential for planning and operation in energy management. It enhances the Energy efficient and reliable operation of a power system. The energy supplied by utilities meets the load plus the energy lost in the system is ensured by this tool. Since in power system the next day's power generation must be scheduled every day. The day- ahead short term load forecasting (STLF) is a necessary daily task for power dispatch. Short term load forecasting is essential for unit commitment, economic allocation of generation, maintenance schedules. This paper presents a solution methodology using fuzzy logic for short term load forecasting. Fuzzy logic approach is implemented on weather sensitive data and historical load data for forecasting the load. The proposed methodology uses fuzzy reasoning decision rules that capture the nonlinear relationships between inputs and outputs. The input data include historical load and hourly data like temperature, humidity and windspeed. Jaipur Vidyut Nigam hourly load data is used for training and testing which is collected from State Load Dispatch and Communication Centre, Rajasthan Vidyut Parasaran Nigam. The forecasted load results are obtained from fuzzy logic model using triangular membership function.**

***Keywords*--Short term load forecasting, fuzzy logic, membership function, Absolute percentage error**

## I. INTRODUCTION

In power system network load forecasting is very important part of energy management system for operation and planning purpose. Load forecasting means that the techniques for predication of electric load[2]. Load forecasting is integral and central process in the planning and operation of electric energy management system [6]. In power systems the next days' power generation must be scheduled every day, day ahead Short-term load forecasting (STLF) is a necessary daily task for power dispatch. In a power system network short term load forecasting play important in non competitive to renewable energy system[3].STLF is also used for prevent overloading in reduce occurrence of equipment of failure. STLF is a very useful tool for basic generation scheduling functions, assessing the security of power system at any time, timely dispatcher information [3]. The types of forecast are classified into three categories Short-term forecasting, Medium-term forecasting and Long-term forecasting. In this paper, discussed about short term load forecasting where short term forecasting is limited to less than one month ahead [2].

Load forecasting is very important in part of the electric industry for the deregulated market. It has many of the application in energy purchasing and generation, infrastructure development. Load forecasting is also important for energy supplier and electric energy generation, transmission, distribution, and markets[2]. There are so many techniques used for short term load forecasting. Time series, multiple linear regression and expert system are used for short term load forecasting. The time series method treats the load pattern as a time series signal with known seasonal, weakly and daily periodicities [1]. The difference between prediction and actual load is considered as a stochastic process. This model uses the historical load data for extrapolation of future loads[1]. It is a non-weather sensitive approach. The main disadvantage of this type model is large amount of data needed and complexity is high. Regression model derive linear models for the system load. This type of modeling technique is frequently divided into smaller segment and this type of model built in each segment of such as season day or week. This fuzzy logic approach is applied for the short term load forecasting using weather data, such as temperature, humidity, wind speed etc. The expert system approach is a rule-based method for load forecasting, using the logic of a power system operator to develop mathematical equations for forecasting. The main disadvantage of these methods is knowledge acquisition [1].

Fuzzy logic models have been proposed as an alternative forecasting method. Fuzzy logic is basically multi valued logic that aloe intermediate value to define a convectional evolution like yes or no, true/false etc. fuzzy logic approach is a generalization of a Boolean logic and it used for digital circuit design. Among the advantages of the use of fuzzy logic are the absences of a need for a mathematical model mapping inputs to outputs and the absence of a need for precise inputs. Fuzzy logic is specially designed for representing knowledge of human reasoning in such way. The main concept of fuzzy logic is fuzzy set, linguistic variable, possibility distribution, and fuzzy IF-THEN rule base. IF-THEN rule base is used for convert the fuzzy input into the fuzzy output [8].

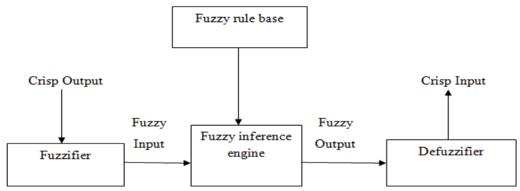


Figure 1. Configuration of Fuzzy logic

## II. DESCRIPTION OF FUZZY LOGIC MODEL

The proposed development and implementation of fuzzy logic based algorithm for load forecasting consists of four stages.

(a) Design of fuzzy rule base

Based on the demonstrated success in generating forecasts, the methodology proposed by Wang and Kosko is used here. This approach consists a five steps as given below:

Step 1. Compile a tentative list of input and output variables using statistical analysis, engineering judgments and/or operator experience. There are three input variables which are used to forecast electric load as an output are:[1]

- Temperature
- Humidity
- Wind speed

Step 2. Normalization of the input and output variables is done by analyzing the input and the output behavior the input space is mapped to the membership value [0,1]. [1]

Step 3. Select the shape of the fuzzy membership for each variable; namely the triangular, trapezoidal, Gaussian and bell shape membership function. The membership function is selected by trial and error method.

Step 4. For each input and output variable, tentatively define the number of fuzzy membership functions. For example, all variables depict three functions. The lengths of the regions under the functions for a given variable need not be equal, nor must the number of functions for all variables be equal.[5]

Temperature data is fuzzified into three main fuzzy sets described as: cold, normal and hot

Humidity data is fuzzified into three main fuzzy sets described as: dry, humid and very humid

Wind speed data is fuzzified into three main fuzzy sets described as: below normal, normal and above normal

Time data is fuzzified into three main fuzzy sets described as: morning, mid-day and night

Step 5. Fuzzy logic rule base is each pair of input and output data, and it's called training data. For example: IF 'temperature' is hot and 'humidity' is humid and 'wind speed' is above average THEN 'load' is above average.

(b) Compute the point forecast value

A fuzzy inference system implements a nonlinear mapping from its input space to output space. This mapping is accomplished by a number fuzzy if-then rule, each of which describes the local behavior of the mapping.

Defuzzification is performed to determine the point estimate of the forecast from the fuzzy forecasts. Centroid of area method approach produces a numerical forecast sensitive to all the rules.

Centroid of area $Z_{COA} = \frac{\int_Z \mu_A(Z)dZ}{\int_Z \mu_A(Z)\, Z\, dx}$

where $\mu_A(z)$ is the aggregated output MF.[1]

(c) Test the performance of the rule base

Forecast accuracy is tested using a different set of historical data set (test set) from the one used to obtain the rule base. If it is unsatisfactory, then the number of fuzzy membership functions and/or shape of the fuzzy membership functions can be changed and a new fuzzy rule base is obtained. The iterative process of designing the rule base, choosing a defuzzification algorithm, and testing the system performance may be repeated several times with a different number of fuzzy membership functions and/or different shapes of fuzzy memberships. The fuzzy rule base that provides the minimum error measure for the test set is selected for real time forecasting. The above method, known as 'Train and Test method', works very well when the size of the test set is sufficiently large. It is assumed (as in all modeling of systems based on historical data) that, if the test set is sufficiently large, then the observed test set error rate will be close to the anticipated real-time forecasting error rate.[1]

(d) Evaluate and update the fuzzy rule base

The new rule designed from the new observation does not conflict with any rules already in the rule base, then the new rule can be immediately added to the fuzzy rule base. When there is a conflict, the THEN part associated with the rule may be modified based on the conflict resolution methods described above.[7]

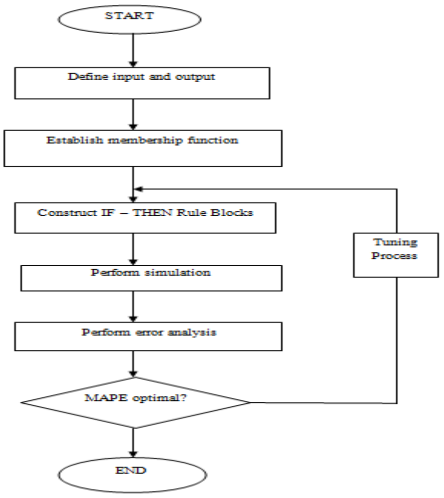


Figure 2. Process Flowchart of modeling using fuzzy logic

(e) Error analysis

In this step find the absolute percentage error and mean absolute percentage error by using this eq. and question is given below.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|Actual(i) - Forecast(i)|}{Actual(i)}.100\%$$

## III. NUMERICAL RESULTS

The performance of a load forecasting system based on this fuzzy logic methodology is demonstrated using data from Jaipur Vidyut Nigam for different day types is used for training and load forecasting. Real time data that includes historical hourly load demand over a week, and weather data in terms of temperature, humidity, wind speed, is collected from Jaipur State Load Dispatch and Communication Center, Rajasthan Vidyut Parasaran Nigam (JVN). In this paper three triangular membership functions is used. The forecasted load is compared with the actual load and average percentage error is calculated. In this paper four cases are included in this paper.

I. Hourly load forecast of a pre-holiday (Saturday)

II. Hourly load forecast of a holiday (Sunday)

III. Hourly load forecast of a weekday (Wednesday)

IV. Hourly load forecast of a post-holiday(Monday)

**Case 1. Hourly load forecast of a pre-holiday (Saturday)**

In this case, hourly load for JVN is forecasted for a pre-holiday i.e. Saturday (23 November 2013).[9][10]

| Time | Temparature | wind speed | humidity | actual load | forecasted load | APE |
|---|---|---|---|---|---|---|
| 0 | 18 | 8 | 36 | 2596 | 2650 | 2.08 |
| 1 | 18 | 8 | 37 | 2540 | 2650 | 4.33 |
| 2 | 17 | 7 | 38 | 2465 | 2650 | 7.5 |
| 3 | 17 | 7 | 39 | 2372 | 2650 | 11.72 |
| 4 | 16 | 7 | 40 | 2428 | 2650 | 9.14 |
| 5 | 16 | 6 | 42 | 2844 | 2650 | 6.82 |
| 6 | 16 | 6 | 43 | 3206 | 2650 | 17.34 |
| 7 | 17 | 6 | 40 | 3337 | 2650 | 20.44 |
| 8 | 20 | 5 | 33 | 3329 | 2630 | 21.65 |
| 9 | 25 | 5 | 29 | 3347 | 2650 | 20.82 |
| 10 | 26 | 4 | 26 | 3079 | 2500 | 18.8 |
| 11 | 26 | 4 | 23 | 2978 | 2490 | 16.38 |
| 12 | 26 | 6 | 21 | 2842 | 2490 | 12.38 |
| 13 | 27 | 8 | 20 | 2634 | 2490 | 5.46 |
| 14 | 27 | 10 | 19 | 2564 | 2650 | 3.354 |
| 15 | 26 | 11 | 20 | 2596 | 2650 | 2.08 |
| 16 | 26 | 12 | 21 | 2693 | 2650 | 15.96 |
| 17 | 25 | 12 | 24 | 2799 | 2650 | 5.32 |
| 18 | 24 | 13 | 24 | 3084 | 2650 | 14.07 |
| 19 | 24 | 14 | 24 | 2904 | 2650 | 8.74 |
| 20 | 21 | 14 | 24 | 2745 | 2650 | 3.46 |
| 21 | 20 | 13 | 24 | 2699 | 2480 | 8.11 |
| 22 | 20 | 13 | 23 | 2662 | 2480 | 6.83 |
| 23 | 19 | 12 | 23 | 2543 | 2250 | 11.52 |

Table 1 Hourly load forecast of a pre-holiday (Saturday)

**Result of case 1 pre-holiday**

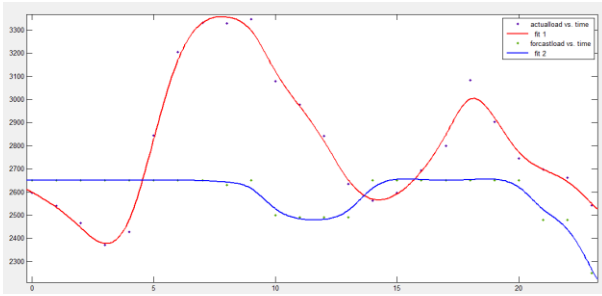

Fig 3Actual load and forecast load vs. time for pre-holiday

**Case 2.Hourly load forecast of a holiday (Sunday)**

In this case, hourly load for JVN is forecasted for a holiday i.e. Sunday (24November 2013).[9][10]

| Time | Temparature | wind speed | humidity | actual load | forecasted load | APE |
|---|---|---|---|---|---|---|
| 0 | 17 | 5 | 32 | 2532 | 2660 | 5.05 |
| 1 | 16 | 5 | 34 | 2488 | 2660 | 6.91 |
| 2 | 15 | 4 | 36 | 2442 | 2660 | 8.51 |
| 3 | 14 | 4 | 37 | 2371 | 2500 | 5.44 |
| 4 | 14 | 5 | 38 | 2424 | 2500 | 3.13 |
| 5 | 14 | 5 | 37 | 2759 | 2500 | 9.38 |
| 6 | 14 | 4 | 38 | 3083 | 2500 | 18.91 |
| 7 | 15 | 4 | 37 | 3239 | 2650 | 18.18 |
| 8 | 20 | 4 | 29 | 3259 | 2850 | 12.54 |
| 9 | 24 | 4 | 25 | 3295 | 2650 | 19.57 |
| 10 | 25 | 4 | 21 | 3187 | 2500 | 21.55 |
| 11 | 25 | 5 | 19 | 3107 | 2500 | 19.53 |
| 12 | 26 | 6 | 17 | 2891 | 2500 | 13.7 |
| 13 | 26 | 7 | 16 | 2781 | 2500 | 10.1 |
| 14 | 27 | 8 | 16 | 2747 | 2350 | 14.45 |
| 15 | 26 | 9 | 17 | 2710 | 2340 | 13.65 |
| 16 | 25 | 9 | 19 | 2662 | 2340 | 12.09 |
| 17 | 24 | 10 | 23 | 2732 | 2500 | 8.49 |
| 18 | 24 | 11 | 24 | 2966 | 2500 | 15.71 |
| 19 | 24 | 12 | 26 | 2834 | 2500 | 11.78 |
| 20 | 21 | 13 | 27 | 2600 | 2340 | 10 |
| 21 | 20 | 13 | 29 | 2585 | 2340 | 9.47 |
| 22 | 20 | 12 | 30 | 2587 | 2350 | 9.16 |
| 23 | 19 | 11 | 31 | 2537 | 2350 | 7.37 |

Table 2Hourly load forecast of a holiday (Sunday)

**Result of case 2. Holiday (Sunday)**

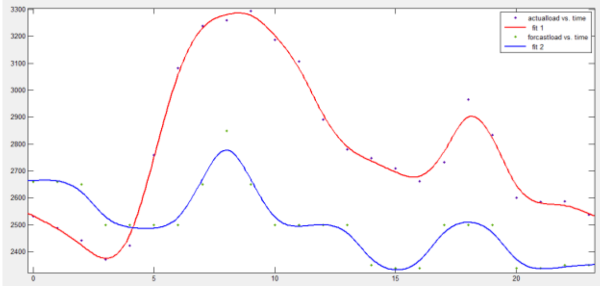

Fig 4 Actual load and forecast load vs. time for holiday

**Case 3 Hourly load forecast of a working day (Wednesday)**

In this case, hourly load for JVN is forecasted for a working day. Wednesday (27 November 2013).[9][10]

| Time | Temperature | wind speed | humidity | actual load | forecasted load | APE |
|---|---|---|---|---|---|---|
| 0 | 18 | 8 | 38 | 2608 | 2600 | 0.3 |
| 1 | 18 | 8 | 39 | 2558 | 2600 | 1.24 |
| 2 | 17 | 8 | 40 | 2507 | 2600 | 3.7 |
| 3 | 17 | 8 | 40 | 2386 | 2600 | 8.96 |
| 4 | 17 | 9 | 40 | 2377 | 2600 | 9.38 |
| 5 | 17 | 9 | 40 | 2768 | 2600 | 6.06 |
| 6 | 17 | 9 | 41 | 3178 | 2600 | 18.18 |
| 7 | 18 | 8 | 40 | 3347 | 2600 | 22.31 |
| 8 | 20 | 7 | 35 | 3323 | 2600 | 21.35 |
| 9 | 25 | 7 | 30 | 3285 | 2620 | 19.93 |
| 10 | 25 | 7 | 26 | 3250 | 2630 | 20.01 |
| 11 | 25 | 6 | 23 | 3168 | 2600 | 17.92 |
| 12 | 26 | 7 | 22 | 3053 | 2600 | 14.83 |
| 13 | 26 | 8 | 21 | 2835 | 2600 | 8.28 |
| 14 | 27 | 9 | 20 | 2867 | 2600 | 9.31 |
| 15 | 26 | 9 | 21 | 2880 | 2600 | 9.72 |
| 16 | 25 | 9 | 23 | 2908 | 2600 | 10.59 |
| 17 | 24 | 9 | 27 | 2981 | 2570 | 13.78 |
| 18 | 22 | 10 | 28 | 3254 | 2600 | 20.09 |
| 19 | 21 | 10 | 29 | 3083 | 2600 | 15.66 |
| 20 | 21 | 10 | 30 | 2793 | 2580 | 7.62 |
| 21 | 20 | 10 | 32 | 2785 | 2580 | 7.36 |
| 22 | 19 | 9 | 33 | 2827 | 2600 | 8.02 |
| 23 | 19 | 9 | 34 | 2804 | 2600 | 7.27 |

Table 3Hourly load forecast of a working day (Wednesday)

**Result of case 3 Working day (Wednesday)**

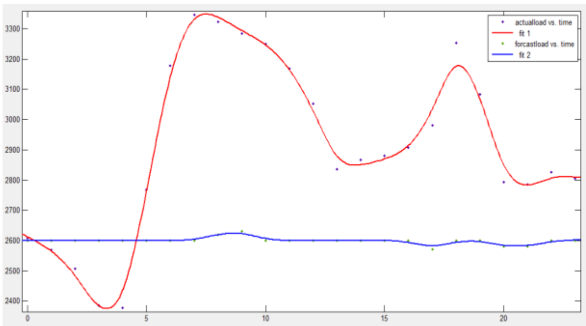

Fig 5 Actual load and forecast load vs. time for working day

**Case 4 Hourly load forecast of a post holiday (Monday)**

In this case, hourly load for JVN is forecasted for a working day. i.e. Monday (27November 2013).[9][10]

| Time | Temperature | wind speed | humidity | actual load | forecasted load | APE |
|---|---|---|---|---|---|---|
| 0 | 19 | 11 | 32 | 2530 | 2650 | 4.74 |
| 1 | 19 | 10 | 33 | 2468 | 2650 | 7.37 |
| 2 | 18 | 10 | 34 | 2429 | 2650 | 9.09 |
| 3 | 18 | 10 | 34 | 2340 | 2650 | 13.24 |
| 4 | 18 | 10 | 35 | 2353 | 2650 | 12.62 |
| 5 | 17 | 10 | 36 | 2756 | 2650 | 3.84 |
| 6 | 17 | 10 | 37 | 3195 | 2650 | 23.77 |
| 7 | 18 | 9 | 37 | 3434 | 2650 | 22.83 |
| 8 | 20 | 9 | 33 | 3443 | 2650 | 23.03 |
| 9 | 24 | 10 | 28 | 3448 | 2650 | 23.14 |
| 10 | 25 | 11 | 25 | 3318 | 2650 | 20.13 |
| 11 | 26 | 12 | 22 | 3142 | 2650 | 15.65 |
| 12 | 26 | 13 | 21 | 2977 | 2650 | 10.98 |
| 13 | 27 | 14 | 21 | 2784 | 2650 | 4.81 |
| 14 | 27 | 14 | 20 | 2729 | 2650 | 2.89 |
| 15 | 27 | 14 | 21 | 2732 | 2650 | 3.01 |
| 16 | 26 | 14 | 23 | 2730 | 2650 | 2.93 |
| 17 | 25 | 13 | 28 | 2854 | 2650 | 7.14 |
| 18 | 25 | 13 | 29 | 3154 | 2650 | 15.97 |
| 19 | 25 | 12 | 31 | 2953 | 2650 | 4.16 |
| 20 | 25 | 12 | 32 | 2702 | 2830 | 4.72 |
| 21 | 20 | 11 | 33 | 2662 | 2830 | 0.45 |
| 22 | 20 | 10 | 34 | 2719 | 2650 | 2.53 |
| 23 | 20 | 10 | 35 | 2709 | 2650 | 2.17 |

Table 4 Hourly load forecast of post-holiday (Monday)

**Result of case 4 post-holiday (Monday)**

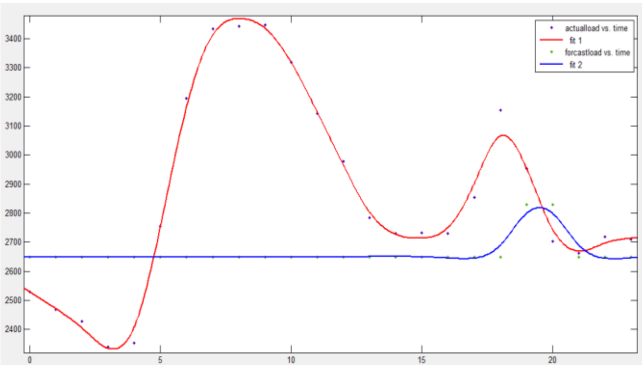

Fig 6 Actual load and forecast load vs. time for post-holiday

## IV. CONCLUSIONS

STLF is a very useful tool for security analysis, unit commitment, and economic allocation of generation. Therefore, the accurate forecasting of the load is an essential element in power system. Economy of operations and control of power systems may be quite sensitive to forecasting errors.

The fuzzy logic approach for STLF, offers a logical set of rules, readily adaptable and understandable by an operator, may be a very good solution to the implementation. Its forecasting reliabilities evaluated by computing the MAPE (Mean Absolute Percentage Error) between the actual and predicted values, by using three triangular membership function MAPE is calculated for four case. In this MAPE for Pre-holiday (Saturday) is 10.55%, holiday (Sunday) error is 9.05%, post-holiday error is 10.05%, and working day error is 11.74%.

## V. FUTURE SCOPE

The mean absolute percentage error in the forecasting the load can even be lowered if a large and accurate training data is used to train fuzzy logic model. The APE can be reduced by increasing the number of membership function and by using the trapezoidal, Gaussian bell membership function. Further by using other artificial intelligence technique like Artificial Neural Network, Genetic Algorithm, the MAPE can be reduced.

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