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Analyzing the Impact of Solar Irradiance on a 50W Monocrystalline Silicon Solar Panel's Performance

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Abstract: Solar energy, a ubiquitous and environmentally friendly source, plays a pivotal role in mitigating carbon emissions and reducing air pollution. This study evaluates the performance of a 50-watt monocrystalline solar panel over a thirty-day period in October 2022, within Merauke Regency, South Papua Province, Indonesia. Adopting an experimental research methodology and comprehensive data collection, measurements of solar intensity, temperature, voltage, and current were systematically gathered using temperature sensors, ammeters, and voltmeters. These measurements were obtained by positioning the solar panel at a perpendicular angle to direct sunlight, with data recorded between 9:00 and 16:00 Eastern Indonesia Time. The analysis of the collected data was conducted to ascertain the panel's efficacy, revealing an average output of 20.68 volts, 1.95 amperes, 40.37 watts, and a 9% efficiency. Notably, peak performance was observed on the tenth day, characterized by 21.30 volts, 2.24 amperes, 47.71 watts, and an efficiency of 11.01%. The findings of this investigation are anticipated to inform the installation and utilization strategies of similar solar panel types within Merauke Regency and potentially broader applications. This study underscores the critical influence of solar irradiance on the operational performance of monocrystalline silicon solar panels, contributing valuable insights to the field of renewable energy research.

Keywords: Solar energy; Monocrystalline silicon solar Panel; Output power; Efficiency; Solar irradiance; Performance evaluation; Experimental research

1 Introduction

Solar energy is one of the most ubiquitous and eco-friendly energy sources. This energy contributes significantly to the environment by reducing carbon emissions and air pollution [1]. Due to the extensive use of conventional energy, specifically fuel oil (BBM), carbon and air pollution have increased [2]. Not only does fuel have a high resale value, but it is also dwindling in supply. As a result, all nations are striving to increase their use of renewable energy. Solar energy is one of the most abundant renewable energy sources. Using solar cells, solar energy can be converted directly into electrical energy [3, 4].

Solar cells are currently a topic of extensive research interest. The photoelectric effect is the underlying principle of solar cells. Since 1839, the photoelectric effect has been investigated, and in 1959, the Bell Laboratory developed and published the first solar cell made of silicon with a 6% efficiency, which was then rapidly improved to a 10% efficiency [5]. The primary issue with solar cells is their relatively low efficiency compared to other sources of electricity generation [6]. Currently, the efficiency of commercial solar cells is between 10 and 15%, with a laboratory record of 39% efficiency [7]. Efficiency is also affected by the type of material used to construct solar cells. Each solar cell material has advantages and disadvantages; selecting the proper type of solar cell to be installed in a given location has a substantial effect on the solar cell's performance [8–10]. Until now, silicon-based solar cells have been the most extensively utilized on both a micro and macro scale. Numerous nations produce large quantities of silicon-based solar cells, which offer a number of benefits. Among the numerous varieties of silicon solar cells are [11], and. The selection of monocrystalline solar cells is due to their suitability for the sun's intensity in Merauke Regency. Merauke Regency has excellent solar intensity for the advancement of solar cell applications as a new renewable energy source. With effective irradiation for 5 hours, the average irradiation can reach 274. $\mathrm{W/m^2}$ [12]. With an average intensity of 400 $\mathrm{W/m^2}$ and a temperature of $40°\mathrm{C}$ [13], this type of monocrystalline solar cell can operate effectively in humid weather. Recent research on monocrystalline solar cells has been conducted both theoretically [14, 15], mathematically [16–18], and experimentally [19–21].

The average results of these studies demonstrate significant data results and efficient operation. This type of solar cell is ideally suited for use in regions with intense sunlight and high temperatures. This research seeks to determine how much intensity affects the performance of monocrystalline solar cells. Current, voltage, and output power will be measured to determine the solar cell's efficiency. This research is anticipated to contribute to the advancement of science, particularly in the implementation of solar cells, as well as determine the type of solar cells to be utilized in a particular area or locale. The structure begins with a presentation that inquires about motivation and problems in Area 1. In contrast, Section 2 explains the materials and methods, including the fundamental concepts of solar cells and monocrystalline types. Following this, the production phases and methods of estimation and testing utilizing the Arduino board are described in direct sunlight. The results of Area 3 are depicted in graphics and tables with real-time estimations. The concluding section presents the results and enhancements of ongoing tests of monocrystalline solar cells.

2 Methodology

2.1 Solar Energy Potential in Merauke Regency

Merauke Regency in southeastern Indonesia has multiple renewable energy potentials, including solar energy, biomass energy, and wind energy [12]. Solar energy has an intensity that is sufficiently stable to be utilized and converted into other forms of energy. The resulting average intensity can reach 274 $\mathrm{W/m^2}$ per day and can be directly converted to electrical energy using a solar cell. The following in Figure 1 is a portrait of the initial measurement data using RETScreen Expert.

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation-horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18°C	Cooling degree-days 10°C
	°C		mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	-9.6	74.1%	70.37	1.58	100.9	4.7	-13.4	856	0
February	-7.8	71.4%	58.52	2.53	100.9	4.5	-11.3	722	0
March	-2.3	70.9%	70.99	3.62	100.9	4.6	-4.3	629	0
April	5.6	63.8%	84.00	4.46	100.7	4.4	5.4	372	0
May	13.4	63.5%	89.90	5.10	100.7	4.2	12.7	143	105
June	18.9	68.6%	100.50	5.61	100.5	3.6	18.0	0	267
July	20.5	74.9%	98.89	5.52	100.6	3.2	20.5	0	326
August	19.5	75.9%	97.34	4.91	100.7	2.8	19.7	0	295
September	15.1	77.7%	92.70	3.77	100.9	3.1	14.9	87	153
October	8.3	76.5%	95.17	2.38	100.9	3.7	7.5	301	0
November	2.1	78.9%	85.80	1.45	100.9	4.2	0.2	477	0
December	-4.5	78.5%	85.56	1.28	100.9	4.4	-8.9	698	0
Annual	**6.7**	**72.9%**	**1,029.74**	**3.52**	**100.8**	**3.9**	**5.2**	**4,284**	**1,145**
Source	Ground	Ground	NASA	NASA	NASA	Ground	NASA	Ground	Ground
Measured at					m	10	0		

Figure 1. Results of measuring solar energy potential in Merauke Regency for a year

2.2 Monocrystalline Solar Cells

The solar module consists of a series of connected solar cells. Solar cells are designed to convert sunlight into electrical energy. Solar cells are typically composed of the semiconductor material silicon. The amount of solar radiation received, the surface area of the panel, and the temperature of the panel determine the amount of energy produced by solar panels. Radiation and surface area are proportional to the amount of power generated, whereas an increase in temperature decreases power. In order for air to circulate under the panels (conditioning effect), the distance to the ceiling must be considered when installing the panels. The output of the most recent model of solar module is 130 $\mathrm{W/m^2}$ [19]. Monocrystalline modules are the most efficient, producing the most electrical power per unit of area. It has a 15% efficacy rate. The disadvantage of this type of solar panel is that it performs poorly in areas with little sunlight (shade), and its efficiency decreases dramatically in cloudy conditions [21]. Figure 2 is a display of the types of monocrystalline solar cells used.

Figure 2. Display Type of monocrystalline solar cell

The ratio of the power absorbed by the solar module to the power absorbed by sunlight is called efficiency. Solar cells can convert the light energy they receive into electrical energy. More electrical energy can be generated as more light energy is absorbed. Maximum efficiency (η) is defined as the optimal light energy efficiency percentage. The ability of solar cells to simultaneously generate voltage under load and current through the load is the source of the electrical energy produced by solar cells when they are exposed to light. A current-voltage (I-V) waveform can be used to represent this characteristic. When the cell is short-circuited, the maximum current, or short-circuit current (I_{sc}), is generated, whereas in the open state, no current can pass, resulting in the maximum voltage. Voc stands for Open Circuit Voltage. The Maximum Power Point (MPP) is the point on the IV curve that generates the highest current and voltage [15].

$$\eta = \frac{P_{\max}}{P_{in}} \tag{1}$$

where, η = solar cell efficiency (percent), P_{max} = solar cell power (watts), and P_{in} = incident light power (watts). The efficacy of the solar cell is calculated by dividing the maximum power generated by the cell (P_{max}) by the incident light power (P_{in}). This efficiency value is used to determine the overall performance quality of a solar cell. Before determining the instantaneous power output, it is necessary to calculate the power received (input), which is equal to the product of the received solar radiation intensity and the area of the PV module.

$$P_{in} = \frac{I_r}{A} \tag{2}$$

Meanwhile, P_{in} = power received due to solar irradiance (watts), I_{r} = Light Intensity ($\mathrm{W/m^2}$), A = Surface area of the solar cell ($\mathrm{m^2}$). By multiplying the open circuit voltage (V_{oc}), the short circuit current (I_{sc}), and the fill factor (FF), it is possible to calculate the output power (P_{out}) of a photovoltaic cell.

$$P_{out} = V_{oc} \cdot I_{sc} \cdot FF \tag{3}$$

In the meantime, P_{out} = Power generated by the solar cell (watts), V_{oc}= Open circuit voltage on the solar cell (volts), I_{sc} = Short circuit current on the solar cell (amperes), FF = Fill Factor (filling factor), and FF value can be calculated using the equation:

$$FF = \frac{V_{oc} - I_{sc}\left(V_{oc} + 0.2\right)}{V_{oc} + 1} \tag{4}$$

The efficiency of solar cells is the ratio between the power that can be generated by solar cells and the input energy obtained from solar irradiation. This efficiency measures the momentary effectiveness of data retrieval.

2.3 Method of Measurement

The research employed is a form of experimental research, to determine the effect of sunlight intensity on the amount of energy generated by solar panels. In this investigation, the constructed prototype will be subjected to firsthand evaluation. The prototype is a mounting frame that has been equipped with wheels so that it can be transported easily. Throughout one month, measurements were taken in real-time at 10-minute intervals for eight hours per day. The intensity of illumination, current, and voltage are among the parameters measured. By accumulating data parameters and calculating quantities using the power and efficiency equation of a solar cell, analytical methods are utilized to perform data analysis. Figure 3 is a picture of installing a solar cell perpendicular to sunlight, while Figure 4 is the process of recording data values.

Figure 3. Installation of solar cell testing perpendicular to the sun

Figure 4. Display of the solar cell data measurement process

The 50 WP monocrystalline solar module is the most efficient solar cell module. The use of solar cells with SiN coating provides solutions for rural and even urban energy requirements, energy-saving solutions, and other applications, including solar home systems, solar water pumps, and solar panels. Table 1 is the specification for the 50 Watt monocrystalline type solar cell used in the research.

Table 1. Data specifications for 50 Watt monocrystalline solar cell type

Parameter	Value
Maximum power (P)	50 W
Maximum power voltage (V_{mp})	18.57 V
Maximum power current (I_{mp})	2.69 A
Open circuit voltage (V_{oc})	22.64 V
Short circuit current (I_{sc})	2.88 A
Dimensions (L*W*H)	$50 \times 50 \times 4$
Material: monocrystalline (m-Si)	
Electrical specifications at standard test conditions; irradiance of 1000 W/m^2, spectrum of 1.5 air mass and cell temperature of 25°C.	

3 Results and Discussion

This experimental research seeks to determine the impact of sunlight intensity on the amount of energy produced by solar panels. In this research, the prototype was tested directly. The prototype is a mounting frame equipped with a roller, allowing it to be simply transported anywhere. For one month, measurements were taken in real-time. Included in the measured parameters are light intensity, current, and voltage. Utilizing an analytical method that accumulates parametric data and calculates the amount based on the power equation and solar cell efficiency, the data analysis is performed.

The first stage in this research is to use a lux meter to measure the intensity of sunlight on the solar cell's surface. In addition, current and voltage data are simultaneously gathered by measuring the solar panels' output terminals. To determine the output voltage of the solar panel, connect a voltmeter in parallel between the positive (+) and negative (-) output terminals, and measure the output current by connecting an ammeter in series with the positive (+) pole of the solar panel output. The subsequent step is to analyze the measurement results to obtain the output power value of the 50 Wp solar panel. The resulting information will be depicted as tables and graphs. Figure 5 depicts the results of data acquisition from the first to the tenth day. As a result of the overcast weather, the average measured intensity value is highly variable. The average value is highest on day 21 with a high intensity power of 437 $\mathrm{W \cdot m^{-2}}$, and lowest on day 1 with a high intensity power of 424 $\mathrm{W \cdot m^{-2}}$.

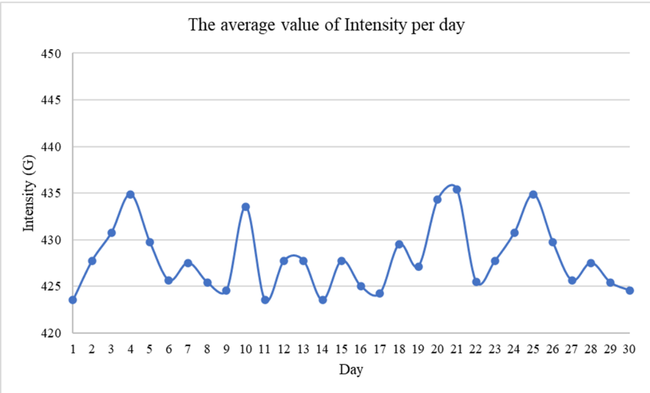

Figure 5. Graph of average daily intensity values

Figure 6 depicts the generally stable average measured current and voltage. The graph of voltage shows fluctuation, while the graph of current is relatively stable. On day nine, the maximum voltage generated is 23 V, while on day sixteen, the minimum voltage generated is 19 V. The maximum current value produced on day 10 is 2.5 A, while the minimum current value produced on day 4 is 2 A.

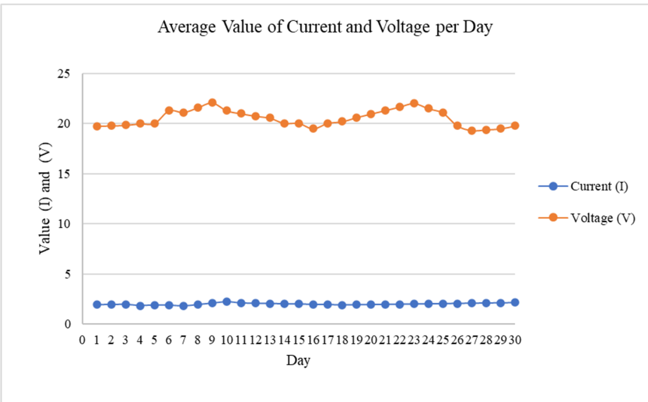

Figure 6. Graph of average daily current and voltage

Figure 7 depicts the average value of the fluctuating output power that was measured. This fluctuating output power graph is a consequence of varying solar intensity. The utmost value of output power is 47 W on day 10, and the minimum value is 36.5 W on day 4.

Figure 8 depicts the fluctuating mean value of efficiency that is measured. This fluctuating graph of efficacy is the result of unstable power generation. Maximum efficiency is displayed on day 10 with a percentage of 11%, and

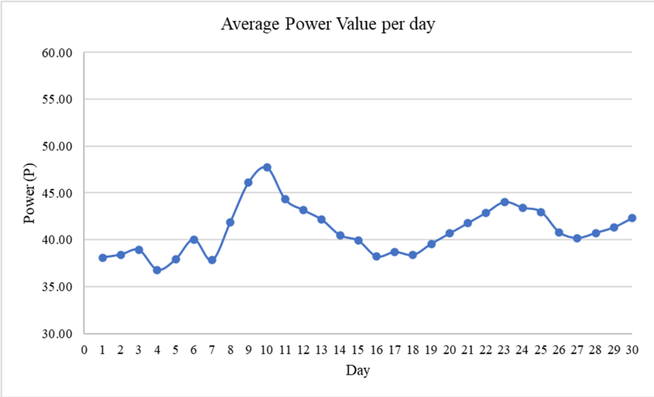

Figure 7. Graph of average daily power output

minimal efficiency is displayed on day 4 with a percentage of 8.50%.

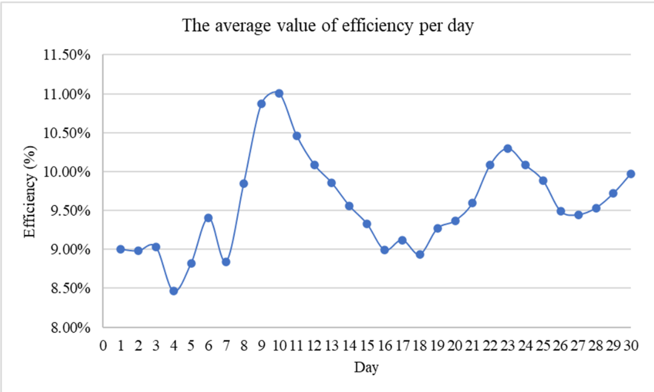

Figure 8. Graph of average daily value for efficiency

4 Conclusions

The findings of this study suggest that variations in solar intensity influence the voltage, current, and output power of solar modules. When solar intensity increases, the voltage value increases, but the current value decreases. The values of current and voltage determine the quantity of electricity produced and its efficiency. The test results of a 50-watt monocrystalline solar panel show an average data collection for one month with a voltage value of 20.68 V, a current of 1.95 A, a power of 40.37 W, and an efficiency of 9%. The best results were obtained on the 10th day with a voltage of 21.30 V, a current of 2.24 A, a power of 47.71 W, and an efficiency of 11.01%.

Author Contributions

Conceptualization, H.H.; D.P.; N.Y.; F.S. and Y.K.; methodology, H.H.; D.P.; N.Y.; F.S. and Y.K.; software, H.H.; validation, Y.K., N.Y. and F.S.; formal analysis, H.H.; investigation, Y.K.; resources, D.P.; data curation, N.Y.; writing—original draft preparation, H.H.; writing—review and editing, H.H.; visualization, F.S.; supervision, Y.K.; project administration, N.Y.; funding acquisition, H.H. All authors have read and agreed to the published version of the manuscript." The relevant terms are explained at the CRediT taxonomy.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare no conflict of interest.

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Nomenclature

$P_{\max}$	Power generated by solar cells, W
P_{in}	Received power, W
P_{out}	Output power, W
I_r	Light intensity, W.m^{-2}
I_{sc}	Short circuit current, A
I	Output current, A
V_{oc}	Open circuit voltage, V
V	Output voltage, V
A	Solar cell surface area, m^{-2}
FF	Fill Factor
Greek symbols	
η	Efficiency, $\%$
Subscripts	
p	Nanoparticle
f	Fluid (pure water)
nf	Nanofluid