International Journal of Applied Power Engineering (IJAPE)
Vol. 13, No. 2, June 2024, pp. 328~334
ISSN: 2252-8792, DOI: 10.11591/ijape.v13.i2.pp328-334

Comparative analysis of single-axis solar tracker performance with and without reflector under various weather conditions

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Article Info

Article history:

Received Jul 25, 2023
Revised Aug 3, 2023
Accepted Sep 6, 2023

Keywords:

Power output
Photovoltaic analysis
Reflectors
Solar panels
Solar tracking

ABSTRACT

This research explores a sun tracking system for solar panels that affects the power output of the panels. To address this, a unidirectional sun tracking system is implemented to ensure the solar panels are perpendicular to the sun, thus optimizing solar radiation. Additionally, reflectors are integrated to capture more sunlight. This research aims to design the system of unidirectional sun tracking to enhance the power output generated by solar panels and compare its performance with stationary (static) solar panels. The results demonstrate that the system of sun tracking improves the power output of solar panels. However, when reflectors are used in conjunction with the sun tracking system, no significant increase in power output is observed. Moreover, solar panels equipped with the unidirectional sun tracking system exhibit a power increase of 52.06 Watts compared to stationary solar panels. This research indicates that employing a unidirectional sun tracking system with the addition of reflectors does not enhance power output but instead reduces it due to the increased temperature effect caused by the sunlight reflection from the added reflectors.

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1. INTRODUCTION

Indonesia is located on the equator where the sun illuminates the Earth's surface throughout the year. In total, Indonesia can receive solar energy up to 4.8 kWh/m^2/day [1]. This provides a foundation for the utilization of environmentally friendly solar energy as part of the effort to optimize the use of renewable energy sources through solar power plants (SPPs) [2], [3]. The employment of solar energy for electricity generation is projected to increase by 18% from 2013 to 2050 [4], [5].

Solar panels, one of the main parts used in SPPs, have the ability to directly convert solar radiation into electricity [6]. The relatively low efficiency of solar panels is still evident [7]. The significant obstacle posed by the limited efficiency of solar panels necessitates the implementation of a system to enhance their efficiency [8]. One approach to addressing this issue is the utilization of sun tracking systems [9], [10]. These systems ensure that solar panels are always positioned perpendicular to the sun, thus maximizing solar energy absorption [11], [12]. Additionally, reflectors can be added to the solar panels to increase the amount of sunlight reaching their surface [13]–[15]. By utilizing reflectors, the total solar irradiance incident on the solar panel's surface is augmented, resulting in a higher electrical power output. Consequently, it is hypothesized that with an increase in the electrical power output, the overall efficiency of the solar panel will also improve.

Based on a comprehensive review of existing literature, it is evident that further exploration is necessary to expand and refine current knowledge on sun tracking systems and reflectors. Therefore, a sun tracking mechanism coupled with the incorporation of reflectors is proposed with the overarching objective of optimizing the power output of solar panels. This research endeavor holds significant potential for advancing the field of solar energy utilization and enhancing the efficiency of solar power generation systems. This research is provided insights into the effectiveness of integrating reflectors into a solar panel system with a tracker.

2. METHOD

This research aims to automatically design a unidirectional solar tracking system on solar panels using a microcontroller to enhance the solar panel's power output. The design utilizes a solar tracking system method controlled by Arduino Uno to regulate the movement of a servo motor that positions the solar panel [16], [17]. In Figure 1(a), the wiring control system of the device is depicted. Meanwhile, Figure 1(b) illustrates the integrated electronic circuitry within the panel box. The device's operation utilizes C programming logic with the Arduino integrated development environment (IDE) software. The Arduino IDE contains several commands that control the servo motor's rotation direction based on the light intensity. Light intensity is identified with the assistance of a light dependent resistor (LDR) sensor, which is converted into resistance values [18], [19]. Following the rule of placing the solar tracking system axis facing north-south, the servo motor rotates towards the east if the LDR reads a higher resistance value on the west side than the east [20]. Conversely, if the resistance value on the east side is higher than the west side, the servo motor rotates towards the west. The placement design of the LDR sensor and the design of the one-way solar tracking system are shown in Figure 2(a).

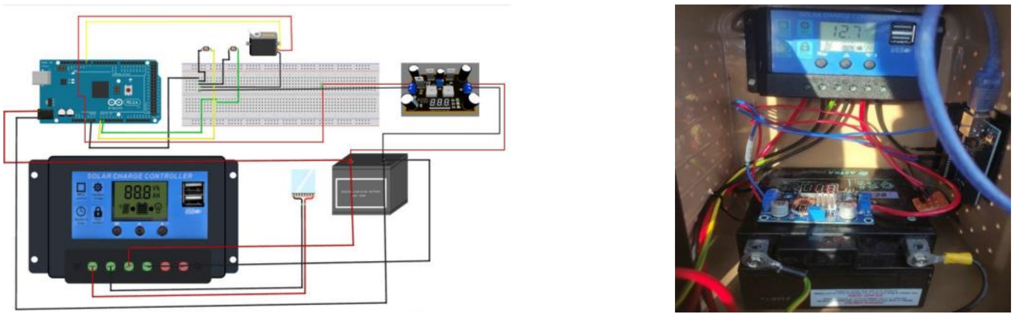
In Figure 2(b), two solar panels are used: i) The first panel is equipped with a one-way solar tracking system; ii) While the second panel includes a one-way solar tracking system with the addition of reflectors; and iii) The three solar panels will be placed in the same locations and conditions as shown in Figures 3(a) and 3(b). In this research, we use GH solar photovoltaic which has specifications as shown in Table 1. voltage (V) and current (I) data will be collected hourly from each panel, requiring the solar panels to be loaded. A 12 V DC battery will be the load [21]. In this study, the solar tracking system will be powered by a different source, namely the national electricity company (grid utility). The entire data display, including solar panel power output (P) and temperature [22], will be simulated simultaneously and compared between the static solar panel, the system of one-way solar tracking, and the solar panel with the system of one-way solar tracking and reflector addition [23], [24]. Subsequently, the power data obtained through measurements will be compared with the calculated power using (1) to determine the magnitude of the power differences produced [25].

$$Ppv = Pstc \frac{Gc}{Gstc}(1 + k(Tc - Tstc)) \quad (1)$$

Where P solar panel is the power output of the solar panel, the standard test conditions (stc) mean that the solar irradiance ($Gstc$) is W/m^2, the solar panel temperature ($Tstc$) is 25 °C, and the relative optical air mass is in condition air masses 1.5. Gc is the operating radiation at the time of measurement, k is the maximum power temperature coefficient, $Pstc$ is the power output value under stc, and Tc is the solar panel operating temperature at the measurement time.

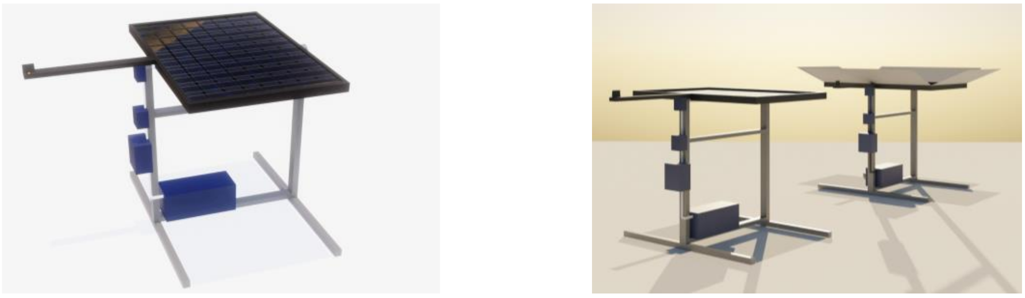
Table 1. GH solar photovoltaic specification

Name	Information
Model	GH50P-36
Rate max. power (Pm)	50 W
PV tolerance	0~+5
Current at Pmax (Imp)	2.72 A
Voltage at Pmax (Vmp)	18.4 V
Short-circuit current (Isc)	22.6 V
Open-circuit voltage (Voc)	2.94 A
Normal operating cell temp (NOCT)	47÷2 °C
Max. series fuse rating	10 A
Max. system voltage	1000 VDC
Operating temperature	40 to + 85 °C
Application class	Class A
Cell technology	Poly - SI
PV weight	3.65 kg
Dimension (mm)	540*670*30 mm



(a) (b)

Figure 1. Illustrates the solar power plant in the form of (a) a schematic diagram and (b) the assembled configuration in the panel box



(a) (b)

Figure 2. The 3D design of the solar power plant along with (a) the components arrangement and (b) the added reflector

(a) (b)

Figure 3. The testing of the solar power plant utilizing (a) a tracker and (b) both the tracker and reflector

3. RESULTS AND DISCUSSION

The experiment's main objective is to design a one-way solar tracking system on solar panels using a microcontroller and compare it with solar panels equipped with a one-way solar tracking system and reflector addition to determine the difference in power output from the solar panels. The research was conducted in the Laboratory Building of Kalimantan Institute of Technology environment from 08:00 GMT+8 to 16:00 GMT+8. The solar panel is positioned at an inclination angle of 25° for the static (stationary) panel with a north-facing orientation. The output current, voltage, power, and solar irradiance are measured every 60 minutes during the testing. The testing is conducted by placing all three solar panels under standard conditions at the same location and conditions.

After equipment testing and data collection, the obtained results are in the form of comparison graphs of the power output generated by the static (stationary) solar panel, the solar panel with a one-way solar tracking system, and the solar panel with a one-way solar tracking system and reflector addition. Then, in Figure 4, it can be observed that the static solar panel has an average power of 34.63 Watts, the solar panel with a one-way solar tracking system has an average power of 40.41 Watts, and the solar panel with a one-way solar tracking system and reflector addition has an average power of 38.18 Watts. It is further noted that the measurement of the solar panel with a one-way solar tracking system and reflector addition resulted in lower power output compared to the solar panel with a one-way solar tracking system without a reflector. Here, this data is verified by calculations using (1) taken from one of the data on the power output of the one-way solar tracking system with reflector addition at 12 noon, where the power output obtained was lower than that of the solar panel with a one-way solar tracking system without a reflector, which should have been 51.84 Watts.

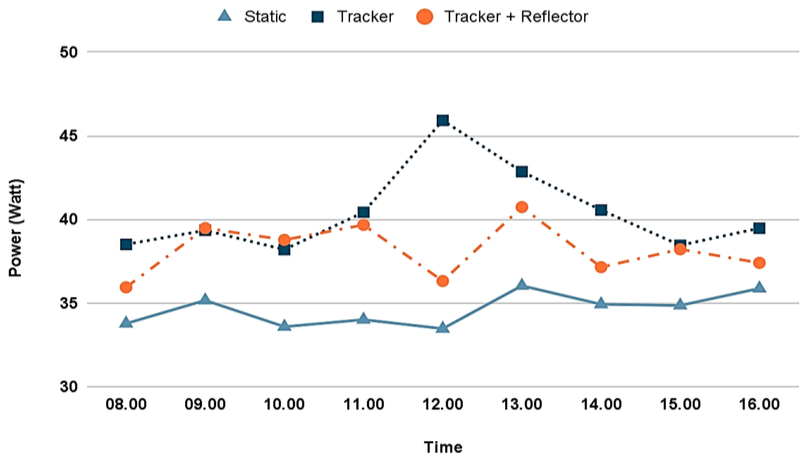


Figure 4. The results of the comparative testing of the power output from the solar power plant in three scenarios: without a tracker, with a tracker, and with both a tracker and reflector

The data utilized in these calculations serves as the fundamental reference basis, as having a more extensive dataset enhances the accuracy of the average values. Table 2 presents the results obtained from both manual calculations and measurements taken at the same hours, from 08:00 to 16:00 GMT+8. The calculated power values can be determined by utilizing solar irradiance and solar panel temperature data during the measurements. The power differences can then be determined by comparing the measured and calculated power values from Figures 5 and 6. The difference in power output between the solar panel with a tracking system and the tracking system with reflector addition was found to be 20.05 Watts, indicating that the one-way solar tracking system method has been proven to enhance the solar panel's power output. The research also stated that solar tracking with reflector additions on both sides of the panel can increase the electrical energy obtained by the solar panel, with a percentage increase in energy in a day reaching up to 75.20% compared to statically installed solar panels. The energy consumption required to operate the tracking system is less than 0.15% of the total energy that the solar panel can generate.

Table 2. The results of two cases of photovoltaic calculation and measurement

Time	Photovoltaic using tracker		Photovoltaic using tracker and reflector	
	Calculation (W)	Measurement (W)	Calculation (W)	Measurement (W)
08.00	41.2	38.5	41.2	35.9
09.00	41.4	39.3	41.2	39.4
10.00	43.7	38.1	43.6	38.7
11.00	45.2	40.4	44.9	39.6
12.00	53.1	45.9	51.8	36.3
13.00	44.5	42.8	44.2	40.7
14.00	44.4	40.5	43.7	37.1
15.00	43.6	38.4	42.9	38.2
16.00	43.0	39.4	42.4	37.4

In this research, it has been found that high temperatures can lead to a decrease in efficiency, as demonstrated through experimental measurements and mathematical calculations. In a photovoltaic specification, there is a reference to the nominal temperature for standard test conditions, and if the nominal temperature is too high, it will result in a reduction of effectiveness in the photovoltaic power output. Therefore, a reflector that can reflect light or irradiation while minimizing the reflection of heat from the sun, such as an aluminum foil-based light reflector, is required.

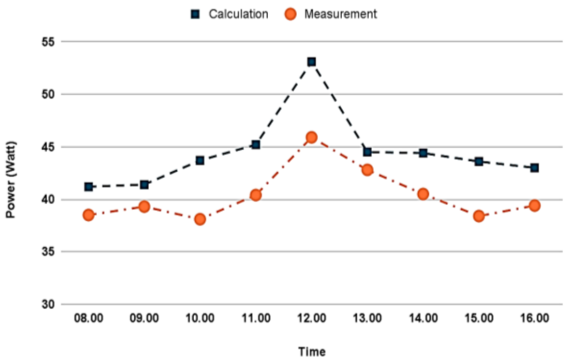


Figure 5. The results of the comparison between photovoltaic using tracker based on calculations and measurements

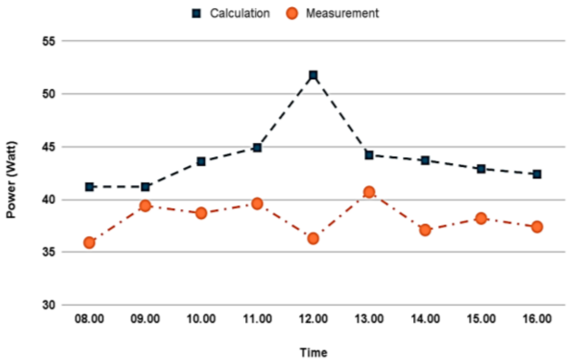


Figure 6. The results of the comparison between photovoltaic using tracker and reflector based on calculations and measurements

4. CONCLUSION

Based on the results of the analysis conducted in this study, we found that the temperature increase observed in solar panels with the addition of reflectors is attributed to the reflectors absorbing and reflecting additional sunlight onto the solar panel. While the reflectors aim to enhance the light reception of the panel, this process also leads to a significant rise in heat. Consequently, the elevated temperature reduces the efficiency of solar energy conversion into electrical power, resulting in a decline in average power output. Furthermore, we observed that the temperature increase in the solar panel is directly proportional to the intensity of received sunlight and the duration of exposure. Hence, the reduction in power output is more pronounced during sunny weather conditions and when the solar panel receives prolonged high-intensity sunlight exposure.

Nonetheless, the findings of this research contribute valuable insights to the development of solar panels and tracking systems. These results underscore the importance of a deeper understanding of the impact of temperature on solar panel efficiency and highlight the necessity for appropriate strategies to address this issue. As a next step, we intend to investigate the potential implementation of cooling or temperature regulation technologies on solar panels with tracking systems, with the aim of mitigating the negative effects of temperature rise on panel efficiency. Thus, it is hoped that this research can serve as a foundation for the advancement of superior and more efficient solar panel technologies in the future.

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