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Prediction Method for Solar Power using Linear Regression and Fuzzy Logic

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Abstract: The world is running out of fossil energy sources. Because of this, we are searching for alternative energy sources for next generation energy needs. However, solar energy may be the best choice for the future world because solar energy is the most abundant renewable energy sources. Photovoltaic power is unpredictable and depends on solar irradiation and temperature. Therefore, a prediction method is required. The maximum error can be obtained using this prediction method. Fuzzy logic system was used to get the accurate value of power. With the help from fuzzy logic and linear regression, the maximum error will be shown accurately.

Keywords: PV Module, Fuzzy Logic, Linear Regression

1. Introduction

Nowadays, the depletion of fossil fuels become a crisis in energy sector. Because of this, we are looking for new sources of energy for the energy needs of the next decade. We should also make all forms of energy more environmentally, socially and economically sustainable. [1].

Taking into consideration, renewable energy sources such as solar, wind, hydropower and geothermal energy are important because they are environmentally friendly. However, solar energy may be the best choice for the future world because solar energy is the most abundant renewable energy sources. Asian countries have the highest potential to receive more sunlight compared to other temperate countries within a year. A lot of solar radiation is unused and wasted essentially [2].

Solar photovoltaic (PV) is becoming an integral component of our energy consumption and will soon become an energy source to our world. Photovoltaic panels continue to be more efficient, keeping solar power replacing other conventional sources of energy. Photovoltaic energy is unpredictable and

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depends on solar irradiation and other meteorological factors such as temperature, humidity, precipitation, wind speed, and cloud coverage [3].

From the previous researchers some of them describe the same objective which is to collect data for solar power using various parameter which are solar irradiation and temperature. The data for solar irradiation and temperature used in this project collected at UTHM Parit Raja. The prediction method used is different from this project. Linear regression and fuzzy logic are used from this project to predicting the value of maximum error and RMSE values. It also to predict which predicting method performance is better.

Fuzzy logic helps to conceptualizing the fuzziness in the system into a crisp quantifiable parameter. Thus, fuzzy logic-based models can be adopted for effective energy planning to arrive at pragmatic solutions. Fuzzy logic deals with reality and it is a form of many valued logic. It deals with reasoning that is approximate having also linguistic values rather than crisp values. Fuzzy logic handles the concept of truth value that ranges between completely true and completely false (0–1). Fuzzy logic has been applied in many areas. Fuzzy logic and probability are different ways of indicating variability [4].

Linear regression is a supervised machine learning algorithm where the predicted output is continuous and has a constant slope. Linear regression makes prediction for continuous/real or numeric variables based on the value of another variable [5].

2. Methodology

Figure 1 shows the whole process of developing PV module, fuzzy logic and linear regresion in Matlab/Simulink. The PV module was generated to predict the solar output power using two types of parameters which are temperature and irradiance. The value of temperature and solar irradiance was collected at UTHM Parit Raja. Then the data obtained will inserted in PV module simulink model to predict the value of output power.

The input value of temperature and irradiance has been inserted in fuzzy logic system to get the output power and current from that system. If the output result has error, the step will be repeated until it show the best result from fuzzy logic system. Linear regression and fuzzy logic model has been developed using matlab code to get the desired output. The results from linear regression and fuzzy logic is been being compared to get the value of maximum error. The results data from the two prediction method then been analysed. The PV Module supply for this project is 200 Watt.

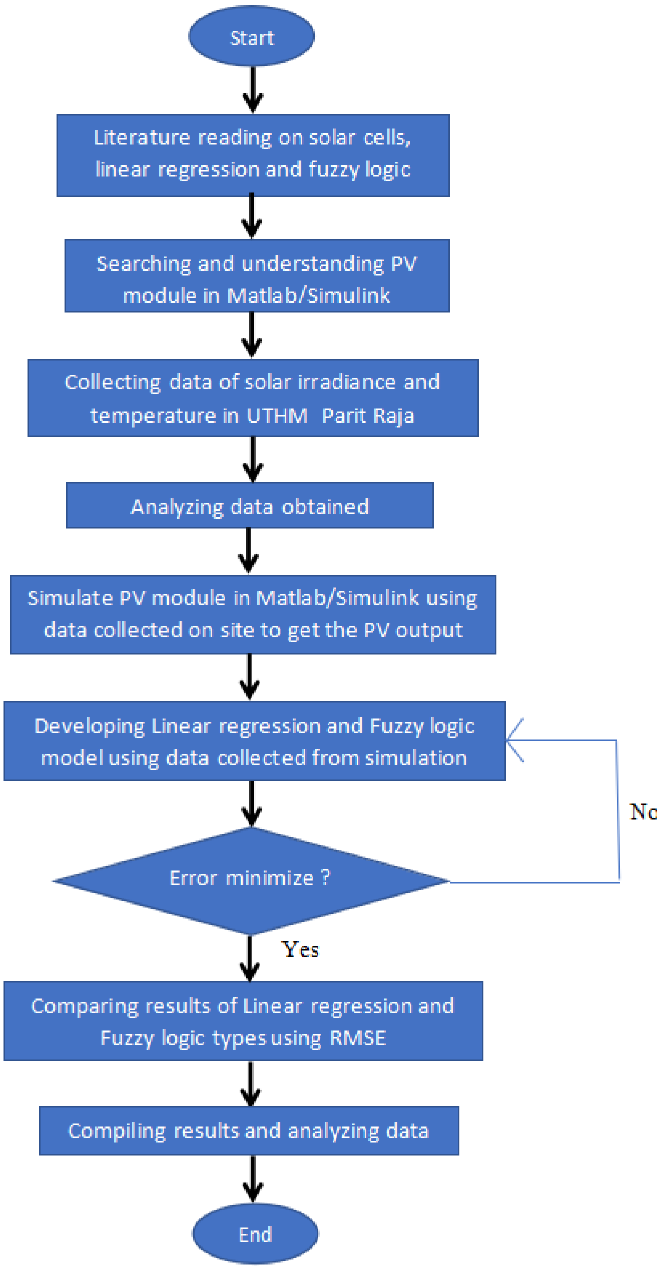

Figure 1: Flow chart of the whole system

2.1 Modelling of PV module

There are many equivalent circuits of a solar cell, where the single-diode and two-diode models could be the most commonly used. Since the single-diode model is simple and reliable enough in many cases. The general model of solar or PV cell [6][7] shown in Figure 2. Equivalent circuit of solar cell includes photocurrent source, diode, parallel resistor expressing the leakage current and series resistor describing the internal resistance to the current flow. Table 1 shows constants and the variables used in the PV module and Table 2 show module rating for modeling in Simulink.

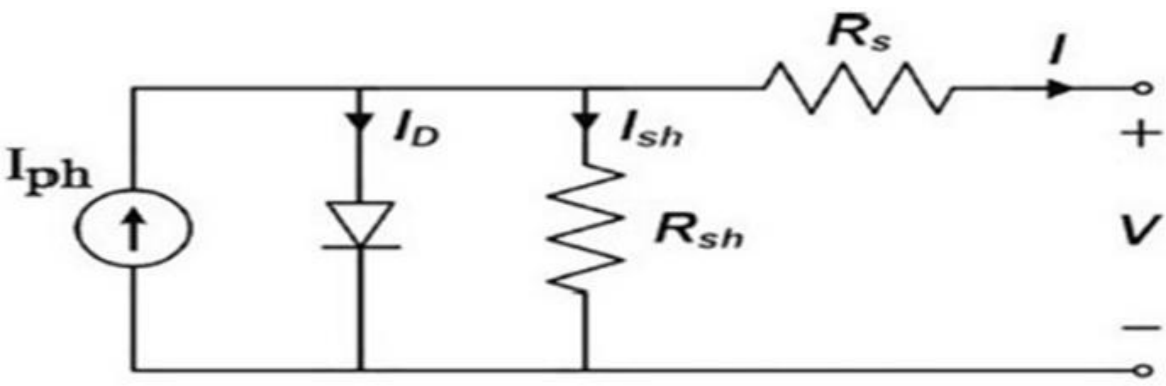

Figure 2: Equivalent circuit of PV cell

Table 1: Constants and variables value for PV module

I_{ph}	Photo-current (A)	I_{ph}
I_{sc}	Short circuit current (A)	I_{sc}
k_i	Short circuit current of cell at 25˚C and $1000W/m^2$	0.0032
T	Operating temperature (K)	T
T_n	Nominal temperature (K)	298
G	Solar irradiation (W/m^2)	G
q	Electron charge (C)	1.6 X 10^{-19}
V_{oc}	Open circuit voltage (V)	V_{oc}
I_{ph}	The identity factor of the diode	1.3
n	Boltzmann's constant (J/K)	1.38 X 10^{-23}
K	Band gap energy of the semiconductor (eV)	1.1
E_{go}	Number of cells connected in series	54
N_s	Number of PV modules connected in parallel	1
N_p	Series resistance (Ω)	0.221
R_s	Shunt resistance (Ω)	415.405
R_{sh}	Diode thermal voltage (V)	-

Table 2: Specification of PV module

Rated power (V)	200 W
Voltage at maximum power ($\boldsymbol{V_{mp}}$)	26.4 V
Current at maximum power ($\boldsymbol{I_{mp}}$)	7.58 A
Open circuit voltage ($\boldsymbol{V_{oc}}$)	32.9 V
Short circuit current ($\boldsymbol{I_{sc}}$)	8.21 A
Total number of cells in series ($\boldsymbol{N_s}$)	54
Total number of cells in parallel ($\boldsymbol{N_p}$)	1

The simulation of PV module is carried out based on mathematical equations in Matlab/Simulink. The different equations involved for the simulation of PV module are detailed below which divided into five equations.

Saturation Current (I_0):

$$I_0 = I_{rs}(\frac{T}{T_n}).exp\ [\frac{q.E_{g0}.(\frac{1}{T_n}-\frac{1}{T})}{n\ .K}] \qquad \textit{Eq. 1}$$

Reversed Saturation Current (I_{rs}):

$$I_{rs} = \frac{I_{sc}}{e^{(\frac{q\ .V_{OC}}{n\ .N_S\ .K\ .T})}-1} \qquad \textit{Eq. 2}$$

Shunt Current (I_{sh}):

$$I_{sh} = (\frac{V + I\ .R_S}{R_{sh}}) \qquad \textit{Eq. 3}$$

Photo Current (I_{ph}):

$$I_{ph} = [I_{sc}\ +\ k_i\ .(T - 298)]\ .\frac{G}{1000} \qquad \textit{Eq. 4}$$

PV Current (I):

$$\mathrm{I}\ =\ \mathrm{I_{ph}} - \mathrm{I_0}\ .[\exp(\frac{q.(V + I\ .R_S)}{n\ .K\ .N_S\ .T})\ -\ 1]\ -\ \mathrm{I_{sh}} \qquad \textit{Eq. 5}$$

2.2 Simulink Model of PV Module

The simulink model of PV module is developed in Matlab/Simulink using equations 1-5 and each equation is used to developed the subsystem shows in Figure 3. The five subsystems based on the equations of saturation current, reversed saturation current, shunt current, photo current and PV current. The final PV module is modeled by connecting all the subsystems in Matlab/Simulink. Three displays block is used to get the output which are voltage, current and power and the input are temperature and irradiance is shown in Figure 4.

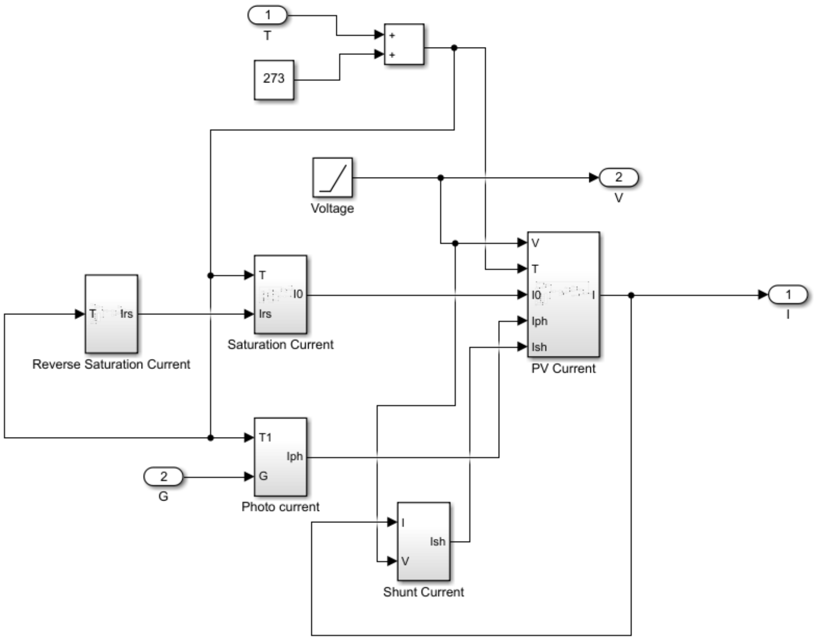

Figure 3: Block diagram of PV Module

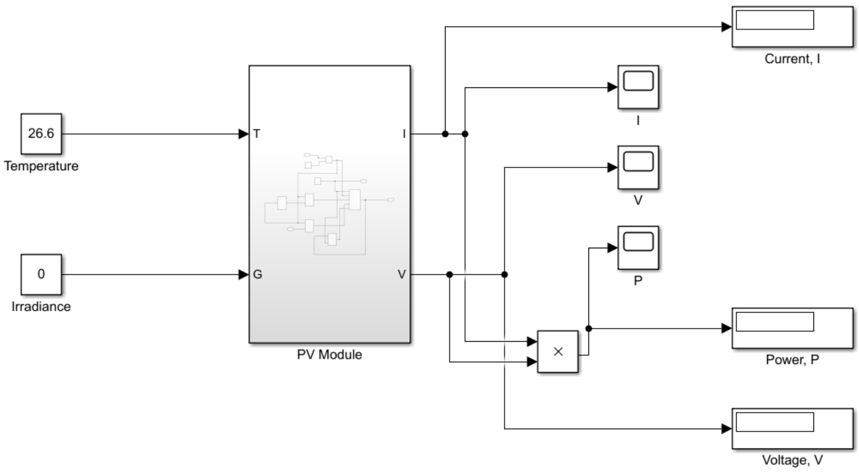

Figure 4: Block diagram of PV module with output display

3. Simulink Result

From the simulation results, there are three types of output. The output power from PV module is obtained from the value of parameters used which are temperature and solar irradiance to get the output power and current .Secondly, the value of output power from fuzzy logic will be obtained. Fuzzification, inference and defuzzification process was used to obtain the predicted output power and current. Linear regression will be perform in Matlab/Simulink using matlab code. The value of output power will be normalized using matlab code then will be inserted in linear regression system to display the scatter graph.

3.1 Performance of PV Module with different temperature and solar irradiance

The two inputs which are temperature and solar irradiance was used to get the output current, voltage and power. The 350 set of input data are collected at UTHM Parit Raja and has been recorded for every 30 minutes in a day. Table 3 shows the value of input and output from solar PV module in Matlab/Simulink.

Table 3: Values of input and output from PV module

Date	Time	Input		Output Display		
		Temperature (ºC)	Irradiance (w/m^2)	Current, I	Voltage, V	Power, P
5/11/2017	7.00 AM	24.2	7	- 0.09403	25	-2.351
	7.30 AM	24.6	70	0.4116	25	10.29
	8.00 AM	25.1	134	0.9226	25	23.07
	8.30 AM	26.1	185	1.318	25	32.96
	9.00 AM	26.3	267	1.976	25	49.40
	9.30 AM	27.8	350	2.609	25	65.23
	10.00 AM	28.9	281	2.028	25	50.69
	10.30 AM	29.6	698	5.317	25	132.90
	11.00 AM	30.1	510	3.812	25	95.30

3.2 Fuzzy Logic

Fuzzy Inference System (FIS) is included in this fuzzy logic system. Fuzzy inference is the formulating process from input to output using fuzzy logic [8]. The process then provides the basis for which the decision can be made by classifying the data caused by the desired output that has been set. In this model Mamdani is used because it used both inference systems which are Multiple Input and Single Output (MISO) and Multiple Input and Multiple Output (MIMO) systems while Sugeno only used Multiple Input and Single Output (MISO) system. This system will have two input, temperature and irradiance and three output which are current, voltage and power.

The fuzzy logic operation consists of three parts which are fuzzification of crisp values, inference logic which includes IF-THEN logic and finally the defuzzification to obtain crisp output. Figure 5 shows the architecture of fuzzy logic system.

The output results from fuzzy logic in Figure 5 shows the value of current and power for all 350 sets of data. The value of current and power obtained to show the Fuzzy rules and membership functions are constructed. The more data and information from current amplitudes is required, so membership functions for low, medium and high will be created.

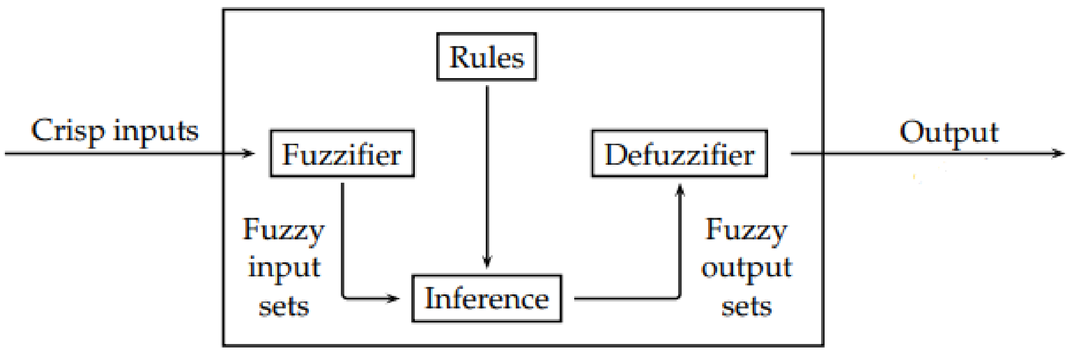

Figure 5: Architecture of Fuzzy Logic system

3.2.1 Fuzzification

Fuzzification is the process of decomposing a system input and/or output into one or more fuzzy sets. The input and output uses same partition grid system in FIS system. It is a step that helps to convert the inputs where crisp numbers are converted into fuzzy sets [9]. The fuzzifier are separated the input signals into three state which are, “small”, “medium” or “high” Then, the sets are passes to the control system for further processing. Figure 6-9 shows the membership function in fuzzy logic.

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The rule used in this system are low, medium and high. Figure 10 shows the rule editor in fuzzy logic system.

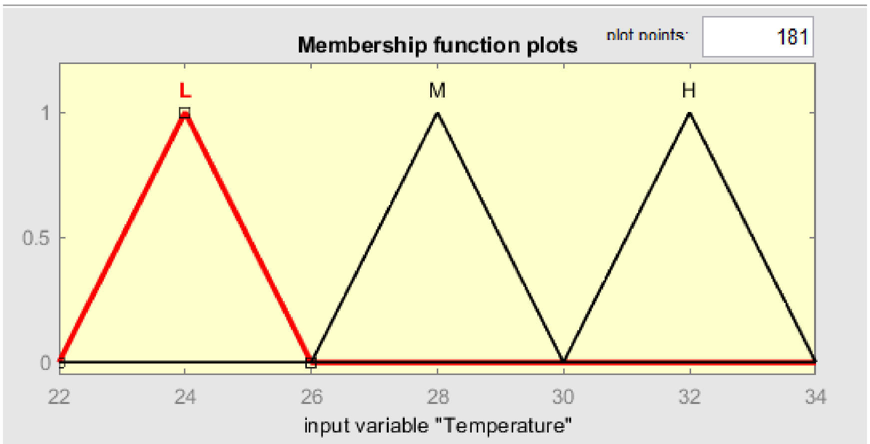

Figure 6: Input 1 (Temperature)

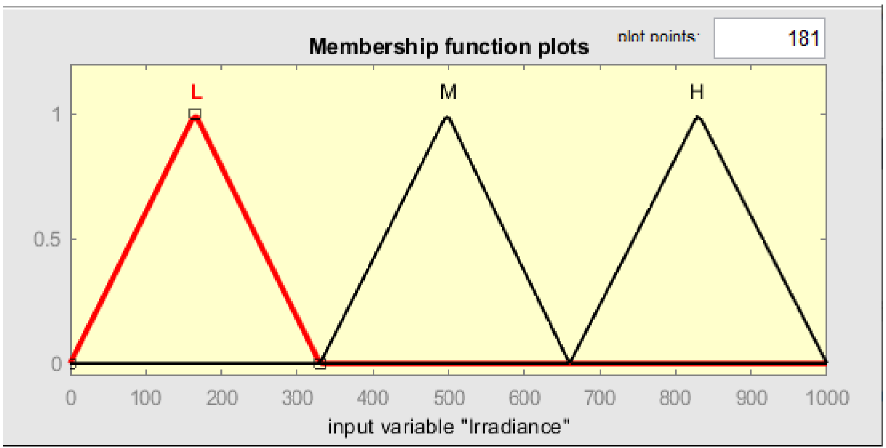

Figure 7: Input 2 (Irradiance)

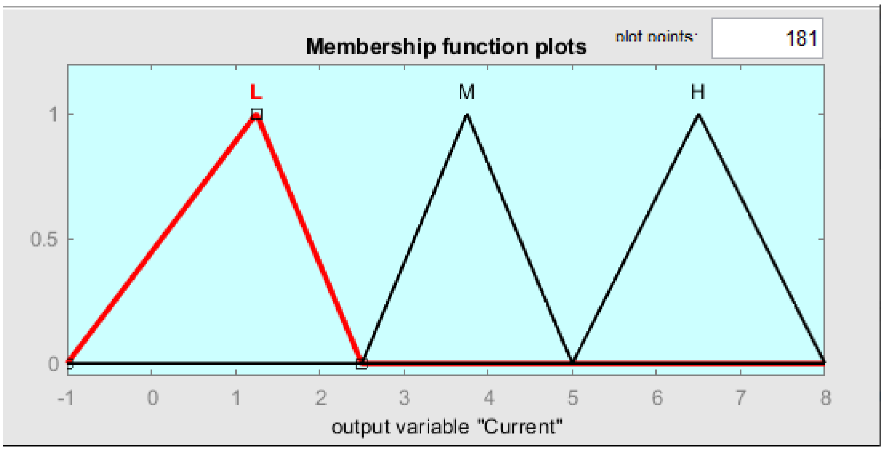

Figure 8: Output 1 (Current)

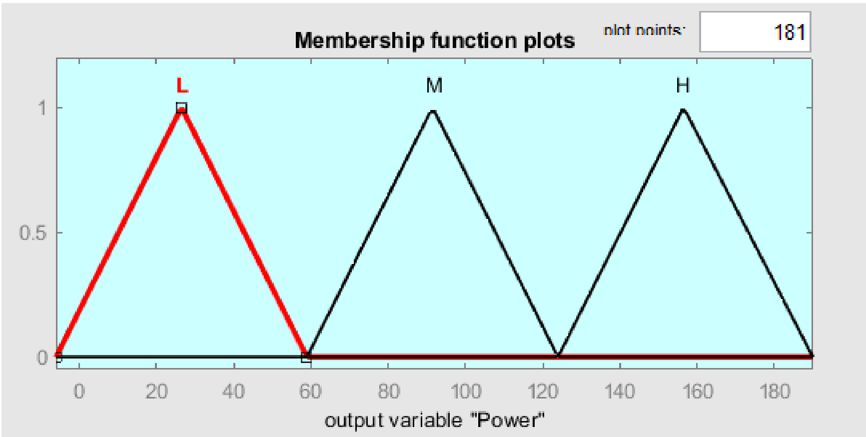

Figure 9: Output 2 (Power)

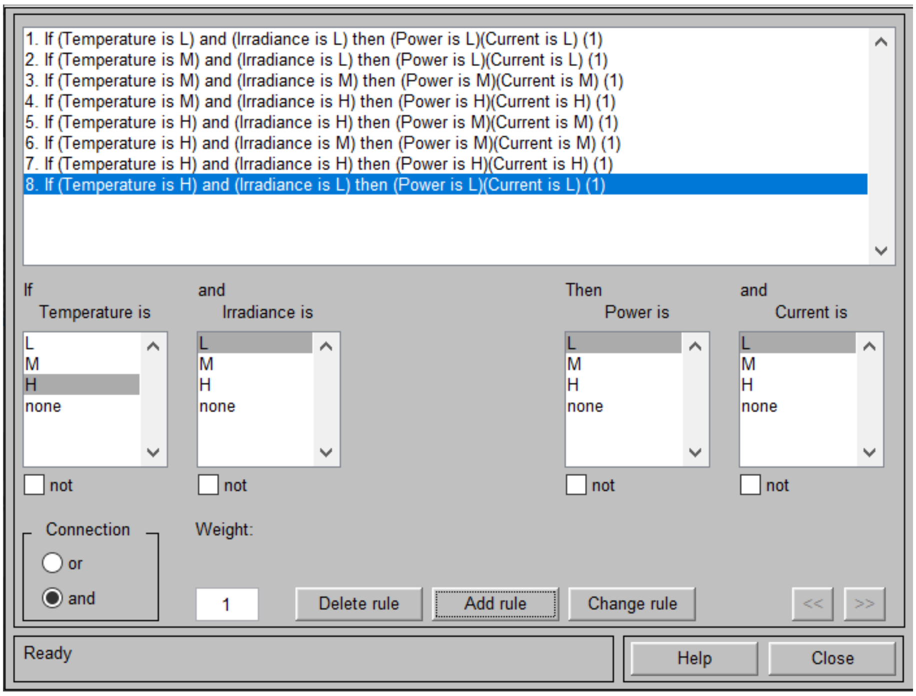

Figure 10: Rule Editor

3.2.2 Defuzzification

The defuzzification is the inverse step of fuzzification which it transforms the fuzzy set into a crisp set. It is typically needed in fuzzy control system. This will have a number of rule that transform a number of variables into a fuzzy result that is described in term of membership in fuzzy set. Defuzzification will interpreting the membership degrees of the fuzzy set into a specific decision or value [10]. Figure 11 shows the defuzzification process in fuzzy logic system.

The final output for prediction can be demonstrated through surface view. This section is a fuzzy implication that helps evaluate the rules involved.

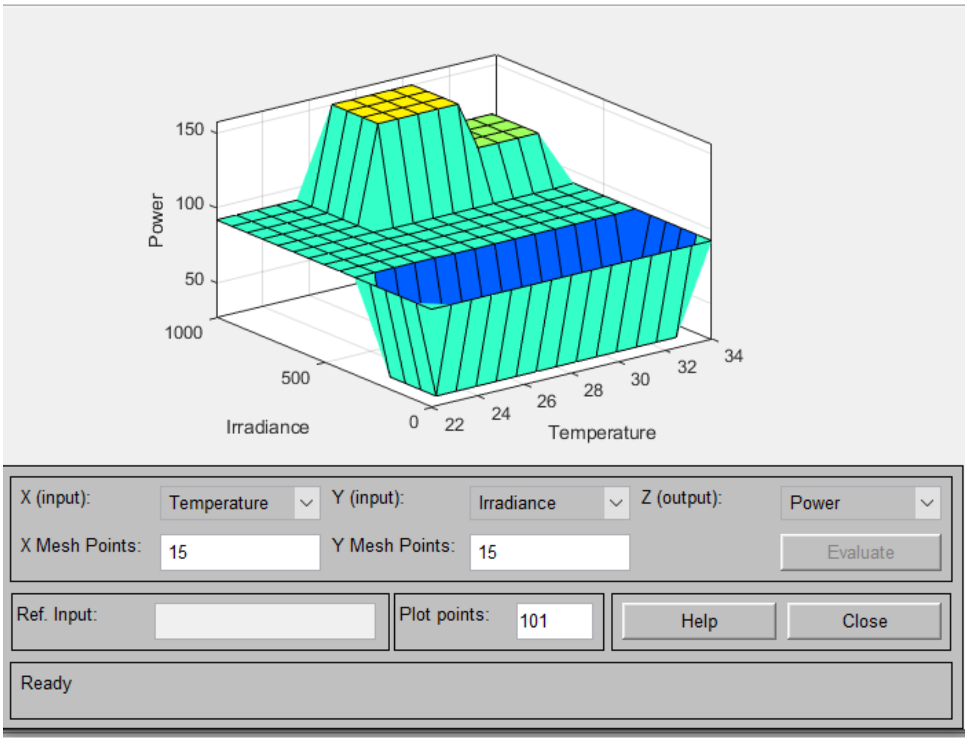

Figure 11: Surface view for output Current and Power

3.3 linear regression

The output for actual data has been divided into testing and training. The value used for the training is 70.00 % while for the testing is 30 % from 350 data sets.

The output power will be normalize using matlab code to plot the output scatter graph. The scatter graph will show the value of correlation coefficient (r^2), Mean Square Error (MSE), and Root Mean Square Error (RMSE). The value of correlation coefficient lies between 0 to 1 and RMSE is lies between 0 to 100 %. If the correlation coefficient equal to 1, and RMSE is near 0 the smaller error that the system will produce. The equation for linear regression is shown below.

Correlation coefficient:

$$r^2 = \frac{S_t - S_r}{S_t} \qquad Eq.\ 6$$

Total sum of the squares around the mean for the dependant variable:

$$S_t = (y - mean\ y)^2 \qquad Eq.\ 7$$

Sum of the squares of residuals around the regression line:

$$S_r = e^2 \qquad \textit{Eq. 8}$$

Error:

$$e = y - (a_0 + a_1 x) \qquad \textit{Eq. 9}$$

Slope:

$$a_1 = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2} \qquad \textit{Eq. 10}$$

Intercept:

$$a_0 = mean\, y - a_1(mean\, x) \qquad \textit{Eq. 11}$$

Mean x and y:

$$Mean\, x = \frac{\sum x}{n} \qquad \textit{Eq. 12}$$

$$Mean\, y = \frac{\sum y}{n} \qquad \textit{Eq. 13}$$

Arithmetic mean:

$$y = a_0 + a_1 x \qquad \textit{Eq. 14}$$

RMSE:

$$\text{RMSE} = \sqrt{(forecast\ values - observed\ values)^2} \qquad \textit{Eq. 15}$$

4. Results and Analysis

4.1 Fuzzy Logic

The input will undergo fuzzification process, then the degree of fulfillment of each rule is calculated using the AND operator. Membership function output is then distributed to the degree of fulfillment. All rules and final final membership function outputs aggregated by operator (THEN) to produce the final fuzzy output. The output value will be affected by the selected defuzzification technique process, so it is necessary to use an appropriate technique such as triangle shaped graph. Figure 12 shows the input value of temperature and solar irradiance for 350 sets of data while output value represents the current and power.

Based on the Table 4, the RPE % has been calculated using equation 16. the RPE shows the different value between actual power and forecast power. The forecast power is obtained using fuzzy logic system.

$$\sum_{Power=1}^{n} \left| \frac{P_{forecast} - P_{actual}}{P_{actual}} \right| x\ 100\% \qquad \textit{Eq. 16}$$

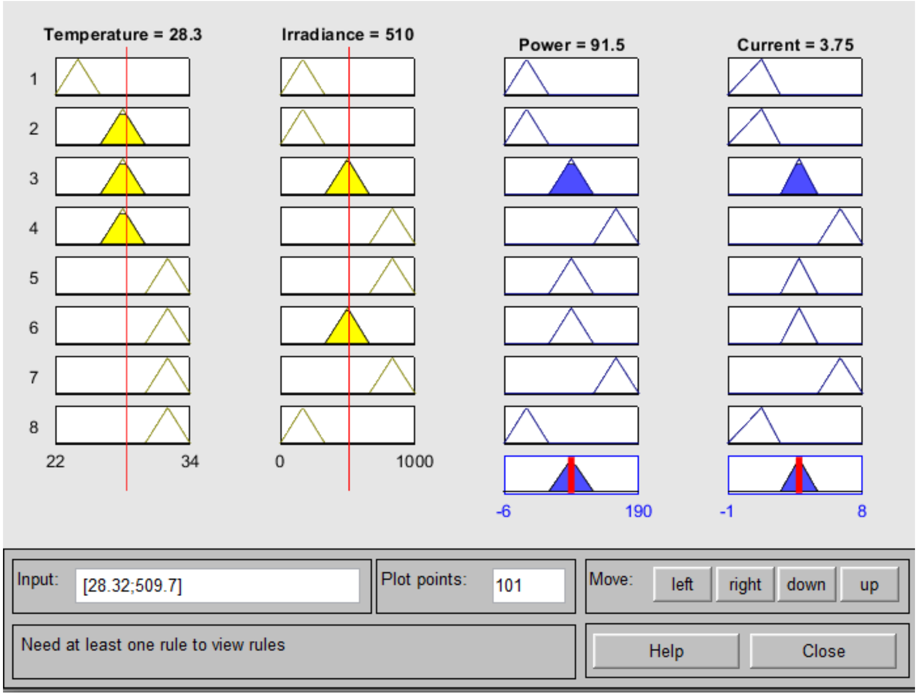

Figure 12: Fuzzy Logic output

Table 4: RPE values between fuzzy logic output and target

Date	Time	Input		Output Display		
		Temperature (°C)	Irradiance (w/m²)	Power actual, P	Power forecast, P	RPE, %
5/11/2017	7.00 AM	24.2	7	-2.351	-2.23	5.15
	7.30 AM	24.6	70	10.29	10.34	0.48
	8.00 AM	25.1	134	23.07	23.10	0.13
	8.30 AM	26.1	185	32.96	33.12	0.49
	9.00 AM	26.3	267	49.40	49.46	0.12
	9.30 AM	27.8	350	65.23	65.42	0.29
	10.00 AM	28.9	281	50.69	50.75	0.12
	10.30 AM	29.6	698	132.90	133.50	0.45
	11.00 AM	30.1	510	95.30	95.98	0.71

4.2 Linear Regression

Figure 13 shows the output for testing and training using linear regression in Matlab/Simulink. The value used for the training is 70.00 % while for the testing is 30.00 % from 350 data sets. Then the data will be normalize using matlab code to plot the output scatter graph. The closer the measured data, the higher efficiency of the graph . So, if the target data approached measured data, the output value will be more accurate.The value of correlation coefficient (r^2), Mean Square Error (MSE), and Root Mean Square Error (RMSE) will be shown in the graph. The value of correlation coefficient lies between 0 to

1 and RMSE is lies between 0 to 100.00 %. If the correlation coefficient equal to 1, and RMSE is near 0 the smaller error that the system will produce. The output value for the scatter graph from Matlab/Simulink of MSE is 2.0078e+0.3, RMSE is 44.8087 and correlation coefficient is 0.0189. As can be seen in figure, there is linear regression gap trend between the measured data and target data. Based on the results it can be seen that the measured data slightly closed to the target. This is because linear regression try to find a best straight line that fitted the data.

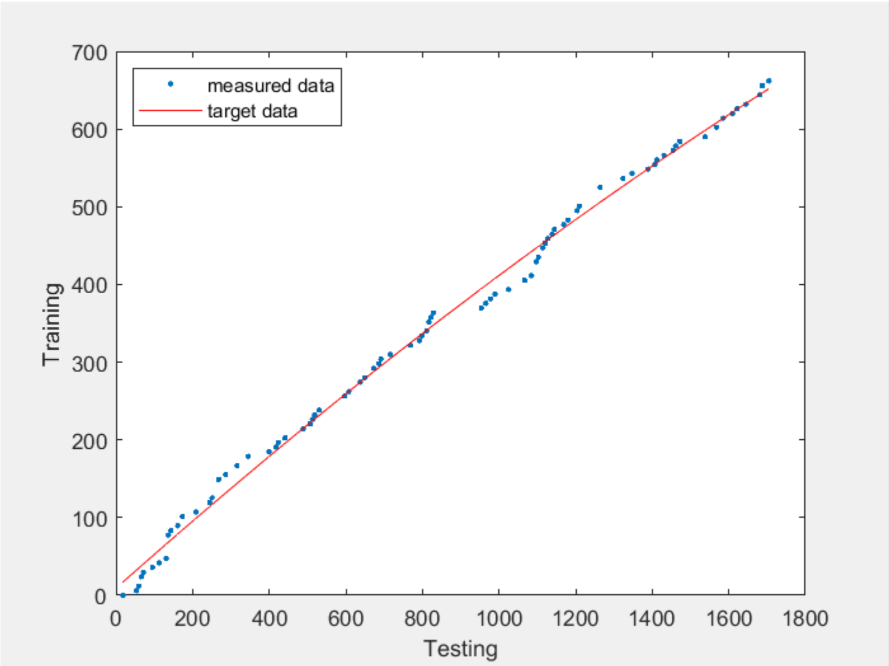

Figure 13: Scatter graph for linear regression

4.3 Summary

The fuzzy logic system and linear regression has been compared. Linear regression shows the maximum error and RMSE value while fuzzy logic only shows the error power output value from the solar irradiance and temperature. The best performance of prediction method is using linear regression because the value of error is nearest 1. The value error in power for fuzzy logic was calculate between output PV module using equation and the error is only between 10.00 %.

5. Conclusion

In conclusion, solar PV module has been developed in Matlab/Simulink to predict the output using two types of parameters which are solar irradiance and temperature. The value of solar irradiance and temperature obtained at UTHM Parit Raja in every 30 minutes in a day. In the beginning, learning about fuzzy logic techniques needs to be mastered to identify the processes that will be involved to predicted the output values. Then, the input values have been used to predict the output value of current and power. Fuzzy logic used to give accurate reasoning to achieve the definite output. Linear regression are used to predict the maximum error between training data and testing data . The training data used was 70 % of the 350 set output data while 30 % of testing data. If the value of correlation coefficient is 1 or near 1, the RMSE will be 0 because all the points lie on the regression line and it also means that no errors. The value of RMSE lies between 0 to 100 %, so the smaller value of RMSE the better because there is only slightly error in that system.

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