Implementation of Mamdani and Sugeno Method for Load Forecasting: A Case Study of Malang City

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***Abstract*—The growth of energy consumption in many developing countries has exceeded the projection, and therefore, the uncertainty of energy forecasting increases. Variables such as economic growth, population, and efficiency standards, coupled with other factors inherent in the mathematical progression of forecasting models, make accurate projections difficult. The objective of load forecasting is to predict the electrical power required to meet short, medium, or long-term demand, power consumption planning and operations. Large energy consumption over a period of time should be predicted and calculated specifically in order to plan and manage the operation of the power plant. Load forecasting allows utility companies to plan well for future consumption or load demand and also minimize risks for utility companies. Therefore, an accurate method is needed to forecast loads, such as accurate models that take into account factors that affect load growth over several years. In this paper, Mamdani and Sugeno's methods for predicting electrical load forecasting are implemented. The supporting data used in this paper was adopted from Polehan and Blimbing Substations from 2011-2020. As a result, the average MAPE value according to the Mamdani and Sugeno methods are respectively 2.49% and 1.16%. It can be concluded that the Sugeno method fulfilled the load forecasting from Mamdani.**

***Index Terms*—Long-Term Electric Load Forecasting, Fuzzy Logic, Mamdani and Sugeno, MAPE.**

I. INTRODUCTION

The need for electrical energy in general is in the household sector, industry, commercial and public services. Energy demand, in general, cannot be calculated precisely, it needs to be predicted and calculated appropriately based on the total energy availability generated by the power plant. Utility companies must forecast supply and demand for electricity in order to meet the target and size of the load demand. Power load forecasting plays an important role for utility companies to improve system efficiency and revenue. It helps to plan and operate installed capacity to increase the reliability and supply of electricity to consumers. Thus, the lack of power can be minimized and the effectiveness of power distribution will also increase, and minimize the investment cost of electricity generation [1].

Taking into account population growth, economic growth and the availability of electrical energy, it is necessary to calculate and forecast new power plants; to expand its transmission and distribution network for long-term power planning. Long-term cost forecasting predicts load demand for a period of several years. Long-term load prediction has an important role in the real-time control and security functions of energy management systems [2].

The Mamdani and Sugeno method are considered as solutions for long-term load forecasting in the next few years. The prediction system uses population growth input, GDP (Gross Domestic Product) value and total electrical load. Mamdani and Sugeno apply the Fuzzy Interference System to evaluate all rules models in sequence to generate the output of electrical power loads.

II. ELECTRICAL LOAD FORECASTING

In general, load forecasting is a prediction of energy supply to meet customer demand for a certain period of time by utility companies [3]. It can improve system efficiency and determine customer load characteristics. There are two categories in load forecasting discussed in this paper, which predict the electrical energy of customer demand and predict the energy supply to meet customer demand. Load forecasting can be short, medium and long-term prediction; for the prediction of electrical loads for domestic, commercial and industrial needs.

III. FUZZY LOGIC

Fuzzy logic was first introduced by Prof. Lotfi Zadeh in 1965 and it used to declare a state of uncertainty (faint) in everyday life. Membership function (MF) is a curve that shows the mapping of points of input data into membership values (often called the degree of membership) is in the interval between 0-1 [4]. There are several membership functions used frequently, such as triangle curve membership, linear curve membership, trapezoidal curve membership, bell shape curve membership, and shoulder shape curve membership. In this paper, a triangle curve membership function is adopted for the long-term electric load forecasting.

A. A Triangle Curve Membership

A triangle curve membership is basically a combination of the two linear lines as shown in Figure 1.

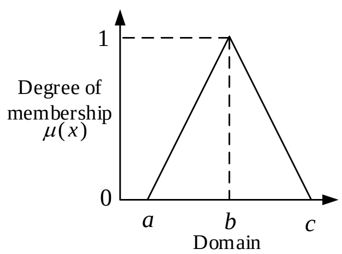

Figure 1: Membership Function Curve Triangle [5]

Membership function equation,

$$\mu[x]\begin{cases} 0; & x \le a \quad atau \ \ x \ge c \\ (x-a)/(b-a); & a \le x \le b \\ (c-x)/(c-b); & b \le x \le c \end{cases} \tag{1}$$

B. Fuzzy Interference System (FIS) Mamdani

Fuzzy inference systems (FIS) is a system that can perform similar principles of human instinct. There are several types of FIS i.e., Mamdani, Sugeno and Tsukamoto Mamdani method and known as the Max-Min method. This method was first introduced by Ebrahim Mamdani in 1975. The output on Mamdani method required four stages [5]:

1. Establishment of Fuzzy Association
   Variable input and output of this method are divided into several fuzzy sets. This fuzzy set is built based on the corresponding rules.
2. Function Application Implications
   Each rule (proportion) of the fuzzy knowledge base will be dealing with a fuzzy relation. In general form of rules used in the implication function is:

   IF x is A, THEN y is B (2)

3. Composition Rules
   The common rule used in the Mamdani FIS itself is a method of Max. In the method of max, the solution of fuzzy sets obtained by taking the rule with the maximum value.
4. Assertions (Defuzzy)
   Input from defuzzification process is a fuzzy set obtained from the composition of fuzzy rules.

C. Means Absolute Percentage Error (MAPE)

The mean absolute percentage error (MAPE), also known as mean absolute percentage deviation (MAPD) is a measure of prediction accuracy of a forecasting method in statistics, for example in trend estimation; can be calculated as described in [6],

$$MAPE = \frac{Actual\ Load - Forecasted\ Load}{Actual\ Load} \times 100\% \tag{3}$$

If the MAPE value is less than 10%, then the forecasting is very good; while less than 20% is good [6].

IV. DATA PREPARATION

For the simulation purposes, there are two areas selected for the data collection. The first area is Blimbing substation with the load data collected based on three transformers with rating capacities of 20 MVA, 30 MVA, and 10 MVA respectively. The second area is Polehan substation with the load data record based on two transformers with rating capacities of 30 MVA and 20 MVA respectively.

The long-term power load forecasting based on the population and economic growth yearly which are adopted from historical data projected from 2011 to 2015. The total population per year depends on the number of people in each certain districts and economic growth depends on the sectoral of household, industrial, commercial, and the public sector.

The population and economic growth affect the consumption of electric demand. The higher the population growth will affect the amount of electrical load consumption. The population growth, economic growth, and electric load demand data obtained from the Central Statistics Agency (CSA) Malang as shown in Table 1, 2 and 3, respectively. All these data are used as a reference for forecasting projection data used for six years 2016-2021.

Table 1
Residents Population [7]

District	Total Population				
	2011	2012	2013	2014	2015
Kedungkandang	177.261	179.512	181.834	183.927	186.068
Sukun	183.69	185.352	187.074	188.545	190.053
Klojen	105.755	105.399	105.06	104.59	104.127
Blimbing	173.838	174.891	175.988	176.845	177.729
Lowokwaru	187.948	189.373	190.847	192.066	193.321
Malang City	828.491	834.527	840.803	845.973	851.298

Table 2
Economic Growth [7]

Sector	Economic Growth (Million)				
	2011	2012	2013	2014	2015
Domestic	575.07	623.37	690.32	737.818	841.20
Industrial	20.765.02	22.730.56	24.814.52	26.293.71	29.162.66
Commercial	8.871.35	10.050.43	11.276.45	12.708.04	14.209.65
Public	4.756.55	5.342.64	6.038.57	6.823.697	7.614.47

Table 3
Electric Load Demand (MW) [8]

Substation	Electric Load Demand				
	2011	2012	2013	2014	2015
Blimbing	22.317	22.618	22.871	23.807	26.643
Polehan	20.127	20.885	21.695	23.947	24.760
Total	42.444	43.503	44.566	47.754	51.403

The procedure steps of forecasting the electric power demand with the aid of MATLAB software, as follows.

1. Determine the prediction variables of resident population, economic growth, and electric load demand.
2. Formation the fuzzy sets and membership function (triangle) for resident population, economic growth, and electric load demand.
3. Composition the rules to obtain the smallest prediction error based on variables relationship.
4. Defuzzification, data is translated into fuzzy rules back in the form of crisp data output to obtain the best forecast of defuzzification centroid and defuzzification weight average.
5. Calculate the mean absolute percent error (MAPE) by Equation (3).

V. RESULT AND DISCUSSION

A. Population Variable Input

The variables used in the long-term power load forecasting are population and economy growth with the actual data of the year 2011 to 2015 and the projection of 2016 to 2021 as shown in Table 4.

From the Table 4, the minimum population is in 2011 and the maximum population in 2020. These data are grouped based on the fuzzy set rules as shown in Table 5.

Table 4
Table Distribution Data Over 10 Years

Year	Total Population	Economic Growth (Million Rupiah)			
		Domestic	Industrial	Commercial	Public
2011	828.491	575.073	20.275	8.871	4.756
2012	834.527	623.373	22.730	10.050	5.342
2013	840.803	690.324	24.814	11.276	6.038
2014	845.973	737.818	26.293	12.708	6.823
2015	851.298	841.195	29.162	14.029	7.614
2016	857.336	887.564	30.860	15.423	8.274
2017	863.042	952.233	32.896	16.576	8.993
2018	868.748	1.016.571	34.932	18.090	9.713
2019	874.454	1.081.571	36.968	19.423	10.433
2020	880.160	1.146.240	39.004	20.757	11.153

Table 5
Fuzzy Association, the Universe Discussion, and Domain on Variable Population

Variable	The Fuzzy set	Value of the Universe	Domain
	Minimum (Min)		[818.8-838]
	Very Rarely (VR)		[828.4-847.5]
	Rarely (R)		[838-857.1]
Total Population	Normal (N)	824.491-880.160	[847.5-866.7]
	Solid (P)		[857-876]
	Very Solid (VS)		[866.7-885.8]
	Maximum (Max)		[876.2-895.4]

The data described in Table 5 is converted to datasets using fuzzy membership function. Serves as a membership function, the curve that maps the points of input of data into membership values were in the range of 0 to 1. The membership functions used in this forecast is the Triangle membership functions as in Equation (1), as shown in Figure 2. The values from 818.8 to 895.4 in the picture above is a triangular membership function values obtained from the universe of discourse data of the population at the time of the lowest and highest number of population in 2011-2021.

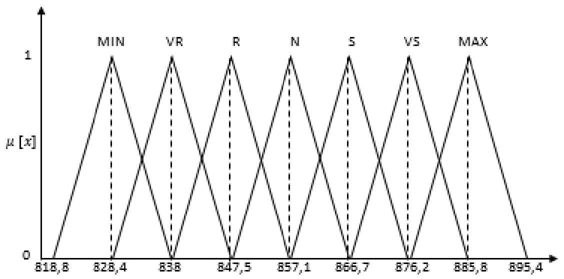

Figure 2: Membership Function Population.

B. *Economic Variable Input*

Based on the economic growth data in 2011 to 2021, the lowest income of the household sector in 2011 is about Rp. 575.073 and highest income is the industry sector is Rp. 39.004.000. The data of economic growth in Table IV are grouped based on the fuzzy set rules shown in Table VI. For more details, data sharing with resident's economy min, max, and the universe of discourse and its domain can be seen in Table 6.

The based domain that has been obtained in Table 6 can be constructed a triangle membership functions for economic variables population into four sectors as shown in Figure 3 to Figure 6. The values from 416.3 to 1369, 15.71 to 46.11, 5.598 to 25.28 in the image triangular membership function of Figure 3, 4, 5, and 7 are the value obtained from the universe of discourse population economic data at the time of lowest income and highest household sector, industrial sector, commercial sector, and public sector in 2011-2021, respectively.

Table 6
Fuzzy Association, the Universe Discussion, and Domain On the economic variables of the population (Million Rupiah)

Economic Variable	The Fuzzy set	The Value of the Universe	Domain
	The Lowest (TL-D)		[416.3-733.8]
	Low (L-D)		[575-892.5]
Domestic Sector	Medium (M-D)	5.75-12.10	[733.8-1051]
	High (H-D)		[892.5-1210]
	The Highest (TH-D)		[1051-1369]
	The Lowest (TL-I)		[15.71-25.81]
	Low (L-I)		[20.76-30.90]
Industrial Sector	Medium (M-I)	20.27-39.04	[25.81-35.95]
	High (H-I)		[30.90-41.04]
	The Highest (TH-I)		[35.95-46.11]
	The Lowest (TL-C)		[5.59-12.17]
	Low (L-C)		[8.87-15.45]
Commercial Sector	Medium (M-C)	8.87-20.76	[12.17-18.70]
	High (H-C)		[15.45-22]
	The Highest (TH-C)		[18.7-25.28]
	The Lowest (TL-P)		[2.988-6.512]
	Low (L-P)		[4.75-8.275]
Public Sector	Medium (M-P)	4.75-11.8	[6.512-10.04]
	High (H-P)		[8.275-11.8]
	The Highest (TH-P)		[10-13.6]

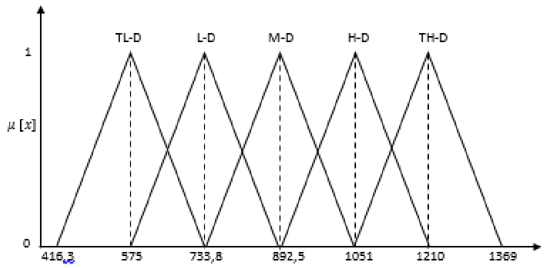

Figure 3: Membership function of resident economic: Domestic Sector

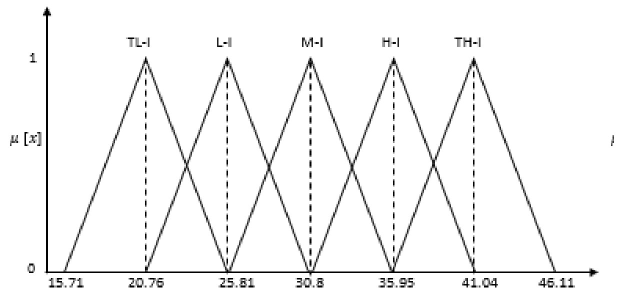

Figure 4: Membership function of resident economic: Industry sector

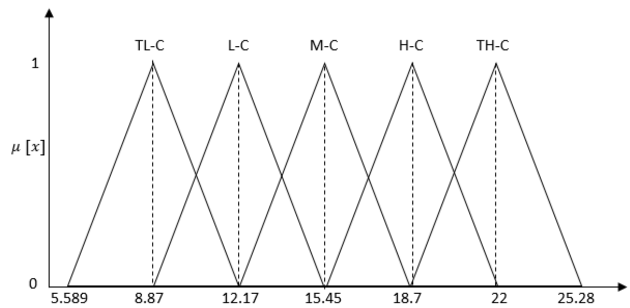

Figure 5: Membership function economic growth: Commercial Sector

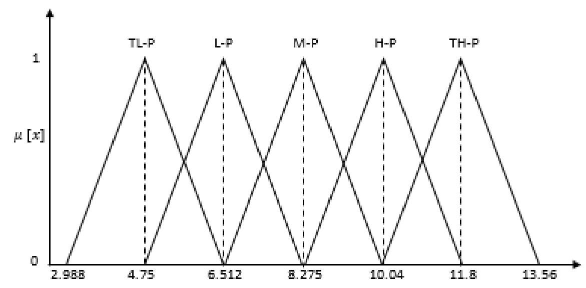

Figure 6: Membership function of resident economic: Public sector.

C. Electrical Load Variable Output

Based on data from the electrical load in the year 2011-2021 obtained the minimum electric load in 2011 was 42.4 MW and a maximum load of 61.8 MW, so that its fuzzy set can be determined by dividing the variable regions are of equal size.

The universe of discourse and has a value ranging from 42.4 to 61.8. For more details, sharing data with a population of min, max and the universe of discourse and its domain can be seen in Table 7 below.

Table 7
Fuzzy Association, the Universe Discussion, and Domain On Load Variable Power (MW)

Variable	The Fuzzy Set	Value of The Universe	Domain
Electrical Load (MW)	Minimum (Min)	42.44-61.8	[39.24-45.68]
	Veri Small (VS)		[42.44-48.92]
	Small (S)		[45.68-52.12]
	Medium (M)		[48.92-55.32]
	Big (B)		[52.12-58.6]
	Very Big (VB)		[55.32-61.8]
	Maximum (Max)		[58.6-65.04]

To change the firm obtained the data into the dataset used fuzzy membership function. Membership functions used in this forecast is the Triangle membership functions as in Eq. (1). The based domain that has been obtained in Table VII can be constructed a triangle membership function for a variable electrical load as shown in Figure 7.

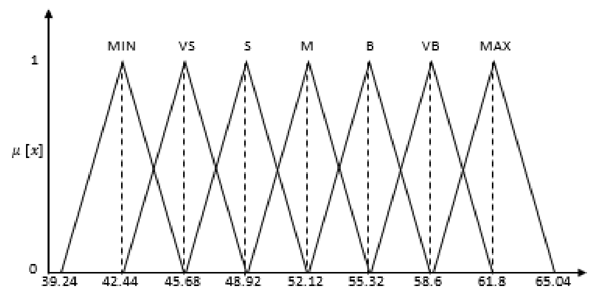

Figure 7: The Electric Load Membership Function

The values of 39.24 to 65.04 on the image above triangular membership function is the value obtained from the universe of discourse electrical load data at the time of the lowest and highest power load in 2011-2021.

D. Rule Evaluation

The second step is called fuzzy logic process with evaluation rules (rule). In linguistic rules fuzzy logic is used to determine what control actions should be done in response to a given input value. The initial step in the phase of building a fuzzy rule is to change the data in the form of the firm (crisp) into a fuzzy set, then every variable that is to be calculated the degree of membership and have degrees of membership that is not zero. To calculate the values of membership degree for four sectors such as residents population, economic growth for domestic, commercial, industry, and public sector, Equation (1) can be used for all variables, from which the population of the year can be determined. For example, to seek the membership degree calculation of resident population, in the year 2017 there are 863 people as shown in Figure 8.

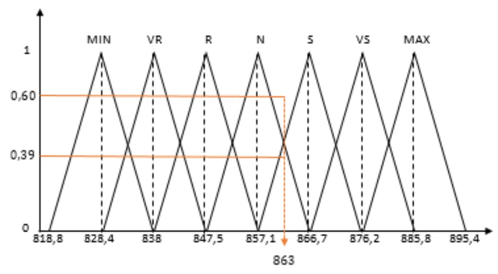

Figure 8: Value Degrees of Membership Population Year 2017

$$\mu_{normal}[x] = \frac{866.7 - x}{866.6 - 857.3}, \quad 857.3 \le x \le 866.7$$

$$\mu_{normal}[863] = \frac{866.7 - 863}{9.4} = 0.39$$

$$\mu_{medium}[x] = \frac{x - 48.7}{50.2 - 48.7}, \quad 48.7 \le x \le 50.2$$

$$\mu_{solid}[863] = \frac{863 - 857.3}{9.4} = 0.60$$

In a similar way for economic growth in the industry sector, commercial sector, public sector, and electrical load variation, the values degree of membership is shown in Table 8.

Table 8
Values Degrees of Membership Year 2017

Variable	The Fuzzy Set	Degree of Membership
Total of Population	Normal	0.39
	Solid	0.60
Economic of Domestic Sector	Medium	0.62
	High	0.37
Economic of Industrial Sector	Medium	0.61
	High	0.38
Economic of Commercial Sector	Medium	0.59
	High	0.40
Economic of Public Sector	Medium	0.59
	High	0.40

E. Mean Absolute Percentage Error (MAPE) Calculation

In forecasting methods should be included as a reference to a percentage error forecasting method used can be trusted, to calculate the MAPE can use equation (3). The results of forecasting are said to be very good if it has a value of MAPE is less than 10% and has a good forecasting ability if MAPE is less than 20%.

F. Mamdani Method

MATLAB software is used to find the results of prediction. For forecasting, the results of the year 2011-2020 by using Fuzzy Mamdani can be seen in Table 9 and Figure 9.

Table 9
Results of Fuzzy Mamdani Year Forecast 2011-2020

Year	Result		
	Electric Loads (MW)	Mamdani	Error (%)
2011	42.4	43.5	2.6
2012	43.5	46.3	6.4
2013	44.7	46.7	4.9
2014	47.7	47.8	0.2
2015	51.4	50.6	1.6
2016	53.5	53.6	0.2
2017	53.8	54.9	2.0
2018	56.0	56.2	0.4
2019	58.2	57.0	2.1
2020	60.4	57.7	4.5
Average Error		2.49	

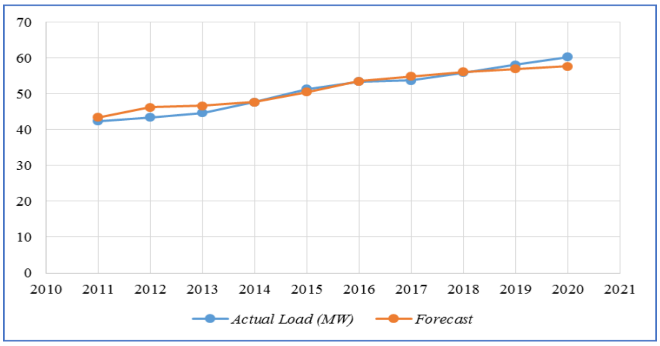

Figure 9: Graph Mamdani Year Results Forecasts 2011 - 2020

Based on the results of forecasting using fuzzy Mamdani in Table 9, forecasting in 2012 obtained the highest error value by 6.4% and the smallest obtained in 2014 and 2016 by 0.2%, with the average error of 2.49%. It can be seen from the 3-D view, as shown in Figure 10, Fuzzy Mamdani input values entered are Total of population X (input) and the economy of residents of the household sector in the Y (Input) and for Z (Output) put the resulting value is in this case is the electrical load functions X, Y, and Z adapted to the variable that will be entered.

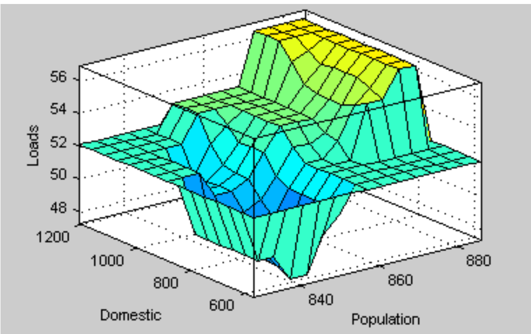

Figure 10: Surface Display Viewer Mamdani Fuzzy Relationship between Variable Expenses, Total Population and Population Economic variables Household Sector

The input variable for economic growth in the industrial sector, the total population X, the economic growth Y and the output Z is shown in Figure 11.

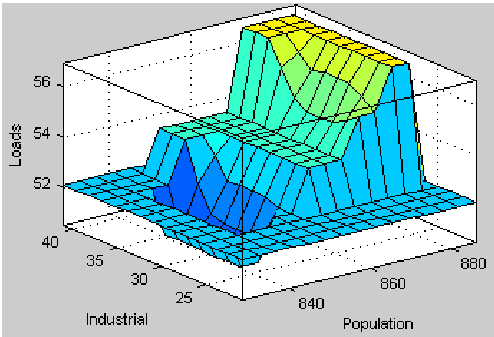

Figure 11: Surface Display Viewer Mamdani Fuzzy Relationship between Variable Expenses, Total Population and Population Economic variables Industrial Sector

The surface display viewer of Mamdani fuzzy relationship in the commercial sector and all variables are defined as well as in economic growth, the output result for the commercial sector and public sector are shown in Figure 12 and 13, respectively.

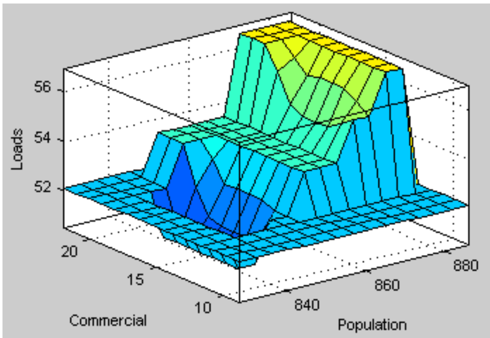

Figure 12. Surface Display Viewer Mamdani Fuzzy Relationship between Variable Expenses, Total Population and Population Economic variables Industrial Sector

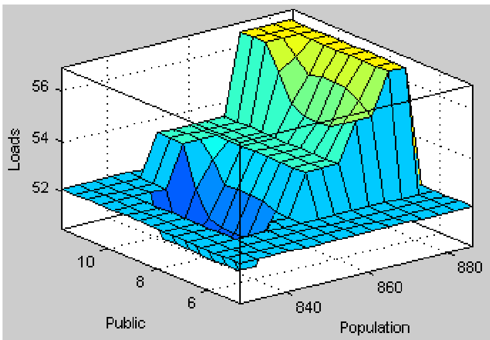

Figure 13. Surface Display Viewer Mamdani Fuzzy Relationship between Variable Expenses, Total Population and Population Economic variables Public Sector

G. Sugeno Method

Sugeno method is also implemented to calculate the forecasting results for the year of 2011 to 2020. This calculation result is shown in Table 10 and Figure 14 and 15, respectively.

Table 10
Results of Fuzzy Sugeno Year Forecast 2011-2020

	Result		
Year	Electric Loads (MW)	Sugeno	Error (%)
2011	42.4	42.3	0.4
2012	43.5	44.1	1.4
2013	44.7	45	1.1
2014	47.7	47.6	0.2
2015	51.4	50.6	2.7
2016	53.5	53.2	0.6
2017	53.8	54.9	2.0
2018	56.0	56.1	0.2
2019	58.2	57.5	1.2
2020	60.4	59.2	2.0
Average Error		1.16	

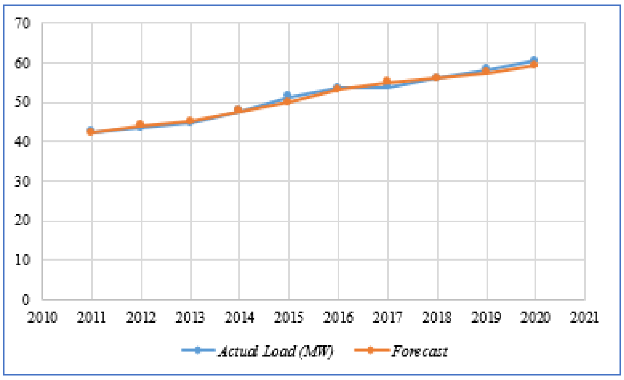

Figure 14: Graph Sugeno Year Results Forecasts 2011 – 2020

Figure 15 shows the comparison method of Mamdani and Sugeno.

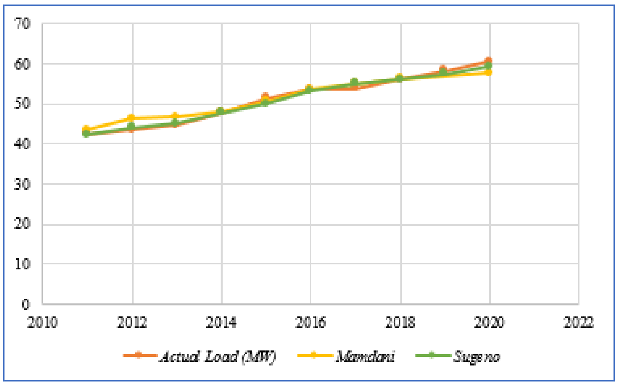

Figure 15: Comparison of Results Forecast chart Mamdani and Sugeno Year 2011– 2020

Based on the results of forecasting using fuzzy Sugeno from Table 10, forecasting in 2015 obtained the highest error value by 2.7% and the smallest obtained in 2014 and 2018 by 0.2%, with the average error of 1.16%. The comparison of Mamdani and Sugeno method is shown in Figure 16. It can be seen that the error value for Mamdani is higher than the error value of Sugeno, the error value to the highest Mamdani in 2012 is to reach 6.4% and 4.6% in 2020, while Sugeno reaches 2.86% in 2015 and 2.0% in 2020.

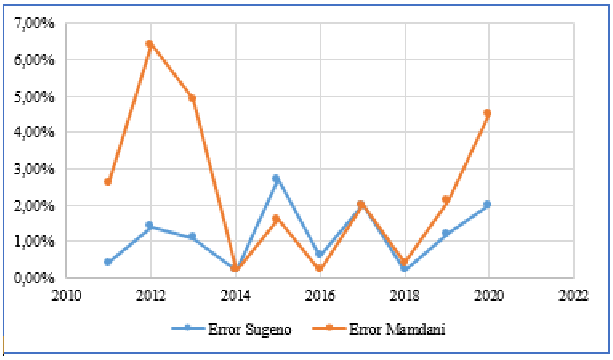

Figure 16: Comparison chart Error Mamdani and Sugeno Year Forecast 2011 – 2020

From the 3-D view, the surface display viewer relationship of Fuzzy Sugeno with all variables sector are shown in Figure 17, 18, 19, and 20, respectively.

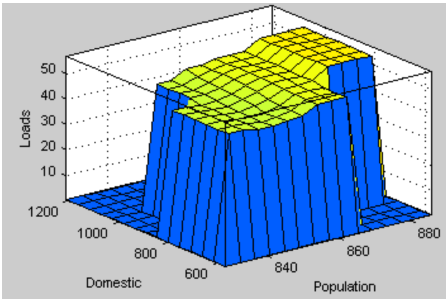

Figure 17: Surface Display Viewer Relationship between Fuzzy Sugeno Variable Expenses, Total Population and Population Economic variables Household Sector

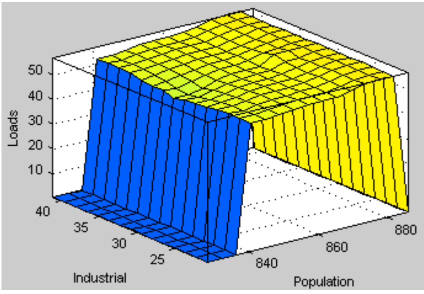

Figure 18: Surface Display Viewer Relationship between Fuzzy Sugeno Variable Expenses, Total Population and Population Economic variables Industrial Sector

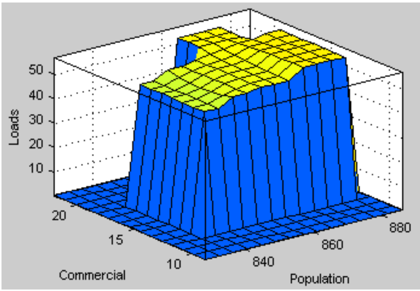

Figure 19: Surface Display Viewer Relationship between Fuzzy Sugeno Variable Expenses, Total Population and Population Economic variables Commercial Sector

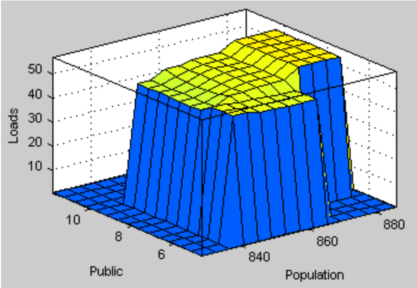

Figure 20: SDV relationship between fuzzy Sugeno Variable Expenses, Total Population and Population Economic Variables Public Sector.

VI. Conclusions and Recommendation

The study of Long Term Electricity Load forecasting using fuzzy logic based on Mamdani and Sugeno method can be summarized as follows. Forecasting the long-term electric power with a period of 10 years in the Malang City based on the resident population, economic growth variables, with focus on four sectors such as household sector, industrial sector, commercial sector and the public sector. Electrical load forecasting based on Mamdani method obtained the error value of 2.49% while for the Sugeno method the error value is 1.16%. By comparing the results of forecasting for ten years based on these two methods, it can be concluded that Sugeno method is the best prediction. The accurate prediction of the load forecasting lies in the rules (rule) that are built from existing data so the selection of proper rules may be better for forecasting results.

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