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Electricity Consumption Forecasting Using Fuzzy Inference System

K. G. Tay[1], Audrey Huong[2], W. K. Tiong[3], Shukur Saleh[4]

[1]Faculty of Electrical and Electronic Engineering UTHM, Malaysia, tay@uthm.edu.my
[2] Faculty of Electrical and Electronic Engineering UTHM, Malaysia, audrey@uthm.edu.my
[3] Faculty of Computer Science and Information technology, UNIMAS, Malaysia, wktiong@unimas.edu.my
[4] Development and Maintenance Office UTHM, Malaysia, shukur@uthm.edu.my

ABSTRACT

Electricity consumption in Universiti Tun Hussein Onn Malaysia (UTHM) has previously been forecasted using a time series model, fuzzy time series (FTS) and multiple linear regression (MLR). Even though FTS gives the best prediction among these methods, the manual implementation of FTS can be a time consuming and laborious process. Like FTS, Fuzzy inference system (FIS) is an alternative system that utilizes fuzzy logic concept. The prediction using FIS, however, required multivariate data such as day, time, temperature, humidity and historical consumption data as its input. In this study, monthly univariate data of UTHM electricity consumption from January 2009 to December 2018 was employed for the forecasting of electricity consumption for the year 2019. FIS was chosen to be compared with the FTS method. Historical univariate data were fuzzified using trapezoidal rule following the FTS method before Sugeno type FIS was chosen to give constant output. A simple fuzzy rule was applied to map the input to output. 2.3173% of mean absolute percentage error (MAPE) was obtained in FIS which is considerably low if compared to the time series model (11.14%), MLR (10.62%), and FTS (5.74%).

Key words : UTHM; forecasting; FTS; FIS: MLR; time series; MAPE

1. INTRODUCTION

Universiti Tun Hussein Onn Malaysia (UTHM) is a developing Malaysian Technical University located in south peninsular Malaysia. UTHM has seen progressive development since its emergence in the year 1993. In 2017, it has a branch campus in Pagoh, Johor in addition to its main campus in Parit Raja, Johor.

The campus expansion and increase in the population of university students increase electricity usage and monthly electricity bill. Hence, there is a need for the Development and Maintenance Office, UTHM to monitor the usage of energy in the hope to reduce the electricity bill. Besides, accurate electricity consumption forecasting may help Development and Maintenance Office UTHM to foresee future electricity consumption for the allocation of the appropriate financial budget for the coming year and take necessary action to reduce the energy consumption.

UTHM electricity consumption forecasting has previously conducted using a time series model [1], fuzzy time series (FTS) [2] and multiple linear regression [3]. The mean absolute percentage errors **(**MAPEs) were obtained as 11.14%, 5.74% and 10.62%, respectively, for studies in [1]-[3].

Time series model and multiple linear regression forecasting are traditional methods, while FTS is an application of a fuzzy logic concept introduced by Zadeh in the year 1965 [4]. Comparatively, FTS gives the best prediction among these three methods. However, the manual implementation of FTS can be tedious. To make the calculation simple, one needs to possess strong programming skills to program the fuzzy logic in time series prediction. The fuzzy inference system (FIS) is an alternative system that utilizes the fuzzy logic concept. There are three types of load forecasting depending on the duration of forecasting which are short term load forecasting (STLF), medium-term load forecasting (MTLF) and long-term load forecasting. STLF ranges from a few minutes up to one week [5], MTLF varies from one week up to a year [6] while LTLF is a prediction for more than a year [5-6].

Fuzzy logic concept or FIS can be applied on prediction for power load, electricity consumption, rainfall, number of tourists, etc. Besides, Fuzzy logic concept or FIS aas employed in proportional integral (PI) controller of frequency for small hydropower plant design [7] and healthcare application [8]. A study in [6] performed STLF using time and temperature as its input while temperature and humidity as the inputs in LTLF using FIS, artificial neural network and ANFIS.

Meanwhile, last day consumption (MWh), last week's consumption (MWh), last day temperature, forecasted temperature, weather, day (binary sets determine whether it is a normal workday or holiday) were used as the inputs to predict short term load [9].

STLF using day, weather conditions and day temperature as input by employing the fuzzy method and neural network as carried out in [10].

In another related study, researchers in [11] used semester, day, previous weekdays average load demand, previous Saturday and Sunday load demand, maximum temperature of the forecasted week, maximum temperature of forecasted Saturday and Sunday as inputs in STLF of Universiti Teknologi Petronas, Malaysia by using FIS.

Similarly, STLF using FIS by considering four cases of load: pre-holiday, holiday, weekday and post-holiday was conducted by [12]. Researchers included temperature, humidity and wind speed as inputs in these four cases.

While time, previous and forecast temperatures as well as previous load were utilized as inputs to forecast the next day electricity demand in FIS [13].

Two years of data on monthly temperature and humidity were used as inputs, and load as output in FIS [14] to predict LTLF of the two years of previous monthly loads.

Relatedly, time, day, past electricity consumption, past temperatures were utilized in [15] to predict electricity consumption in individual housing using FIS.

Study in [16] adopted number of tour objects, accommodation and hotel sites, foreign and domestic tourists from the previous period as input to forecast the number of domestic and foreign tourists visiting east Kalimantan using FIS and ARIMA.

Eleven years of monthly rainfall data from the year 2006 to 2016 was used in [17] to predict the next two years of rainfall rate in the east of Kalimantan using autoregressive (AR) with FIS. However, it is unclear how they fuzzified the monthly rainfall data using the second-order AR.

Most of the load forecasting problems [6, 9-14] using fuzzy logic concept utilized multivariate data as its input such as weather parameters (temperature, humidity and wind), previous load, time, hour of the day and day (weekday or weekend) in load forecasting so that it is easy to establish the fuzzy rule. Besides, most of the previous studies [6,9-12], [14] forecast existing data, but not future events. However, in this study, only univariate input of the past ten years' monthly electricity consumption is available and used in the prediction of the next year's monthly electricity consumption. It is a challenging task to define fuzzy rule-based on univariate data alone for forecasting of future data. Even though electricity consumption has been forecasted using Artificial Neural Network [18-20] and ANFIS (a neural fuzzy logic) [21-23], FTS method in [2] can be simplified using FIS. For this reason, FIS is chosen in this study to forecast electricity consumption in UTHM for the year 2019 by using univariate input of 2009-2018 monthly UTHM electricity consumption data.

2. FUZZY INFERENCE SYSTEM (FIS)

FIS is a system that fuzzifies the input and defuzzifies output by appropriate membership functions. It then maps the input and outputs with its fuzzy rules as shown in Figure 1 [1].

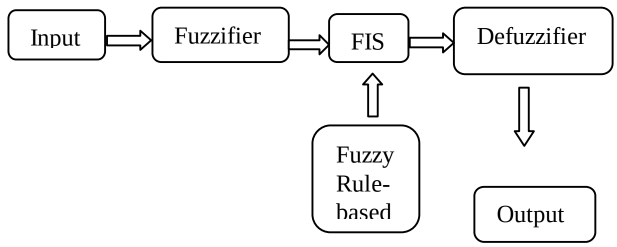

Figure 1: FIS

FIS consists of four main steps:

1. Fuzzification of input and output
2. Application of Fuzzy rules (IF-THEN) using Fuzzy operators (AND or OR)
3. Defuzzification
4. Prediction of output

3. METHODOLOGY

The monthly UTHM electricity consumption data from January 2009 to December 2018 were first sorted by month. For example, by using the January dataset for the past ten years, UTHM electricity consumption for January 2019 was forecasted. The January data from the year 2009 to 2018 were included as input in the Fuzzy Logic Designer Apps (See Figure 2) in MATLAB R2019b. The Sugeno type Fuzzy rule was applied, while the output would be the forecast for January 2019 UTHM electricity consumption.

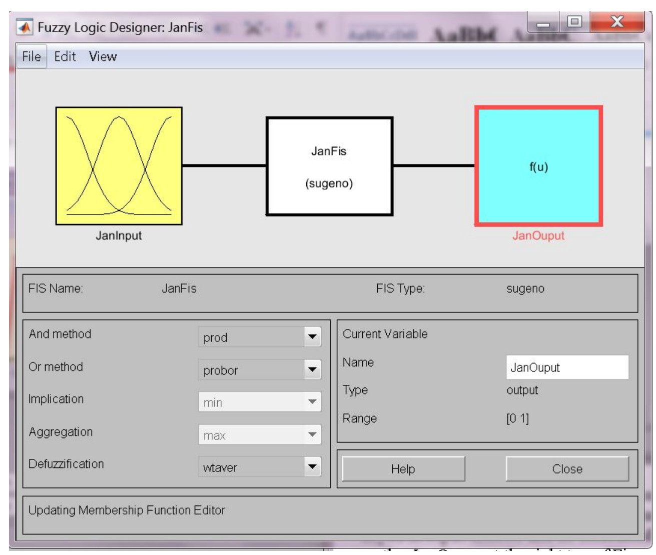

Figure 2: Fuzzy Logic Designer Apps

The input was fuzzified using trapezoidal rule chosen from *Type* dropbox. The range of input, number of membership functions and trapezoidal numbers (a, b, c, d) was set in *Params* input box according to the FTS method [2] as can be seen in Figure 3.

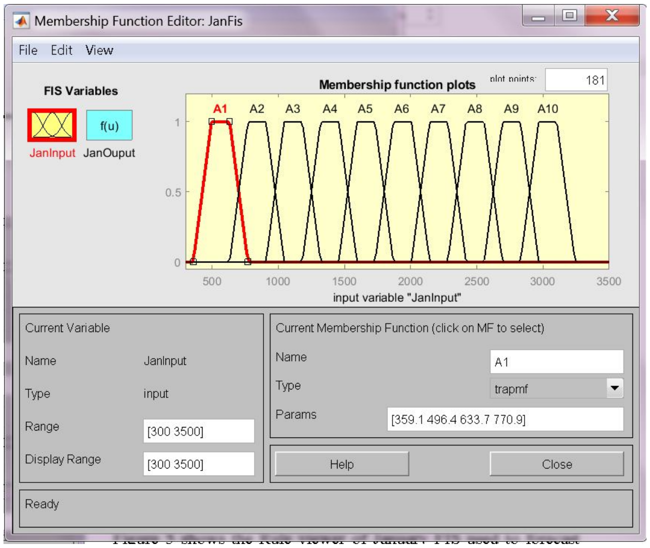

Figure 3: Input of January FIS

The output of Sugeno type FIS is a linear function [24]. Here, the constant output was set based on the average of each of the trapezoidal membership set as given in Figure 4.

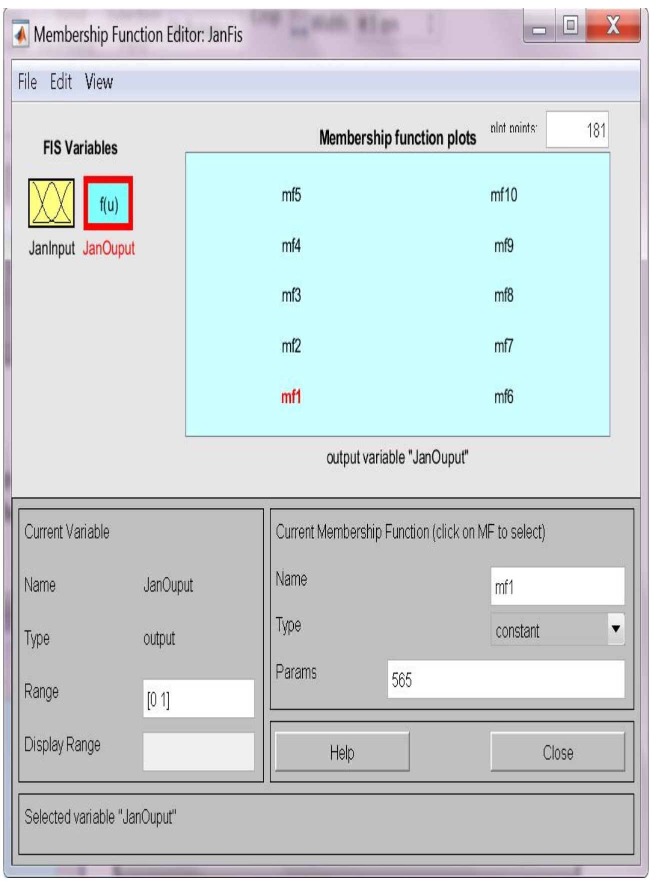

Figure 4: Output of January FIS

The fuzzified input would be connected by fuzzy rule as shown in Figure 5. As the data is univariate, a simple rule was set. For example, if the input is in fuzzy set A_1 then the output belongs to the midpoint of A_1.

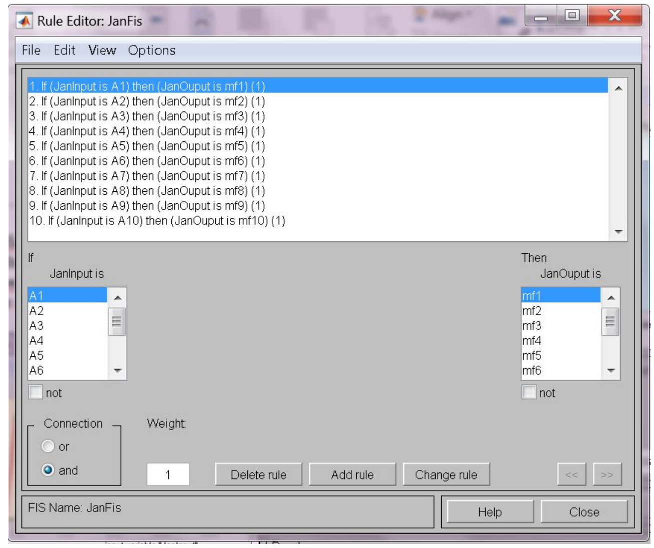

Figure 5: Rule Editor of January FIS

The Rule viewer of January FIS in Figure 6 is used to forecast January energy consumption of any year (in between the year 2009 to 2018), the input can be keyed into the *Input* textbox and its forecasted results would be shown in the *JanOutput* on the top right of Figure 6.

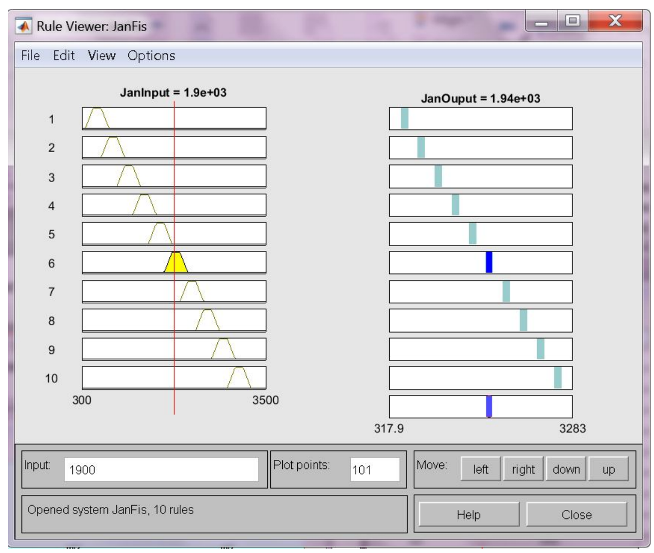

Figure 6: Rule Viewer of January FIS

To forecast all the January energy consumption consecutively, the FIS was exported to the workspace as variable *JanFis*. Then, the January data from the year 2009 to 2018 were forecasted using the following command:

JanForecasted= evalfis(Jan, JanFis)

where *JanForecasted* is the forecasted January data while Jan is the ground truth January data.

Here, to forecast January 2019 electricity consumption, the January 2017 and 2018 data were averaged to give the input of

January 2019, hence the Input of January FIS in Figure 2, the output of January FIS in Figure 3 and then *JanForecasted* would all be changed from 2009-2019.

Once, the January forecasted consumption was obtained, the forecasting process in FIS is recurrent for months from February, March till December.

3.1 Performance Evaluation

The performance of the FIS was assessed using mean absolute percentage errors (MAPE) as follows:

$$MAPE = \frac{\sum_{i=1}^{n} \frac{|y_i - \hat{y}_i|}{y_i}}{n} \times 100\%, \quad (1)$$

where n is the number of consumption data, y_i and $\hat{y}_i$ are real and predicted values, respectively.

4. Results and Discussion

Figure 7 reveals the UTHM electricity consumption (MWh) by years. It is noticeable that the year 2009 has minimum consumption as its consumption range from 496.379 MWh to 1619.835 mWh while the year 2015 has maximum consumption that ranges from 2291.53mWh to 3228.53MwH.

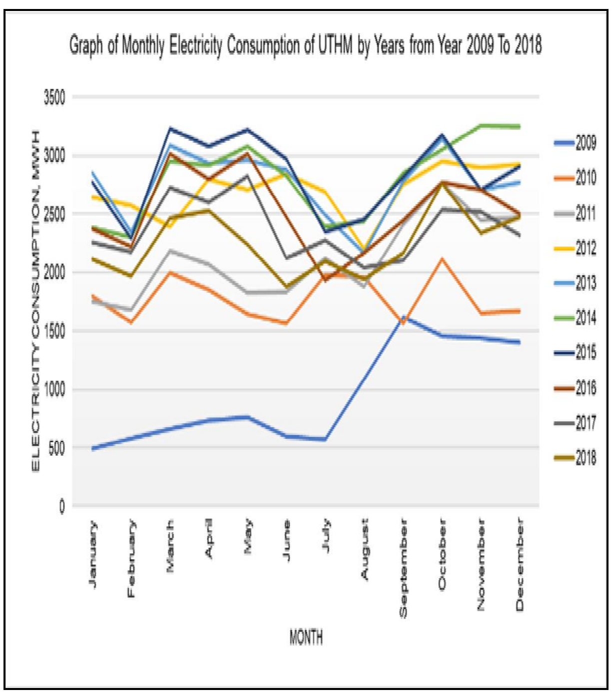

Figure 7: The actual data by years

The time-series data of UTHM electricity consumption (MWh) from January 2009 to December 2018 is shown in Figure 8. It is not stationary as it shows increasing followed by decreasing trends.

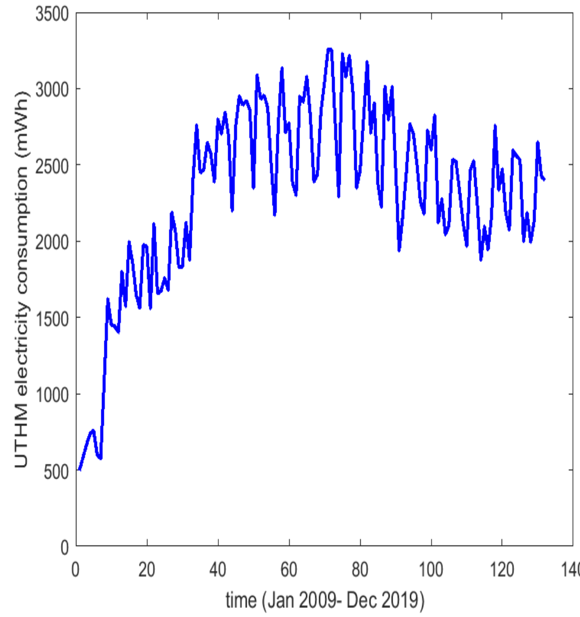

Figure 8: The actual data from the year 2009-2018

The real and forecasted UTHM electricity consumption from the year 2009-2019 using FIS is shown in Figure 9. The actual data was portrayed in blue color while the predicted data was plotted in red. Both lines reveal good agreement, which indicates FIS can predict considerably well. The MAPE of FIS is given by 2.3173%, which is significantly low if compared to the time series model [1] (11.14%), MLR [3] (10.62%), and FTS [2] (5.74%). This can be explained by the fuzzification of existing data using trapezoidal membership function similar to that of FTS [2], but a simple fuzzy rule was applied in this study which indicates if the data falls in membership function A_i, then its output would be the midpoint of membership function A_i. However, in FTS [2], a fuzzy linear relationship function as follows was applied:

Let the time series variable $F(t\text{-}1)$ and $F(t)$ are fuzzified as A_i and A_j respectively. If A_i is related to A_j hence the first order Fuzzy set relationship is represented as $A_i \to A_j$.

The fuzzy linear relation group (FLRG) can be determined by categorizing the same fuzzy set which is associated with more than one set. For example, if $A_i \to A_j$ and $A_i \to A_k$, then they would be grouped as $A_i \to A_j, A_k$. FTS uses previous one input to forecast the next output, which means if $A_i \to A_j$, then the forecasted output would be the midpoint of A_j. Contrary, if the data belong to FLRG which has $A_i \to A_j, A_k$, then the average of the midpoint of both A_j and A_k would be used to give the forecasted results.

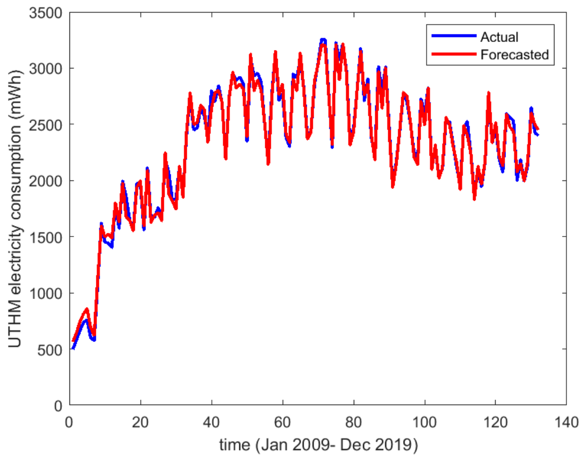

Figure 9: The actual and forecasted UTHM electricity consumption from the year 2009-2019

Figure 10 shows the extrapolated year 2019 forecasted results. It is shown that August 2019 has the lowest consumption as it is a semester break. Later, the consumption climbs back from September to its maximum in October as Semester starts in September, while October is the month when convocation would be held.

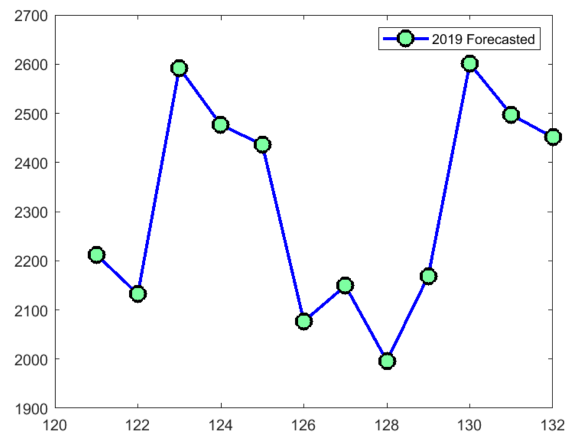

Figure 10: The enlarged year 2019 forecasted UTHM electricity consumption

5. CONCLUSION

Monthly UTHM electricity consumption data from January 2009-December 2018 was adopted in FIS to predict 2019 electricity consumption. Previous existing data were sorted according to month of the years. The trapezoidal fuzzy set was used to fuzzify the existing UTHM electricity consumption data of the month. The range of input, number of membership functions and trapezoidal numbers (a, b, c, d) chosen followed the FTS in [2]. The Sugeno type Fuzzy rule was applied to give a constant output. The MAPE of FIS was obtained as 2.3173% which is comparatively low if compared to the time series model (11.14%), MLR (10.62%), and FTS (5.74%).

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