MECOMARE, 13 (3) (2024) pp. 98-104

Published by: TRIGIN Publisher

International Journal of Mechanical Computational and Manufacturing Research

Journal homepage: www.trigin.pelnus.ac.id

Solar energy demonstrator design and testing series circuit with 35^0 panel tilt angle in the sunrise and sunset direction

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ARTICLE INFO

Article history:

Received Nov 3, 2024
Revised Nov 28, 2024
Accepted Nov 30, 2024

Keywords:

Energy efficiency;
Panel orientation;
Renewable energy;
Solar panels;
Tilt angle.

ABSTRACT

This research focuses on the design of a solar energy demonstrator with a 35-degree tilted panel configuration, as well as testing its performance in orientation towards sunrise and sunset in real environmental conditions. The evaluation was conducted to analyze the effect of tilt angle and orientation on the efficiency of the solar panel system. The tests were conducted for five days (October 07-12) between 8 a.m. and 4 p.m. The maximum power was achieved at 10 a.m. and 10 p.m., respectively. Maximum power was achieved from 10:00 to 12:00, with a peak of 70 watts on October 07, indicating optimal conditions for sunlight absorption. In contrast, the power generated in the morning (08.00-09.00) and afternoon (15.00-16.00) was lower, ranging from 10-30 watts, due to lower solar intensity. In terms of efficiency, the highest peak reached 50% at 10:00 to 12:00 on October 07, while in the morning and afternoon, the efficiency decreased to 10-20%. The difference between days was influenced by weather conditions, with October 07 and 08 having higher power and efficiency. This research shows the importance of tilt angle, orientation, time of day, and weather conditions in determining the optimal performance of solar panels.

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1. INTRODUCTION

Solar energy has become one of the most promising renewable energy solutions in answering the increasing global energy needs (Moriarty & Honnery, 2020; Varun Sivaram, 2018). This energy source has the advantages of abundant availability, emission-free, and flexibility of use at various scales, ranging from household needs to large industrial scale (Kabeyi & Olanrewaju, 2022; Mekuye et al., 2024). In recent decades, the development of solar panel technology has become a major focus to improve its efficiency and sustainability (Choudhary & Srivastava, 2019). One of the main factors that affect the performance of solar energy systems is the tilt angle and orientation of the panels towards the sun (Adenle, 2020; Obaideen et al., 2021).

Previous studies have shown that the tilt angle of solar panels significantly affects the amount of solar radiation that can be absorbed, which in turn affects the overall efficiency of the system (Aslam et al., 2022; Laveyne et al., 2020; Mamun et al., 2022). In addition, the use of a series connection system on solar panels can increase the output power but requires an optimal configuration to minimize losses due to partial shading or misalignment (Bapurao et al., 2023; Bonthagorla & Mikkili, 2022; Pendem & Mikkili, 2018).

Although many studies have been conducted to optimize the tilt angle of solar panels, there are still gaps in empirical testing on specific configurations such as 350° angle with orientation towards sunrise and sunset. Many studies focus on theoretical analysis, but lack field testing that takes into account local environmental factors such as humidity, light intensity, and temperature (Ganesh et al., 2021). In addition, series circuit optimization in solar panel systems still faces challenges in terms of energy collection efficiency under varying operating conditions (Abualigah et al., 2022; Al-Shahri et al., 2021; Hassan et al., 2023).

There have been many studies related to solar panel efficiency. Babatunde et al. (2018) studied the effect of panel orientation on the efficiency of solar energy systems and found that optimal panel orientation can increase efficiency by up to 20% (Babatunde et al., 2018). Yunus Khan et al. (2020)showed that the panel tilt angle affects the amount of solar radiation received, especially in locations with high light intensity. Mehedi (2021) explored the impact of partial shading on solar panels connected in series and identified that proper circuit arrangement can reduce losses by up to 15%. Furthermore, research conducted by Said (2018) proposed an experimental model to evaluate panel orientation under various environmental conditions. The results show that field testing provides more accurate results than numerical simulation.

This research aims to fill the gap by designing and building a solar energy demonstrator that uses a 35-degree tilted solar panel configuration. The demonstrator will be tested under real environmental conditions to evaluate its performance, particularly in terms of panel orientation towards sunrise and sunset. By combining experimental approaches and quantitative analysis, this research is expected to provide new insights into how tilt angle and circuit configuration affect solar panel performance.

2. RESEARCH METHOD

The results of the planned Solar Energy Demonstrator design are in the form of a portable model that is composed of all the main components and supporting components with the aim of making it easier to operate and move. Figure 1 shows the planned solar energy demonstrator model.

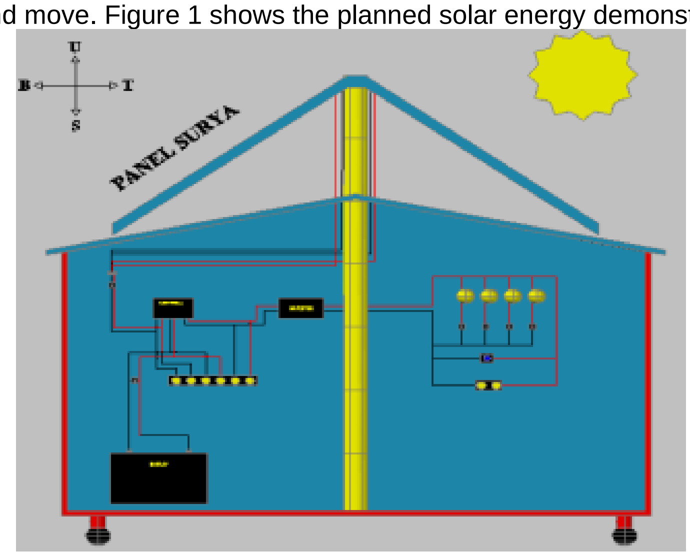

Figure 1. Solar Energy Demonstrator Model

In this study, testing was carried out on a series circuit with a panel tilt angle of 350 in the direction of sunrise and sunset. The testing time was carried out from 08.00 to 16.00 WIB every day from Monday to Saturday. The steps of the experiment are as follows:

1. Checking each measuring instrument whether it can function properly.
2. Placing the solar energy demonstrator in a direct sun position or not blocked by anything.
3. Assemble the panels in series.
4. Positioning the panel at a slope of 350 in the direction of sunset.
5. Provided the test data sheet.
6. Pressing each switch to the ON position.

7. Recording the amount indicated by each measuring instrument into the test data sheet every 5 (five) minutes until the specified time.
8. Returning the switch to the OFF position after the test is completed.
9. Repeating steps 1 through 8 for testing on the following days.
10. Testing is complete.

The specifications of the solar panel used in this study are shown in Table 1 below:

Table 1. Specifications of solar panel solarindo

Specifications	Description
Max. Power (Pmax)	120W
Max. Power Voltage (Vmp)	17,2V
Max. Power Current (Imp)	6,98A
Open Circuit Voltage (Voc)	21,6V
Short Circuit Current (Isc)	7,72A
Power tolerance	±5%
Max. System Voltage	1000Vdc
Weight	10,5kg
Dimension (mm)	1285 x 715 x 85

3. RESULTS AND DISCUSSIONS

From the results of solar panel testing data with a tilt angle of 35o in the direction of sunrise and sunset. Testing time is carried out from 08.00 to 16.00 WIB every day from Monday to Saturday. The following are the results of the research data shown in table 2 below :

Table 2. test data results of solar panels with a tilt angle of 35^0

Waktu	07-Okt		08-Okt		10-Okt		11-Okt		12-Okt	
	Vs (Volt)	Is (Ampere)	Vs (Volt)	Is (Ampere)	Vs (Volt)	Is (Ampere)	Vs (Volt)	Is (Ampere)	Vs (Volt)	Is (Ampere)
08.00	30	0,5	35	0,5	14,5	0,5	26	1	26	1
09.00	32	0,5	30	0,5	13,5	2	26	0,5	26	2
10.00	30	0,5	30	2	13,3	3	28	2	27	2,5
11.00	32	0,5	30	2	27	1	25	1	27	2
12.00	45	1	30	0,5	27	1	26	0,5	28	2
13.00	40	0,5	30	1	27	0,5	26	0,5	27	2
14.00	25	1	35	1	27	0,5	25	0,5	25	0,5
15.00	20	0,5	32	1	25	0,5	25	0,5	28	1

The optimal tilt angle for solar panels during winter differs from summer due to the variation in sun angle throughout the year, as illustrated in Figure 2.

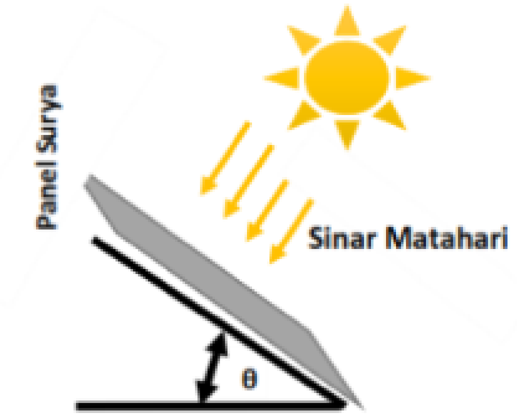

Figure 2. Schematic of solar panel tilt angle optimization

The solar radiation energy received by solar panels can be calculated using Equation 1 below:

$$E = G \times A \times cos\,\theta \times \eta \tag{1}$$

Where:
E: Energy received (Watt), G: Solar radiation intensity (W/m^2), A: Solar panel surface area (m^2), cos θ: Correction factor for the angle between sunlight and the panel surface, where θ is the angle, η: Solar panel efficiency or photovoltaic system efficiency.
The calculation of the efficiency (η) of a solar panel or photovoltaic system can be done using the following Equation 2:

$$\eta = \frac{P_{output}}{P_{capacity}} \times 100\% \tag{2}$$

$$\eta = \frac{15\ watt}{120\ watt} \times 100\% \quad = \quad 12{,}5\ \%$$

Where:
η: Power efficiency (%), Poutput: Electrical power generated by the solar cell (Watt), Pinput: Solar radiation power received by the solar cell (Watt). The electrical power generated by solar cells (Pcapacity) can be calculated using Equation (3) as follows:

$$= \frac{15\ watt}{120\ watt} \times 100\% \quad = \quad 12{,}5\ \% \tag{3}$$

$$P_{output} \ = \ 30 \times 0{,}5 \ = \ 15\ \text{watt}$$

Where:
V: Output voltage of the solar cell (Volts), I: Output current of the solar cell (Ampere). The results of the calculation analysis using the above equation are presented in the form of Table 3 below:

Table 3. The results of the analysis of the calculation of power and efficiency of solar panels

Waktu	Power Solar Panel (Ps)					Spesifikasi Soalr Panel	Efisiensi Solar Panel (η)				
	07-Okt	08-Okt	09-Okt	10-Okt	11-Okt		07-Okt	08-Okt	09-Okt	10-Okt	11-Okt
08.00	15	17,5	7,25	26	26	120	12,5	14,6	6,0	21,7	21,7
09.00	16	15	27	13	52	120	13,3	12,5	22,5	10,8	43,3
10.00	15	60	39,9	56	67,5	120	12,5	50,0	33,3	46,7	56,3
11.00	16	60	27	25	54	120	13,3	50,0	22,5	20,8	45,0
12.00	45	15	27	13	56	120	37,5	12,5	22,5	10,8	46,7
13.00	20	30	13,5	13	54	120	16,7	25,0	11,3	10,8	45,0
14.00	25	35	13,5	12,5	12,5	120	20,8	29,2	11,3	10,4	10,4
15.00	10	32	12,5	12,5	28	120	8,3	26,7	10,4	10,4	23,3

From the table, the average power generated by the solar panel shows variations between days. The highest average occurred on October 11 at 43.75 W, while the lowest on October 07 at 20.25 W, with the panel specification remaining at 120 W. This shows that the efficiency of the panel is affected by external conditions such as weather and sunlight intensity. Solar panel performance tends to be optimal under favorable environmental conditions, but the average power generated is still far below its maximum specification, indicating potential improvements in system configuration or customization.

The following is a trend of the output power distribution (Ps) of the solar panel for five days (October 07-12) between 08:00 and 16:00. This graph illustrates the power fluctuations by time and date, with power peaks seen in the morning towards noon, specifically around 10am to 12pm as shown in Figure 2.

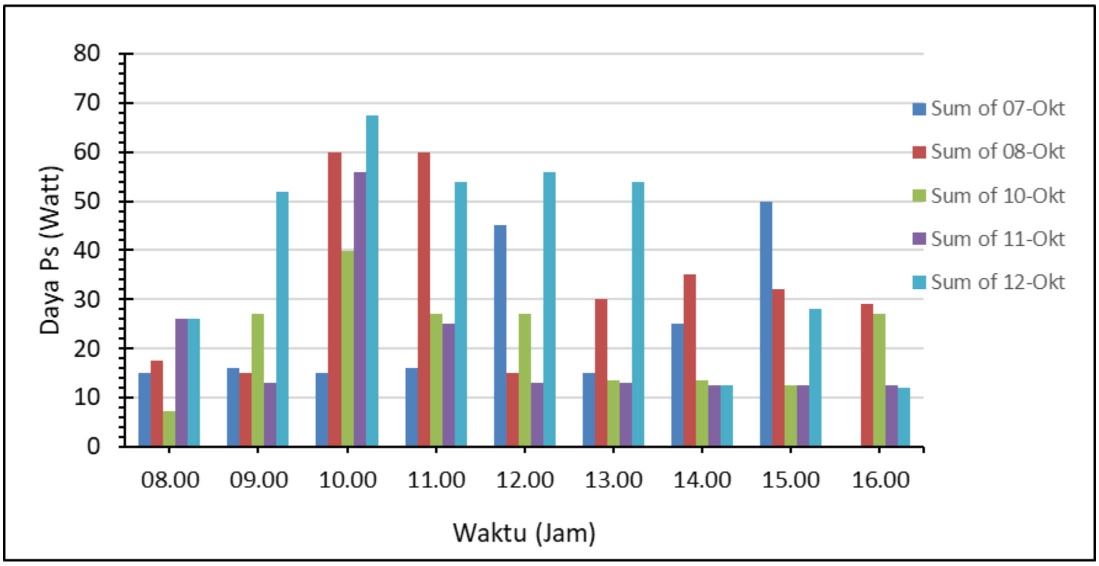

Figure 3. Solar panel output power results

The graph shows the output power of the solar panel (Power Ps) at various times from 08:00 to 16:00 for five days (October 07-12). The maximum power was reached at 10am to 12pm, with a peak of about 70 watts on October 07, indicating optimal conditions for sunlight absorption. In the morning (08.00-09.00) and afternoon (15.00-16.00), the power generated was lower, ranging from 10-30 watts, due to lower solar intensity. There was a difference in power between days, with October 07 and 08 producing higher power than the other days, possibly due to the sunny weather. This graph confirms that the peak time for solar panel performance is in the middle of the day, while power production decreases outside of this time.

The following shows the solar panel efficiency (%) for five days (October 07-12) based on the operational time from 08:00 to 15:00. This graph shows the variation of solar panel efficiency on each day, with the highest efficiency usually occurring between 10:00 am and 11:00 am, indicating the optimal time of solar energy absorption shown in Figure 4.

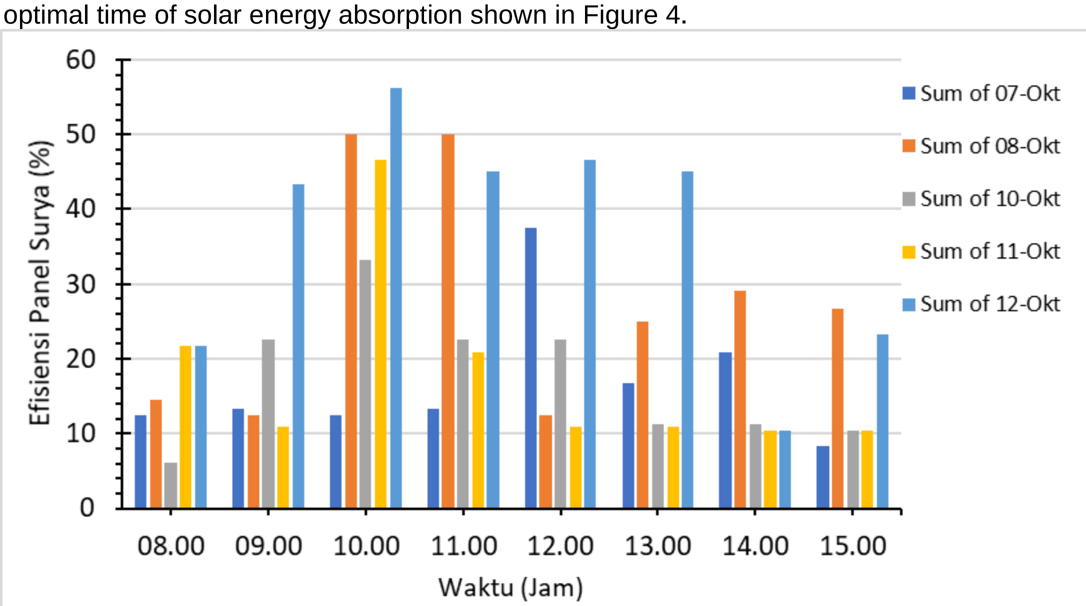

Figure 4. Solar panel efficiency results

The graph shows the variation of the solar panel efficiency between 08:00 and 15:00 for five days (October 07-12). The highest efficiency occurs from 10:00 to 12:00, with a peak of about 50% on October 07, indicating optimal conditions for solar radiation on that day. In contrast, the efficiency was lower in the morning (08:00) and afternoon (15:00), with an average value of about 10-20%, which was due to the low position of the sun. There were fluctuations between days, with October 07 and 08 having higher efficiencies than other days, possibly influenced by clear weather conditions. This graph confirms the importance of time of day and weather conditions in determining the efficiency of solar panels, with 10am to 12pm being the most optimal period for energy generation.

4. CONCLUSION

This study confirmed that the performance and efficiency of solar panels are strongly influenced by tilt angle, orientation, time of day, and weather conditions, with an optimal angle of 35 degrees pointing towards sunrise and sunset, resulting in a maximum power of 70 watts and a peak efficiency of 50% in the 10:00-12:00 time range. These findings have significant implications in solar energy system optimization, particularly in panel design and installation to improve energy conversion effectiveness. However, this study has limitations in covering a wider range of weather variability and has not considered additional factors such as dust accumulation and panel degradation in the long term. Therefore, further studies are recommended to explore machine learning-based predictive models to estimate panel efficiency under various environmental conditions, as well as long-term experimental analysis to understand the impact of material degradation on solar energy system performance.

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