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# Photovoltaic module augmented by commercial reflectors in Southern Algeria: Comparison between different reflective materials

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ABSTRACT
Even though the southeast region of Algeria, especially Ouargla city, enjoys a lot of sunshine all over the year, fixed photovoltaic (PV) solar panels are not sufficient due to two main reasons. Firstly, these panels are unable to capture sunlight during the early morning and late afternoon, and secondly, their efficiency is low, requiring the use of economical methods to enhance their performance. To overcome these limitations, this research suggests incorporating commercial reflectors to enhance sunlight capture. Furthermore, this paper compares the effects of three types of reflective materials: mirrors, aluminium, and transparent glass, on the performance of the PV module. To achieve this objective, reflectors are installed at the top and bottom of the PV module at their optimal tilt angles. Moreover, the effect of the adjacent module's mirrors was studied by installing two big mirrors (3X). The obtained results show an average improvement of 14.24 %, 11.41 %, and 4.7 % in the electrical energy generated by the PV panel with mirrors, aluminium, and transparent glass, respectively, compared to the module without reflectors. Subsequently, in the large mirror case, the results were positive, with an average 20.84 % increase in the maximal electrical power produced compared to the conventional one.

**Section:** RESEARCH PAPER

**Keywords:** PV panel; solar irradiation; flat plate reflectors; reflective materials; electrical measurements; southern Algeria

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## 1. INTRODUCTION

The world has been using solar energy more frequently in recent years, which has required a lot of work. To generate power from sunshine, solar photovoltaic systems are commonly employed [1]-[8]. Therefore, increasing solar gain with commercial booster reflectors for fixed PV modules is a crucial topic of study in the context of lowering the systems' cost. Moreover, solar concentrator has been investigated as one of the most effective and cost-effective solutions for increasing the energy produced and efficiency of a solar PV system.

In the last decades, various research studies have investigated the use of different types of reflectors at different emplacements and angles to enhance the performance of flat plate solar collectors [9]-[16]. On the other hand, numerous papers have studied the impact of this economical solution (reflectors) on the PV panel efficiency [17]-[26]. For example, Rönnelid et al. [17] experimented with the efficacy of PV modules with flat reflectors of variable length and inclination under Swedish conditions. They demonstrated that a no-tracking planar reflector can augment the PV modules' annual output by 20–25 %. Recently, in Dezful, Iran, with very hot summers, Ekbatani et al. [18] studied the integration of reflectors with the PV module and their influence on its power output. They discovered a 4.1 % increase in electrical output when compared to the standard one. Again, using both experimental and MATLAB simulation methods, Azhan et al. [19] investigated the use of mirror reflectors to increase the efficiency of solar PV panels. They analysed the impact of using various reflector types at different angles on the performance of monocrystalline solar PV panels. They concluded that the percentage increase in output power was

37 % for aluminium, 35 % for white, and 22 % for mirror reflectors. In another study, Palaskar et al. [20] presented the design and performance study of a commercial silicon-based PV panel with anodized aluminium sheet reflectors mounted to the PV modules' shorter sides in a north-south direction. They examined and debated the performance of photovoltaic modules at various module tilts and reflector orientations.

Subsequently, in order to find the ideal geometric and optical parameters that maximise the power output at two chosen locations (Cairo, Egypt, and Ma'an, Jordan), for different panel technologies (monocrystalline, polycrystalline, and thin film), and for various commercial reflectors, Hamed et al. [21] developed a novel genetic algorithm in MATLAB R2020a. For the three PV systems, they discovered that the ideal system designs improved yearly energy output up to 6.05 %, 5.14 %, and 8.34 %, respectively. Agrawal et al. [22] discovered an effective method for artificially enhancing solar photovoltaic performance by using a flat commercial stainless-steel (SS) reflector. The yearly energy gain was calculated at 18.35 %, but it increased to 34.16 % after the reflector dimension was adjusted for the Jaipur location (26 °N).

Additionally, within the latitude range of 20-30 °N, the gain improved to 28.31 % - 31.33 % for effective reflector size. Moreover, Zubeer et al. [23] evaluated the efficacy of a

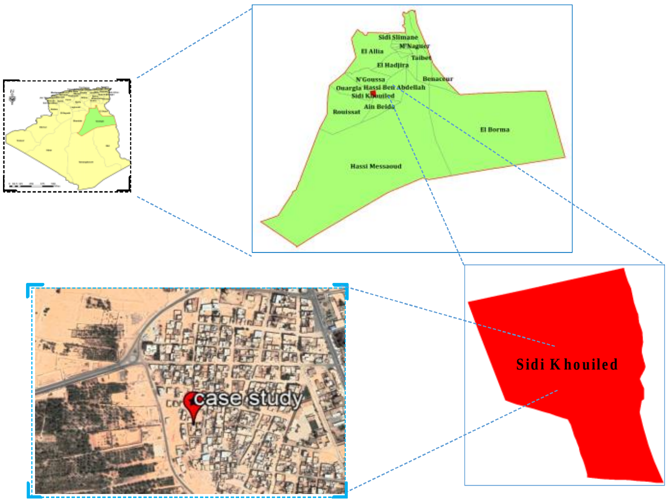


Figure 1. Geographical position of Sidi Kouiled village.

Figure 2. Installation of reflectors on the PV module

conventional PV module, a concentrated PV (CPV) system, and a water-cooling CPV system in the climate of Duhok, Iraq. They determined that the electrical power produced by the water-cooling CPV system and the CPV system enhanced by 24.4 % and 10.65 %, respectively. In addition, the electrical efficacy of the PV panel improved from 14.2 % to 17 % by incorporating reflectors and a water-cooled technique. The changes in the power gain of three different PV module types (polycrystalline, thin film, and monocrystalline) before and after using reflecting panels under Egyptian climatic circumstances were practically investigated by Ahmed et al. [24]. They discovered that the PV systems' total output power measured the lowest and maximum average power ratios of 1.2157 and 1.3185, respectively. This indicates that the total output yield power had grown by a range varying between 21 % and 31 % in comparison to the basic output. Furthermore, the performance of solar photovoltaic panels was enhanced by Kumar et al. [25] by combining inexpensive aluminium reflectors, aluminium sinks, and phase change material (PCM) with zinc oxide (ZnO) nanoparticles. They found that, in comparison to the uncooled PV panel, the average maximum power output of the PV/PCM and the reflector/PCM/nanoparticles rose by 12.18 % and 18.16 %, respectively. On the other hand, Al Asfar et al. [26] examined experimentally the performance of bi-axial solar tracking systems with various reflector materials utilising commercial silicon-based photovoltaic modules. This study deduced that the modified module with reflectors produced 5 % more PV power than the two-axis solar tracking systems without reflectors and 12.5 % more PV power than the fixed PV module with a 26 ° inclination angle. M. Asvad et al. [27] investigated the effects of several types of reflectors on PV panel performance. They discovered that those reflectors may increase the power output of the solar module by up to fourfold, but that an increase in module temperature would have a negative impact on the module's efficiency. In another study, D. Malwad et al. [28] conducted a comprehensive analysis of reflector material testing specifically for concentrated solar power. The researchers determined that the glass mirror and aluminium are the primary components suitable for the solar collector.

In our previous study [29], we simulated the annual solar irradiation reflected on the PV module surface from the top planar mirror and from the bottom one (those mirrors have the same dimensions as the PV panel and are placed very close to the sensitive surface of the PV module). We concluded that the reflected sunlight from the top mirror takes a minimum in the summer period and a maximum in spring and autumn. On the other hand, the irradiation reflected from the bottom one extended their superior in the summer months when the sun will be at its highest and less so in the winter when the sun will be at its lowest. As previously stated, it is clear that the two mirrors are mutually complementing, and the optimal approach for capturing the highest possible amount of solar radiation reflected on the panel's surface throughout the year is to use them simultaneously. Additionally, to mitigate the end-effect caused by the short mirror length, larger mirrors were fitted to achieve enhanced uniformity of solar irradiation captured throughout both morning and afternoon periods.

So, the main goal of this experiment is to improve the performance of fixed solar photovoltaic panels by using two planar reflectors made of mirror (M), aluminium (Al), and transparent glass (TG) at the top and bottom of the panels in Sidi Kouiled village, Ouargla city, south-east Algeria. Those PV modules are tilted at the latitude angle of the Ouargla region and

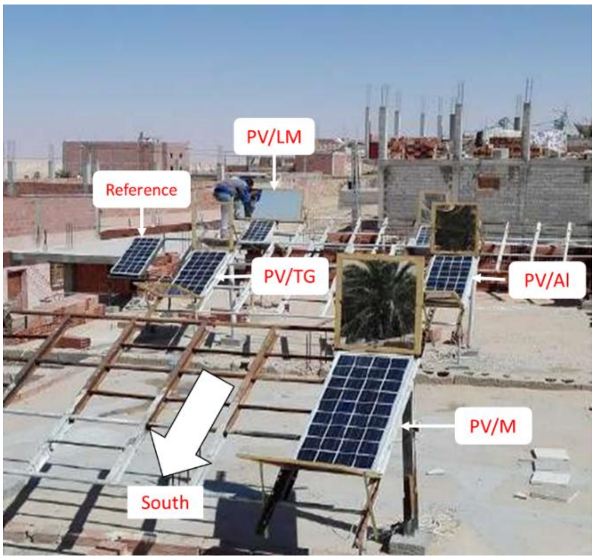


Figure 3. System description.

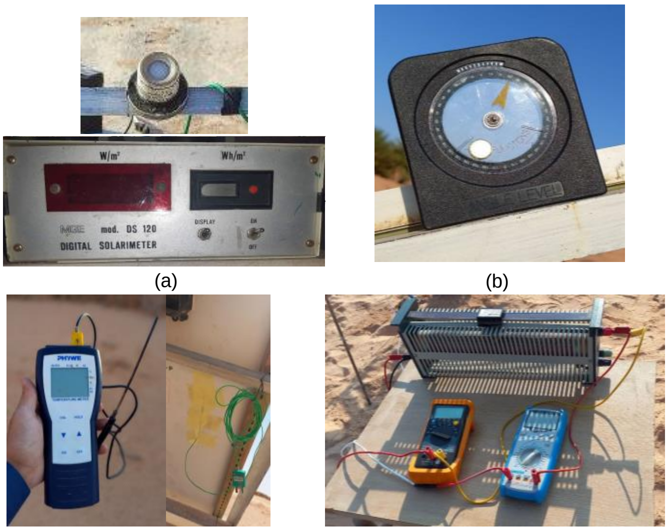


Figure 4. Instruments used in the experiments.

oriented due south. The effect of the adjacent module's mirrors will be taken into account in this study. It's very important to declare that statistical evaluation of the obtained results is beyond the scope of the study.

To achieve this objective, the present study is structured as follows: Section 2 describes the methodology employed in the experimentation. This section begins with an exploration of the climatic conditions in the test region and introduces the measuring instruments used to obtain the results that will be presented and discussed in Section 3. In the latter Section, a comprehensive comparison of the performance of PV modules augmented by planar reflectors made from various reflective materials is conducted. Additionally, this Section presents and analyses the effects of the adjacent PV module reflectors. Finally, Section 4 serves as the conclusion, summarising the principal findings from this study and providing insightful suggestions based on the present research.

## 2. METHOD

### 2.1. Geometrical situation & climatic conditions of the test region

As shown in Figure 1, the village of Sidi Khouiled (Ouargla region, southern Algeria) covers 5.164 km² and is at 164 m, 31° 57' N, 5° 21' E. It is characterised by a desert environment; hence, the summers are quite hot, and the winters are mild. There is very little precipitation, and the sky remains clear for most of the year (135 days on average) [29].

### 2.2. Description of the System

In order to accomplish the objective of this research, the studied system is composed of four identical PV panels (i.e., reference, PV/M, PV/Al, and PV/TG), which have the electrical properties shown in Table 1, were used in experiments to evaluate their electrical efficiency. All reflectors have the same width as the PV module, with a length of 60% of the PV panels', and are tilted at their optimum inclination angles to reflect maximum sunlight on the PV module surfaces. In addition, the influence of the adjacent panels will be investigated by adding two large mirrors (LM) to the fifth module (PV/LM) (See Figure 2 and Figure 3).

The different structures are spaced apart from each other to prevent shading as well as multiple reflections.

### 2.3. Measurement apparatus

Several measuring instruments were used in the experiments conducted in this study to record electrical and thermal parameters, tilt angles, and the intensity of global solar radiation for different structures.

For solar irradiation measurement, a DS 120 digital solarimeter with an external probe (Silicon photodiode) was used by placing its probe at the centre of the PV module for each structure, as shown in Figure 4(a).

To set the tilt angles of both reflectors and the PV panels, an Actu Angle inclinometer was used, as exposed in Figure 4(b). While the ambient temperature and that of the PV module were measured using K-type thermocouples, as described in Figure 4(c). Figure 4(d) shows the electrical apparatus for recording current, voltage, and electrical power output of the PV module.

### 2.4. Procedure of experiments

As shown in Figure 3, five different structures have been installed in the test region, in which all photovoltaic modules are tilted at the latitude of Ouargla city (≅ 32°) and facing south. One of them is considered a reference, while the others are equipped with two reflectors (made of different reflective materials and having the same dimensions) on their top and bottom sides. The fifth one is equipped with large mirrors.

Under outdoor climate conditions on a clear day (April 29, 2018) from 08:00 to 19:00 local time, solar irradiation captured by five structures, ambient temperature, the temperature of PV panels, and electrical parameters (current, voltage, and power) of the photovoltaic modules were hourly evaluated and recorded experimentally using the measurement apparatus shown in Figure 4.

Table 1. Characteristics of the PV panel.

| Parameter | Specification |
|---|---|
| Type | TE 500-P |
| peak power, $P_{max}$ | 55 W |
| maximum power voltage, $V_{mp}$ | 17.5 V |
| maximum power current, $I_{mp}$ | 3.14 A |
| open circuit voltage, $V_{oc}$ | 22.2 V |
| short circuit current, $I_{sc}$ | 3.5 A |

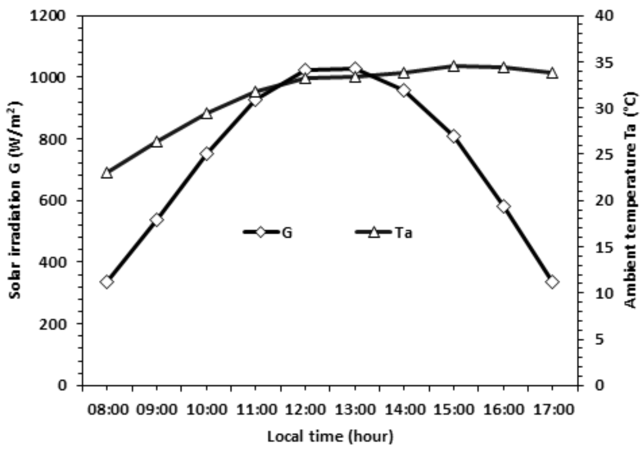


Figure 5. Solar irradiation and ambient temperature on the day of tests.

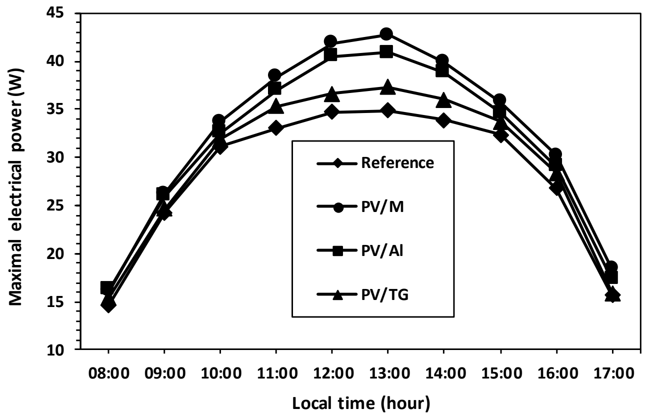


Figure 7. Maximal electrical power produced by structures with different type of reflector on April 29, 2018.

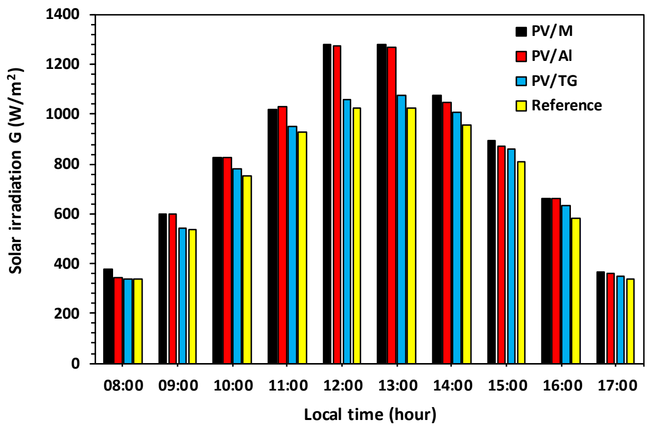


Figure 6. Captured solar irradiation on structures with different type of reflector on April 29, 2018.

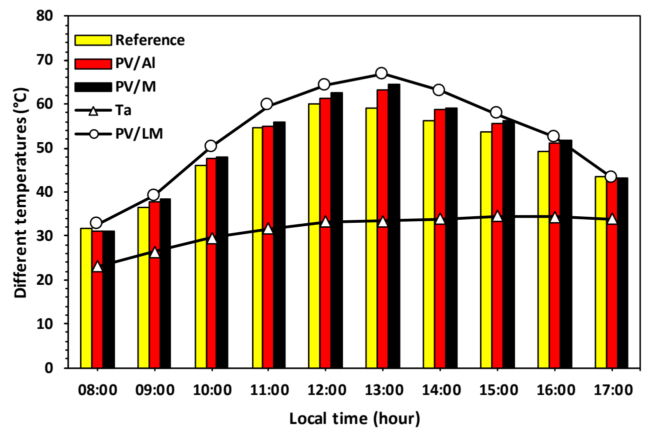


Figure 8. Ambient temperature (Ta) and temperature of different PV modules.

## 3. RESULTS AND DISCUSSIONS

Figure 5 presents the daily solar irradiation (G) and ambient temperature (Ta), recorded on April 29, 2018, from 08:00 to 19:00, as a function of local time. It was a highly sunny day with clear skies, an average ambient temperature of 31.25 °C, and a peak solar irradiation of 1025.6 W/m² recorded at 13:00 local time.

### 3.1. Comparison between Different Type of Reflectors

In this section, we compare between three structures (PV/M, PV/Al, and PV/TG) and the conventional one (see Figure 3), in captured sunlight and electrical power output.

Figure 6 depicts the daily variation of solar irradiance collected by PV surface modules of various structures as a function of local time. Throughout the entire day of testing, the reflective mirror is clearly superior to the others, followed by aluminium and then transparent glass. At 13:00 local time, all structures captured their maximal amount of sunlight: 1279.6, 1272.8, 1077.6, and 1025.6 W/m² for PV/M, PV/Al, PV/TG, and reference, respectively. The variation in the collected solar irradiance increase was caused by the different reflectance of used materials.

Similarly, all PV modules reached their maximum power output at 13:00 in which PV/M produced 8 W, 5 W, and 2 W more than the reference, PV/TG, and PV/Al, respectively, as shown in Figure 7.

Due to the difference in solar radiation concentration on the receiving surface of the five structures (see Figure 8), the PV modules will be heated in different ways. As a result, the PV/LM heats up more rapidly than the others, followed by PV/M and PV/Al, respectively. Moreover, a significant gap is observed between the ambient temperature and that of the PV modules, as exposed in Figure 9, reaching its maximum (33 °C) at 13:00 in the PV/LM, which represents the major drawback of this technique, requiring cooling during these periods.

### 3.2. Effect of the adjacent module reflectors

Figure 9 exposes a comparison between the maximum electrical power produced by structures with mirror reflectors (PV/M and PV/LM) compared to the reference. The power output of PV/LM was superior to that produced by PV/M during the majority of time, except for the period between 12:00 and 13:00, which is due to the strong heating of the PV/LM in this period (see Figure 8).

### 3.3. Increment percentages in electrical power output

Due to the limited timeframe of the collected results, the determination of the optimal reflecting material is based primarily on preliminary observations rather than statistical analysis. Therefore, among the three types of reflective materials, mirror was the most effective during the majority of the day, with an average maximum electrical power output increase of 14.24 %, followed by aluminium and transparent glass with increases of 11.41 % and 4.7 %, respectively, as shown in

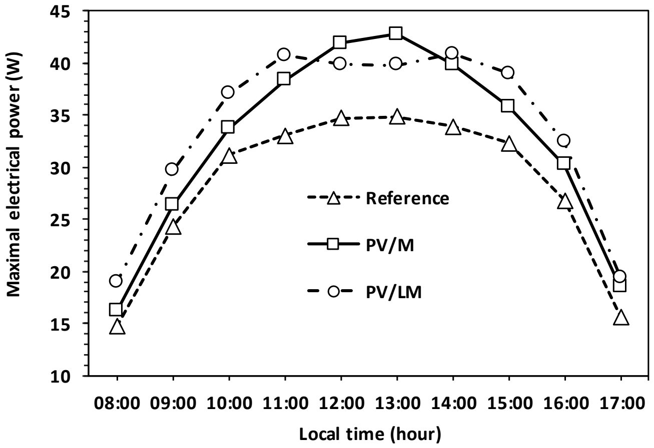


Figure 9. Maximal electrical power produced by PV/M and PV/LM compared to the reference in April 29, 2018.

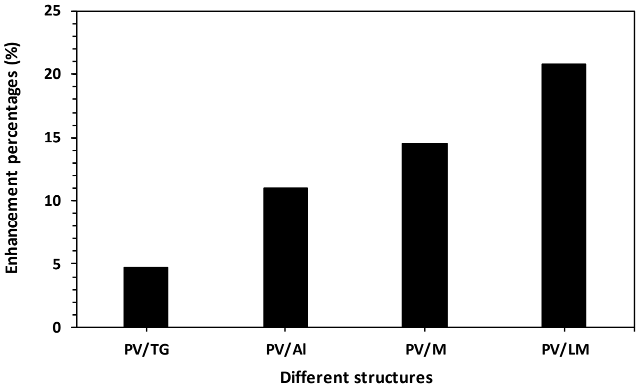


Figure 10. Average electrical power produced enhancement percentages of different structures compared to the reference.

Figure 10. In addition, in PV/LM structure, the power output increment percentage was 20.84 % compared to the conventional one.

These percentages can be further improved if the structures are equipped with a cooling system, which will be the objective of the next study.

## 4. CONCLUSION

This paper investigates experimentally the performance of PV modules augmented by two reflectors made of different reflective materials under Sidi Kouiled climatic conditions (Ouargla city, southern Algeria). Again, the effect of adjacent module mirrors was also studied in this research. The most commonly obtained results are listed as follows:

1. Adding reflectors to the PV module has a positive effect on its performances,
2. Mirrors are the best reflective materials between aluminium and transparent glass,
3. PV modules with mirror reflectors increases the average maximum power output compared to the conventional one by 14.24 %, 11.41 %, and 4.7 % for aluminium and transparent glass reflectors, respectively.

Finally, this work suggests equipping the PV module with an economical flat plate reflector, especially planar mirrors in order to improve their performances. But under hot conditions, the whole system must be cooled.


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