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Electric Long Term Load Forecasting using Fuzzy Logic Algorithm with least error technique: A Comparative Analysis

Er. Daljeet Kaur[1], Er. Sonika Dogra[2], Er. Sonia Grover[3]

Assistant Professor, Department of Electrical Engg. GZSCCET, Bathinda[1,3]

Assistant Professor, Department of Electrical Engg. SSCET, Badani[2]

Abstract: Long term load forecasting have important role in generation, transmission, and distribution network planning in a power system. A good forecasting reflects current and future trends, tempered with good judgment. The present paper is devoted to study the long term load forecasting of Amritsar city using fuzzy logic methodology along with various mathematical equations i.e. Straight line, Parabola, Exponential and S-Curve equations. Electric load and population data of Amritsar City for last 18 years (from 1997 to 2014) is taken and load is calculated for next nine years (from 2015 to 2023). To obtain the results from Fuzzy Logic methodology error corrections are applied individually and which type of mathematical equation gives least error for load calculations is also taken into consideration. MATLAB programming is used for all the computational work. The same methodology can also be applied for short term and medium term load forecasting, by doing so load shedding in particular area can be reduced. This study is important for an electric utility so that they have an idea about the maximum required power well in advance so that it can be made available as and when required.

Keywords: Long term load forecasting, DDF(Data Dependent Factor), MDF(Model Dependent Factor), ES(Expert System), Straight line(SL), Parabola(P), Exponential(E), S-curve(SC), Fuzzy logic.

I. INTRODUCTION

Electrical energy consumption increases more and more on a daily basis. Technological development is the main reason for the use of electric energy. In order to meet this increasing demand, a utility can plan for electric power in advance. So, for this reason it is very necessary to forecast the active load at various load buses ahead of an actual load occurrence.

The accuracy of a forecast is very important to any electric utility, because it determines the timing and characteristics of major system additions. Overestimation of the future load may lead to financial crisis, as more money will be spent on new building. Underestimation of load may cause troubles in supplying this load from the available electric supplies. The main aim of any power system is to supply electricity to customers as and when required, and as economically and reliably as possible. Load forecasting is very helpful for an electric utility to make important decisions in power system planning.[16]

The forecasting of future loads for a relatively large lead time (months to few years) is studied in long term load forecasting. Future load demand estimation is done for different lead times, ranging from few seconds to years. These different lead times are called forecasting intervals.

Fuzzy control system is a decision mechanism represented by a set of fuzzy rules. This model gives an algorithm which will convert strategy based on expert knowledge into an automatic strategy. The aim of this system is to replace a skilled human operator with a fuzzy rule-based system. These models can be combined with neural network to train ANN.

Fuzzy logic model uses forecaster's knowledge and experience. This method gives quite accurate load forecasts.[14]

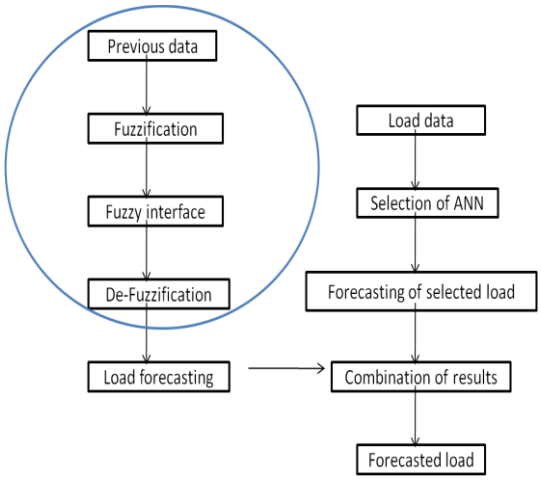

Fig1: Fuzzy Logic System

The basic configuration of a fuzzy logic system is represented by above Fig1.

This figure shows fuzzification, knowledge base, fuzzy interface and a defuzzification. Fuzzy rules will improve the model accuracy by avoiding arbitrariness.

The fuzzy rules consist of some rules generated from the analysis of the historical load data. This method of forecasting could provide a considerable improvement of the forecasting accuracy.

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In this paper, Fuzzy logic is used for forecasting the load of Amritsar city by using mathematical equations. Error correction is generated from the difference of actual and calculated load and these errors are fitted to fuzzy model individually. The errors obtained from mathematical equations are compared and most suited type (with least error) of mathematical equation for load forecasting is proposed.

II. LITERATURE REVIEW

There are various study carried out for the load forecasting. Eisa Almeshaiei et.al,[11] presents a pragmatic methodology to construct Electric Power Load Forecasting models. This methodology was based on decomposition and segmentation of the load time series. Several statistical analyses and load features were involved in this study. The results were used to guide forecasting future needs. They studied that the segmentation process results in homogeneous regions for which polynomial trends have been identified.

Ghods et.al, [9] discussed the past and current practices of long term load forecasting. Methods like neural network, GA, Fuzzy rules, support vector machines, wavelet systems and expert systems were found out to be used. In Patel Parth Manoj, [2] et.al carried a fuzzy logic approach for short term load forecasting. Various independent variables like time, temperature were used to carry out this study. Based on these independent variables, fuzzy rule base is prepared and used for short term load forecasting.

MATLAB Simulink software is used. Abbas Karimi et.al,[13] presented an approach for dynamic load balancing algorithm. They used fuzzy logic systems which make absolute outputs from uncertain inputs. In their future works, they followed the load balancing issue in parallel systems and found that response was quicker. They predicted the nodes status as sender, receiver or neutral less time complexity by using neuro fuzzy techniques.

III. OBJECTIVE

The main objective is to forecast the load of Amritsar city for nine years. In Amritsar, the load growth is estimated to be commercial and residential loads, that is expected to increase rapidly every year as population and standard of living is increasing rapidly.

During this study, it is proposed to utilize the load data of last 18 years, apply extrapolation technique, select different years as base years and use Fuzzy logic rules with mathematical equations to forecast load for next nine years.

IV. METHODOLOGY

The load data of last 18 years for Amritsar is collected from the substation of Amritsar city and Population of respective years is also collected from Indian Planning Commission. As shown in Table no.1, for Amritsar city the load is commercial in nature, and with increase in population in this city the load demand is also increasing every year. Hence for load forecasting the population factor is also included.

Table1: Actual Load Data and Population Data of Amritsar city for last 18 years from 1997 to 2023.

Years	Actual Load(MVA)	Population
1997	40.65	8,81,444
1998	41.85	8,92,145
1999	42.08	9,00,010
2000	45.73	9,10,012
2001	43.21	9,15,144
2002	62.02	9,20,111
2003	60.43	9,25,010
2004	63.58	9,34,010
2005	63.42	9,35,190
2006	73.01	9.48,190
2007	71.92	9,62,190
2008	105.09	9,76,453
2009	111.02	9,91,063
2010	114.49	11,04,069
2011	114.44	11,18,761
2012	129.04	11,40.017
2013	129.21	11,51,273
2014	140.36	11,90,940

The algorithm developed for long term fuzzy load forecasting can be represented as a flowchart in order to demonstrate the algorithm, load data & data regarding factors influencing load for domestic consumers was collected for a period of 18 years (from Jan 1997- Dec 2014). The main factor which affects the load consumption of domestic consumers is number of domestic consumers. The relationship between load and these factors is linear. Following flowchart is used to forecast load for next nine years with fuzzy logic model:

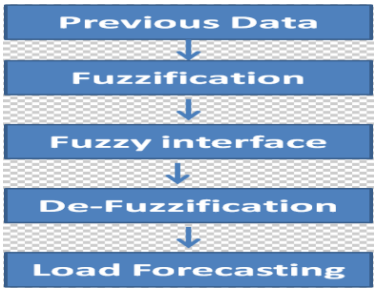

Fig.2 Flowchart for Fuzzy Logic Methodology

With the help of first nine years (1997- 2005) of actual load data, next nine years of load data can be determined (2006-2014), in order to demonstrate the efficiency of the algorithm determined values of load is compared with available actual values. Further, load values for next nine years are also forecasted (from year 2015 to 2013). Here, Fuzzy model-I is used to determine error in forecast load value due to DDF & MDF & Fuzzy model-II is used to determine error in forecast load value due to ME. Various mathematical equations which are used to calculate the load with the help of previous data are as follows:-

Straight line $y = a + bx$
Parabola $y = a + bx + cx^2$
S-curve $y = a + bx + cx^2 + dx^3$
Exponential $y = ce^{dx}$

Where a, b, c and d are coefficients, y is year and x is actual load.

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In this technique, above mentioned fitting trend curves are used into basic historic data to reflect the growth. Other than this, the relationship between load growth and population, which is linear, is also taken into consideration.

With the help of previous data, it has been found that in case of Amritsar city

Load = 4.5 times of population

V. RESULTS AND DISCUSSION

Results shows the load comparison of last 18 years (1997-2014) with various mathematical equations i.e. straight line curve fitting technique(SL), Parabola (P), Exponential (E) and S-Curve (SC) techniques and load is forecasted for next 9 years (from 2015-2023).

Where; **x** is actual load,
$\mathbf{L_C}$ is calculated load ,
$\mathbf{L_F}$ is forecasted load and
% error is the percentage error between x & L_C

A. Results of Forecasted load using Fuzzy logic with Straight line technique(SL)

Fig.3 and Table2 shows the comparison of load and also shows the %error between actual and calculated load from 1997-2014 and other factor that shows in table2 and fig3 is forecasted load from 2015-2023 with straight line equation and it is seen that from Fig3 , Forecasted load is increases for next nine years.

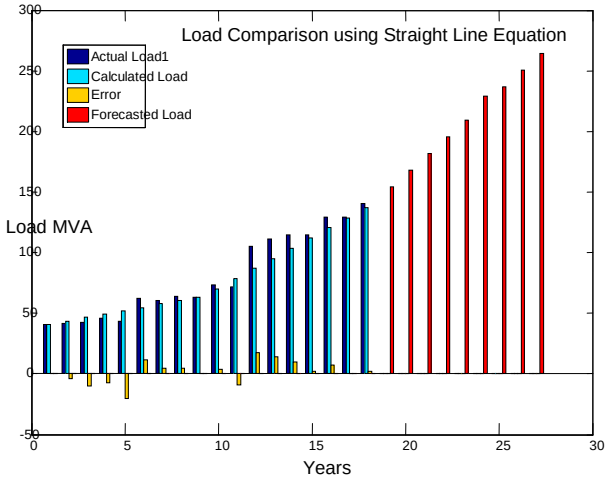

Fig3: %error and Forecasted load for next nine years using Straight Line Technique

Table2: Load comparison and Load Forecasted for Amritsar City (SL)

S.No	Years (y)	x	L_C	% error	L_F
1	1997	40.65	40.65	0	_
2	1998	41.85	43.49	-3.92	_
3	1999	42.08	46.34	-10.1	_
4	2000	45.73	49.19	-7.57	_
5	2001	43.21	52.04	-20.4	_
6	2002	62.02	54.88	11.51	_
7	2003	60.43	57.73	4.47	_
8	2004	63.58	60.57	4.73	_
9	2005	63.42	63.42	0	_
10	2006	73.01	70.26	3.76	_
11	2007	71.92	78.61	-9.3	_
12	2008	105.09	86.96	17.25	_
13	2009	111.02	95.3	14.16	_
14	2010	114.49	103.64	9.47	_
15	2011	114.44	111.99	2.13	_
16	2012	129.04	120.34	6.76	_
17	2013	129.21	128.69	0.405	_
18	2014	140.36	137.03	2.37	_
19	2015	_	_	_	154.11
20	2016	_	_	_	167.86
21	2017	_	_	_	181.61
22	2018	_	_	_	195.36
23	2019	_	_	_	209.11
24	2020	_	_	_	228.86
25	2021	_	_	_	236.61
26	2022	_	_	_	250.36
27	2023	_	_	_	264.11

B. Results of Forecasted load using Fuzzy logic with Parabola equation (P)

Fig.4 and Table3 shows the comparison of actual load , calculated load and error between both from 1997 to 2014 and also shows forecasted load from 2015-2023 with Parabola equation and it is seen that from Fig 4 , Forecasted load is increases for next nine years and %error is more as compared to calculations done with straight line technique.

Parabola equation; $y = a + bx + cx^2$

Where a, b, and c are coefficients, y is year and x is actual load.

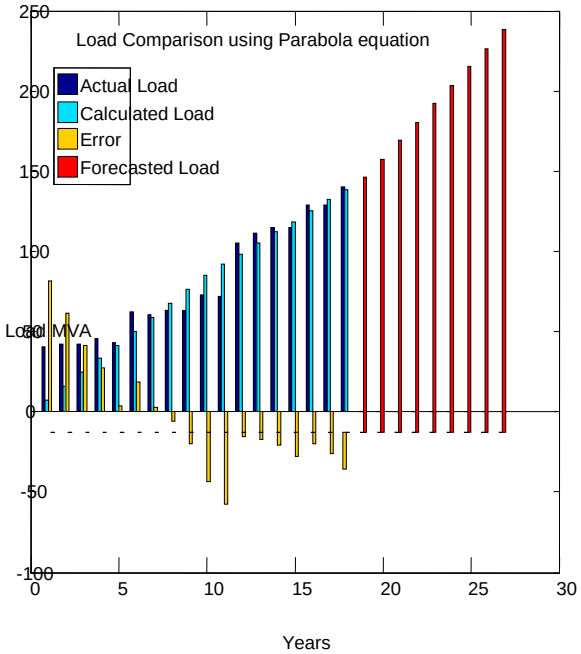

Fig. 4: %error and Forecasted load for next nine years using Parabola equation

Table 3: Load comparison and Load Forecasted for Amritsar City (P)

Sr. No.	Years (y)	x	L_C	% error	L_F
1	1997	40.65	7.52	81.48	_
2	1998	41.85	16.08	61.56	_
3	1999	42.08	24.64	41.44	_
4	2000	45.73	33.19	27.41	_
5	2001	43.21	41.74	3.4	_
6	2002	62.02	50.28	18.92	_
7	2003	60.43	58.82	2.66	_
8	2004	63.58	67.36	-5.94	_
9	2005	63.42	75.89	-19.65	_

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10	2006	73.01	85.11	-43.93	_
11	2007	71.92	91.82	-57.6	_
12	2008	105.09	98.53	-15.7	_
13	2009	111.02	105.24	-17.0	_
14	2010	114.49	111.94	-20.7	_
15	2011	114.44	118.64	-28.0	_
16	2012	129.04	125.33	-19.8	_
17	2013	129.21	132.03	-26.2	_
18	2014	140.36	138.72	-22	_
19	2015	_	_	_	151.32
20	2016	_	_	_	162.28
21	2017	_	_	_	173.24
22	2018	_	_	_	184.2
23	2019	_	_	_	195.16
24	2020	_	_	_	206.12
25	2021	_	_	_	217.08
26	2022	_	_	_	228.05
27	2023	_	_	_	239.01

C. Results of Forecasted load using Fuzzy logic with Exponential equation (E)

Fig.5 and Table 4 shows the comparison of actual load , calculated load and error between both from 1997-2014 and forecasted load from 2015-2023 with Exponential equation and it is seen that from Fig5 , forecasted load is increases for next nine years and % error is more than straight line technique and less than parabola equation.

Exponential $y = ce^{dx}$

Where 'c' and 'd' are coefficients 'y' is year and 'x' is actual load.

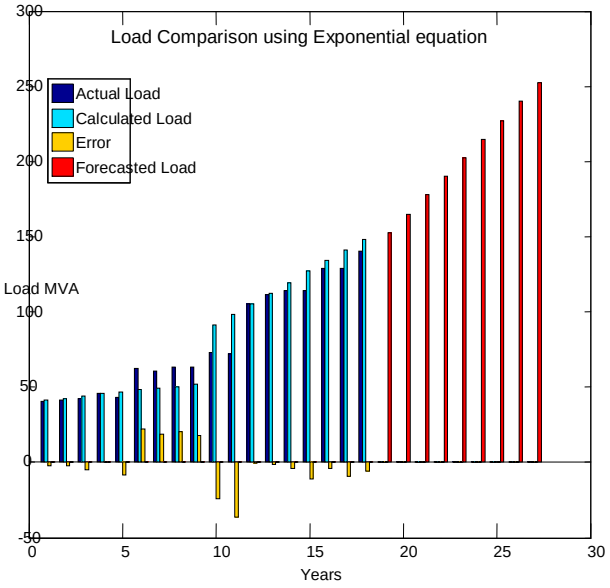

Fig.5 %error and Forecasted load for next nine years using Exponential equation

Table 4: Load comparison and Load Forecasted for Amritsar City (E)

S. No.	Years (y)	x	L_C	% error	L_F
1	1997	40.65	41.67	-2.51	_
2	1998	41.85	42.08	-2.63	_
3	1999	42.08	44.22	-5.09	_
4	2000	45.73	45.501	0.501	_
5	2001	43.21	46.77	-8.24	_
6	2002	62.02	48.05	22.53	_
7	2003	60.43	49.32	18.39	_
8	2004	63.58	50.59	20.39	_
9	2005	63.42	51.87	18.21	_
10	2006	73.01	90.93	-24.54	_

11	2007	71.92	98.1	-36.4	_
12	2008	105.09	105.27	-0.17	_
13	2009	111.02	112.44	-1.28	_
14	2010	114.49	119.59	-4.46	_
15	2011	114.44	126.76	-10.76	_
16	2012	129.04	133.9	-3.74	_
17	2013	129.21	141.06	-9.17	_
18	2014	140.36	148.21	-5.59	_
19	2015	_	_	_	152.77
20	2016	_	_	_	165.18
21	2017	_	_	_	177.59
22	2018	_	_	_	190
23	2019	_	_	_	202.41
24	2020	_	_	_	214.82
25	2021	_	_	_	227.23
26	2022	_	_	_	239.65
27	2023	__	_	_	252.05

D. Results of Forecasted load using Fuzzy logic with S-Curve equation (SC)

Table5 and Fig.6 shows the comparison of actual load , calculated load and %error between both from 1997 to 2014 and forecasted load from 2015-2023 with S-Curve technique and it is clear from Fig5 that Forecasted load is increases and %error is less as compared to error calculated from other mathematical equations.

S-curve $y = a + bx + cx^2 + dx^3$

Where a, b, c and d are coefficients, y is year and x is actual load.

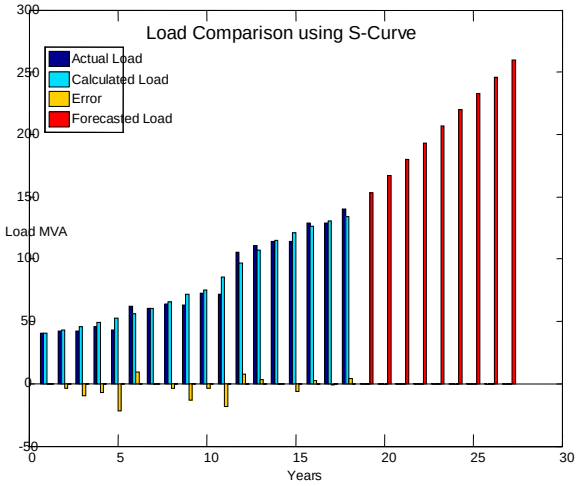

Fig 6: Load comparison of actual value & calculated and Forecasted load using S-Curve equation

Table 5: Load comparison and Load Forecasted for Amritsar City (SC)

Sr. No.	Years(y)	x	L_C	% error	L_F
1	1997	40.65	40.66	-0.25	_
2	1998	41.85	43.26	-3.37	_
3	1999	42.08	46.08	-9.51	_
4	2000	45.73	49.14	-7.46	_
5	2001	43.21	52.53	-21.57	_
6	2002	62.02	56.33	9.17	_
7	2003	60.43	60.67	-0.397	_
8	2004	63.58	65.76	-3.43	_
9	2005	63.42	71.96	-13.47	_
10	2006	73.01	75.42	-3.3	_
11	2007	71.92	85.24	-18.52	_
12	2008	105.09	96.89	7.8	_
13	2009	111.02	107.21	3.4	_
14	2010	114.49	115.08	-0.511	_
15	2011	114.44	121.19	-5.9	_
16	2012	129.04	126.17	2.2	_

17	2013	129.21	130.39	-0.916	_
18	2014	140.36	134.07	4.48	_
19	2015	_	_	_	153.56
20	2016	_	_	_	166.79
21	2017	_	_	_	180.02
22	2018	_	_	_	193.24
23	2019	_	_	_	206.47
24	2020	_	_	_	219.69
25	2021	_	_	_	232.92
26	2022	_	_	_	246.15
27	2023	_	_	_	259.37

E. Comparison of error that fitted to fuzzy logic methodology for load forecasting

Fig 7 shows comparison of % error occur by using various mathematical equations i.e. Straight line, Parabola, Exponential and S-curve. This error is different for different curve fitting techniques. It is seen that minimum %error occurs when load calculations are done by using S-Curve equation and Straight line equation and maximum %error occurs when using Parabola equation and Exponential equation for load calculations.

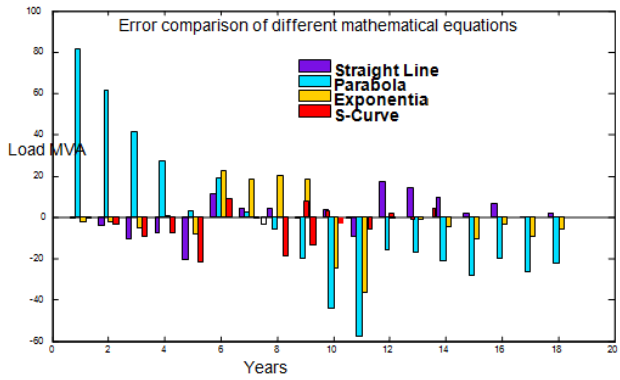

Fig 7: Error comparison of various mathematical equations

VI. CONCLUSION

In this paper, Long term load forecasting using fuzzy logic methodology with different mathematical curve fittings for Amritsar city has been discussed. It is concluded that by using population and electric load data of previous years as input, and by formulating rule base of fuzzy logic with various mathematical equations, forecasting can be done with certain margin. By comparing the results for straight line, parabola, exponential and S-curve techniques for load forecasting, it is concluded that maximum %error is occurred when Parabola equation is used for load calculations and minimum %error is occurred when S-curve equation is used for load calculations as seen from Fig7. So, S-curve trending method is best suited for conduct accurate long term load forecasting using fuzzy logic.

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