

ANALYSIS OF THE EFFECT OF MIRROR REFLECTORS ON POWER OUTPUT OPTIMIZATION IN FLOATING SOLAR POWER PLANTS

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Abstract

Floating Solar Power Plants (FSPP) are a potential renewable energy solution, but their power output is highly influenced by fluctuating solar intensity. This research aims to analyze the optimization of power output in a floating solar power plant with the addition of mirror reflectors. The research method used is experimental, comparing the performance of series-connected solar panels, both without reflectors and with the addition of reflectors at various angles of 30°, 45°, and 60°. Data was collected over four days from 09:00 to 15:00 WIB, including measurements of light intensity, current, and voltage. The results show that the use of mirror reflectors significantly increases power output. The 60° reflector angle yielded the most optimal performance, with the highest light intensity reaching 1210 W/m², a current of 3.90 A, a voltage of 14.22 V, and an input power (P_{in}) of 349.20 Watts. Although the highest peak output power (P_{out}) was recorded at the 45° angle (51.76 Watts), the highest average P_{out} (29.76 Watts) and the highest peak efficiency (23.39%) were achieved with the 60° angle. It is concluded that the addition of a mirror reflector at a 60° angle is the most effective method for optimizing power harvesting in floating solar power plants.

Keywords: Floating Solar Power Plant, Mirror Reflector, Power Optimization, solar panels, Energy Efficiency.

INTRODUCTION

Renewable energy is an energy source that comes from sustainable natural processes and can be renewed continuously, including solar, wind, and water energy. The use of renewable energy is becoming increasingly important in the global context to reduce dependence on fossil energy and overcome climate change (Nadandi et al., 2021). Indonesia, as a country located around the equator with a tropical climate, has a very abundant solar energy potential and great opportunities for its development. With optimal management, these resources can make a significant contribution to the national energy mix, where the potential for daily electrical energy from the sun is estimated to reach 4.8 kWh/m² (Nadhiroh et al., 2022).

In response to this potential, many researchers are competing to develop photovoltaic (PV) technology. The energy derived from solar radiation is photon energy that is directly converted into electricity through solar panels composed of solar cells. This technology generates direct current (DC) electricity which can then be converted into alternating current (AC) with the help of an inverter to meet conventional electricity needs (Nadhiroh et al., 2022).

Increasing global energy demand and climate change issues are driving the transition to sustainable renewable energy sources (Nadandi et al., 2021). Solar energy, with an average potential of 4.8 kWh/m²/day in Indonesia, is a promising solution (Afif & Martin, 2022). (1) The object of this research focuses on floating Solar Power Plants (PLTS), an innovation that saves land and has the potential to increase efficiency through natural cooling by water (Rinaldi & Mulyono, 2021). However, the power output of solar PV is highly fluctuating and is influenced by the intensity of solar radiation (Damanik & Silaban, 2023). (2) Several methods have been used before for optimization, such as solar tracker systems and the use of reflectors. (3) Each method has its drawbacks and strengths: solar trackers are effective but expensive and complex, while reflectors are a low-cost alternative that is able to increase the flux of solar radiation to the panel (Kaban et al., 2020). However, the effectiveness of the reflector is highly dependent on the angle of installation (Sidopekso et al., 2010).

The dependence of reflector effectiveness on the angle of inclination raises (4) the main research problem: how to maximize power harvesting in floating solar PV through optimal reflector angle configuration. Specifically, this study aims to answer: (a) How does the use of mirror reflectors with angles of 30°, 45°, and 60° affect the power produced? (b) How much power does floating solar power without reflectors produce as comparative data? (c) Which angle of inclination of the reflector is the most maximal in improving power harvesting? (5) As a solution, this study proposes an experimental approach by comparing the performance of a floating solar power plant without a reflector with a configuration that uses a mirror reflector at three different angles. (6) The contribution of this study includes: (i) the provision of empirical data comparing the performance of floating solar power plants with and without reflectors, and (ii) the determination of the most effective mirror reflector angles for power optimization. (7) The rest of this article is structured as follows: Part 2 discusses the literature review, Part 3 describes the research methodology, Part 4 presents the results and discussion, and Part 5 summarizes conclusions and suggestions.

Utilization of Reflectors to Increase Solar Power Plant Output

The basic principle for increasing the output of solar panels is to maximize the amount of solar irradiation received by their surface. One of the most researched methods due to its cost-effectiveness is the use of reflectors. The reflector functions to reflect and concentrate additional sunlight that should not fall on the surface of the panel, thereby increasing the total light intensity received (Ruliyanta et al., 2024). A number of studies have consistently shown positive results from the application of reflectors. (Kaban et al., 2020) in their study proved that mirrors can effectively optimize the reception of light intensity in solar cells. Similarly, (Nadandi et al., 2021) also reported an increase in solar panel output power after using mirrors and aluminum. These findings confirm that the use of reflectors, regardless of the type of material, is a valid

strategy to improve the performance of solar PV. (Fuadiyah & Sudarti, 2022) even showed that the addition of a reflector mirror was able to speed up the battery charging time up to 2 hours faster than without a reflector, underlining the practical impact of this method.

Influence of Tilt Angles and Research Gaps

Although the benefits of using reflectors are proven, their effectiveness is largely determined by geometric parameters, especially the angle of inclination of the reflector against the solar panel. This angle should be set in such a way that the reflection of sunlight can fall right on the surface of the panel to the maximum. Several studies have tried to identify this optimal angle. For example, (Sidopekso et al., 2010) found that an increase in power can occur when the reflector is installed at an angle of 60°. Similarly, research by (Abdullah et al., 2024) also highlights the 60° angle as one of the most optimal angles to effectively reflect sunlight. From the literature search, a research gap was identified.

Most of the existing studies focus on conventional land-based solar systems. Comparative analysis of the influence of different reflector angles (30°, 45°, and 60°) specifically on floating solar PV systems is still very limited. Floating solar PV has unique environmental characteristics, such as the presence of additional light reflection from the water surface and cooling effects, which can interact with the performance of the reflector. Therefore, this study aims to fill the gap by providing direct experimental data that compares the effectiveness of three different mirror reflector tilt angles on a floating solar PV system to determine the most optimal configuration.

Basic Principles of Photovoltaics

Solar power plants (PLTS) basically function by capturing photons from sunlight. Solar cells, as the main component, play an important role in converting the photon energy into electrical energy through the photovoltaic effect. This process is made possible by the nature of the semiconductor material that makes up solar cells, which generally consist of two layers with different charges: a negatively charged upper layer (n-type) and a positively charged lower layer (p-type). When sunlight hits the surface of a cell, it produces electron pairs and holes. The electrons then move out of the cell and flow through external circuits, resulting in a direct electric current (DC) (Darwin et al., 2020).

Solar Panel Types and Selection Justification

Solar panels are made from semiconductor materials, and one of the most common types with the highest efficiency is Monocrystalline Silicon. This type of panel is made of thinly sliced single-crystalline silicon, making it highly efficient in converting sunlight into electricity, especially in high irradiation conditions. These superior

performance characteristics are the basis for the selection of monocrystalline solar panels in this study, as the main goal is to maximize the harvestable power output (Amalia et al., 2022).

Characteristics of Floating Solar Power Plants

Floating solar power plants are solar power generation systems that are installed above the surface of water such as lakes or reservoirs. This system offers several significant advantages over onshore solar PV, among which is higher energy efficiency. This is due to the natural cooling system of the water which can reduce the operating temperature of the panels, thereby increasing their conversion efficiency. In addition, floating solar power plants allow for effective use of space because they do not require large land land. However, this system also has challenges, such as higher infrastructure costs for floating structures and potential impacts on aquatic ecosystems that need to be managed properly (Nanda et al., 2024).

A crucial aspect that has not been widely discussed in the literature is the unique synergy between the use of reflectors and floating solar platforms. Reflectors function to increase the concentration of solar radiation, which inherently also increases the operating temperature of solar panels. In onshore solar systems, this increase in temperature often leads to a decrease in energy conversion efficiency. However, in a floating solar power plant, the water body below it functions as a massive natural heat sink, providing a passive cooling effect that can neutralize the negative impact of the temperature increase. This interaction has the potential to make the combination of reflectors and floating solar PV very effective. Therefore, this study not only aims to identify the optimal reflector angle, but also implicitly test the effectiveness of this synergistic combination under real field conditions, filling an important gap in the understanding of floating solar PV optimization.

RESEARCH METHOD

This study uses an experimental method to analyze the effect of the use of mirror reflectors on the optimization of power output in floating solar power plants (PLTS) systems whose panels are assembled in series. The study design involved a direct comparison between the conditions of the system without a reflector (as a control) with three experimental conditions using reflectors with different tilt angles. The research location is in Cushion Lake, Tangerang Regency, Banten, a representative open water area for floating solar PV testing.

Experimental Design and Algorithms

The design of the floating solar PV system and equipment used in this study are as follows:

- Solar Panels: Two monocrystalline type solar panels with a total cross-sectional area (A) of 0.2886 m², assembled in series.
- Floating Structure: A series of buoys of PVC pipe and hollow iron to support the solar panels above the water surface.
- Reflector: A frame-mounted flat glass mirror whose angle is adjustable.
- Electrical System: Consists of a 20A Solar Charger Controller (SCC), a 12V battery (battery), and a 1000W inverter.
- Measuring Instrument: Using a Solar Panel Power Meter, a digital Watt Meter, and a Multimeter to measure light intensity, current (A), and voltage (V).

The data collection process was carried out systematically for four consecutive days according to the procedure described in Algorithm 1.

Algorithm 1. Experimental Data Collection Procedures

Step : Activity Description

INPUT : Reflector Angle Condition (Without Reflector, 30°, 45°, 60°)

EXODUS : Light Intensity (W/m²), Current (A), Voltage (V) Data

Day 1 (Control): Set up a floating solar PV system without using a reflector.

Day 2 (Experiment 1): Install a mirror reflector on the system with a 30° tilt angle.

Day 2 (Experiment 1): Install a mirror reflector on the system with a 45° tilt angle.

Day 4 (Experiment 3): Change the angle of tilt of the reflector to 60°.

For each day (steps 1–4)

Registration starts at 09.00 WIB.

Repeat every 10 minutes until 15.00 WIB:

Measure and record the value of Solar Radiation Intensity (*I_{rad}*)

Measure and record the value of the Output current (*I_{pv}*).

Measure and record the value of the Output voltage (*V_{pv}*).

Complete the record-keeping.

Move on to data analysis.

Data Analysis

The raw data that has been collected is then processed to calculate the main performance parameters of the solar PV. The input power (*P_{in}*), which is the total power of the solar radiation received by the panel surface, is calculated using the $P_{in} = I_{rad} \times A$ (1) where *P_{in}* is the input power (Watt), *I_{rad}* is the intensity of solar radiation (W/m²), and *A* is the total cross-sectional area of the solar panel (m²).

The output power (P_{out}), i.e. the actual electrical power produced by the panel, is calculated based on the results of current and voltage measurements using the P_{out} equation = $V_{pv} \times I_{pv}$ (2) where P_{out} is the output power (Watt), V_{pv} is the output voltage of the panel (Volts), and I_{pv} is the output current of the panel (Ampere).

The energy conversion efficiency (η) of the solar panel was calculated by comparing the output power to the input power, as shown in Equation $\eta = \times 100\% \frac{P_{out}}{P_{in}}$ (3) The final analysis was performed by comparing the P_{out} value and the average efficiency of the four test conditions to determine the most optimal effect of reflector addition and tilt angle.

RESULT AND DISCUSSION

Findings

The test results showed that the addition of mirror reflectors consistently improved the performance of floating solar PV. The most significant improvements were observed in the output power (P_{out}) parameters and energy conversion efficiency. Table 1 summarizes the peak values recorded for each key parameter during the test period.

Table 1. Comparison of Peak Values of Floating Solar Power Plant Performance Parameters

Parameters	No Reflector	Reflector 30°	Reflector 45°	Reflector 60°
Light Intensity (W/m²)	999	999	1111	1210
Current (A)	0,99	1,85	3,64	3,90
Voltage (V)	13,81	13,71	14,22	14,22
Output Power (Watts)	13,12	24,06	51,76	50,33
Efficiency (%)	9,71	21,51	16,14	23,39

The data in Table 1 show that the reflector angle of 60° produces the highest light intensity, current, and efficiency. Although the highest peak output power is achieved by the 45° angle, the average value of the output power at the 60° angle is consistently more optimal throughout the day.

For a performance comparison visualization, Fig. 1 displays the output power (P_{out}) graph of all four test conditions. It is clear that the power curve for all configurations with reflectors is above the curve without reflectors. The peak of the highest power occurs around noon, between 12.00 and 13.00 WIB, which correlates with the maximum intensity of the sun.

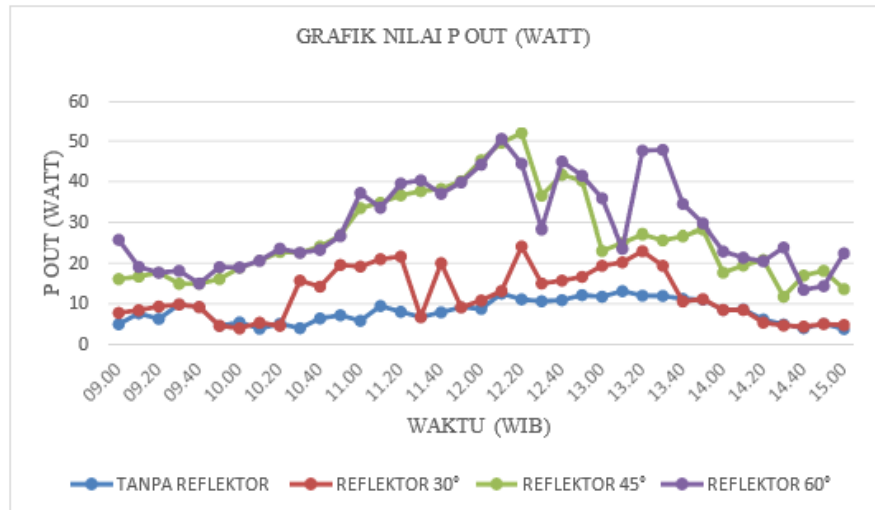


Fig. 1. Output Power Comparison Chart (Pout)

Next, Fig. 2 presents a comparison of the efficiency of the system. The highest efficiency of 23.39% is achieved by using a 60° angled reflector. This shows the ability of this configuration to convert the received photon energy into electrical energy more effectively than other configurations.

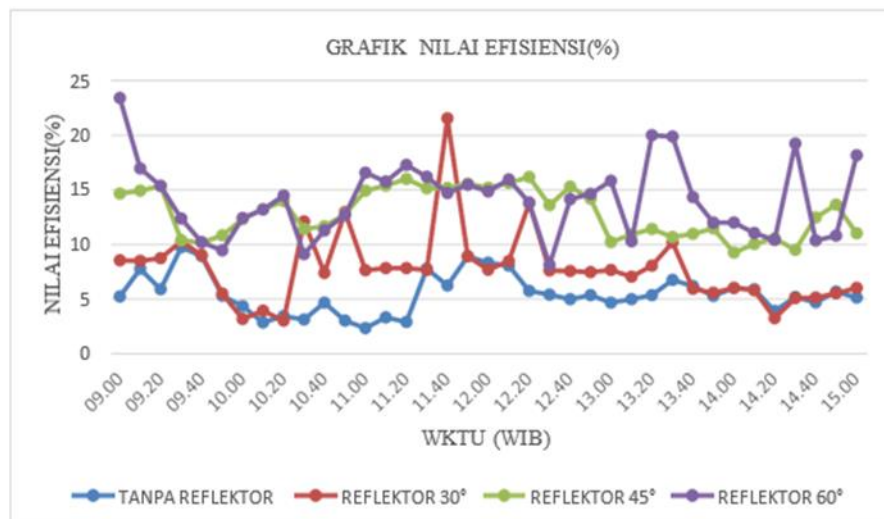


Fig. 2. Efficiency Comparison Graph (%)

Discussion

The main finding of this study is that the use of mirror reflectors significantly improves the performance of floating solar PV, with the reflector tilt angle of 60° providing the most optimal results overall. This increase occurs because the reflector reflects additional solar radiation onto the surface of the solar panel, thereby increasing the total flux of photons received. This directly leads to an increase in the generated current, which then leads to an increase in output power (Pout) as shown in Fig. 1 and Equation (2).

These results are in line with previous research by (Sidopekso et al., 2010) and (Abdullah et al., 2024), which also found that reflectors with an angle of about 60° provide the most substantial increase in power. The initial hypothesis that the addition of reflectors would increase power output proved to be correct. The finding that the 60° angle is superior to 30° and 45° can be explained by the fact that at that angle, the reflection of sunlight is likely to fall more evenly and perpendicular to the surface of the solar panel during the peak period of solar intensity.

While the 45° configuration recorded the highest instantaneous peak power (51.76 W), the 60° configuration showed a higher and more stable average power, as well as achieving the highest peak efficiency (23.39%). This higher efficiency indicates that at an angle of 60°, the additional reflected solar energy can be converted into electricity more effectively by the solar cells. This phenomenon confirms that optimization depends not only on the capture of the maximum light intensity, but also on the angle of light coming that is ideal for photovoltaic processes.

Although the 45° reflector configuration recorded the highest peak power of 51.76 W (Table 1), the 60° configuration showed superior overall performance with the highest average output power (29.76 W) and the highest peak efficiency (23.39%). This difference highlights a crucial difference between peak power and total energy yield. High peak power is possible because at an angle of 45°, the reflection of light forms a highly focused 'hotspot' and is perfectly aligned with the sun's position at its peak. However, as the sun moves, this narrow focus quickly disappears. In contrast, a 60° angle is likely to result in a wider, consistent spread of reflection across the entire surface of the panel for a longer duration throughout the day. For practical applications such as battery charging, the higher total energy yield reflected by the superior average power is far more valuable than a momentary peak. Therefore, a 60° angle can be considered the most optimal configuration for overall energy harvesting.

From a techno-economic perspective, the addition of a mirror reflector shows high feasibility. Based on the cost analysis in this study, the implementation of reflectors is estimated to only increase the initial investment cost by around 5-10%. However, the resulting increase in output power reaches more than 200% at peak conditions compared to without a reflector far outstrips the additional cost. This significant increase in energy output and efficiency will directly accelerate the *Return on Investment* period and lower the *Levelized Cost of Energy* (LCOE) of floating solar PV systems. This makes the addition of reflectors a relatively low-cost modification strategy with a very high yield impact, increasing the overall economic viability of the floating solar PV project.

Comparison

To measure the contribution of this study, the results obtained were compared with several previous studies that focused on the optimization of solar panels using

reflectors. This comparison highlights the consistency of the findings as well as the significance of performance improvements achieved in the context of floating solar PV. Table 2 presents a quantitative comparison between this study and the key studies.

Table 2. Comparison of Research Results

Research	Focus/Method	Key Results	Comparison with This Study
Sidopekso & Febtiwiyanti (2010)	The use of flat mirror reflectors on static solar modules.	The largest power increase (92.76%) occurred at a reflector angle of 60°.	The results of this study are consistent, which also finds the 60° angle to be the most optimal.
Abdullah et al. (2024)	Four-sided reflector drive system to find the ideal angle.	An increase in output power by 16.75% at a 60° angle.	This study showed a more significant increase in power (increased peak power >200%), which indicates the high effectiveness of the reflector configuration in a floating system.
Ade (2021)	Utilization of 60° angle mirror reflectors for water pumps.	Battery charging 2 hours faster; voltage increase of 0.7% per hour.	These findings support the results of this study, where the increase in power and voltage directly speeds up the charging process.
This research	Flat mirror reflector on Floating Solar Power Plant with angle variations of 30°, 45°, 60°.	Increased peak efficiency of up to 23.39% and peak output power up to 51.76 W. 60° angle provides the most optimal performance overall.	Confirms that the 60° angle is highly effective and specifically demonstrates its potential in the context of floating solar PV, where the thermal efficiency of the water can

			contribute to higher yields.
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When compared quantitatively, the peak power increase observed in this study was more than 290% (from 13.12 W to 51.76 W) significantly exceeding the results reported by previous studies. For example, research by reported a power increase of 92.76%, noting an increase of 16.75%, although both also identified a 60° angle as optimal. This huge difference in performance is most likely due to the context of the application in the floating solar system. The natural cooling effect of the water under the panel is thought to play a significant role in keeping the panel's operating temperature low, even when receiving additional irradiation from the reflector. This allows solar cells to operate at higher efficiency, an advantage that the ground-based systems that have been the focus of previous studies do not have. (Abdullah et al., 2024)

The practical implications of this power increase are also in line with other findings. Research by , which also uses a 60° angle reflector, shows that increased power can speed up battery charging time up to 2 hours faster. A significant increase in average (Fuadiyah & Sudarti, 2022)output power in this study would directly contribute to such tangible benefits, shortening the time it takes to store energy and increasing the availability of power for loads, such as water pumps or lighting systems.

CONCLUSION

This research succeeded in providing a conclusive answer to each formulation of the problem posed. First, regarding the basic performance of the system, the test results on a floating solar power plant (PLTS) without the addition of reflectors showed a maximum *output* power of 13.12 W and achieved a peak efficiency of 9.71%. This data becomes a fundamental benchmark for evaluating the effectiveness of the use of reflectors.

Second, the use of mirror reflectors with angle variations of 30°, 45°, and 60° has been shown to have a significant influence on the increase in power harvesting. The entire experimental configuration showed a clear improvement in performance compared to the control conditions, which confirms that the addition of reflectors is an effective optimization method for floating solar PV.

Third, among the angle variations tested, the 60° tilt angle was identified as the most maximal configuration in improving power harvesting. At this angle, the system was able to achieve the highest energy conversion efficiency of up to 23.39% and

produce the most superior average power output, making it the most optimal angle in the study.

In synthesis, these findings strongly support the hypothesis that reflectors can optimize the performance of floating solar PV. The main contribution of this study is quantitative proof of the magnitude of the performance improvement of more than 200% that can be achieved. The practical implication is that the application of reflectors with the right angle can significantly improve the economic viability of floating solar PV projects.

The limitations of this study lie in the relatively short duration of the test and the use of manual recording methods. For future research, it is recommended to implement some improvements to improve the validity and scope of the findings. First, the use of an automatic data logger system will allow for more precise, continuous data retrieval, and reduce the potential for *human error*. Second, follow-up research should explore wider variations of angles and different reflector materials (e.g., polished aluminum or reflective film) to compare effectiveness and cost. Finally, conducting tests at different water locations (e.g., reservoirs with different water depths or temperatures) can help validate the findings and examine the influence of environmental variables on the synergy of floating and reflector solar systems.

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