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Floating Photovoltaic Power Output Prediction by Using Adaptive Neuro-Fuzzy Inference System

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Abstract: This project focuses on the prediction of power output by using computational methods and the development of an Adaptive Neuro-Fuzzy Inference System (ANFIS) configuration for floating solar photovoltaics. This prediction is needed since the power output of the photovoltaic (PV) system will not be the same as the power rating stated on the PV module sheet. Prediction for power output involved two main parameters, ambient temperature (T_{amb}) and solar irradiance (G) of Tasik G3, Universiti Tun Hussein Onn Malaysia. To predict the power output of solar panels, de-rating factors such as dirt, aging and mismatched modules also must be considered to get an accurate prediction. It will be more efficient to be able to estimate the daily power output with accuracy by using deep learning tools such as ANFIS.

Keywords: Photovoltaic, ANFIS, Power Output

1. Introduction

The needs for electricity keep expanding more and more in every aspect of our life. While the world encounter problem of insufficient non-renewable energy such as coal and oil as the main source of electricity, the growth of the population keeps increasing [1]. With limited sources of electricity and the demands that keep rising, it was a necessity to look for new alternatives such as solar, hydropower and geothermal as renewable sources. In addition, the usage of renewable energy can lessen the greenhouse gas (GHG) as well as preserve the environment making it become more useful in any region. There are many developing countries that already exploring renewable energy sources to gain benefits from it. For example, in South Korea, PV energy is spreading very quickly after the launch of the Renewable Portfolio Standards (RPS) program [2].

Photovoltaic (PV) or solar energy will be using sunlight as the main resource for generating electricity. It also is known as the cleanest and most abundant renewable energy available. While floating solar PV power plant is a combination of PV systems that stay on the surface of lakes,

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Corresponding author: fateh@uthm.edu.my water reservoirs, ponds, or irrigation canals [3]. This system was said to be very advantageous as it is unnoticeable since it will stay hidden from public view compared to land-based solar plants. For now, the most large-scale floating PV plants are constructed by using pontoon-type floats, with PV panels mounted at a fixed tilt angle [4]. Next, this system also will produce higher efficiency energy than the land-based system because of the natural cooling system [3],[5].

Adaptive Neuro-Fuzzy Inference System (ANFIS) is an artificial intelligence system that integrates neural networks and fuzzy logic principles. The interference system also is complementary with a set of fuzzy that have the capacity to generate non-linear functions making it to be acknowledged as a universal estimator. Fuzzy neural networks are capable to estimate any kind of power plant with high precision even if it were related to engineering, transportation, business, and medicine. ANFIS generates by modulating all its adjustable parameters in order to obtain the desired output with minimum error. This technique is an outstandingly potential tool but is yet to be analyzed in various other non-linear and complex predictions of control problems [6]-[8].

The aim of this project is to manually predict the power output of floating photovoltaics by using computational methods. A configuration of an Adaptive Neuro-Fuzzy system also will be developed to predict the power output. The performance of artificial intelligence (ANFIS) will be evaluated once results from both methods were obtained.

2. Materials and Methods

To enhance the understanding of this project, some research was done related to floating photovoltaic systems. Formula or computational methods to predict power output also were studied to be applied in this project. Next, data collection for parameters needed in the formula will be obtained from websites. Prediction power output in the computational method was implemented by applying the parameters. ANFIS configuration will be developed to predict power output by using the same parameters and comparing the results from both methods. All results and findings will be discussed further.

2.1 Materials

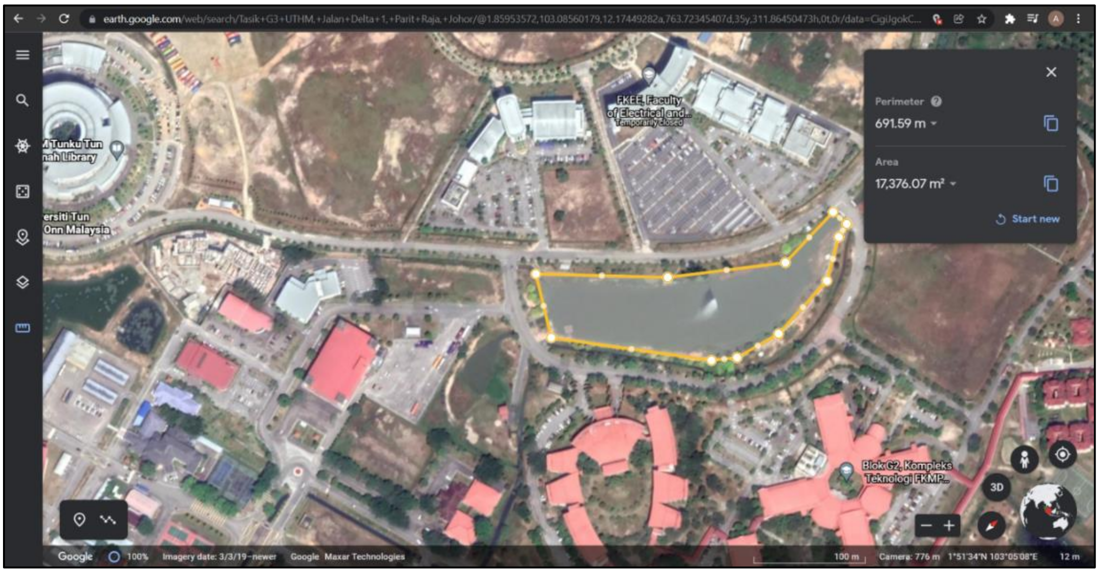
(a) Type of PV module, PV-MLU 250HC [7] will be used in this project as shown in Figure 1. The mono-crystalline type of module with a 250W power rating has been chosen as it is the most suitable for this project. The modules were designed with high efficiency and advanced features. For example, proprietary cells and anti-refection glass can increase light absorption proportionally to the power output.

Figure 1: PV-MLU 250HC

(b) Temperature of the surrounding place or ambient temperature (T_{amb}) for Parit Raja area is another main data that was needed in power output prediction. This is because the temperature was considered as a factor influencing the power output of PV module. The data was able to obtain from the *weather.my* website [8] which provides the history of temperature from daily to monthly. Daily temperature from January 2021 to November 2021 was collected to gain a precise power output.

(c) Data on solar irradiance also was collected on a daily trend from January till November 2021 from RETScreen software. The location of Batu Pahat was chosen instead of Parit Raja in order to obtain the data since this software does not have access to that location. Thus, Batu Pahat was selected in view of the fact that it was the nearest location available to Parit Raja. The daily solar irradiance for all eleven months will be attached in Appendix A.

(d) The space for PV modules installed on Tasik G3 depended on the dimension of a PV panel and the area of Tasik G3, UTHM. Figure 2 shows the area that is available to install the PV panel. The total area for Tasik G3 is 17,376.07m^2. Despite the large space available, this project will only consider 50% of the total space to ensure the PV panel can be arranged properly. The ideal arrangement is that all PV arrays must have some gaps or pathways (within 5-6 inches) [9], to allow maintenance works in the future. Further calculations will be shown in the next subtopic.


earth.google.com/web/search/Tasik+G3+UTHM,+Jalan+Delta+1,+Parit+Raja,+Johor/@1.85953572,103.08560179,12.17449282a,763.72345407d,35y,311.86450473h,0t,0r/data=CigiJgokC...

Perimeter
691.59 m

Area
17,376.07 m²

Figure 2: Area of Tasik G3, UTHM measured on Google Earth

2.2 Methods

Figure 3 shows the flowchart of the project.

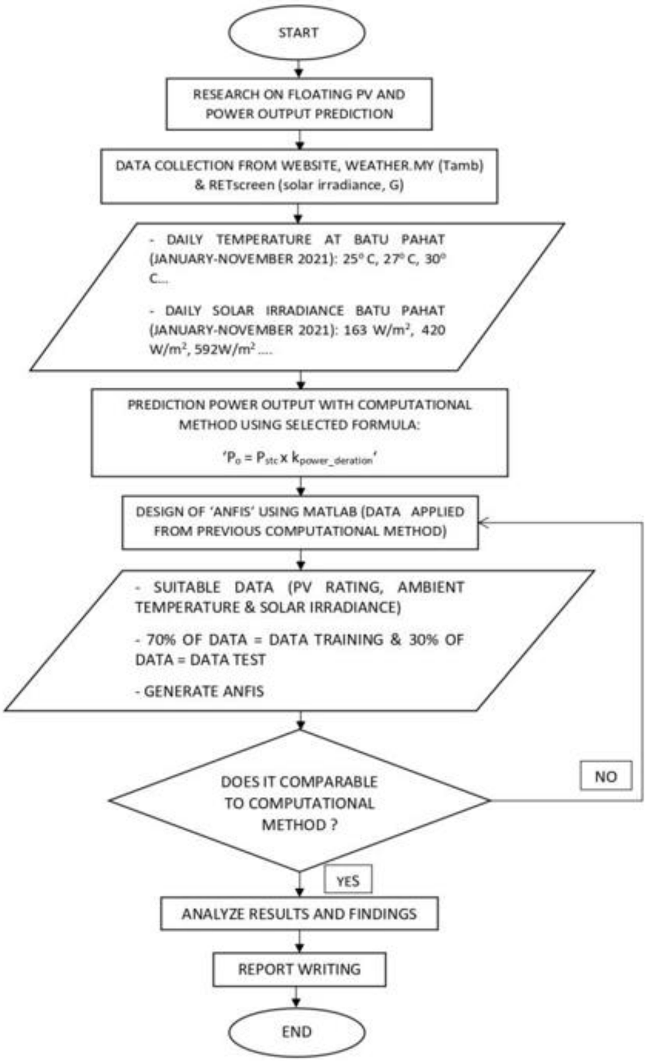


Figure 3: Flowchart of the project

2.3 Prediction Power Output (Computational method)

The prediction of power output must consider the ambient temperature and solar irradiance of the location. Plus, the rating power of 250W provided by the datasheet also is very important to calculate predicted output power. For the first step, cell temperature must be calculated according to Eq. (1) [10]. Next, the derating factor due to the temperature effect is calculated as Eq. (2) [10]. Power output prediction was obtained when all derating factors are considered multiplied with the power rating from the datasheet as shown in Eq. (3) [10].

Cell or module temperature at ROC can be calculated by using Eq. (1),

$$T_{cell} = T_{\text{amb}} + [\left(\frac{\text{NOCT} - 20^{\text{O}}\text{C}}{800\ \text{Wm}^{-2}}\right) x\ G] \quad Eq.1$$

Where,

T_{amb} = Ambient temperature (° C)
NOCT = Nominal Operating Cell Temperature (° C)
G = Solar irradiance

Derating factor of power due to cell temperature effect can be calculated by using Eq. (2)

$$k_{tem\_p} = 1 + [\left(\frac{\alpha}{100\%}\right) x\ (T_{cell} - T_{stc})] \quad Eq. 2$$

Thus, power output for Real Operating Condition (ROC) can be calculated by using Eq. (3)

$$P_{ROC} = P_{stc}\ x\ k_{power\_deration}$$
$$= P_{stc}\ x\ k_{mm} x\ k_{tem\_p}\ x\ k_g\ x\ k_{dirt}\ x\ k_{age} \quad Eq. 3$$

Peak sun factor, $k_g = \left(\frac{\text{G}}{1000}\right)$

Where,

α = Temperature coefficient of power (% per ^{o} C)

T_{stc} = Temperature at Standard Test Condition (STC)

$k_{power\_deration}$ = Total de-rating factors related to power

k_{mm} = De-rating factor due to module mismatch (2-5% is acceptable)

k_g = Derating factor due to irradiance effect / peak sun factor

k_{dirt} = De-rating factor due to dirt (2% is acceptable for brand new panel)

k_{age} = De-rating factor due to ageing (consider as ‘0’ since the system is new)

2.3 Prediction Power Output (ANFIS configuration)

Prediction power output by using Adaptive Neuro-Fuzzy Inference System was executed by inserting the suitable data from previous manual calculation. The data were chosen based on its suitability and highly related to power output of photovoltaic system. The data were consisting of PV rating, ambient temperature and solar irradiance. The data will be divided in two different data set which were ‘Training’ data (70% of data) and ‘Test’ data (30% of data). As the total of whole data were 334, training data will be equal to 234 while test data will be 100. On top of that, ‘Output’ data will be represented from the whole data. FIS rule was generated after a complete table of data included in MATLAB’s ANFIS configuration. Iteration of the data were set to Epochs = 100 where it can be varied according to the suitable prediction as we desired. Rules of ANFIS configuration were obtained once simulation of FIS was completed. The rules and result of ANFIS configuration will be discussed on the next chapter.

Root Mean Square Error (RMSE) is one of the measures that can evaluate the accuracy of predicted value with ANFIS output while training the regression models. It measures the error in predicted values when target or response value is a continuous number. The lower the RMSE value obtained, the accuracy of ANFIS output will be more precise.

Hence, the value of RMSE can be calculated by using Eq. (4),

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(fi - oi)^2} \qquad Eq. 4$$

3. Results and Discussion

Total number of PV modules were calculated by considering 50% from the total area of Tasik G3, UTHM. This calculation also will exclude the 20% space of the total area for underground cables, mooring system, pontoons, inverter and balance of system (BOS) components [11]. Hence, while considering those facts and five to six inches added for gap between solar panels, 3652 modules was the total number of modules for floating PV system. The gap is to accommodate expansion of the module during the day and pathways for any reparation whenever its necessary [9].

3.1 Total average of monthly PV power output

Overall power output prediction was done to enhance the findings. Figure 3 shows total monthly of average PV power output from January till November 2021. The highest average power output was on January, 356.48 kWh followed by August with 353.67 kWh. While the lowest average power output was predicted on February with 342.7 kWh. January and August have the highest power output despite it having the lower temperature and solar irradiance than other months according to Table 2. This data has proven that higher temperature and solar irradiance does not ensure to produce higher power output. For a PV module to be able to produce maximum power rating, it must comply with few conditions which were 25°C of module temperature with 1000 W/m^2 under air mass 1.5. If the temperature of PV module exceeds from the mentioned value, it's power output will drop. This is because electrons on PV module are at rest (low energy) in lower ambient temperature and get excited by sunlight (high energy) to produce potential difference or power output. However, when the PV module was already at certain heat, the electrons will no longer get excited yet only produce only optimum energy. Hence, as the PV panels get hotter, the less power output will be produced.

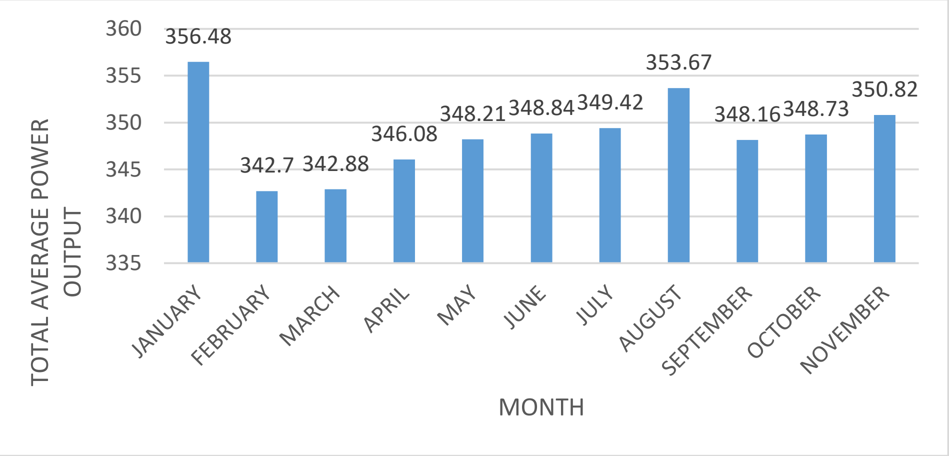


Figure 3: Total monthly average power output prediction

Table 2: Data parameters for power output prediction

Month	Temperature	Solar Irradiance	Power Output (Kw)
January	29.81	419.71	356.48
February	32.36	585.71	342.7
March	33.16	557.48	342.88
April	33	506.57	346.08
May	32.65	478.65	348.21
June	32.5	471.9	348.84
July	32.16	472.1	349.42
August	31.23	425.52	353.67
September	31.9	502.73	348.16
October	32.68	468.45	348.73
November	32.13	457.63	350.82

3.2 ANFIS Configuration

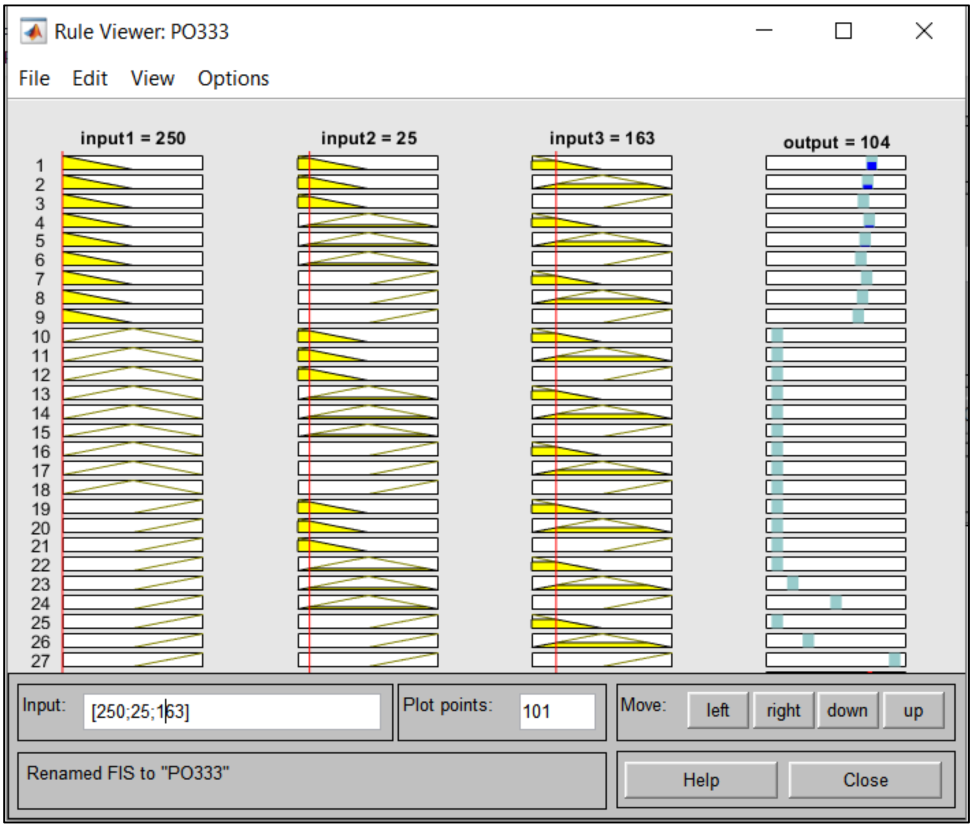
ANFIS configuration is an artificial neural network with reference of Takagi-Sugeno fuzzy inference system. The ability for this inference system to create a set of fuzzy IF-THEN rule allow it to approximate nonlinear function or forecasting parameters of certain system. The main idea of ANFIS configuration is the capability to process input data so that the desired output from FIS will be as same as possible with data from training method. For this project, three parameters (PV rating, ambient temperature & solar irradiance) were inserted in Sugeno type of FIS to generate same power output as computational method. Defuzzification of the system was set at 'wtaver' or weighted average of all rule outputs since it was a default setting. This method was formed by weighting each function in output by its respective maximum membership value.

Figure 4 shows the rule view of ANFIS configuration for prediction power output. Number of fuzzy rules that were generated is 27 with hybrid model composed of a fuzzy and artificial neural network. ANFIS has constructs these series of fuzzy IF-THEN rules with appropriate membership functions to get stipulated input-output pairs. The two basic rule of fuzzy can be described as:

Rule 1: If (x is $A1$) and (y is $B1$) then ($z1 = p1x + q1y+r1$),

Rule 2: If (x is $A2$) and (y is $B2$) then ($z2 = p2x + q2y+r2$),

where x and y are the inputs, Ai and Bi are the fuzzy sets, zi ($i = 1,2$) are the outputs within the fuzzy region specified by the fuzzy rules, and pi, qi, and ri are the parameters determined during the training process. Based on the rules, inputs were set out from generated FIS training data to achieve the targeted output as shown in Figure 4.



input1 = 250

input2 = 25

input3 = 163

output = 104

Input: [250;25;163]

Plot points: 101

Renamed FIS to "PO333"

Figure 4: The rule view of ANFIS configuration for prediction power output with triangular function.

Figure 5 shows the plot graph of ANFIS output and training data. If the ANFIS data was not match training data well, it can be improved by increasing the number of membership function in FIS structure or number of training epochs. Both data are matching well from the figure below since the number of training epochs is quite high which is 100. Epoch means that number of entire datasets passed forward and backward through neural network. The validation of performance for this ANFIS configuration are based on comparison between training data and ANFIS output. The comparison will produce as error or Root Mean Square Error (RMSE). Low value of RMSE will indicates great performance of ANFIS as universal estimator. The gain RMSE value of this project is 0.000032. The effect of low RMSE value can be seen from resulted power output of generated ANFIS. The value of computational method and ANFIS (MATLAB) are almost accurate except for few that has differences in decimal point.

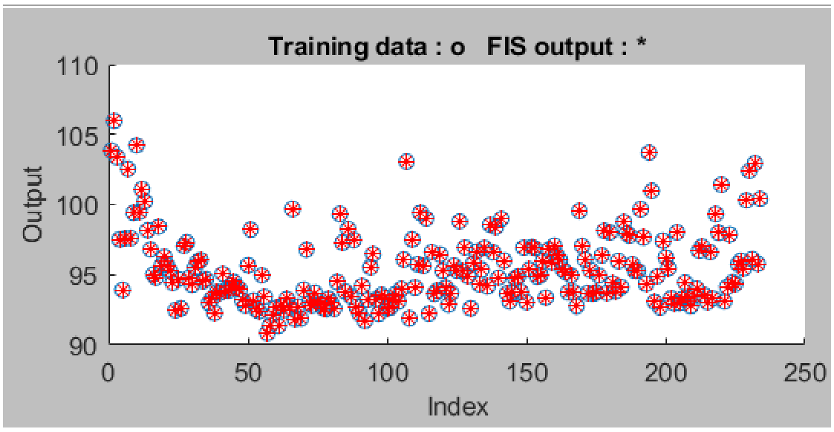


Figure 5: Plotted training data with ANFIS output

From the results obtained, it can be observed that high temperature does not ensure a high amount of solar radiation and produce massive power output. This is because based on the average temperature that was calculated, March and April had the highest number of average temperatures. Although ambient temperature and solar irradiation were crucial for the prediction, de-rating factors that were being considered also contributed to a more precise and reasonable prediction. Therefore, the graphs as explained previously are the results that considering those possible factors. Those parameters are also included to develop ANFIS configuration for power output prediction. Results obtained from MATLAB software managed to prove that ANFIS can help in predicting or estimating parameters with great performance and tools.

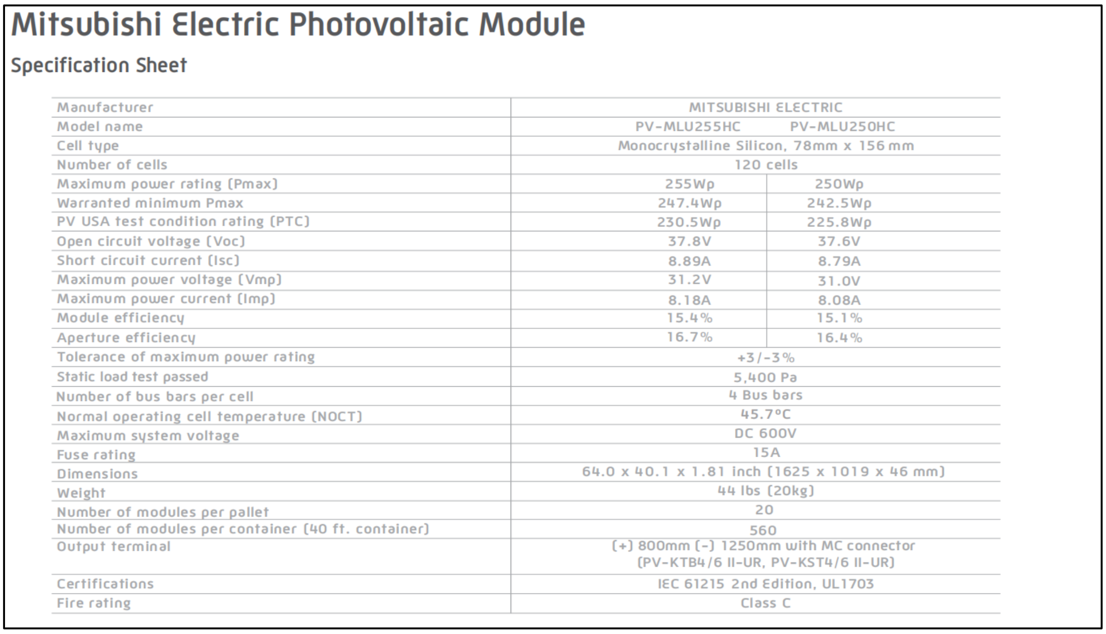
4. Conclusion

To sum up everything that has been stated so far, it shows that the PV modules system will be depending on environmental factors such as temperature, solar irradiance and de-rating factors for dirt, age and so on. Consequently, the actual power output will not be the same as the one that was stated on datasheet of a PV module. Hence, this is one of the main reasons of why predicting PV power output is extremely important, especially when designing a PV system. The objective number one of this research has been achieved which is to manually predict floating photovoltaic power output by using computational method. The result shows that highest average power output was in January with 356.48 kWh followed by August with 353.67 kWh. On top of top of that, rules of ANFIS configuration have been developed through MATLAB software to evaluate its performance. The performance of ANFIS in estimating data from selected input was successful. ANFIS tool’s robustness and speed was proved due to its calculation speed and accuracy in estimating data. Hence, both second and third objectives also were achieved following the great result of ANFIS configuration development.

Acknowledgement

The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

Appendix A



Mitsubishi Electric Photovoltaic Module

Specification Sheet

Manufacturer	MITSUBISHI ELECTRIC	
Model name	PV-MLU255HC	PV-MLU250HC
Cell type	Monocrystalline Silicon, 78mm x 156 mm	
Number of cells	120 cells	
Maximum power rating (Pmax)	255Wp	250Wp
Warranted minimum Pmax	247.4Wp	242.5Wp
PV USA test condition rating (PTC)	230.5Wp	225.8Wp
Open circuit voltage (Voc)	37.8V	37.6V
Short circuit current (Isc)	8.89A	8.79A
Maximum power voltage (Vmp)	31.2V	31.0V
Maximum power current (Imp)	8.18A	8.08A
Module efficiency	15.4%	15.1%
Aperture efficiency	16.7%	16.4%
Tolerance of maximum power rating	+3/-3%	
Static load test passed	5,400 Pa	
Number of bus bars per cell	4 Bus bars	
Normal operating cell temperature (NOCT)	45.7°C	
Maximum system voltage	DC 600V	
Fuse rating	15A	
Dimensions	64.0 x 40.1 x 1.81 inch (1625 x 1019 x 46 mm)	
Weight	44 lbs (20kg)	
Number of modules per pallet	20	
Number of modules per container (40 ft. container)	560	
Output terminal	(+) 800mm (-) 1250mm with MC connector (PV-KTB4/6 II-UR, PV-KST4/6 II-UR)	
Certifications	IEC 61215 2nd Edition, UL1703	
Fire rating	Class C	

Figure A: Specification sheet of the selected PV module

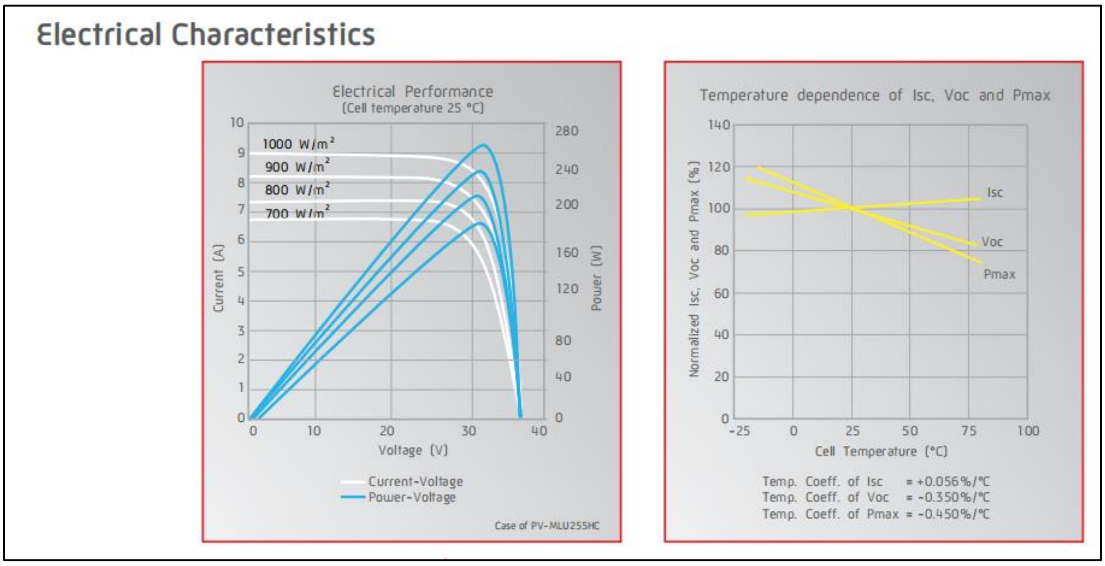
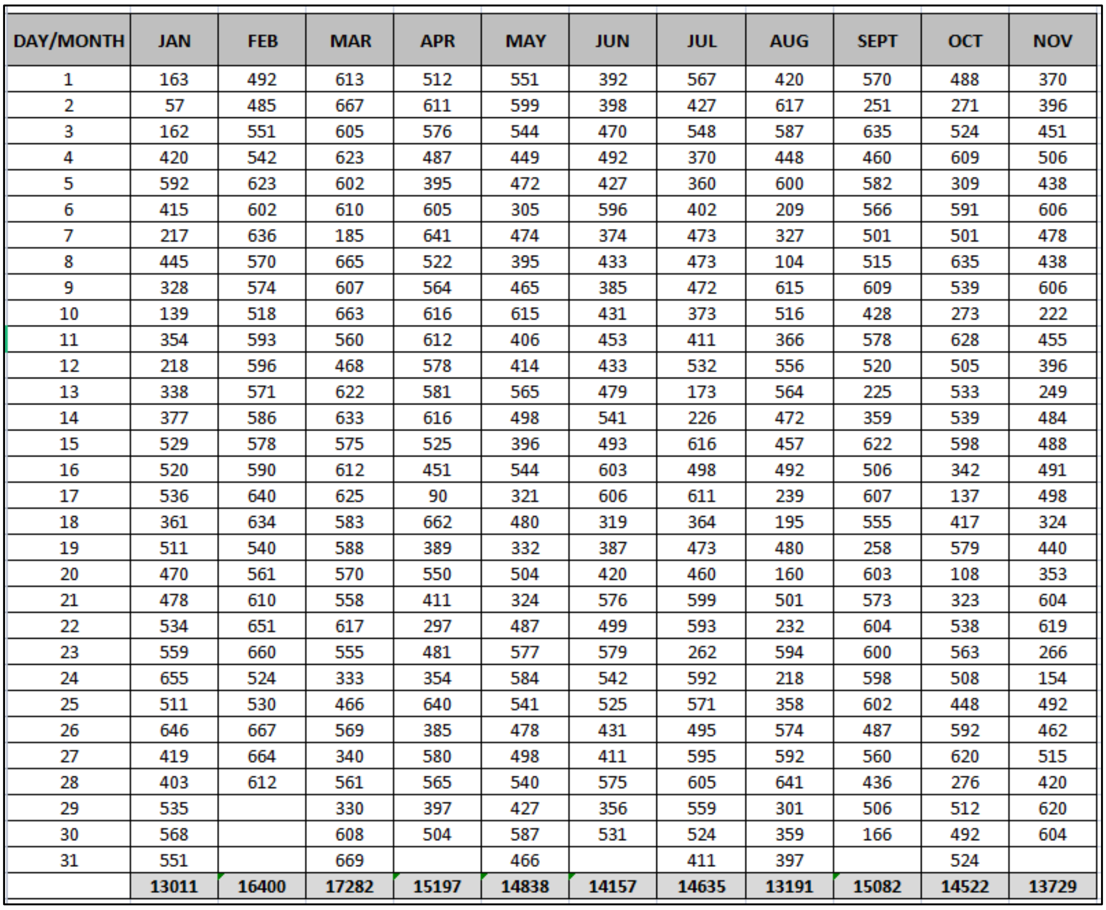


Figure B: Electrical characteristics of PV module

Table A: Daily Solar Radiation (W/m^2)



DAY/MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV
1	163	492	613	512	551	392	567	420	570	488	370
2	57	485	667	611	599	398	427	617	251	271	396
3	162	551	605	576	544	470	548	587	635	524	451
4	420	542	623	487	449	492	370	448	460	609	506
5	592	623	602	395	472	427	360	600	582	309	438
6	415	602	610	605	305	596	402	209	566	591	606
7	217	636	185	641	474	374	473	327	501	501	478
8	445	570	665	522	395	433	473	104	515	635	438
9	328	574	607	564	465	385	472	615	609	539	606
10	139	518	663	616	615	431	373	516	428	273	222
11	354	593	560	612	406	453	411	366	578	628	455
12	218	596	468	578	414	433	532	556	520	505	396
13	338	571	622	581	565	479	173	564	225	533	249
14	377	586	633	616	498	541	226	472	359	539	484
15	529	578	575	525	396	493	616	457	622	598	488
16	520	590	612	451	544	603	498	492	506	342	491
17	536	640	625	90	321	606	611	239	607	137	498
18	361	634	583	662	480	319	364	195	555	417	324
19	511	540	588	389	332	387	473	480	258	579	440
20	470	561	570	550	504	420	460	160	603	108	353
21	478	610	558	411	324	576	599	501	573	323	604
22	534	651	617	297	487	499	593	232	604	538	619
23	559	660	555	481	577	579	262	594	600	563	266
24	655	524	333	354	584	542	592	218	598	508	154
25	511	530	466	640	541	525	571	358	602	448	492
26	646	667	569	385	478	431	495	574	487	592	462
27	419	664	340	580	498	411	595	592	560	620	515
28	403	612	561	565	540	575	605	641	436	276	420
29	535		330	397	427	356	559	301	506	512	620
30	568		608	504	587	531	524	359	166	492	604
31	551		669		466		411	397		524	
	13011	**16400**	**17282**	**15197**	**14838**	**14157**	**14635**	**13191**	**15082**	**14522**	**13729**

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