Photovoltaic Power Output Prediction using Graphical User Interface and Artificial Neural Network

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ABSTRACT:
This paper focuses on the development of a Graphical User Interface (GUI) and Artificial Neural Network (ANN) for the prediction of photovoltaic (PV) power output. PV power is generated based on the time, location, and surrounding climate conditions. Therefore, solar power generation predictions using computational methods are needed since the changing weather, which will impact the output power will not generate according to its rating. The objectives of this research are to predict photovoltaic power output at Universiti Tun Hussein Onn Malaysia (UTHM), develop an ANN configuration that can perform the prediction of solar power generation, and design GUI system that can both perform the calculations of power generation and ANN. In order to test the efficiency and reliability, MATLAB software has been used to develop the GUI and ANN, and the output is compared with the proposed mathematical equations. The real data as input data was obtained from the PV solar panel located at GSEnergy Focus Group fertigation site. The GUI with user-friendly features and ANN have been successfully designed and developed which can perform daily prediction of solar power output. On top of that, the results have shown that the ANN predictions are more precise to the real data than the GUI.

KEYWORDS: prediction, PV panel, solar output, GUI, ANN.

1. INTRODUCTION

Renewable energy sources are referred to as clean energy sources and they are highly essential since they are ecologically friendly. These energy resources are increasing in popularity as they improve the efficiency of producing electricity. Wind, solar, biomass, and tidal energy are examples of renewable energy sources in Malaysia. However, this energy is not fully exploited. Renewable energy technologies are attempts at sustainable development that help to minimize reliance on fossil fuels while also potentially reducing the consequences of climate change [1]-[3]. Photovoltaic energy is the most essential clean, renewable energy source, having the greatest ability to resolve the world's energy concerns. It is crucial to take into account the possibility of employing eco-friendly renewable energy sources and expanding the amount of them in the global main energy supply [4, 5].

Among all renewable energy systems, photovoltaic systems (PV) stand out as the most important since they are able to convert solar energy into electric energy along with its low cost and great efficiency, through the use of materials like silicon [6]-[8]. Only power will be produced by the PV panel in parallel with its rated capacity under the Standard Test Condition (STC). STC demands a temperature of 25 degrees Celsius and 1000 Watts of solar energy per square meter of solar irradiation. Therefore, the changing weather, which may impact the output power, requires prediction. Since the solar panel output will not generate according to its rating, the development of photovoltaic-based systems involves climate data, including temperature and solar irradiances [9]. Not only that, the predictions for solar power output, which include forecasts of factors like weather, sun hours, and temperature, are important as well. Many equations and complicated calculations are used in the predictions. As a result, in terms of enhancing the prediction process, power output value prediction utilizing Graphical User Interface (GUI) and Artificial Neural Network (ANN) was developed. The benefit of ANN approaches is that they do not require knowledge of mathematical computations between parameters, but also require less computing effort and give a possible resolution for

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multi-variable problems [10].

This paper embarks on the following objectives which are to predict photovoltaic power output at Universiti Tun Hussein Onn Malaysia (UTHM), Batu Pahat, Johor, Malaysia by using computational methods. Data of power output values of PV panel for the prediction are taken daily at 9.00 am, 12.00 pm, and 5.00 pm depending on the weather of Malaysia since it is a country that has a tropical rainforest climate. In short, a GUI and an ANN system are designed using MATLAB in order to perform the prediction of PV power output. Not only that, these are designed and developed to perform calculations of the solar power output in comparison to the real data.

In the power output prediction, the GUI system is utilized which is a system that is of an interactive visual component that can get photovoltaic forecasting data and estimated power data as both visual and vector data [11]. It also displays the parameters and equations involved in generating the required solar power generation output. The self-learning, self-organizing, and high-speed computing capabilities of the ANN system, which are particularly adept at handling complicated nonlinear problems without assuming the connections between variables, also be implemented into the GUI [12].

2. MATERIAL AND METHODS

2.1. PV Module Datasheet

PV module that has been used for this project is Q. PEAK DUO ML-G10 SERIES [12]. The 132 layout of monocrystalline Q. ANTUM solar cells with power rating ranging from 395 to 415W was chosen as the best option for this project. This module with a high-tech aluminum alloy frame with wind and snow load certification is one of the most in-depth testing programs in the industry as long as an innovative for all-weather technology. It is because, it gave an optimal yield under all conditions, with outstanding low-light and temperature tolerance. The PV module specifications template was also attached as in Table 1 since it is also acknowledged as one of the important data to predict power output. Moreover, the real PV power output is taken into account from the multiplication of PV voltage and its current which can be measured from the solar panel inverter located at UTHM. Moreover, the geographical location of UTHM at 1.8573° N latitude and 103.0821° E longitude establishes it within a diversified cultural and ecological environment, which helps to create a well-rounded and harmonious integration with current infrastructure and the natural surroundings.

Table 1. Datasheet of Q.Peak Duo Ml-G10 series.

Maximum Power, Pmax [W]	405W
Voltage at maximum power, Vmp [V]	37.85
Current at maximum power, Imp [A]	10.7
Open Circuit Voltage, Voc [V]	45.09
Short Circuit Current, Isc [A]	11.19
Efficiency [%]	≥ 20.6
Electrical Rating STC	1.5
Irradiance [W/m^2]	1000

2.2. Temperature

In this research, PV cell temperature (T_{cell}) and ambient temperature (T_{amb}) are required for power output prediction. It is because the output power and efficiency are dependent on the temperature. Ambient temperature refers to being present in the surroundings. This is also known as the average temperature or the baseline temperature. If the user does not have measurements for PV cell temperature to be entered in the GUI, these data are utilized in order to determine the cell temperature in the PV power output prediction.

The cell temperature is obtained from the PV cells at the research location. The temperature data are obtained three times a day which are taken at 9 a.m., 12 p.m., and 5 p.m. by using the digital thermometer. The cell temperature data collected as in Table 2 are used to calculate the prediction of PV power generation. Section 2.4 outlines the calculations used to compute the cell temperature.

Table 2. Data sheet of Q.Peak Duo Ml-G10 series.

Date	Cell Temperature (°C)		
	9am	**12pm**	**5pm**
28-12-22	26.6	37.9	27.8
29-12-22	30.5	35.9	33.5
30-12-22	26.7	46.6	36.9
31-12-22	26.6	44.8	48.8
01-01-23	29	37.8	34.7
02-01-23	29.5	42.8	33.5
03-01-23	32.3	42.1	23.9
04-01-23	26.7	47.2	32.7
05-01-23	29.2	41	30.2
06-01-23	27.4	46.6	39.4
07-01-23	28.8	41.4	30.9
08-01-23	29.8	42.9	28.5
09-01-23	23.7	43	36.5
10-01-23	33.6	43.4	26.4
11-01-23	29.7	40.2	33.6
12-01-23	30.5	57.8	31
13-01-23	28.3	55.2	24.2

2.3. Solar Irradiance

Daily solar irradiance is obtained from the solar power meter to be utilized in calculating PV power output. The measurement work is carried out by placing the solar power meter next to the solar panel and observing until the value reaches the maximum level. Daily solar irradiance data as in Table 3 was taken as one of the inputs in the prediction of power generation in GUI and ANN.

Table 3. Data collection of solar irradiance

Date	Solar Irradiance (W/m²)		
	9am	12pm	5pm
28-12-22	160.7	404.5	64.7
29-12-22	292.8	335.5	186.6
30-12-22	181.2	1015.7	269.3
31-12-22	165.2	905.4	730.2
01-01-23	140.2	523.7	253.3
02-01-23	273	875.5	264.4
03-01-23	405.4	865.3	87.5
04-01-23	144.4	770.5	168.5
05-01-23	281.3	682	103.6
06-01-23	162.2	1015.7	322.5
07-01-23	200.4	622.6	125.5
08-01-23	210.2	636.6	122.5
09-01-23	72.8	742.1	140.3
10-01-23	280	303	16
11-01-23	145.2	413.9	220.2
12-01-23	143.4	340.4	58.6
13-01-23	219.6	972.5	10.2

2.4. Equations

The ambient temperature and solar irradiation of the area must be included when predicting power output. Furthermore, the datasheet's rated power of 450W is important for calculating predicted output power. The cell temperature must be estimated in the first step using Equation (1) [13] where T_{amb} is the ambient temperature (ºC), NOCT is the Nominal Operating Cell Temperature (ºC) and G is solar irradiance. Power output prediction was achieved by considering all derating factors and multiplying them by the power rating from the datasheet, as indicated in Equation (2) [13] where $k_{power\_deration}$ is total derating factors related to power, k_{mm} is derating factor due to module mismatch of power [14], k_g is peak sun factor, k_{dirt} is derating factor due to dirt [14] and k_{age} is derating factor due to ageing [14].

Cell or module temperature at ROC, as in:

$$T_{cell} = T_{amb} + \left[\left(\frac{NOCT - 20\ deg\ C}{800\ W_{m^{-2}}}\right) \times G\right] \quad (1)$$

Thus, the power output for Real Operating Condition (ROC) is:

$$P_{roc} = P_{stc} \times k_{power_{deration}} = P_{stc} \times k_{mm} \times k_{tem\_p} \times k_g \times k_{dirt} \times k_{age} \quad (2)$$

Peak sun factor, $kg = \frac{G}{1000}$ (3)

2.5. GUI and ANN configuration

MATLAB App Designer was selected to design the GUI and develop ANN since it is exceptionally user-friendly and offers a completely integrated version of the MATLAB editor. The layout or layout and code views of GUI are closely linked, enabling changes in one to quickly affect the other called Design View in App Designer. This application recognizes and adapts to changes in screen size through the use of pictures, automated reflow settings, and other features. Fig. 1 and Fig. 2 depict the intended layout of the GUI apps.

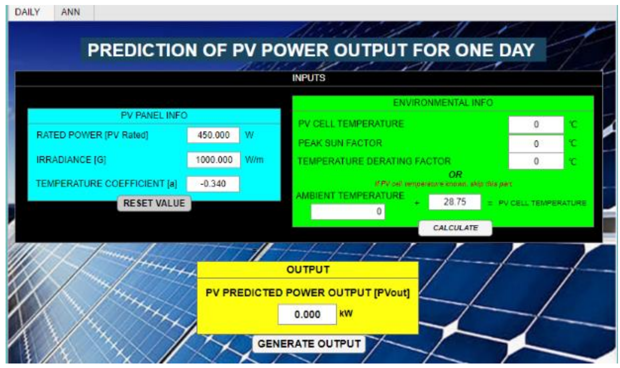

Fig. 1. Prediction of PV power output for one day.

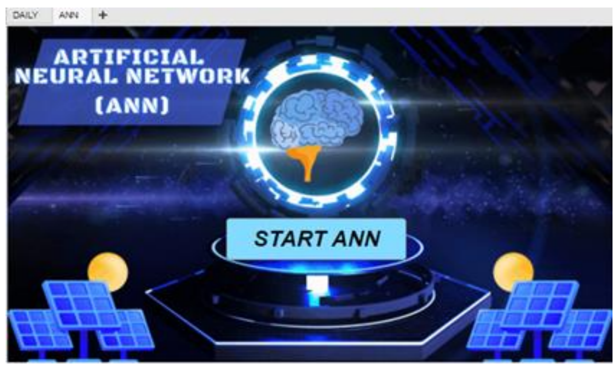

Fig. 2. ANN tab.

The ANN Tab is developed in MATLAB software, as in "Figure 2" and it reads the real data acquired in this research. When users click "START ANN," ANN will begin producing and all integrated ANN outputs and results will display. PV power output values are predicted using ANN. The main inputs, targeted inputs, ANN outputs, and errors will all be shown. The inputs of the optimized multilayer perceptron with backpropagation (MLPBP) ANN network are PV cell temperature, solar irradiance, PV power rating and PV current. Following that, the predicted results will be compared to the computed PV power output values to determine the errors. Error detection is essential for improving the ANN prediction values. In addition, the comparison is excellent for the early phases of a project since it does not require a lengthy training time and may easily be adjusted to estimates at various time scales, ranging from hours to days, given the appropriate data is available [15]. The default number of hidden neurons which is 10 is selected. Fig. 3 illustrates the optimized MLPBP ANN model, which consists of an input layer (PV cell temperature, solar irradiance, PV power rating, and PV current), a hidden layer, and an output layer (real data of PV power output).

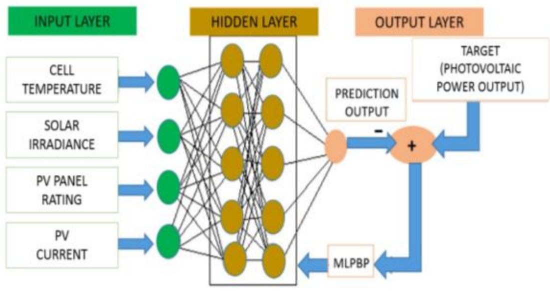

Fig. 3. Optimised MLPBP ANN model.

3. RESULTS AND DISCUSSION

Following the installation of solar panels, the power output value was measured at three specified periods, which are 9 a.m., 12 p.m. and 5 p.m. each and every day as tabulated in Table 4. The outcomes are presented in a bar graph as illustrated in Fig. 4 to make the comparison work easier.

Table 4. PV panel power output data.

Date / Time	PV Power Output (W)		
	9am	12pm	5pm
28-12-22	62.64	170.4	17.94
29-12-22	95.58	122.85	35.37
30-12-22	69.4	37.44	31.84
31-12-22	66.88	33.2	36.63
01-01-23	54.56	195.44	36.18
02-01-23	99.12	37.17	35.37
03-01-23	55.52	211.06	31.7
04-01-23	54.56	37.17	35.19
05-01-23	77.66	191.88	32.3
06-01-23	62.46	35.46	32.08
07-01-23	66.88	166.56	34.29
08-01-23	81.19	36.54	34.11
09-01-23	20.79	265.24	34.2
10-01-23	110.36	121.72	2.8
11-01-23	69.4	36.36	35.55
12-01-23	45.5928	97.9901	18.5991
13-01-23	70.3521	282.737	3.31379

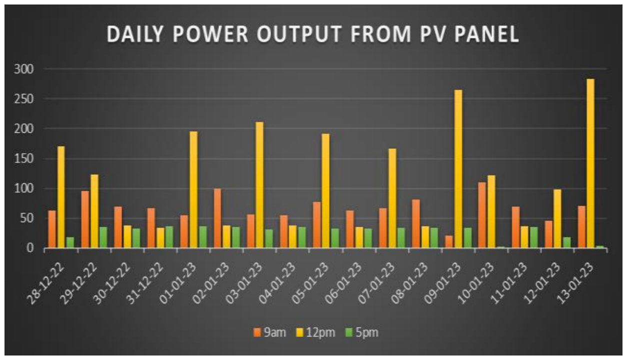

Fig. 4. Daily power output from PV panel graph.

Fig. 4 clearly shows that the highest output reading was 282.737 W on January 13, 2023, at 12 p.m. Since the sun is at its highest point at noon, when its rays are at right angles to the modules or perpendicular to them, the solar panel will receive more peak sun hours. Not only that, it was also impacted by the weather at that moment, when it was sunny and had scorching temperatures, 43ºC. This clearly proves that both environmental and technical factors such as temperature, solar irradiance, wiring and mismatch losses, soiling, and temperature derating have a significant impact on PV power output. As a result, it can be stated that these parameters must be included, especially when predicting or measuring the power output from a PV panel.

Moreover, the GUI developed includes all calculations required in this research to compute PV power output in a user-friendly tab layout. The tabs demonstrate how to accumulate PV power step by step. The user could predict power output each day by utilizing the GUI application developed in the first tab. In order to acquire the results, users must enter the desired inputs into the blank boxes on the input section and simply tap generate output. It is proven that the computations and output results are remarkably accurate. Furthermore, as represented in Fig. 5, users can also calculate the PV cell temperature by entering the ambient temperature value if T_{cell} is not acquired. Therefore, users have two alternatives either entering or calculating the PV cell temperature.

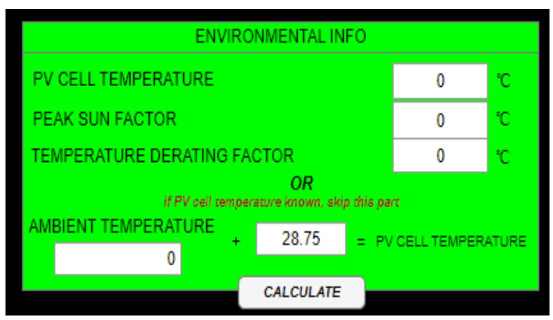

Fig. 5. Cell temperature calculation section.

PV cell temperature, solar irradiance, PV power rating, and PV current values are the input parameters that are automatically displayed in ANN configuration. The ANN reads the data gathered for this project and predicts the values of PV power-generating output, requiring less training time and being suitable for use in the early phases of a comparative project. [16, 17]. The outcomes from the prediction of PV power output by the optimized ANN model are shown in Table 5. The prediction results are shown together with the real data power output values to keep the analytical process continuing much easier. It clearly shows that the optimised ANN model prediction is close to the target values. The most variance values between the target and ANN prediction values are getting very close to zero and have no error.

Table 5. PV panel power output data.

Date/Time	PV Power Output (W)								
	Real Data (Target)			ANN Prediction			Average Error		
	9am	12pm	5pm	9am	12pm	5pm	9am	12pm	5pm
28-12-22	62.64	170.4	17.94	62.6394	170.4	17.94	0.0006	0.0001	0
29-12-22	95.58	122.85	35.37	95.5808	122.845	35.3698	0.0008	0.0053	0.0002
30-12-22	69.4	37.44	31.84	69.3998	37.44	31.8402	0.0002	0	0.0002
31-12-22	66.88	33.2	36.63	66.8799	33.1996	36.6299	0.0001	0.0004	0.0001
01-01-23	54.56	195.44	36.18	54.5609	195.44	36.1797	0.0009	0	0.0003
02-01-23	99.12	37.17	35.37	99.1188	37.1703	35.3697	0.0012	0.0003	0.0003
03-01-23	55.52	211.06	31.7	55.5127	210.982	31.7001	0.0073	0.0784	0.0001
04-01-23	54.56	37.17	35.19	54.5593	37.1704	35.1902	0.0007	0.0004	0.0002
05-01-23	77.66	191.88	32.3	77.6591	191.88	32.2999	0.0009	0	0.0001
06-01-23	62.46	35.46	32.08	62.4597	35.4608	32.0804	0.0003	0.0008	0.0001
07-01-23	66.88	166.56	34.29	66.8797	166.56	34.2901	0.0003	0	0.0001
08-01-23	81.19	36.54	34.11	81.1915	36.5399	34.1099	0.0015	0.0001	0.0001
09-01-23	20.79	265.24	34.2	20.7902	265.304	34.1998	0.0002	0.06439	0.0002
10-01-23	110.36	121.72	2.8	110.36	121.563	2.8149	0.0004	0.1566	0.0149
11-01-23	69.4	36.36	35.55	69.4003	36.3576	35.55	0.0003	0.0024	0
12-01-23	30.42	34.65	23.24	30.4197	34.65	23.2438	0.0003	0	0.0038
13-01-23	89.75	334.4	0	89.7513	334.4	0.0114	0.0013	0	0.0114

Nntraintool as shown in Fig. 6, is used for configuring the ANN in this application. With this instrument, neural network training on the GUI is enabled. It may be used to bring the training GUI to the front if the window has been closed or simply to make it visible before training and after training. Within the training window, network training features handle all activities.

Following the development of the GUI and ANN, the outputs of both programs were compared to the real data computation. The predicted power output from the ANN is more satisfactory than the predicted power output from the GUI as in Table 6. The computation on the GUI makes a significant difference is due to the fact that it affected by the data of environmental surroundings. On the other hand, ANN offers better modeling flexibility than the general computational method. This is because the computed collected data will be automatically compared to the real PV power output values to find the errors. Error detection is crucial for enhancing the prediction of ANN configuration and generating more precise results. Fig. 7 illustrates PV power output data comparison for 12 pm in a bar graph since the sun is at its peak at noon. Therefore, it clearly has shown that the ANN prediction values are closer and more precise to the real data compared to the prediction from GUI applications.

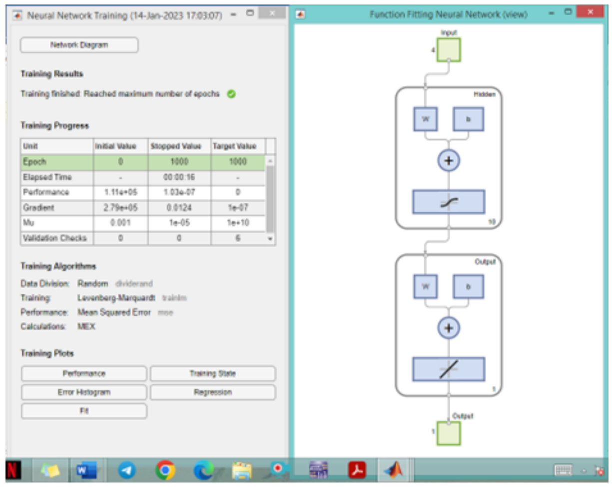

Fig. 6. *Nntraintool.*

Table 6. PV power output comparison of real data with predicted data of GUI and ANN applications.

Date	PV Power Output (W)		
	GUI	ANN	Real Data
28-12-22	125.3097961	166.54	170.4
29-12-22	104.6735039	128.1411	122.85
30-12-22	262.8899038	32.847	37.44
31-12-22	273.6013049	28.9211	33.2
01-01-23	162.2943786	193.1739	195.44
02-01-23	266.4947758	36.4282	37.17
03-01-23	264.0572324	209.3459	211.06
04-01-23	230.7990218	36.8551	37.17
05-01-23	208.9473408	184.8124	191.88
06-01-23	165.112992	32.847	35.46
07-01-23	190.474359	166.3705	166.56
08-01-23	193.7055138	35.7633	36.54
09-01-23	225.7254475	258.9809	265.24
10-01-23	92.03035968	121.415	121.72
11-01-23	127.173126	36.3746	36.36
12-01-23	97.99010381	34.65	34.65
13-01-23	282.7365588	334.4	334.4

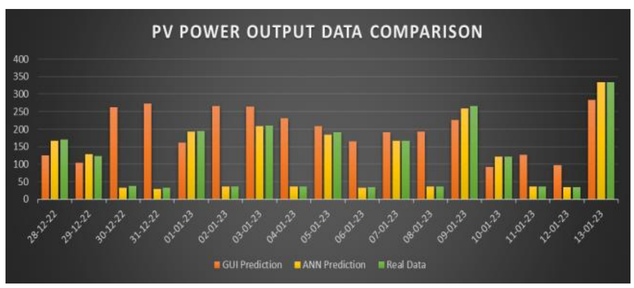

Fig. 7. PV power output data comparison graph.

4. CONCLUSION

In conclusion, the data collection for predicting PV power output has been presented in this project. The data collection is based on actual data from the PV solar panel located at UTHM. PV power output calculations with cell temperature being included have also proven successful. The prediction has comprised several factors including calculations and real-world data collecting. Furthermore, the GUI application that could predict PV power generation achieved by implementing MATLAB software and ANN configuration has successfully generated better outcomes of PV power output with the fewest errors. The PV power output prediction of the MATLAB application can be exported as a standalone application. The application can then be installed and used without limitation by users who are not MATLAB users. Furthermore, the GUI design can be improved by including features that allow the application to estimate the number of PV panels and their rating. This enables the user to generate a more precise prediction of PV power output.

5. ACKNOWLEDGMENT

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