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Modeling the Effect of Changes in Solar Radiation Rays on Solar Cell Output Using MATLAB/Simulink

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ABSTRACT
The intensity of solar radiation is the main factor that affects the performance of solar cells in generating electrical power. This study modeled the effect of solar radiation changes on the power output of solar panels using Matlab/Simulink, with solar radiation data from Nasa Power for the Tanjung Anom location. The simulation was carried out to measure the output power based on variations in solar radiation intensity and ambient temperature in the effective time range, namely 09.00 to 16.00. The results show that the intensity of solar radiation is directly proportional to the output power of solar panels. At the highest radiation intensity of 620.35 W/m², the maximum power produced reaches 107.6 W, with a voltage of 20.35 V and a current of 5.286 A. On the other hand, at the lowest radiation of 205.61 W/m², the power decreases to 11.94 W. The model successfully illustrates the linear relationship between solar radiation, voltage, current, and output power, and shows the sensitivity of solar panels to changes in environmental parameters. Using MATLAB/Simulink, this model can be used to design and optimize photovoltaic systems according to local conditions. This research makes an important contribution to a deep understanding of the characteristics of solar cells, as well as a reference in the development of more efficient and environmentally friendly solar energy systems.

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INTRODUCTION

The intensity of solar radiation is a factor that greatly determines the performance of solar cells. Solar energy, as a source of energy that will never run out, has the main advantage of minimal environmental impact. (A. Dani & Erivianto , 2024; A. Dani & Erivianto , 2022). In several studies, MATLAB/Simulink has been used to model the effect of solar radiation variations on the performance of solar cells and photovoltaic (PV) systems. For example, Yau et al. and Ergashev et al. successfully developed a Simulink model to analyze the internal temperature as well as the thermal performance of the greenhouse under changing solar radiation conditions. (Ergashev et al., 2022; Yau et al., 2020). Meanwhile, Hui et al. introduced a dynamic Simulink model that can predict the intensity of solar radiation in real-time, the temperature of the collector's fluid output, as well as the rate of solar energy utilization in the solar heating system.(Hui et al., 2017)

In addition, modeling of the internal parameters and electrical characteristics of solar cells has also been carried out using MATLAB/Simulink. Li and Zhou, for example, developed a Simulink model to simulate the mathematical logic and dynamics of solar cell parameter operation. (Li & Zhou, 2014). Al-Ezzi and Ansari highlighted the use of MATLAB/Simulink to evaluate the power conversion efficiency of PV cells, as well as determine the key factors affecting power output under various conditions.(Al-Ezzi & Ansari, 2022)

More specific Simulink models have also been designed to describe the behavior of photovoltaic modules at varying irradiation and temperature conditions.(Jumaat et al., 2018; Rahmaniar et al., 2023). The results show that an increase in the irradiation level will increase the output current and voltage of the PV module, which in turn results in an increase in output power. (Rahmaniar et al., 2023). Maximum Power Point Tracking (MPPT) is a key element in PV systems because this method ensures solar cells operate at maximum power points. Studies conducted by Khalf et al., Singh et al., as well as Revankar and Gandhare show that MPPT techniques such as Perturb and Observe (P&O), Incremental Conductance (INC), and fuzzy logic control can be effectively implemented using MATLAB/Simulink to improve the efficiency and reliability of PV systems.(Khalf et al., 2022; Revankar & Gandhare, 2017; Singh et al., 2014)

In addition to MPPT, MATLAB/Simulink is also used to model various PV system configurations, such as grid-connected PV systems, standalone PV systems, PV-powered water pumps, PV-based electric vehicles, and PV-wind hybrid systems. Sood and Kalpesh, as well as Thanh and Quang, examined the performance, power quality, and optimization of these systems under a variety of operating and interference conditions.(Sood & Kalpesh, 2017; Thanh & Quang, 2018). The effect of partial shadow on PV system performance has also been studied using MATLAB/Simulink. Sarniak, Nguyen, and Alsayid et al. developed a Simulink model to examine the impact of partial shadows on the function and characteristics of PV modules and circuits. (Alsayid et al., 2013; Nguyen, 2015; Sarniak, 2020). Das et al. also investigated multi-junction PV cells through simulations aimed at optimizing energy conversion efficiency.(Das et al., 2015)

Other research utilizes MATLAB/Simulink to model different types of PV modules, such as monocrystalline, polycrystalline, and thin film, as well as their integration with other systems, such as greenhouses and solar dryers. (Jadallah et al., 2015; Jumaat et al., 2018; Kıyan et al., 2013). In addition, solar energy has also been applied as an alternative source for various needs, such as portable fertilizer dryers designed to meet the household electricity needs of farmers while reducing dependence on the power grid.(Aryza et al., 2017)

Although various studies have used MATLAB/Simulink to model the characteristics and performance of solar cells, more in-depth studies are still needed on the effect of changes in solar radiation on the internal parameters of solar cells and the characteristics of simultaneous current-voltage (I-V) and power-voltage (P-V) relationships. This study will study the impact of changes in solar radiation on solar cell output through modeling using MATLAB/Simulink. The main focus of the research is to understand and measure the influence of solar radiation variations on solar cell characteristics, such as current-voltage (I-V) and power-voltage (P-V) relationships, as well as internal parameters that affect solar cell performance.

RESEARCH METHODS

Figure 1. Tanjung Anom Research Location

In this study, data from NASA POWER (Prediction of Worldwide Energy Resources) was used to analyze the potential for generating electrical energy from renewable energy sources, especially solar power. NASA POWER provides access to comprehensive meteorological data and energy resources, which includes information on solar radiation, temperature, and other climate parameters relevant to the planning and design of renewable energy systems. (NASA POWER | Docs | Methodology - NASA POWER | Docs, n.d.) One of the advantages of NASA POWER is its large database that includes meteorological information for various locations around the world. Users also have the ability to manually add measurable data for locations that are not covered in the database, improving the accuracy of analysis.

The design of a solar power system can vary depending on the location, due to differences in the amount of solar radiation received. By utilizing data from NASA POWER, researchers and engineers can optimize the design of the Solar PV system according to the specific conditions in each location, thereby improving the efficiency and effectiveness of generating electrical energy from solar panels.

In this study, the coastal area chosen as the location for collecting solar radiation data is Tanjung Anom (Latitude 3.52060 N, Longitude 98.59020 E). By using solar radiation data from the NASA POWER database, solar energy as a source of solar power generation is one of the most relevant options to be applied in Tanjung Anom. In addition to being environmentally friendly and pollution-free, the use of solar energy can also reduce dependence on fossil energy sources that are increasingly depleted.

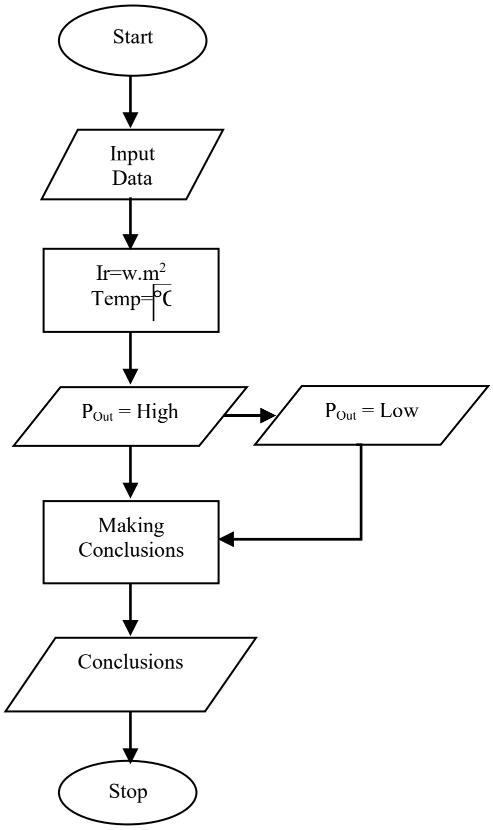

Figure 2. Research flowchart

This research was carried out by simulating the changes in solar radiation rays that change each time period to the solar panel and the power output generated from the solar panel. The simulation was carried out using Matlab/Simulink, so that the effect of changes in solar radiation rays in the face of the output power of solar panels is known. The research was conducted in Tanjung Anom Village, Pancur Batu District.

The methods carried out in the research began with:

1. Literature Study, which is by examining and studying theories that support the problem solving being researched. These theories can be sourced from scientific journals, the results of previous research and from books that support this research. In addition, literature studies are also carried out to obtain data from previous research that can be used as a reference.
2. Data Collection, which is collecting the data needed to conduct simulations taken from *power.larc.nasa.gov data*
3. Discussion, namely by consulting and guiding with lecturers and other parties who can help the implementation of this research
4. Conduct data testing and collect data results from simulations.

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After the data was successfully collected, the author made a research stage that was used as a research flow, as for these stages can be seen from the research flowchart in figure 2.

Table 1. Data on solar radiation values and temperature

No.	Time	Radiatio (w/m^2)	Temp (^{oC})
1	0	0	23,17
2	1	0	23,04
3	2	0	22,59
4	3	0	22,44
5	4	0	22,29
6	5	0	22,14
7	6	7,48	22,03
8	7	126,07	22,03
9	8	282,93	24,03
10	9	433,93	25,44
11	10	547,16	26,44
12	11	607,87	27,25
13	12	620.35	27,76
14	13	559,02	27,99
15	14	467,23	27,64
16	15	346,03	27,36
17	16	205,61	26,88
18	17	74,11	26,02
19	18	7,17	26,02
20	19	0	25,46
21	20	0	24,84
22	21	0	24,34
23	22	0	23,52
24	23	0	23,21

In this study, data was obtained from *power.larc.nasa.gov*. power.larc.nasa.gov website provides solar radiation data from various parts of the world. To get solar radiation data, first determine the position of the location of the area where the solar radiation value will be known. The data taken is data on changes in solar radiation and temperature at each hour. From the results of data collection at the location point, the value of changes in solar radiation rays and temperature is shown in table 1.

The simulation was carried out using Simulink on the matlab. Matlab provides solar panel components to be able to carry out simulations. Simuasi is prepared using the components provided in Lib. Simulink.

Simulations were carried out to measure the output power on solar panels. This simulation does not add any additional devices or components to become a Solar Power

Plant, here is a program image from simulink. To run the simulation program, 2 variables are needed, namely in the variables Ir and T. Where Ir is the input value of solar radiation rays and T is the input for the temperature value.

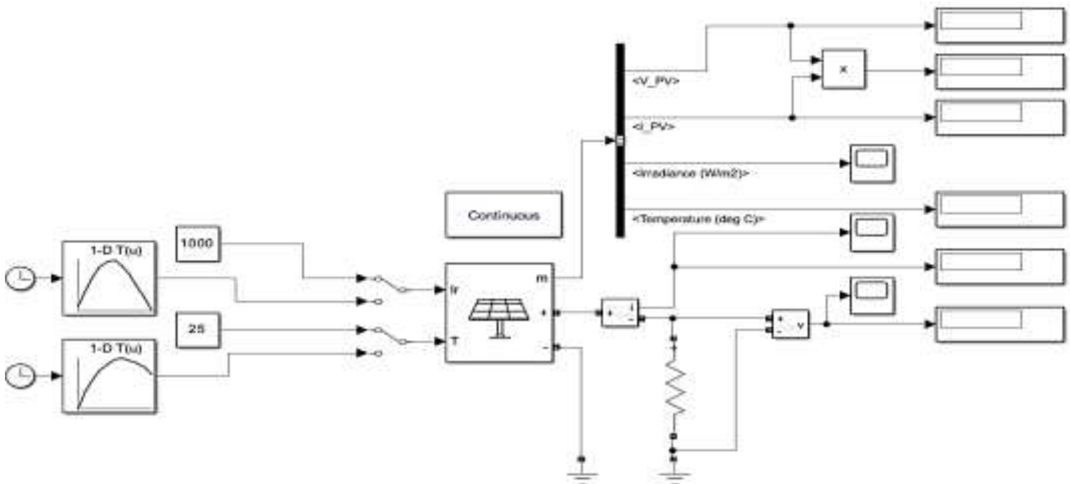

Figure 3. Simulink program to calculate the output power of the solar panel

RESULTS AND DISCUSSION

Effective Data

The test data used comes from Table 1, which contains information on solar radiation and ambient temperature. To ensure that the test results are more relevant and accurate, this data is then focused on the effective time range of sunlight exposure, which is between 09.00 am and 16.00 pm. This time range was chosen because the intensity of solar radiation tends to be optimal during that period, allowing for a more in-depth analysis of the performance of solar cells under actual conditions.

Table 2. Effective sunlight exposure time data

No.	Time	Radiation (w/m^2)	Temp (^{oC})
1	09.00	433,93	25,44
2	10.00	547,16	26,44
3	11.00	607,87	27,25
4	12.00	620,35	27,76
5	13.00	559,02	27,99
6	14.00	467,23	27,64
7	15.00	346,03	27,36
8	16.00	205,61	26,88

This effective sunlight exposure data reflects fluctuations in solar radiation and temperature over that time period, which is crucial for understanding how environmental variations affect the performance of photovoltaic systems. By limiting the observation time range, this study aims to evaluate the performance of the system at hours where solar energy can be utilized to the fullest, while eliminating the influence of data from times outside of effective hours that may be less relevant.

The test was carried out using solar panels that are widely available on the market, so the results of this research are expected to be more applicable and relevant to the needs of daily users. The solar panel used has a capacity of 220 Wp, which is one of the popular types of solar panels with efficiency and performance suitable for various applications, both household and small industrial scales. The following is the data of the solar panels used.

Table 3. Solar Panel Data

Trina Solar TSM -250PA05		
1	Maximum Power (W)	249.86
2	Open Circuit Voltage Voc (V)	37.6
3	Short-Circuit Current Isc (A)	8.55
4	Voltage at maximum power point Vmp (V)	31
5	Current at maximum power point Imp (I)	8.06

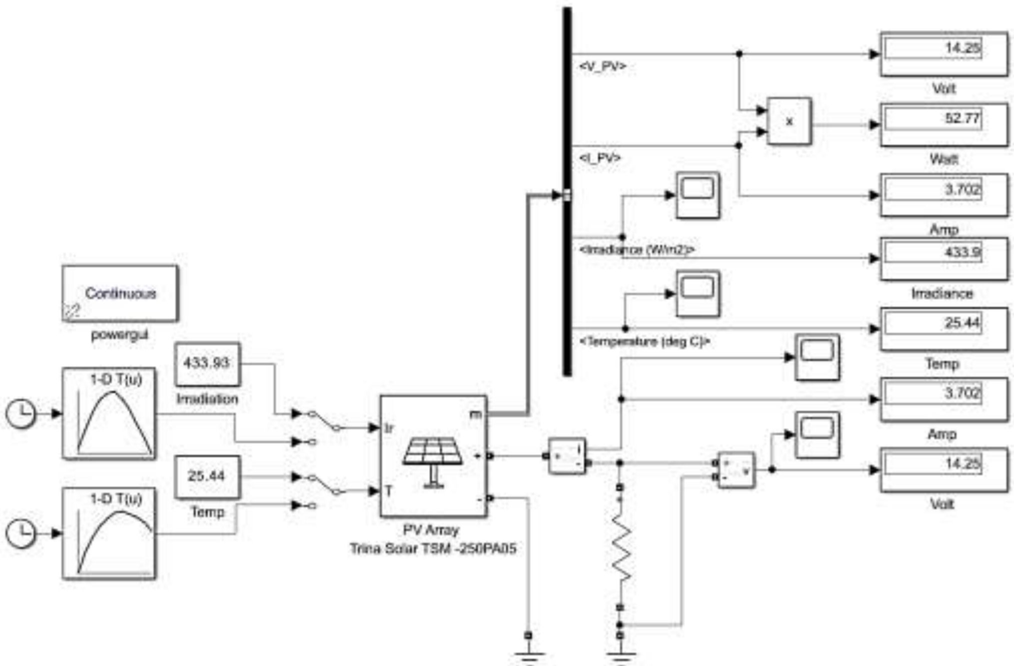

Figure 3. Solar panel output power measurement at 09:00

Radiation and Temperature Test Data at 09.00

Based on solar radiation data received by solar panels at 09.00 am, the radiation intensity was recorded at 433.93 W/m² with an ambient temperature of 25.44 °C. Under this condition, the solar panel produces an output power of 52.77 W, with a voltage of 14.25 V and a current of 3.702 A. The results of the measurement of the output power of the solar panel can be seen in Figure 3 from the solar radiation data and temperature at 09:00.

Radiation and temperature test data at 12.00

At 12.00 pm, the solar panel received a solar radiation intensity of 620.35 W/m² with an ambient temperature of 27.76 °C. Under these conditions, the solar panel is able to produce an output power of 107.6 W, with a voltage of 20.35 V and a current of 5.286 A. This increase in output power shows that during the day, when the intensity of solar radiation reaches its peak, the solar panel works more optimally in converting solar energy into electricity. The voltage and current generated also reflect the panel's positive response to a combination of high radiation and slightly elevated temperatures. The solar panel's power output data for this time can be seen in more detail in Figure 4, which shows the relationship between solar radiation, temperature, and the panel's electrical performance at 12:00 p.m.

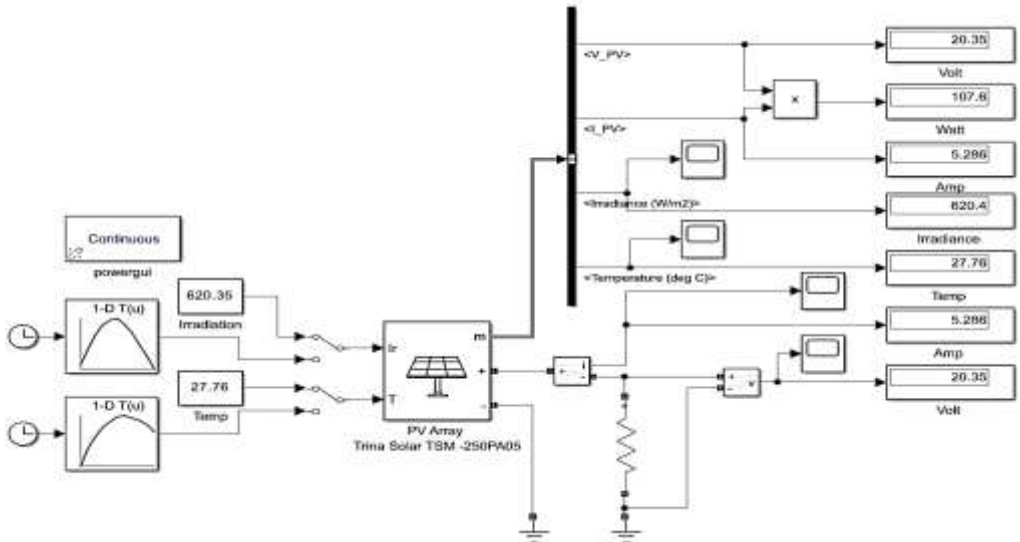

Figure 4. Solar panel output power measurement at 12:00 p.m.

Radiation and temperature test data at 16.00

At 16.00 pm, the solar panel received a solar radiation intensity of 205.61 W/m² with an ambient temperature of 26.88 °C. Under these conditions, the solar panel produces an output power of 11.94 W, with a voltage of 6.78 V and a current of 1.761 A. These results show that although the intensity of solar radiation begins to decrease in the afternoon, the solar panel is still able to generate electrical energy, even though the output power produced is lower than during the day. The solar panel performance data at 4:00 p.m. can be seen in more detail in Figure 6, which illustrates the relationship between solar radiation intensity, temperature, and the panel's electrical output.

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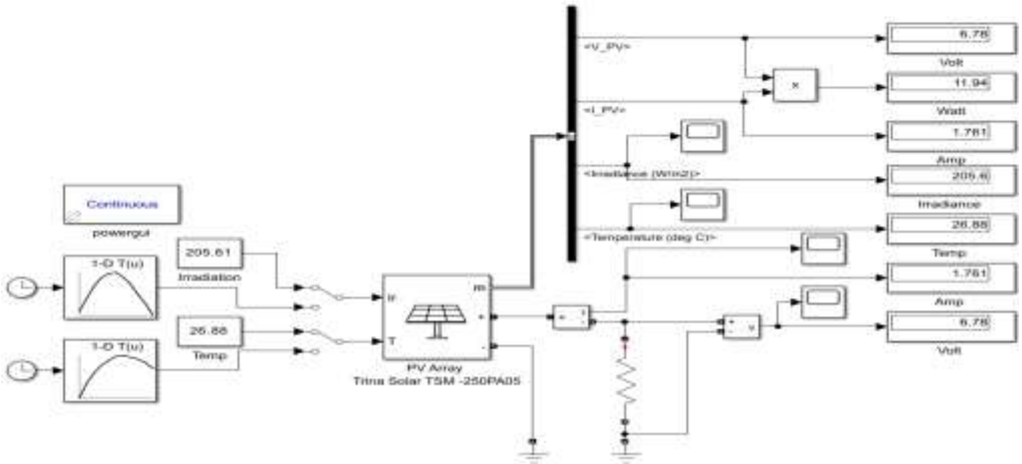

Figure 6. Solar panel output power measurement at 16:00

Table 4. Rated Solar Panel Output Power

No.	Time	Radiation (w/m²)	Temp (°C)	Power (P)	Voltage (V)	Current (I)
1	09.00	433,93	25,44	52,77	14,25	3,702
2	10.00	547,16	26,44	83,74	17,96	4,664
3	11.00	607,87	27,25	103,3	19,94	5,179
4	12.00	620,35	27,76	107,6	20,35	5,286
5	13.00	559,02	27,99	87,54	18,36	4,768
6	14.00	467,23	27,64	61,28	15,36	3,99
7	15.00	346,03	27,36	33,71	11,39	2,959
8	16.00	205,61	26,88	11,94	6,78	1,761

From the results of measuring the output power to the value of solar radiation and the temperature that influences. Then the value is obtained as shown in table 4 above. From table 4, it can be seen that the change in the value of solar radiation rays every hour affects the output power value of the solar panel. The following is a garafic explanation of the comparison of several variables to the value of change.

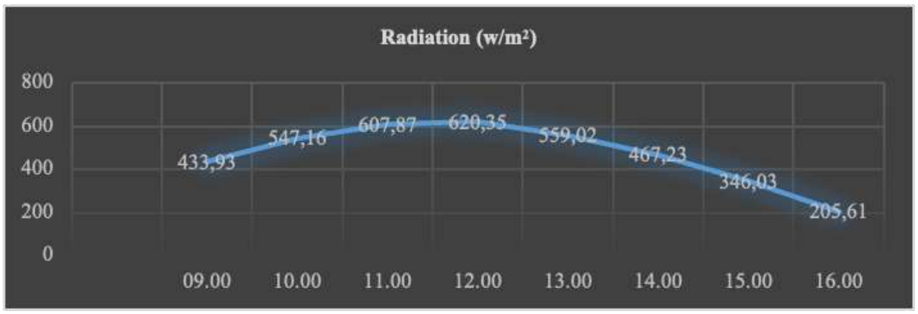

Figure 7. Changes in solar radiation values every hour

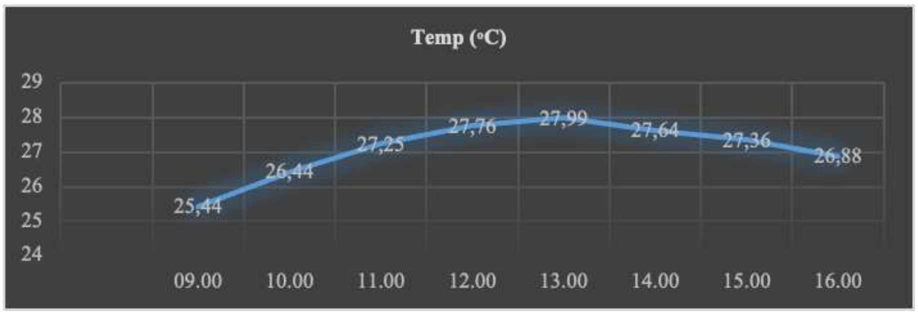

Figure 8. Changes in temperature values every hour

In Figure 7, you can see a graph that shows the change in the intensity of solar radiation every hour. Solar radiation reached its highest value at 12.00 p.m. with an intensity of 620.35 W/m², indicating that noon is the optimal time for solar energy utilization. Meanwhile, Figure 8 illustrates the change in ambient temperature over a full day. The lowest temperature was recorded at 09.00 am, which was 25.44 °C, and reached its peak at 13.00 pm with a temperature of 27.99 °C. After that, the temperature began to decrease slowly as time went towards the afternoon.

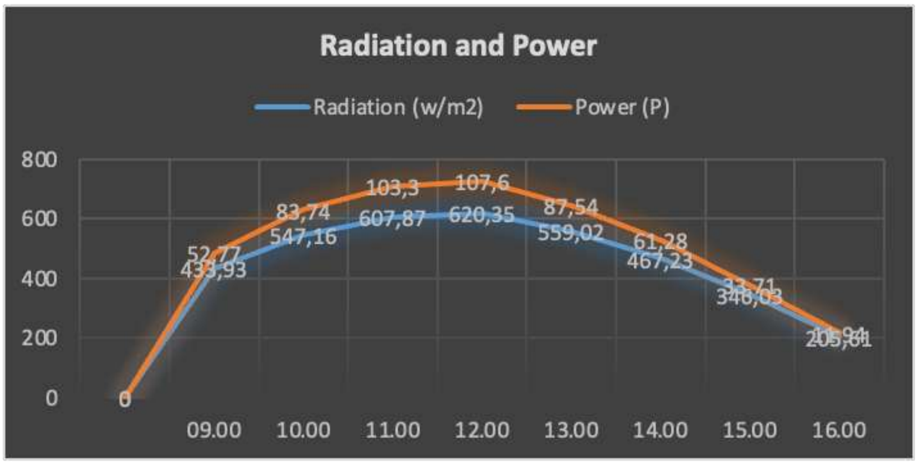

Figure 9. Comparison graph of changes in radiation value to output power on solar panels

Figure 9 shows that the change in the intensity of solar radiation that occurs every hour directly affects the output power value of the solar panels. The observations show that the highest output power, of 107.6 W, occurs at 12.00 p.m. when the radiation intensity reaches its peak, which is 620.35 W/m². In contrast, the lowest output power, at 11.94 W, was recorded at 16.00 pm with the radiation intensity decreasing to 205.61 W/m².

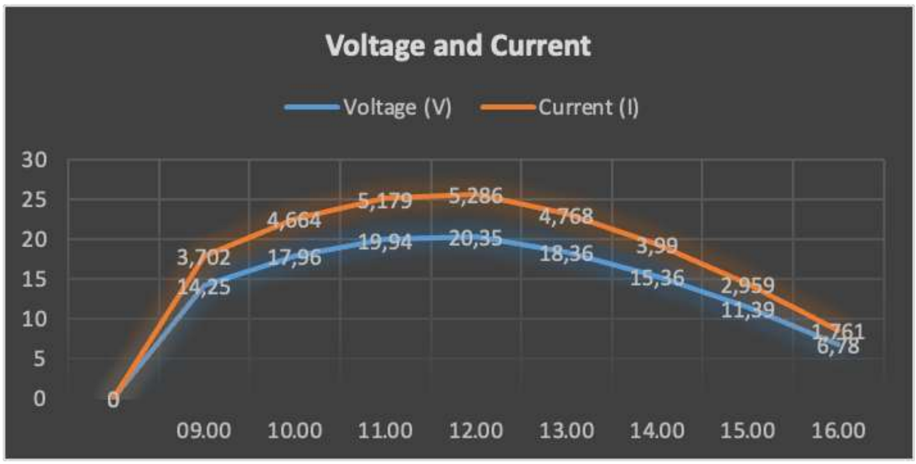

Figure 10. Changes in current and voltage values that occur every hour

This change in output power reflects the close relationship between the intensity of solar radiation and the voltage and current generated by the solar panels. At 12.00 p.m., when the radiation intensity reaches its peak, the solar panels produce a maximum voltage of 20.35 V and a current of 5.286 A. Meanwhile, at 16.00 p.m., the voltage and current produced decrease to 6.78 V and 1.761 A, as the intensity of solar radiation decreases.

The linear relationship between the intensity of solar radiation and the output power of the solar panel shows that the performance of the panel is highly dependent on the optimal availability of sunlight. This data provides important insights for the development and management of photovoltaic systems, especially in optimizing operating times during hours with high solar radiation intensity.

CONCLUSION

This study has modeled the effect of changes in solar radiation on the output of solar panels using MATLAB/Simulink. The simulation results show that the intensity of solar radiation has a linear relationship with the output power of solar panels. At a peak radiation intensity of 620.35 W/m² at 12.00 noon, the maximum power generated reaches 107.6 W, with a voltage of 20.35 V and a current of 5.286 A. In contrast, at a lower radiation intensity of 205.61 W/m² at 16.00, the output power decreases to 11.94 W, with a voltage of 6.78 V and a current of 1.761 A. This model provides information on how variations in solar radiation affect the electrical characteristics of solar panels, So that it can be an important reference in photovoltaic system optimization for various environmental conditions.

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