Effect of Increasing Solar Radiation Reflected with Mirrors Perpendicularly on the Power Output of Photovoltaic System with Cooling

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Abstract. Solar energy is one of the most popular renewable energies in the world as solar energy can be easily accessed throughout most places of the world. However, converting solar energy into other sources of energy is not very cheap and numerous efficiency improvements methods are under investigation by researchers around the world. The current study proposes a low concentration photovoltaic system (LCPVS) with 4 mirrors and cooling. The aim of this project was to examine how using mirrors to concentrate solar radiation affects the amount of power generated by solar panels. The mirrors (ranging from 1 to 4) radiated the sun reflection onto the panel with a cooling system. The results obtained from the proposed project were compared to the results collected from the normal panel without concentration to measure the differences which revealed that the proposed system output power was almost three times more than conventional photovoltaic (PV) panel without concentration.

1. Introduction
The demand for energy and concerns over the climate changes have been the pressing issues within the current world [1]. Energy is also closely related to environmental, economic, social, and human development factors. Thus, safe and abundant sources of energy are always the main concern of the social development of countries [2,3]. Attempts are being made to substitute fossil energy sources with renewable sources of energy due to environmental and social concerns over fossil energy sources [4-6]. One source of renewable energy which can be easily accessed in almost most parts of the world is solar energy [7]. According to the World Energy Outlook report, photovoltaics are considered to be the most commonly used technique that can convert solar radiation to electric current [8]. The concentrator photovoltaics (CPV) is seen as the most promising technique to produce electricity from solar energy, especially in areas where high direct normal irradiance exists [9].

The efficiency of a solar panel with a flat mirror was studied by Faten Sh. et al. [10]. They used two mirrors to focus sunlight to increase the efficiency of the solar panel system. It was shown in their experiments, using the mirror can increase the efficiency of the panel from 51% to 64%. In another study, Gokul et al. [11] investigated the performance of photovoltaic (PV) Cell output power by
Cooling and with Mirror. The efficiency of PV cells with and without mirrors is compared using their proposed model, which is simulated in MATLAB. The study findings demonstrated the average power boost of 54% when they were integrated with a cooling system by the mirror. Further, Ramy et al. [12] examined the performance of 3 types of solar panels before and after applying reflecting panels. The results indicated that the highest average power ratio of the whole 3 types is increased by about 42% from the normal system without reflection.

Research in this area has focused on various aspects of solar panels, namely new shapes, orientation, cooling and ideal tilt angle of solar panels, with or without tracking [13-17]. The studies reviewed before indicated that most majority of the mirror panel configurations increased energy production. However, none of the studies have focused on the power output enhancement through the optimized perpendicular systems of mirrors on the low concentrator photovoltaic system (LCPVS). Thus, this study conducted an experimental study to determine how adjusted perpendicular mirrors improved the performance of the LCPV system. The study attempted to examine the variation in the solar panel power output when they are integrated with mirrors to concentrate radiation. To better evaluate the features of the constructed system, the obtained results from this experiment were compared to the results of a normal PV system [18].

2. Materials and methods

The suggested LCPVS was in fact a normal solar panel with mirrors attached to a wooden stand that could adjust the angle of the mirrors. Thus, for the experiment in this study, we employed 2 normal PV panels, with and without a concentrator with mirrors; in the mirrored one, attempt was made to keep the solar reflection from the mirrors in direct perpendicularity with the PV panel. The Wooden stand also allowed the four mirrors to be adjusted into the system. It should be noted here that all the mirrors used were of plane types. It is also noteworthy that during the experiment, the value and quantity of reflection of sunlight by the mirrors were equal to the entire surface of the mirrors and was reflected in the most perpendicularity position possible on the whole surface of the PV panel.

Various experiments were conducted, and the specs of the used PV panels are model number is Polycrystalline DS-A1-15, Pmax=15 W, Vmp= 17.3 V, Im= 0.87 A, Voc= 21.6 V, Isc= 0.96 A, temperature coefficient of Vmp=-0.38 %/°C, temperature coefficient of Im= +0.1 %/°C, Operating temperature range= (-40°C ~ 85°C), weight 1.8 Kg, Power Tolerance 5%. Four digital multimeters, infrared thermometer, Eppley Radiometer PSP model, were applied for the measurement of solar radiation, short-circuit current (Isc) open-circuit voltage (Voc), and surface temperature from the PV panel.

To accurately estimate the amount of radiation, the time of the day and the date of the year needs to be precisely specified. For this purpose, direct global solar radiation amount is of utmost importance. The sun's location is usually calculated using 2 angles: solar azimuth α and solar altitude γ. The sun elevation and sun azimuth are determined by the date and time of day, as well as the viewer's geographic location. This experiment was conducted at Eastern Mediterranean University, Famagusta, Northern Cyprus, Standard Time zone = GMT+2 (see figure 1. for the location of the sun).

![Figure 1. Angle designations for the sun's location.](image)
3. Experimental with and without concentration

The experiment in this study was conducted through 1 to 4 concentrating mirrors reflecting the sun radiation onto the PV panel between 09:00 a.m. to 03:00 p.m. in September 2020 under Famagusta, Cyprus climatic conditions [18]. Initially, all reflections of four mirrors were adjusted manually to the PV panel in the most perpendicular position. Then we covered the three mirrors and the reflection of the sun was done with 1 mirror to the surface of the PV panel. The amount of solar radiation, DC current (A), DC voltage (V), and surface temperature was measured hourly. The same was done with 2, 3, and 4 mirrors, and the results were recorded. No shading was observed during the experiments as it could affect the PV system. The results were also compared with the results obtained from a conventional PV panel without concentration. The study aimed to see how the use of mirrors enhanced the output power. Figure 2 shows the proposed system with 4 mirrors.

![Figure 2. The set-up for the experiment.](image)

4. Results and discussion

The data were obtained on an hourly and are denoted in table 1. Solar radiation's intensity onto the PV panel on an hourly basis increased 3 times more than the conventional PV panel without a mirror when the number of mirrors used was 4. It is important to note that the intensity of radiation increased over three times when compared to the conventional PV Panel without a mirror.

| Time   | 1 Mirror (W/m²) | 2 Mirrors (W/m²) | 3 Mirrors (W/m²) | 4 Mirrors (W/m²) | Conventional PV (W/m²) |
|--------|----------------|------------------|------------------|-----------------|------------------------|
| 9 a.m. | 778.57         | 1386.90          | 1967.85          | 2602.38         | 825.85                 |
| 10 a.m.| 853.57         | 1503.57          | 2145.23          | 2816.66         | 902.04                 |
| 11 a.m.| 884.52         | 1558.33          | 2210.71          | 2873.80         | 930.61                 |
| 12 a.m.| 878.57         | 1526.19          | 2199.99          | 2863.09         | 934.69                 |
| 1 p.m. | 860.71         | 1502.38          | 2129.76          | 2773.80         | 911.56                 |
| 2 p.m. | 822.61         | 1473.80          | 2101.19          | 2744.04         | 877.55                 |
| 3 p.m. | 736.90         | 1342.85          | 1916.66          | 2478.57         | 790.47                 |

4.1. Power (W) of proposed LCPV system

Table 2 shows the DC power (W) generation for conventional PV panel and the proposed system. The results showed that the average output generation without the load on the proposed system was almost 3 times higher than the conventional PV panel. This increase in DC power was related to the perpendicularity of the sun radiation to the surface of the solar panel. The outcomes validated the proposed system's efficacy (LCPVS with cooling by 4 mirrors).
Table 2. Time vs. average power, current, and voltage of the test days in September 2020.

| Time   | DC Voltage (V) for 4 Mirrors with Cooling | DC Voltage (V) for Conventional PV | DC Current (A) for 4 Mirrors with Cooling | DC Current (A) for Conventional PV | DC Power (W) for 4 Mirrors with Cooling | DC Power (W) for Conventional PV |
|--------|------------------------------------------|-----------------------------------|------------------------------------------|-----------------------------------|----------------------------------------|---------------------------------|
| 9 a.m. | 19.31                                    | 19.64                             | 2.54                                     | 0.86                              | 49.15                                  | 16.99                           |
| 10 a.m.| 19.08                                    | 19.31                             | 2.73                                     | 0.94                              | 52.19                                  | 18.23                           |
| 11 a.m.| 19.08                                    | 19.25                             | 2.79                                     | 0.97                              | 53.38                                  | 18.77                           |
| 12 a.m.| 19.19                                    | 19.59                             | 2.75                                     | 0.96                              | 52.96                                  | 18.97                           |
| 1 p.m. | 19.40                                    | 19.77                             | 2.70                                     | 0.94                              | 52.46                                  | 18.76                           |
| 2 p.m. | 19.41                                    | 19.60                             | 2.67                                     | 0.92                              | 51.85                                  | 18.12                           |
| 3 p.m. | 19.49                                    | 19.71                             | 2.41                                     | 0.85                              | 47.11                                  | 16.80                           |

5. Conclusion

Two different systems were used in this study; with concentrator by mirrors and without concentrator. The aim of the experiment was to increase the amount of solar radiation reflected onto the same PV surface in order to boost output power. Moreover, employing mirrors reduced the size of the solar panels and proved to be more economical. The findings of this study revealed that solar radiation significantly enhanced the efficiency of the PV panel, as the average output power of the proposed system reached 2.84 times higher compared to conventional PV panel. According to the findings, the cooling system had a significant impact on the output power of the proposed system. Therefore, the authors do not recommend the LCPVS by 4 mirrors without cooling.

6. References

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