Effects Of Reflectance And Shading On Parabolic Dish Photovoltaic Solar Concentrator Performance

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Abstract: Photovoltaic concentrating systems have recently become one of the topics of interest to researchers around the world due to the high cost of semiconductors used in the manufacture of solar cells, as well as the wide area of traditional photovoltaic panels. The target can be met by compensating for the vast areas of solar cells with smaller cell areas made of reflective or refractive materials that concentrate higher intensity solar radiation to reach a higher outward power. In this research a parabolic dish solar photovoltaic concentrator is studied theoretically. The concentration ratio at the reflecting concentrator has been studied as a function of reflectance and shading losses under five different rim angles (45°, 55°, 65°, 75° and 85°) using equations simulated in the MATLAB software. Following that, the total absorbed solar radiation and output power provided by CPV with multi-junction solar cells. The results indicated that the concentration ratio increase linearly with reflectance, while it increases as the rim angle decrease. The best value of concentration ratio is about 172 for rim angle 45° and reflectance 95%.

Key Words: Solar concentrators, Parabolic dish PV concentrator, concentrators with Multi-junction solar cell

1. Introduction
Solar energy has the potential to be altered directly to electricity by photovoltaic devices [1]. The main issue with solar energy is that it is not evenly distributed across the world, and its conversion efficiency is generally poor. However, the high cost of this technology has hampered its spread. One method for lowering the cost is to use concentrators, which maximize the amount of light that falls on the cells [2]. Since the current generated by photovoltaic cells is proportional to the irradiance on the cells, more light on the cells increases the electrical output, allowing for a decrease in the area of modules (the most costly part of a PV system) required for the same output. The replacement of costly modules with less expensive optical materials (e.g., lenses or mirrors) will result in a decrease in PV energy costs. As a result, several kinds of concentrators, such as parabolic trough concentrators, parabolic dish concentrators, lens concentrators, central tower concentrators, Fresnel lens concentrators, and more creations [3]. Each concentrator, however, need to precise monitoring devices for ensuring that solar radiation is accurately localized in the receiving...
position [4]. Tracking errors has the important ability that impact in terms of efficiency of collectors. Multi-junction (MJ) solar cells are one of the better types of solar cells because they have several p–n junctions consisting of various semiconductor materials. In addition to various wavelengths of light, the p–n junction of each material can emit an electric current. Using some Semiconducting materials make it possible for the capacity to absorb a wider spectrum for number of wavelengths, increasing the cell efficiency of converting solar energy to electrical energy. The overall theoretical efficiency of multi-junction cells that has been around for quite some time is 33.16 percent. Under extremely intense illumination, a limitless number of junctions will theoretically have a finite efficiency 86.8 percent. In addition to solar cells, there is a parabolic dish as shown in Fig. 1 [5]. There are many researchers that studied the solar photovoltaic concentrators with parabolic dish reflector.

In 2015 Yaseen et al. made designed calculation of geometrical concentration parameters and heat transfer that was undesired with the help of the MATLAB program. Hence, the merger provided extra power and increased the power conversion efficiency. The system was operated in two cases, in the first case PV module was operated without a parabolic dish and in the second case, a parabolic dish was interconnected with the PV module. Comparative analysis of both the systems was carried out when it comes to their open-circuit voltage, short-circuit current, and output average power [6].

In 2016 Saša et al. proposed the optical design of a solar parabolic dish concentrator by using TracePro program to provide the optical analysis and performance assessment of a solar parabolic dish concentrator. 11 curvilinear trapezoidal reflecting petals constructed of polymethyl methacrylate with a unique reflective coating make up the parabolic dish concentrator. The theoretical focus point distance is 2.26 m, while the dish diameter was 3.8 m [7].

In 2018 Duo et al. proposed the evaluation of a large dish-type concentrator solar lighting subterranean parking garage system. The beam split thin film has been devised to selectively reflect a portion of visible light while transmitting the remainder of visible and invisible light. Using a laminated layer of beam split coating and thin-film solar cell, the suggested construction of a big dish may concentrate solar radiation, divide spectra, and create energy. Solar cells have a conversion efficiency of around 19%. The gathered sunlight divided into two parts: one is reflected into a fiber optical bundle (FOB) and transmitted for daylighting, while solar cells absorb the other for energy generation. Four solar lighting systems with a 3.28m diameter dish have been constructed to satisfy the lighting needs of an underground parking garage. [8]

In 2019 Mohsin et al proposed designed and development building electrification using an efficient standalone solar parabolic dish system. To improve the efficiency of photovoltaic panels installed at its focal point, the solar dish used a dual-axis solar tracking technology. Dual-axis solar tracking system will move the dish in horizontal and vertical directions to track the sun continuously throughout the day. The design parameters of the proposed dish system will be selected based on the continuous ratings within the building to be electrified [9].

In 2020 Lokeswaran, et al. suggested developed and analysis of dense array CPV receiver for square parabolic dish system with CPC array as secondary concentrator. A two-stage square parabolic concentrating photovoltaic (CPV) receiver dish with an overall geometric concentration ratio of 500 suns is built to produce a uniform intensity distribution on high-efficiency. Triple-junction solar CPV cell module The highest optical and CPV module efficiencies are 68.30 percent and 32.03 percent, respectively, for optimal homogenizer lengths of 0.005 m and receiver heights of 3.7 m, and the year-round electrical power production of the proposed CPV system is 2.19 MWh, which is up to 33.54 percent greater than traditional CPV systems [10].

The present work aims to discusses the impact of changes in reflectance and shading losses on solar energy and its effect on the efficiency of a PV system. A parabolic dish concentrator with a multijunction solar cell has been used.

2. Parabolic dish
A parabolic dish concentrator is the point-focusing system and its receiver positioned at its focus as shown in Fig.1. Two-axis tracking system is necessary in order to remain the sun aligned with the focus and vertex of the parabolic [11].

![Figure 1](image1.png)

**Figure (1):** parabolic dish concentrator [12].

To define the dimension of the paraboloid segment, it can use terms like aperture area, aperture diameter, or rim that formed by the optical axis and the line between the focus point and the rim, Fig.2 shows the geometrical representation of these parameters [13].

![Figure 2](image2.png)

**Figure (2):** The relationship between focal length and rim angle with a constant reflector diameter [14].

The distance between the vertex and focus called focal length [15]:

\[ F = \frac{d^2}{16h} \]  

(1)

The rim angle (\( \varphi_{\text{rim}} \)) can be calculated using the formula [16]:

\[ \tan \varphi_{\text{rim}} = \frac{f/d}{2(f/d)^2 - \frac{1}{2}} \]  

(2)

**Geometric Concentration Ratio (CR_g) is the ratio of the collector Aperture's surface area (Aa) to the receiver's surface area (Ar), as shown in the equation below. [17]:**

\[ CR_g = \frac{Aa}{Ar} \]  

(3)

The optical concentration ratio (CR_{op}) takes into account the effect of rim angle, reflectance (R), shading losses (SH), and scattering losses (SC) as in the following equation [18]:

\[ CR_{op} = CR_g \times \sin^2(\varphi_{\text{rim}}) \times \cos^2(\varphi_{\text{rim}}) \times R \times \text{SH} \times \text{SC} \]  

(4)
The amount of optical energy consumed by the receiver can be calculated by using the following equation [19]:

\[ P_{in} = H_{bn} \times CR_{op} \times A_r \]  \hspace{1cm} (5)

\( H_{bn} \): Normal beam solar radiation.

The amount of electrical energy from the cell is given by [20]:

\[ P_{out} = I_{sc} \times V_{oc} \times FF \]  \hspace{1cm} (6)

\( I_{sc} \) is short circuit current, \( V_{oc} \) is Open-circuit voltage, and \( FF \) is Fill factor.

The Efficiency given by:

\[ \eta_{collector} = \frac{P_{out}}{P_{in}} \times 100\% \]  \hspace{1cm} (7)

### 3. Theoretical Design

Matlab program has been used in this work to simulate the effect of reflectance and shading losses on input and output power of parabolic dish CPV system which are Concentration ratio, \( P_{in} \), \( I_{sc} \), \( V_{oc} \), \( P_{out} \), and the Efficiency for the multijunction solar cell as illustrated in Fig.3.

![Figure (3): Schematic diagram of simulation program used to calculate geometrical, optical and electrical parameters of CPV.](image)
4. Results and discussion

A CPV system’s optical performance influenced by material and surface structure used as well as the geometrical design. The relationship between concentrator reflectance and optical concentration ratio has been studied in order to determine the input power to the solar cell which effect on all output parameters produced from it. The theoretical calculations done on 15th April for Baghdad conditions.

- Fig. 4 shows the concentration ratio at the reflecting concentrator with varied reflectance under five different rim angles (45°, 55°, 65°, 75° and 85°). It is evident that the concentration ratio increase linearly with reflectance, while it increases as the rim angle decrease. The best value is about 172 for rim angle 45° and reflectance 95%. Consider multi-junction solar cell at the focus of the parabolic dish concentrator, one can calculate the input power with the same above conditions. Fig. 5 shows also the increasing of Reflectance and concentration ratio leads to an increase in the input power (P_input) in the multi-junction cell, but the P_input is inversely proportional with rim angle. The input power is 10 W for rim angle 75° and it becomes 37 W for rim angle 45° which represent 3.7 times higher between these two cases.

Fig (4): The relation between concentration ratio and reflectance.

Fig (5): The relation between input power (P_input) and reflectance.

Fig. 6 shows that the short circuit current (I_{SC}) of a multi-junction solar cell typically increases linearly as the reflectance increase because of increasing the intensity of the light or input power; the open circuit voltage (Voc) in Fig. 7 increases logarithmically with reflectance.
Fig (6): Effect of reflectance on $I_{sc}$ of multi-junction solar cell.

Fig (7): Effect of reflectance on $V_{oc}$ of multi-junction solar cell.

The $P_{out}$ and efficiency of CPV were also investigated by a varying reflectance as shown in Fig.8 and Fig.9. It can be seen that increasing in the output power ($P_{out}$) relative to the increasing in concentration ratio and input power. The $P_{out}$ also inversely proportional with rim angle and the increase in the efficiency with the effect of reflectance when the rim angle decreases.
Fig (8): Effect of reflectance on $P_{\text{out}}$ of multi-junction solar cell.

Fig (9): Effect of reflectance on efficiency of multi-junction solar cell.

Fig. 10 shows the concentration with varied value of shading under five different rim angles (45°, 55°, 65°, 75° and 85°). It is evident that the concentration ratio decrease linearly with increase of shading, while concentration ratio inversely proportional with rim angle. The best value is inversely proportional about 170 for rim angle (45°) and shading 10%.

Fig. 11 shows also the increasing of shading and decreasing of concentration ratio leads to decrease in the input power ($P_{\text{input}}$) in the multi-junction cell, but the $P_{\text{input}}$ is inversely proportional with rim angle. The input power is 2 W for rim angle 85° and it becomes 38 W for rim angle 45° which represent 19 times higher between these two cases.
Fig. 12 shows that the short circuit current ($I_{sc}$) of a multi-junction solar cell typically decreases linearly as the value of shading increase because of decreasing the intensity of the light or input power; the open circuit voltage ($V_{oc}$) in Fig. 13 decreases logarithmically with shading.
The $P_{\text{out}}$ and efficiency of CPV were also investigated by varying shading as shown in Fig.14 and Fig.15. It is shown that the decreasing in the output power ($P_{\text{out}}$) due to the decreasing in concentration ratio and input power. The $P_{\text{out}}$ also inversely proportional with rim angle. In addition, the decrease in the efficiency with the effect of shading when the efficiency inversely proportional with rim angle.
5. Conclusions

It is concluded from this research that:
1. The concentration ratio increase linearly with reflectance, while it increases as the rim angle decrease.
2. The best value of rim angle is 45º which give concentration ratio 172 when the reflectance 95%.
3. The concentration ratio decrease linearly with increase of shading, The best value is about 170 for rim angle (45º) and shading 10%.

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