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Experimental Comparison of Planar and Parabolic Reflectors for Improved Photovoltaic Output

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Abstract: The global demand for renewable energy sources has propelled advancements in photovoltaic (PV) technology, aiming to enhance the efficiency and cost-effectiveness of solar power generation. This study empirically examines how reflector geometry affects photovoltaic (PV) system performance by contrasting flat and parabolic reflector designs. The two reflector types were tested in a controlled outdoor area with the same ambient factors and solar irradiation. Over 30 days, important performance indicators such as power output, current-voltage characteristics, and temperature impacts were measured. Because parabolic reflectors are better at concentrating diffuse and directing sunlight, the results show that they can increase PV output by up to 28% compared to planar reflectors. Planar reflectors, on the other hand, showed less vulnerability to hotspot development and more uniformity in light distribution. The results provide useful insights for developing reflector-integrated PV systems in a variety of climatic settings by highlighting the trade-offs between operational stability and efficiency benefits.

Keywords: Photovoltaic system, Reflector geometry, Parabolic reflectors, Planar reflectors, Power output

Introduction

Photovoltaic (PV) systems play a pivotal role in the transition to renewable energy due to their numerous advantages and wide range of applications. Solar energy is a reliable and sustainable resource that contributes to reducing environmental pollution and carbon dioxide emissions (Sarayu et al., 2023). PV systems facilitate the development of zero-energy buildings and enable households to function as small-scale energy producers (Islam, 2023). Their low maintenance requirements and affordability make them particularly suitable for decentralized electricity generation in urban environments (Vlad & Lungu, 2022). Recent advancements in PV technology, including material innovations and real-time monitoring algorithms, have further enhanced system efficiency and overall performance (Schilling, 2023). Additionally, PV systems offer a viable solution for electrification in remote areas, eliminating the need for costly grid infrastructure (Farooq & Talib, 2022). As a result, PV technology plays a crucial role in sustainable development by reducing energy consumption and mitigating greenhouse gas emissions.

Enhancing PV panel efficiency remains a key research focus. Several studies have emphasized the importance of maintaining optimal surface temperatures, utilizing dissipated heat, and capturing unused infrared photons to maximize electricity generation and efficiency (Kumari et al., 2023). The adverse effects of elevated module

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temperatures on power conversion efficiency have also been highlighted, with solutions such as multi-pipe copper cooling frames integrated with phase change materials (PCM) proposed to mitigate thermal losses and improve electrical performance (Saeed & Fazal, 2023). Furthermore, artificial intelligence (AI) techniques have been introduced to analyze efficiency degradation patterns and optimize the performance of PV modules and large-scale solar plants (Manimegalai et al., 2023). Additionally, the indirect benefits of rooftop PV panels have been explored, revealing their potential to reduce reliance on the electrical grid and facilitate net-zero energy consumption in buildings.

The integration of parabolic and planar reflectors has been widely investigated as a method to enhance PV panel performance. Research indicates that reflectors can significantly increase solar irradiance, short-circuit current (I_{sc}), and maximum output power (P_{max}), while having minimal impact on open-circuit voltage (V_{oc}) (Ismail et al., 2023). Reflectors effectively capture additional solar radiation compared to non-reflector PV systems, leading to power output improvements ranging from 5% to 37%, depending on factors such as PV module type, reflector geometry, and reflector inclination angle (Tsing, 2023). Studies have also examined the optimal reflector angles to maximize power generation, demonstrating variations in efficiency based on the orientation and positioning of the reflectors (F., 2023; Pradhan et al., 2022). Overall, both planar and parabolic reflectors have proven to be effective in enhancing PV system performance (Pradhan et al., 2022).

This study presents a real-time experimental comparison of two PV panels subjected to different reflector configurations under varying solar radiation and temperature conditions. One panel is equipped with planar reflectors, while the other utilizes parabolic reflectors. To ensure cost-effectiveness and maximize solar reflection, aluminum foil was selected as the reflector material. Aluminum foil is an economical and widely available reflective material, with a thickness ranging from 0.006 mm to an upper limit of 0.2 mm, as defined by the International Organization for Standardization (ISO). The findings of this study aim to provide insights into the practical implementation of reflector-integrated PV systems to improve energy yield and overall system efficiency.

Experimental Setup

The experiment was conducted in September 2024 at the Laboratory of Sustainable Development and Informatics (LDDI) in Adrar, Algeria, located at a latitude of 31.38° and a longitude of -2.15° . Two photovoltaic (PV) modules, each with a rated power of 150 W, were used to assess the impact of planar and parabolic reflectors on PV panel performance. The modules were installed at an inclination angle of $\alpha_2 = 31.63^\circ$ relative to the horizontal plane and oriented southward. The first PV module was mounted on a fixed metal support and equipped with two mobile planar reflectors (Belhadj et al., n.d.), allowing an inclination adjustment relative to the horizontal plane at $\alpha_1 = 25^\circ$, as illustrated in Figure 2 (Belhadj et al., n.d.).

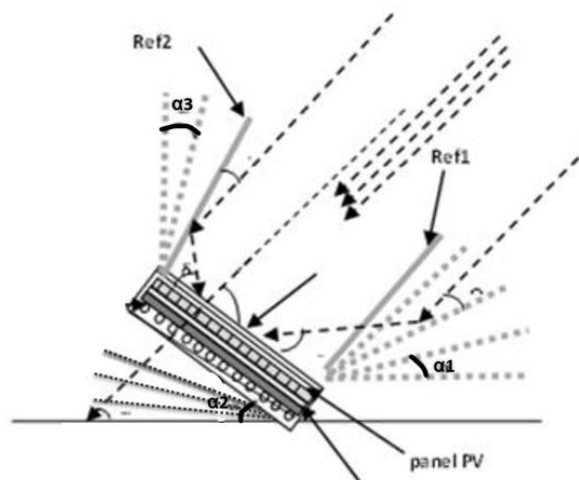


Figure 1. Diagram of PV panel with planar reflectors

The second PV module was also mounted on a fixed metal support but was paired with movable parabolic reflectors, which enabled inclination adjustments in relation to the vertical plane at $\alpha_3 = 25^\circ$ (Benlaria et al., n.d.), as depicted in Figure 2. The reflectors were covered with aluminized foil, a cost-effective material known

for its ability to reflect diffuse solar radiation. Each reflector had a length of 1480 mm and a width of 600 mm and was installed in a movable configuration to optimize sunlight redirection.

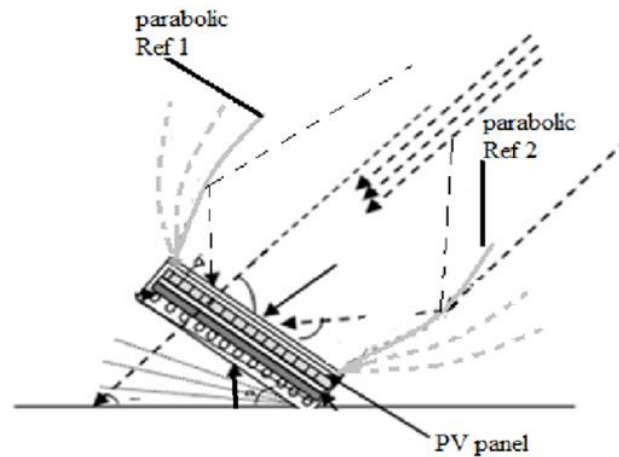


Figure 2. Diagram of PV panel with parabolic Bi-reflectors

The PV module specifications are given in Table 1 (at Standard Test Conditions 1.5 25 °C , 1000 W/m²).

Table 1. PV module specification

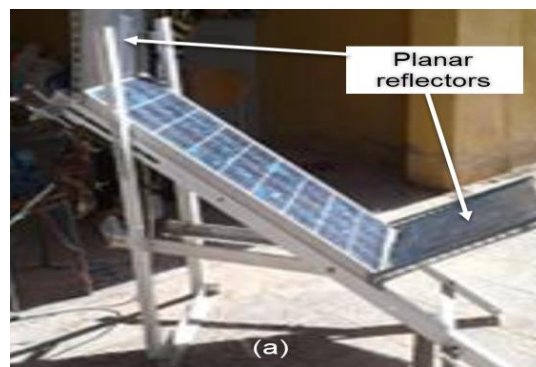
	Characteristic	Value
Current	Maximum Current (Imax)	8.34 A
Characteristics	Short Circuit Current (Ish)	8.98 A
Voltage	Maximum Voltage (Vmax)	18 V
Characteristics	Open Circuit Voltage (Voc)	22.54 V
Output Power	Maximum Power (Pmax)	150 W
	Standard Test Conditions	AM 1.5, 25°C, 1000 W/m ²

The output voltage and current were measured with a multimeter under various irradiance and temperature conditions. According to the solar panel specifications that we use, with the equation we can calculate the output power of solar panel that is (Khanna et al., 2013):

$$\begin{aligned}
 P_{OUT} &= V_{OC} \times I_{SC} \times FF \\
 P_{OUT} &= 22.54 \times 8.98 \times 0.74 \\
 P_{OUT} &= 149.78W
 \end{aligned}$$

we can calculate the solar panel's maximum efficiency output, which is defined by the percentage of optimum output power (Wong et al., 2010),

$$\eta = \frac{P_{OUT}}{P_{IN}} \times 100\%$$



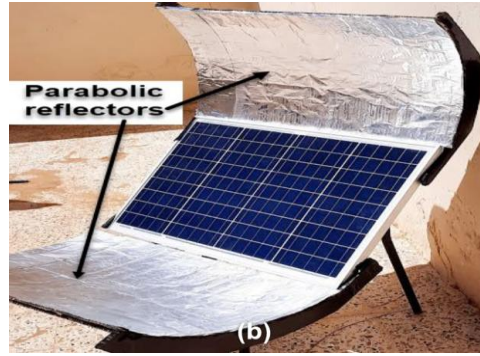


Figure 3. Experimental setup of PV modules with reflectors (a)with planar Reflectors - (b) with Parabolic Reflectors

The working principle of solar panel with optical reflectors is to obtain the maximum amount of sun radiation , Figure 3 illustrates the pv panels with optical (planar and parabolic) reflectors. Table 2 and table 3 illustrate the measurement of voltage, currant and power of the pv panels with planar and parabolic reflectors, the measurement was taken between 08:00 AM to 12:00 AM.

Table 2. Measurement results of PV panels with planar reflectors

Time	Voltage (V)	Current (A)	Power (W)	Optical Output
08:00	10	1.5	15	0.5
08:10	10.2	1.6	16.32	0.49
08:20	10.7	1.5	16.05	0.47
08:30	10.3	1.9	19.57	0.45
08:40	14	2	28	0.41
08:50	14.6	2.3	33.58	0.39
09:50	15	2.5	37.5	0.37
10:00	15.4	2.9	44.66	0.34
10:10	16	3	48	0.33
10:20	16.2	3.2	51.84	0.32
10:30	16.4	3.3	54.12	0.3
10:40	16.6	3.5	58.1	0.28

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10:10	16	3	48	0.33
10:20	16.2	3.2	51.84	0.32
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10:40	16.6	3.5	58.1	0.28

Results and Discussion

We conducted a comparative analysis of the experimental results by evaluating key performance parameters, including short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), output power, and surface temperature of the PV modules equipped with planar and parabolic reflectors. The test results are presented in the corresponding figures.

For temperature measurements, data were recorded between 08:00 AM and 03:00 PM to assess the impact of temperature variations on PV panel performance. This time range was selected to capture the effects of solar irradiance and ambient temperature fluctuations throughout the peak sunlight hours.

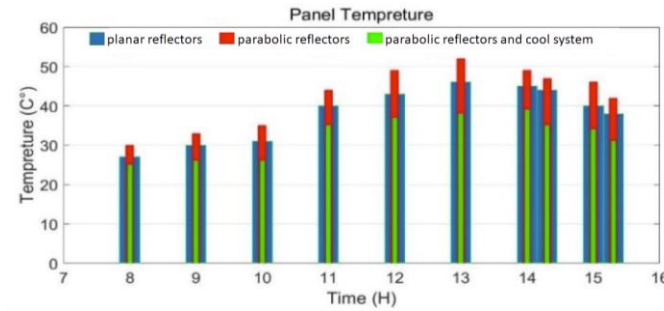


Figure 4. Solar panels temperature

The use of parabolic reflectors resulted in a steady increase in the surface temperature of the PV module, rising from 30°C at 08:00 AM to 52°C at 01:00 PM. In contrast, the surface temperature of the PV module equipped with planar reflectors increased from 27°C at 08:00 AM to 45°C at 01:00 PM, as illustrated in Figure 4. This difference indicates that parabolic reflectors, due to their enhanced concentration of sunlight, lead to higher thermal accumulation on the PV surface compared to planar reflectors.

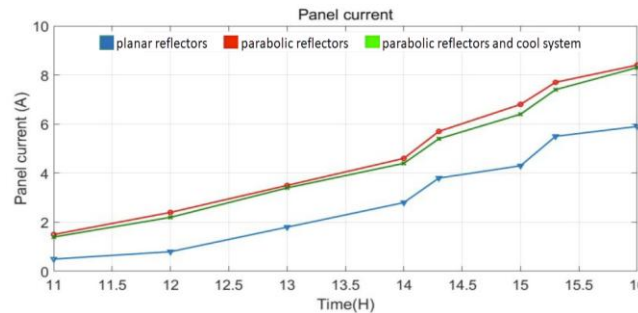


Figure 5. Panels output current.

Figure 5 presents the comparison of PV module current measurements between the panel equipped with parabolic reflectors and the panel with planar reflectors. The results indicate that the current PV panel with planar reflectors remained within the range of 0.5 A to 5.5 A, whereas the PV panel with parabolic reflectors exhibited a higher current range of 1.5 A to 8 A. This increase in current for the panel with parabolic reflectors can be attributed to the enhanced solar irradiation concentration provided by the reflector geometry, which effectively directs more sunlight onto the PV surface, thereby improving electrical performance.

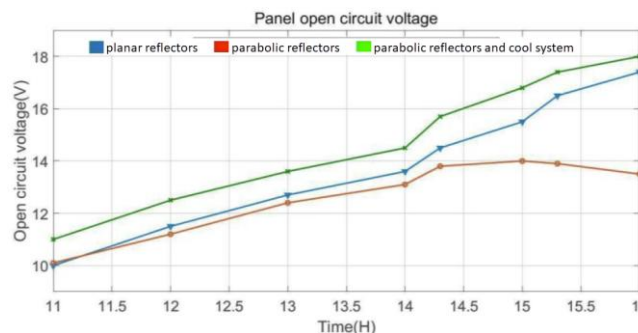


Figure 6. Panels Voc open circuit voltage

Figure 6 illustrates the open-circuit voltage (Voc) variation of the PV modules equipped with parabolic and planar reflectors. The results show that the Voc of the PV module with parabolic reflectors remained within the range of 10 V to 13 V, whereas the Voc of the PV module with planar reflectors was maintained between 11 V and 18 V. This reduction in Voc for the parabolic reflector configuration is primarily due to the higher surface temperature of the PV module, which negatively impacts the voltage output as temperature increases.

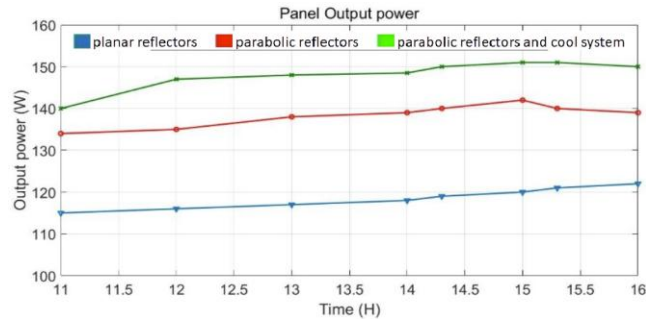


Figure 7. Panels output power

Figure 7 presents the output power measurements of PV panels equipped with planar and parabolic reflectors. The results indicate that the output power of the PV panel with planar reflectors ranged between 105 W and 117 W, whereas the PV panel with parabolic reflectors exhibited a higher output power range of 125 W to 139 W. This increase in power output for the parabolic reflector configuration is primarily attributed to the higher current generation, resulting from the enhanced solar irradiation concentration provided by the reflectors.

Conclusion

This study investigated the impact of solar irradiation enhancement on PV system performance through the integration of planar and parabolic reflectors. The experimental findings demonstrate that the use of reflectors significantly increases the output current and power of PV panels by redirecting additional sunlight onto the module surface. However, this technique also results in a temperature rise, with the parabolic reflector configuration causing surface temperatures to reach up to 55°C, which may negatively affect module efficiency and longevity.

The results indicate that parabolic reflectors outperform planar reflectors in enhancing PV panel output performance, as they enable a greater concentration of solar irradiation, leading to a higher increase in output power. Nevertheless, this advantage comes with a major drawback, as the excessive heat accumulation on the PV module surface can lead to thermal stress and potential panel degradation over time. To address this limitation, the integration of cooling systems is recommended to regulate surface temperature and maintain optimal operating conditions.

Overall, the use of reflectors presents a cost-effective and practical solution for improving PV system efficiency, particularly in high solar radiation regions. Further research is needed to explore hybrid reflector-cooling systems to mitigate thermal effects while maximizing energy yield.

Recommendations

To improve the performance of PV systems with reflectors, it is recommended to integrate cooling solutions, especially with parabolic reflectors, to reduce the risk of overheating and damage. Future studies should focus on optimizing reflector angles and materials to balance efficiency and thermal impact. The use of hybrid systems combining reflectors with smart control and monitoring can enhance performance. Finally, an economic analysis is suggested to evaluate the cost-effectiveness of using reflectors, particularly in hot climates.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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