Fuzzy Logic Approach for Short Term Electrical Load Forecasting

M. Rizwan[1], Dinesh Kumar[2], Rajesh Kumar[3]

[1, 2, 3] Department of Electrical Engineering, Delhi Technological University, Delhi 110042, India

[1]rizwaniit@yahoo.co.in; [2]dinesh030989@gmail.com; [3]1991rajesh@gmail.com

***Abstract*- The demand of electricity in India is increasing exponentially at the rate of 8-9% per annum. However, the installed power generation capacity of India as on 31st October 2012 was 209276 MW with a peak power shortage of more than 12%. In addition, the demand of electricity is increasing due to increased population, urbanization and comfort level of the peoples. These indicate that India's future energy requirements are going to be very high. Keeping in view of aforesaid, proper energy management system is required. In this paper an attempt has been made for short term load forecasting which helps in load management with on line dynamic voltage control, load flow studies and exchange of power as requirement for load frequency control. In this paper, the daily hourly demand of Shahpura, Jaipur, India has been collected from Rajasthan Electricity Board (Shahpura Sub-station), India. To avoid the convergence problems, the input and output load data are scaled down such that they remain within the range of (0.1-0.9). The inputs of the fuzzy logic based models are the hourly electrical demand during the day for the four consecutive days of November 2012 and the output or forecasted value is the hourly demand of the fifth day. The results obtained from fuzzy logic model has been validated with the actual value and found accurate. The mean absolute percentage error (MAPE) in the forecasted demand is 1.39% in comparison with the desired demand.**

Keywords*- Fuzzy Logic; Load Forecasting; Energy Management

I. INTRODUCTION

The demand of electricity is increasing drastically day by day. This increase in demand of electrical energy has drawn the attention of power system engineers towards the reliable operation of power system. For reliable operation of integrated power supply systems, a close tracking of electrical load is required [1]. Load forecasting predicts the load which is going to be required at a particular time of day or on any particular day. Load forecasting plays an important role in the smooth operation of any power system. It is absolutely essential for load switching, area planning and also load flow analysis during contingencies. It is also a determining factor during infrastructure development or capital expenditure decision making. Therefore, load forecasting is important for proper management of any power system. It is desirable to know prior to demand profile of the system. Load forecasting also helps in load scheduling. Depends on the time range, the load forecasting can be divided into three categories which include long term, medium term and short term. Long term load forecasting (LTLF) is applicable for system and long term network planning. Mid Term Load Forecasting (MTLF) refers to quarterly, half yearly and yearly load forecasting needs. Short Term Load Forecasting (STLF) means days ahead and weeks ahead load forecasting needs. There are many techniques that could be employed for loads forecasting like linear regression, statistical method, exponential smoothening, neural network based artificial intelligence technique, fuzzy logic, genetic algorithm, autoregressive model, similar day approach, time series, expert system, support vector machine, and data mining model [3-12]. Among these, ANN is widely used when there is no fluctuation in condition like temperature, weather and load. In case of sudden fluctuation in load and temperature, fuzzy logic based approach is used. It has advantage over ANN that it leads with non-linear part of the forecasted load curve as well as it has ability to deal with sudden variation in load i.e. load and temperature variation. In addition, fuzzy logic approach is easy and robust. Keeping in view of the aforesaid variation in the inputs, an attempt has been made to develop the fuzzy logic based model for short term load forecasting. The proposed model is simple, accurate and incorporates the uncertainties in the input variables.

This paper is organized as follows: Brief idea about the fuzzy logic is given in Section II. Section III presents the data collection and normalization of input and output data. Development of fuzzy logic model for short term load forecasting is presented in Section IV. Results are discussed in Section V. Conclusion followed by references is presented in Section VI.

II. BASICS OF FUZZY LOGIC

The concept of Fuzzy Logic was introduced by Professor Lotfi A. Zadeh at the University of California, Berkeley in the 1960's. His goal was to develop a model that could more closely describe the natural language process. This model was intended to be used in situations when deterministic and/or probabilistic models do not provide a realistic description of the phenomenon under study. The fuzzy sets and fuzzy operators are the subjects and verbs of fuzzy logic. But in order to say something useful, we need to make complete sentences. The condition statements, IF-THEN rules, are things that make fuzzy logic useful. The fuzzy logic IF-THEN statements are used to characterize the state of a system and truth value of the proposition is a measure for how well the description matches the state of the system [1,13]. The fuzzy set can be defined as follows:

Let X, be a universal set. The characteristic function μ_A of a subset of X takes its values in the two element set {0, 1} and μ_A (x) = 1, if x ϵ A and zero otherwise. A fuzzy set A has a characteristic function taking its values in the interval

{0, 1}. μ_A is also called a membership function and $\mu_A(x)$ is the grade of membership of $x \in X$ in A. In fuzzy set, the transition between membership and non membership is gradual rather than abrupt. The union and intersection of two fuzzy subsets A and B of X having membership function μ_A and μ_B respectively is defined as

Union: $\mu_{A\cup B}(x) = \max[\mu_A(x), \mu_B(x)]$ (1)

Intersection: $\mu_{A\cap B}(x) = \min[\mu_A(x), \mu_B(x)]$ (2)

Fuzzy logic describes the vague concepts such as fast runner, hot weather, weekend days etc. It is convenient to map an input to an output space. The concept of fuzzy provides a natural way dealing with the problems in which source of impression is the absence of sharply defined criterion rather than the presence of random variables. Prof. Zadeh also introduced linguistic as variables whose values are sentences in natural or artificial language.

III. DATA COLLECTION AND NORMALIZATION

The hourly daily electrical load of Shahpura, Jaipur has been collected from Rajasthan Electricity Board for the purpose of short term load forecasting. The hourly daily electrical load for the month of November 2012 is presented in TABLE I.

TABLE I ELECTRICAL LOAD (MW) DURING 19, 20, 21, 22 AND 23 NOVEMBER, 2012 AT SHAHPURA, JAIPUR

Time	Nov. 19	Nov. 20	Nov. 21	Nov. 22	Nov. 23
	Input 1 (MW)	***Input 2 (MW)***	***Input 3 (MW)***	***Input 4 (MW)***	***Output (MW)***
6:00	31.98	34.98	32.65	27.42	28.2
7:00	30.58	34.98	32.65	25.09	27.04
8:00	18.96	17.73	17.49	18.39	21.60
9:00	20.66	17.35	17.35	18.39	20.31
10:00	18.54	18.31	19.67	20.71	27.36
11:00	28.62	32.9	33.48	29.07	28.2
12:00	20.44	24.31	12.75	13.43	18.5
13:00	15.14	29.8	29.8	14.5	23.35
14:00	14.99	24.27	15.63	23.82	14.95
15:00	14.10	15.43	15.93	18.88	13.62
16:00	15.10	15.3	21.5	14.38	14.11
17:00	16.10	16.15	16.05	16.15	16.1
18:00	13.62	12.76	14.62	16.56	18.92
19:00	37.17	36.77	37.39	39.95	39.53
20:00	36.24	30.07	34.93	36.941	35.74
21:00	32.44	31.88	32.23	35.44	32.69
22:00	31.65	26.91	33.85	35.08	32.91
23:00	33.12	25.88	20.91	23.45	26.23
24:00	33.62	26.91	29.25	25.35	39.54
1:00	30.94	28.89	27.12	30.20	29.75
2:00	28.65	27.88	24.7	26.93	26
3:00	31.01	28.89	23.67	23.19	21.82
4:00	36.98	36.07	30.72	27.12	27.91
5:00	34.85	34.86	32.19	29.49	26.65

The input and output data is further normalized and scaled in the range of 0.1-0.9 to avoid the convergence problem during the rules formation [1]. The actual data is scaled by using the following expression and presented in TABLE II.

$$L_S = \frac{(Y_{max} - Y_{min})}{(L_{max} - L_{min})}(L - L_{min}) + Y_{min} \quad (3)$$

TABLE II NORMALIZED INPUT AND OUTPUT DATA

Time	Nov. 19	Nov. 20	Nov. 21	Nov. 22	Nov. 23
	Input 1 (MW)	***Input 2 (MW)***	***Input 3 (MW)***	***Input 4 (MW)***	***Output (MW)***
6:00	0.724	0.833	0.746	0.522	0.551
7:00	0.677	0.833	0.746	0.452	0.515
8:00	0.282	0.264	0.254	0.249	0.346
9:00	0.339	0.251	0.249	0.249	0.307
10:00	0.267	0.283	0.324	0.319	0.525
11:00	0.61	0.764	0.774	0.572	0.551
12:00	0.332	0.481	0.1	0.1	0.251
13:00	0.152	0.662	0.654	0.132	0.401
14:00	0.147	0.48	0.194	0.414	0.141
15:00	0.116	0.188	0.203	0.264	0.1
16:00	0.15	0.184	0.384	0.129	0.115
17:00	0.184	0.212	0.207	0.182	0.177
18:00	0.1	0.1	0.161	0.194	0.264
19:00	0.9	0.9	0.9	0.9	0.899
20:00	0.869	0.671	0.821	0.81	0.784
21:00	0.74	0.731	0.733	0.765	0.689
22:00	0.713	0.567	0.786	0.754	0.696
23:00	0.763	0.533	0.366	0.403	0.489
24:00	0.78	0.567	0.636	0.463	0.9
1:00	0.69	0.632	0.567	0.506	0.598
2:00	0.611	0.599	0.488	0.408	0.483
3:00	0.69	0.632	0.455	0.295	0.353
4:00	0.89	0.87	0.684	0.413	0.542
5:00	0.82	0.83	0.732	0.485	0.503

The hourly electrical loads of Shahpura, Jaipur on 19th, 20th, 21st, 22nd and 23rd November, 2012 are also presented graphically in Fig. 1, Fig. 2, Fig. 3, Fig. 4 and Fig. 5 respectively.

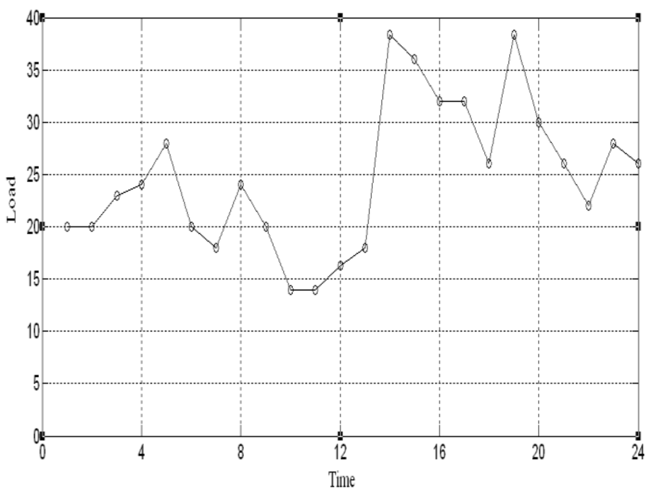

Fig. 1 Hourly electrical load on 19th November, 2012

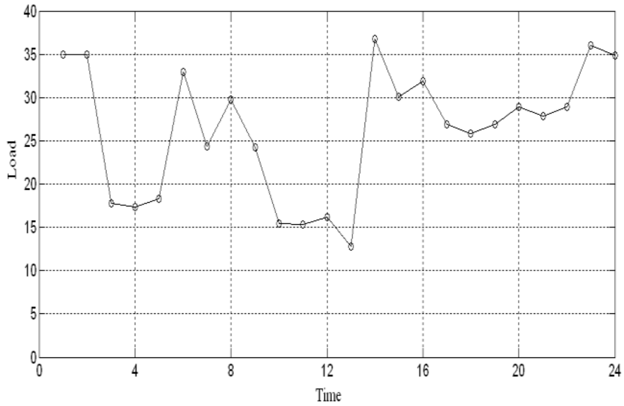

Fig. 2 Hourly electrical load on 20th November, 2012

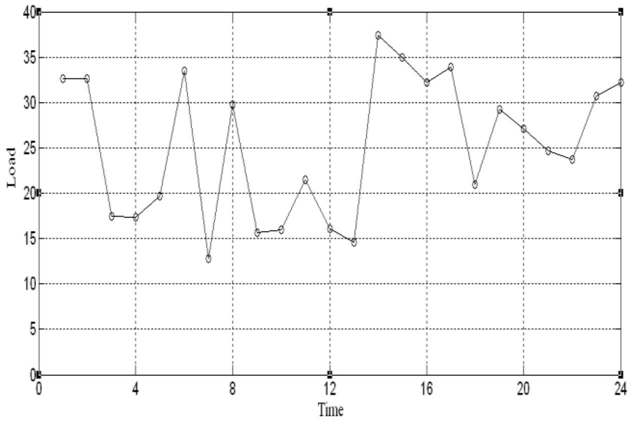

Fig. 3 Hourly electrical load on 21st November, 2012

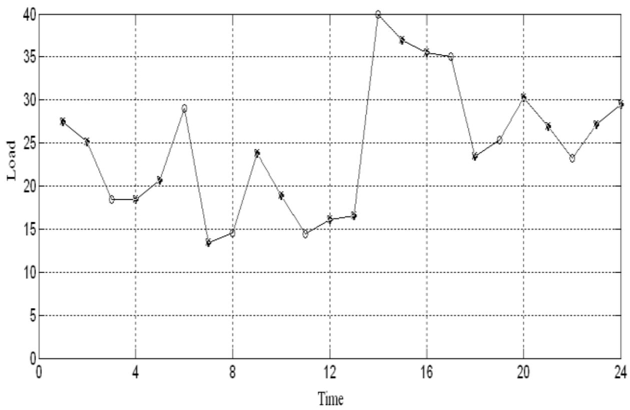

Fig. 4 Hourly electrical load on 22nd November, 2012

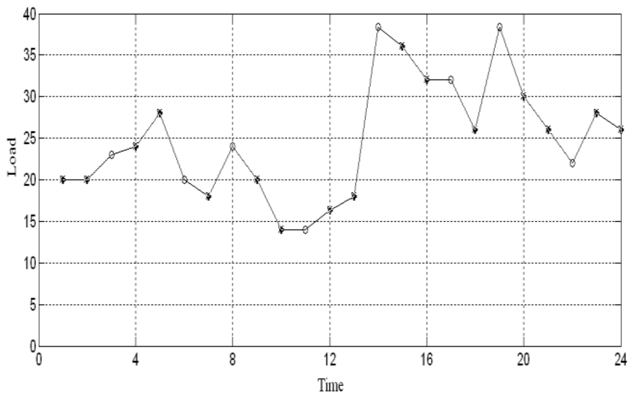

Fig. 5 Hourly electrical load on 23rd November, 2012

These load curves are helpful in determining the load pattern.

IV. MODEL DEVELOPMENT

The fuzzy logic model for the short term electrical load forecasting is developed and presented. The developed model contains a set of rules which are developed from qualitative descriptions. The fuzzy linguistic variables are described as low, medium and high. The membership function for the actual load is presented in Fig. 6. A concern for the development of fuzzy systems is the assignment of appropriate membership functions. Construction of membership functions can be based on intuition, experience or probabilistic methods [2]. Nevertheless, it has shown that the choice of membership degrees in the interval [0, 1], does not matter, as it is the order of magnitude that is important.

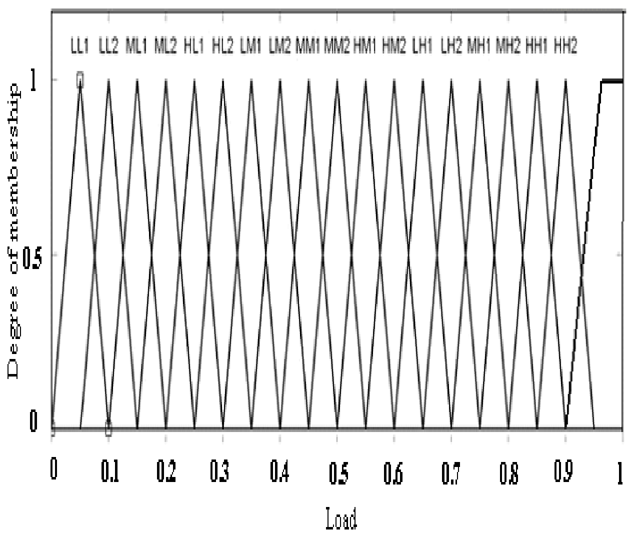

Fig. 6 Fuzzy subsets membership functions for electrical load

In fuzzy systems, rules may be fired with some degree using fuzzy inferencing; whereas, in conventional expert systems, a rule is either fired or not fired. For the short term load forecasting (STLF) problem, rules are defined to determine the accuracy in terms of absolute relative error. Such rules are expressed in the following form [2].

IF premise (antecedent), THEN conclusion (consequent)

For the STLF problem, a set of multiple-antecedent fuzzy rules have been established. The input to the rules is electrical load demand during 19, 20, 21 and 22 November, 2012 respectively and the output consequent is the electrical load on 23rd November 2012. The rules are summarized in TABLE III.

TABLE III FUZZY RULE BASE FOR STLF

S. No.	Inputs				Output
	Input 1	*Input 2*	*Input 3*	*Input 4*	
1.	HM2	HH1	HL2	HL2	HL2
2.	HM1	HH1	HL1	HL1	HL2
3.	MM1	MM1	MM1	MM1	MH1
4.	MM2	MM1	MM1	MM1	MH2
5.	MM1	MM1	MM2	MM2	HL2
6.	HL2	HM2	HM1	HM1	HL2
7.	MM2	MH2	LH2	ML1	MM1
8.	ML2	HM1	HM1	ML1	MH2
9.	ML1	MH2	ML2	HL1	ML1
10.	ML1	ML2	ML2	MM1	ML1
11.	ML2	ML2	MH1	ML1	ML1
12.	ML2	ML2	ML2	ML2	ML2
13.	ML1	LH2	ML1	ML2	MM1
14.	HH	HH2	HH	HH	HH
15.	HH2	HM1	HH1	HH2	HH2
16.	HM2	HM2	HM2	HH2	HM2
17.	HM2	HL1	HM2	HH2	HM2
18.	HH1	HL1	MM2	MH2	HL1
19.	HH1	HL1	HM1	HL1	HH
20.	HM1	HL2	HL2	HM1	HM1
21.	HL2	HL2	MH2	HL1	HL1
22.	HM2	HL2	MH2	MH2	MH1
23.	HH2	HH2	HM1	HL2	HL2
24.	HH1	HH1	HM2	HM1	HL1

The rules listed in TABLE III have been implemented using fuzzy logic toolbox of MATLAB for developing the model to forecast the electrical load as shown in Fig. 7.

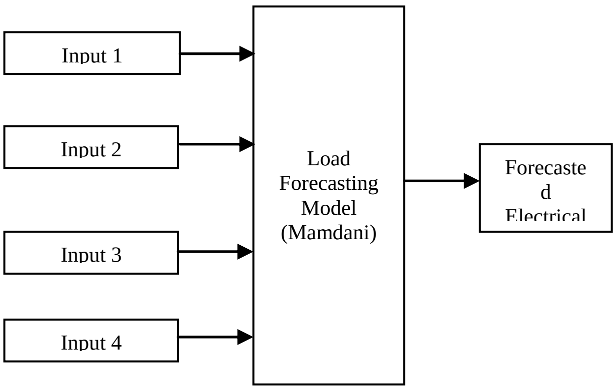

Fig. 7 Fuzzy logic based model for short term load forecasting

V. RESULT AND DISCUSSION

Fuzzy logic based model is developed and presented for the short term load forecasting using the above mentioned data for Shahpura, Jaipur station. The output of the model is demand of electricity on 23rd of November, 2012. Various rules have been established in the development of fuzzy logic based model. The results for 19th rule are presented in Fig. 8. Obtained results are denormalized to get the forecasted electrical load. Results of fuzzy logic based models are compared with the actual demand of electricity for validation.

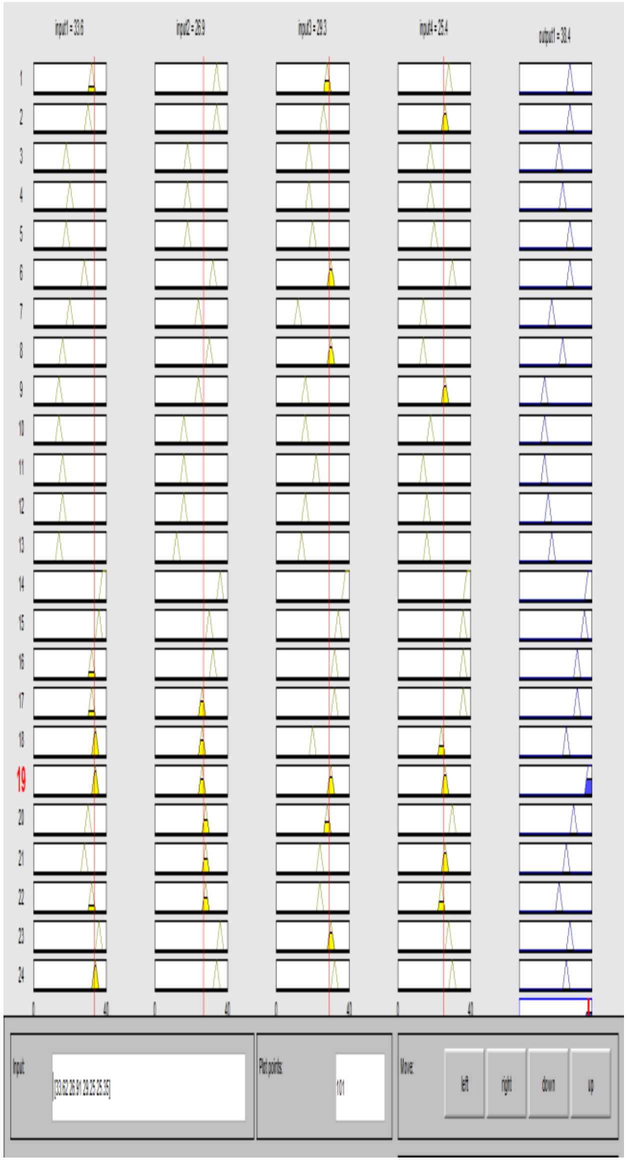

Fig. 8 Rule viewer corresponding to 19th rule

The results of fuzzy logic model are shown in TABLE IV. This table presents forecasted output in comparison with the actual data. The performance of the model is evaluated on the basis of absolute relative error which can be determined by using the following formula:

$$\text{Absolute relative error} = \frac{|P_{desired} - P_{forecasted}|}{P_{desired}} \times 100$$

The absolute relative error (ARE) in the forecasted load in comparison with the actual load is also presented in TABLE IV. The predicted data of electrical load on 23rd November, 2012 is compared with actual load demand and also presented graphically in Fig. 9.

TABLE IV ABSOLUTE RELATIVE ERROR IN FORECASTED LOAD IN COMPARISON WITH DESIRED LOAD

Time	Desired output (MW)	Forecasted Output (MW)	ARE (%)
6:00	28.2	20	8.2
7:00	27.04	20	7.04
8:00	21.60	23	-1.4
9:00	20.31	24	-3.69
10:00	27.36	28	-0.64
11:00	28.2	20	8.2
12:00	18.5	18	0.5
13:00	23.35	24	-0.65
14:00	14.95	20	-5.05
15:00	13.62	14	-0.38
16:00	14.11	14	5.11
17:00	16.1	16.3	-0.2
18:00	18.92	18	0.92
19:00	39.53	38.4	1.13
20:00	35.74	36	-0.26
21:00	32.69	32	0.69
22:00	32.91	32	0.91
23:00	26.23	26	0.23
24:00	39.54	38.4	1.14
1:00	29.75	30	-0.25
2:00	26	26	0
3:00	21.82	22	-0.18
4:00	27.91	28	-0.09
5:00	26.65	26	0.65

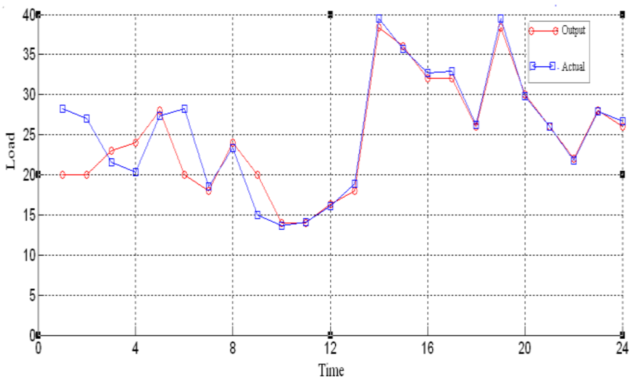

Fig. 9 Predicted electrical load (○) in comparison with actual load (□)

In Fig. 9, it is clearly seen that the forecasted load on 23rd November, 2012 in most of the cases is very close to the actual load. Further, at 2:00 PM, the forecasted value is exactly the same as the actual load. This seems that the developed model is accurate for the short term load forecasting.

From TABLE IV and Fig. 9, it is concluded that the average percentage error is found to be 1.39% in the short term electrical load forecasting.

VI. CONCLUSION

The short term electrical load forecasting is an essential component of any power system planner. Therefore, an attempt has been made for STLF by using fuzzy logic. The performance of the model is evaluated on the basis of statistical indicator i.e. absolute relative error. The average error in the forecasted load in comparison with the desired load is 1.39% which is very close to the desired load. Hence, it is concluded that the developed model is accurate and effective for short term load forecasting.

REFERENCES

[1] D. K. Chaturvedi, Soft computing techniques and its applications in electrical engineering, Springer: Verlag Berlin Heidelberg, 2008.

[2] H. N. Ng., M. M. A. Salama and A. Y. Chikhani, “Capacitor allocation by approximate reasoning: fuzzy capacitor placement”, IEEE Transactions on Power Delivery, vol. 15, pp. 393-398, 2000.

[3] R.J.Campbell and K. Adamson, “Methodologies for load forecasting”, 3rd International IEEE Conference on Intelligent Systems, pp. 800-806, Sep. 2006.

[4] A. Papalexopolous and T. Hesterbe, “A regression based approach to short Term load forecasting”, IEEE Transaction on Power System, vol.5, pp.1535-1547, 1990.

[5] S. Rahman and R. Bhatnagar, “An expert system based algorithm for short term load forecast”, IEEE Transaction on Power Systems, vol. 3, no. 2, pp. 392–399, 1988.

[6] M. Peng, and N.F. Hubele, “Advancement in the application of neural for short term load forecast”, IEEE Transaction on Power Systems, vol. 7, pp. 250-257, 1992.

[7] S. Rahman and G. Shrestha, “A priority vector based technique for load forecasting”, IEEE Transaction on Power Systems, vol. 6, no. 4, pp. 1459–1464,1993.

[8] H. S. Hippert, C. E. Pedreira, and R. C. Souza, “Neural networks for short-term Load forecasting: A review and evaluation”, IEEE Transaction on Power Systems, vol. 16, no. 1, pp. 44–55, 2001.

[9] K. L. Ho, Y. Y. Hsu, C. F. Chen, T. E. Lee, C. C. Liang, T. S. Lai and K. K. Chen, “Short term load forecasting of Taiwan power system using a knowledge based expert system”, IEEE Transaction on Power Systems, vol.5, pp. 1214-1221, 1990.

[10] K.L. Ho, Y.Y. Hsu, and C.C. Yang, “Short term load forecasting using a multilayer neural network with an adaptive learning algorithm”, IEEE Transaction on Power Systems, vo1.7, no.l, pp.141-149, 1992.

[11] E. Srinivas and Amit Jain, “A methodology for short term load forecasting using fuzzy logic and similarity”, The National Conference on Advances in Computational Intelligence Applications in Power, Control, Signal Processing and Telecommunications (NCACI), 2009.

[12] S. C. Pandian, K. Duraiswamy, C. C. A. Rajan, N. Kanagaraj, “Fuzzy approach for short term load forecasting”, Electrical Power System Research, vol. 76, pp. 541-548, 2006.

[13] J. A. Momoh and K. Tomsovic, Overview and literature survey of fuzzy set theory in power systems, IEEE Transactions of Power Systems, vol. 24, pp. 1676-1690, 2009.