Analysis of Solar Power Plants with The Combination Systems of PV Module-Reflective Mirror

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Abstract: - Solar energy is a combination of light and heat produced by the sun, where this energy is utilized by humans through solar collector technology consisting of PV modules to be converted into electrical energy. The development of PV module technology is carried out to improve its performance, where one of these technologies uses a reflecting mirror to increase the amount of sun radiation captured by the surface of the PV module. This research method uses performance analysis of the utilization of reflector mirrors added to the PV module system by using two different cases, among others are the use of two and four mirrors along the sides of the PV module. The results showed that the application of four reflective glass can direct the sun's radiation to the surface of the PV module with the amount of radiation intention doubled. This result is a kind of technology that gives us a good result to utilize it in building the solar power plant.

Key-Words: - Mirror, Module, Photovoltaic, Radiation, Renewable Energy, Solar, Weather

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1 Introduction

Rapid development in alternative energy source increases the utilization of renewable energy [1]. Renewable energy can be utilized from wind [2] and solar power [3]. Storing renewable energy can be done in form of electrical [4] and thermal energy [5]. Storing thermal energy can be combined by electrical energy to generate solar thermal electricity system [6]. Photovoltaic (PV) is a technology of developing rapidly that can utilize Solar Thermal Electricity (STE) which has more potential to convert into electrical power [7–9]. As their accessible markets expand, these technologies look more complementary than competitors [10–12]. One solution to make renewable energy more competitive is to combine reflector mirrors to the PV modules. By install, reflector mirrors can harvest more of the solar irradiance from the direct sunlight to the PV modules surface with the aim to increase the output electricity.

Based on experimental [13], the installation of reflector mirrors to existing 10 Watts cells panel can increase the intensity of light on the PV, and keep a recording of the current and the voltage of solar cells and make a comparison with the traditional model without reflected mirrors. The reflectivity of mirrors provides more energy than traditional panels without the reflector. Solar cells increased the energy power from 10 watts to 22 Watts power. The aim of the reflector-mirrors installation is to optimize the received solar irradiance on the PV module surface, maintaining an overall geometric size of the system as small as possible has been approached earlier. The conclusion is the mirror width decreases with the tracking step duration and the concentration ratio increases with the increase of mirror angle, therefore the huge value of solar irradiance can be reached by the large size of the system required [14]. In order to additional radiation offered by mirrors will lead to a significant increase in output energy of the PV system.

Consequently, the researchers intend to make new research using a slightly different system, thus with this technology being expected electricity generation will be greater compared to existing technologies. Hence, this research is trying to create a solar power plant that can generate electricity of 1 MW with PV technology combined with 4 surrounding mirrors and its results are compared with the performance of a PV module combined with two reflecting mirrors [15]. With reference to the existing solar panel systems, this research tries to create a new system to generate more electricity from sunlight. By building a reflection consist of four mirrors to PVs as showing in Figure 1, it is expected that the energy produced will be increased by up to 50%.

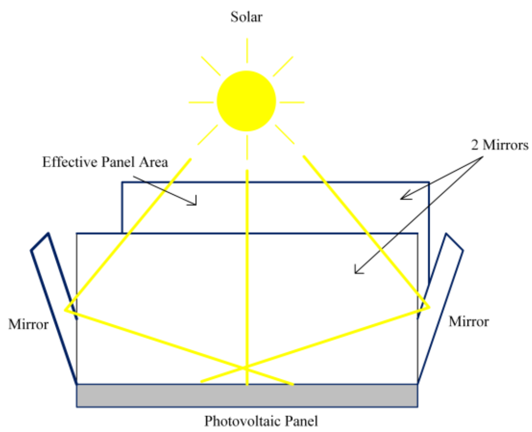


Fig. 1. PV module – 4 mirror systems

2 Methodology

The research methodology that was carried out was to design a power plant by utilizing solar energy in the form of a PV module system combined with sun reflecting mirror. The design process of the power plant begins with the process of mapping the condition of the application area of the solar energy power plant system. Data on the potential of solar energy in the form of solar radiation in the application area is used as basic data for the determination of the parameters of the PV module system design. The process of designing the module system is carried out a performance test by using a combination of sun mirrors which consists of two types, namely two and four mirrors. The combination of the reflecting mirror added to the PV module system has the aim of determining the optimal angle of mirror in capturing sunlight, and determining the optimal angle of incident sunlight into the PV module system. This condition determines the amount of electrical energy produced by the PV module system.

2.1 The coefficient of solar radiation in Libya

Sun radiation is a magnitude of the coefficient of solar energy that can be received by a unit area of the PV module system in an upright position to the sun with an average distance between the earth and the sun. The amount of radiation in each region has a different value, where this occurs due to differences in the sun's tilt angle and azimuth angle to the earth [16], and the latitude of the region [17]. This study took an experimental area in the Libyan area, where data on Libyan weather conditions came from Belgasim *et al* [18]. Each region of Libya has a different latitude position that makes the reception of radiation beams in each location is different from each other.

Libya is a country located in North Africa which has positions 19°-34° LU and 9°-26° BT [18]. Most of Libya is a desert area with a percentage reaching

88% [19], so the influence of the Sahara Desert weather is clearly visible in this zone and the influence of desert weather is getting stronger in the time of summer. This condition can be used as a place for PV module system application combined with two types of reflecting glass amount, namely two glass and four glass. This is supported by the condition of the Libyan state that is able to receive solar radiation with an average value of 7100 Wh $/m^2$/day in the northern region and 8100 Wh $/m^2$/day in the southern region which occurs for 3500 hours per year [20]. In addition, the country of Libya also has a percentage of Global Horizontal Irradiation (GHI) of 58% with details of the receipt of sunlight radiation of 2000 kWh/m^2/year in the north and 2600 kWh/m^2/year in the South [21]. Some supporting data in the system of receiving solar radiation in Libya has also been done by researchers, which can be shown in Table 1.

Table 1. Condition of Libya Weather [20,21]

The last time of sunset	19:48
The early of sun rise	6:00
The last time of sun rise	8:07
The early time of sunset	17:14
The average percentage of cloud	41%
The average time of sunlight per days	11:32

The weather conditions data in Libya became the basic data in the process of designing optimal conditions for the application of the PV module system with a combination of reflection mirror. The process of designing a PV module system is done by calculating the characteristics of the system.

2.2 The calculation of photovoltaic characteristic

The competitive utilization of solar energy can be done by combining the combination of the reflecting mirror system with the PV module system in one system. The use of reflective mirror aims to harvest more solar radiation that directs directly to the surface area of the PV module system so that it can improve the quality and quantity of electrical energy produced by the system. The process of proving this, then this study uses a method of utilizing the reflection of sunlight from four pieces of reflecting mirror to a PV module and compared with the performance conditions of the two reflecting mirrors in a previous study. The mechanism of the solar radiation reflecting system on the four reflecting mirror along with the PV module system can be shown in Figure 2. In addition, this mechanism is expected to improve the function of the PV module system for the process of converting solar radiation into electrical energy. The direction of the incoming sunlight after touching the reflecting mirror will move to the part of the PV module system which can make the angles as shown in Figure 3. The condition of the sun's altitude towards the area land and the azimuth angle between the sun and the PV module system is a key parameter in the construction of the combination model of the PV module and the reflector mirror in series or parallel position.

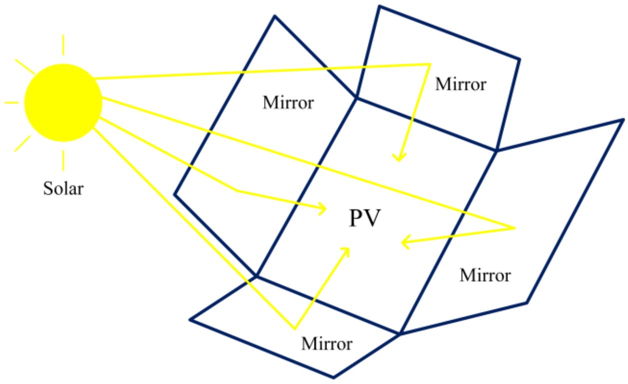


Fig. 2. The combination of PV module-four reflective mirror

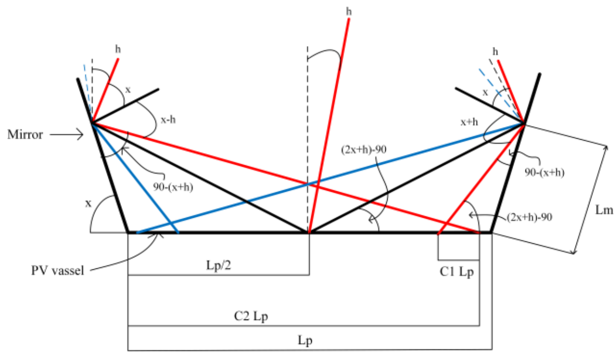


Fig. 3. The direction of irradiation sunlight to the PV module-reflective mirror

The characteristics of solar cells in a PV module system are illustrated by the curve of the relationship between current and voltage of solar cells. The characteristics explains that the relationship between maximum electrical voltage (Vmp) and maximum electric current (Imp) in a PV module system. The relationship between the two parameters can produce electrical energy normally so that it can determine the Fill Factor Value (F.F) shown in Equation 1 [13].

$$F.F = \frac{P_m}{Isc \cdot Voc} = \frac{\mathrm{Im} \cdot Vmp}{Ioc \cdot Voc} \quad (1)$$

The PV module system which consists of solar cell arrays should have a fill factor value (FF) almost close to 80% or 0.8, which with the amount of FF indicates that the PV module system gets the maximum level of efficiency in the process of converting solar radiation energy into electrical energy [13].

2.3 The energy of concentrating solar systems

Concentrating Solar Systems (CPV) construction is a construction that consists of optical reflecting and refracting devices to focus sunlight on the surface of the PV module system. This condition can increase electrical energy as output energy which is indicated by an increase in the output electrical power parameters, in addition to the construction owned by the CPV system can reduce the manufacturing costs of the system [14]. This research deals with the system of low concentration system; which presents geometric modeling and analysis for parameters regarding the amount of solar radiation as input data. The total radiation concentrated in the PV module system can be calculated by Equation 2.

$$R_{Total} = x \,.\, \textit{direct radiation light} + \textit{refraction light} \quad (2)$$

The different magnitude of the solar radiation values can be linked by the Equation 3 [24].

$$Ith = Ib \cdot \cos\theta_z + Idh \quad (3)$$

The concentrator consists of a PV module and four mirrors, which are located on the left, right, front and back sides that are symmetrical with the length of PV module.

2.4 Case study of sun radiation reflection on the PV module surface

Based on the basic model of the CPV system, the research considers two possible cases, the first when the solar radiation reflected from each mirror sweeps the entire surface of PV-module, and the second when the solar radiation reflected from each mirror only sweeps a portion of the PV-module surface.

2.5 The entire surface of PV module

The reflection of solar radiation (n) from each mirror that sweeps the entire surface of the PV module is expressed based on the extreme position of sunlight, which is shown in Figure 4 - the red line. The reflected condition depends on the maximum angle of incidence and the application of the sinus rule to the ratio between L1 and L3 (calculation ε1) expressed in Equation 4 [24].

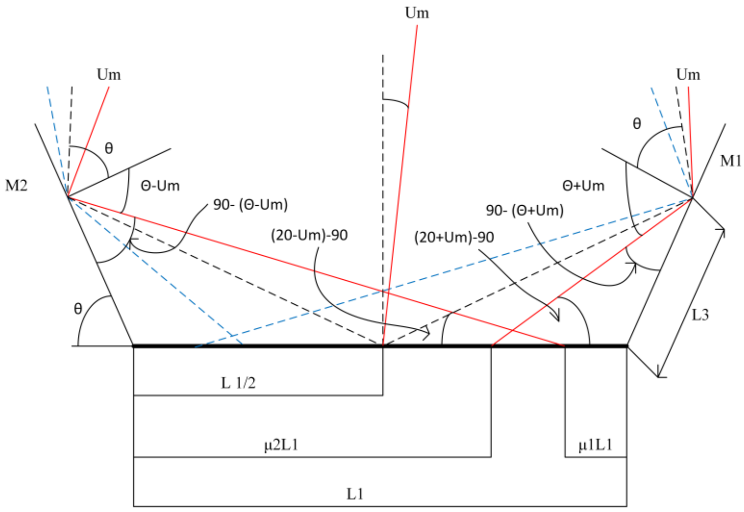


Fig. 4. The geometry model used for CPV systems

$$\varepsilon 1 = \frac{L3}{L1} = \frac{-\cos(2\theta + \vartheta_M)}{\cos(\theta + \vartheta_M)} \quad (4)$$

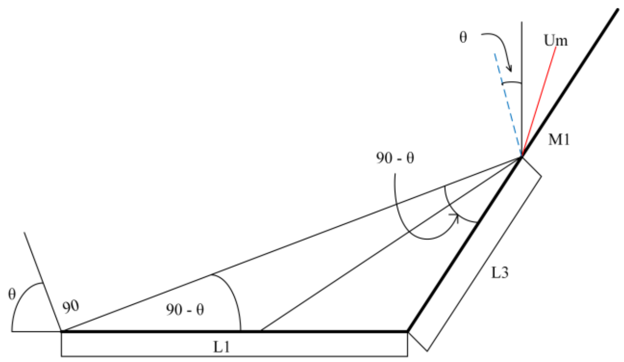


Fig. 5. The triangle geometry of the CPV system

The surface coefficient of the PV module that is affected by the reflection of sunlight can be calculated using Equation 5.

$$\mu_1 = \frac{L3 \cdot \cos(\theta + \vartheta_M)}{-L1 \cdot \cos(2\theta + \vartheta_M)} \quad (5)$$

If N is the number of days in a year, TR is the turbidity factor and α is the angle of elevation, then the Bo value can be calculated by Equation 6 [9].

$$B_o = 1367 \cdot [1 + 0.0334 \cdot \cos(0.9856 \cdot N - 2.27] \quad (6)$$

The amount of solar radiation absorbed into the surface of the PV module can be calculated by Equation 7 [25].

$$B_S = B_0 \cdot \exp\left[\frac{-T_R}{(0.9+9.4\sin\alpha)}\right] \quad (7)$$

The solar irradiation falling onto the surface of the PV module due to the reflection of sunlight on the mirror glass surface can be calculated by Lambert's Law that shown in Equation 8 [24].

$$B_{p\vartheta_{M1,2}} = \mu_{1,2} \cdot B_S \cdot \cos(\vartheta_{M1,2}) \quad (8)$$

2.6 The portion surface of PV module

The reflected sunlight from each mirror is partially exposed to the surface of the PV module shown in Figure 6, as a whole can cover the surface of the PV module area.

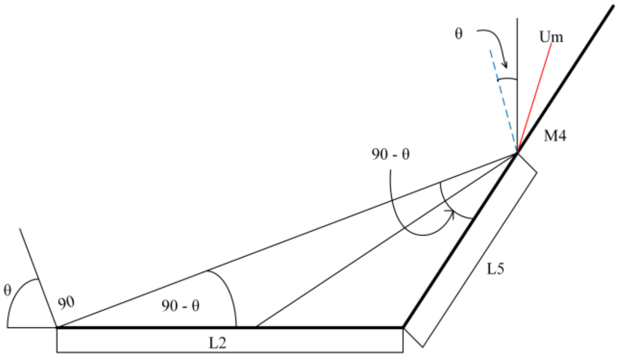


Fig. 6. The triangle geometry of the CPV system

Consideration of sunlight falling on the center of the PV module, shown in Figure 6 with a black line. Based on Figure 6 and the application of sine rules, the ratio between L5 and L2 (calculation ε3) for this case can be explained in equation 9 [25].

$$\varepsilon 3 = \frac{L5}{L2} = \frac{-\cos(2\theta+\vartheta_M)}{\cos(\theta+\vartheta_M)} \quad (9)$$

The coefficient μ3 which is reflected sunlight from M4 mirror based on Figure 7 can be calculated by Equation 10 [9].

$$\mu_3 = \frac{L5 \cdot \cos(\theta+\vartheta_M)}{-L2 \cdot \cos(2\theta+\vartheta_M)} \quad (10)$$

If N is the number of days in a year, TR is the turbidity factor and α is the angle of elevation, then the Bo value can be calculated by Equation 11 [25].

$$B_o = 1367 \cdot [1+0.0334 \cdot \cos(0.9856 \cdot N - 2.27] \quad (11)$$

The amount of solar radiation entering the surface of the PV module can be calculated by Equation 12 [24].

$$B_S = B_o \exp\left\{\frac{-T_R}{(0.9+9.4\sin\alpha)}\right\}\left\{W/m^2\right\} \quad (12)$$

BS is the direct of solar irradiation, TR is the turbidity factor, and α is the angle of elevation and N is the number of days in a year. Sunlight that fall normally into the PV surface can be calculated using Lambert's theorem, in equation 13 [24].

$$B_{p\vartheta_{M3,4}} = \mu_{3,4} \cdot B_S \cdot \cos(\vartheta_{M3,4}) \quad (13)$$

The values of ϑM mentioned are adjusted to the maximum incident angle of sunlight divided into some types among others are 0°, 15°, 30°, 45°, 60°, and 75°. While the parameters used as mirror angles (Θ) among others are 0°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°, 70°, 75°, 80°, 85°, and 90°.

2.7 Efficiency of PV module system

The efficiency of a photovoltaic module system indicates the system's module performance in the process of converting solar radiation energy to be converted into electrical energy. Efficiency calculations can be calculated by Equation 14.

$$\eta = \frac{P_{\max}}{A_{PV} \times Radiation} \quad (14)$$

3 Result and Discussion

The research results on the design of a PV module system combined with the two reflecting mirrors and four reflecting mirrors are shown in Figure 7. The length of the side of the reflecting mirror has the same dimensions as the length of the PV module system, especially on the front and behind mirror sides. The two performance systems are analyzed using the length parameters of the reflecting mirror, and the angle of the reflecting mirror differs from one another, which is done to obtain the angle of the mirror, the angle of sunlight incidence and the optimal dimension of the length of the reflecting mirror in the absorption of sunlight.

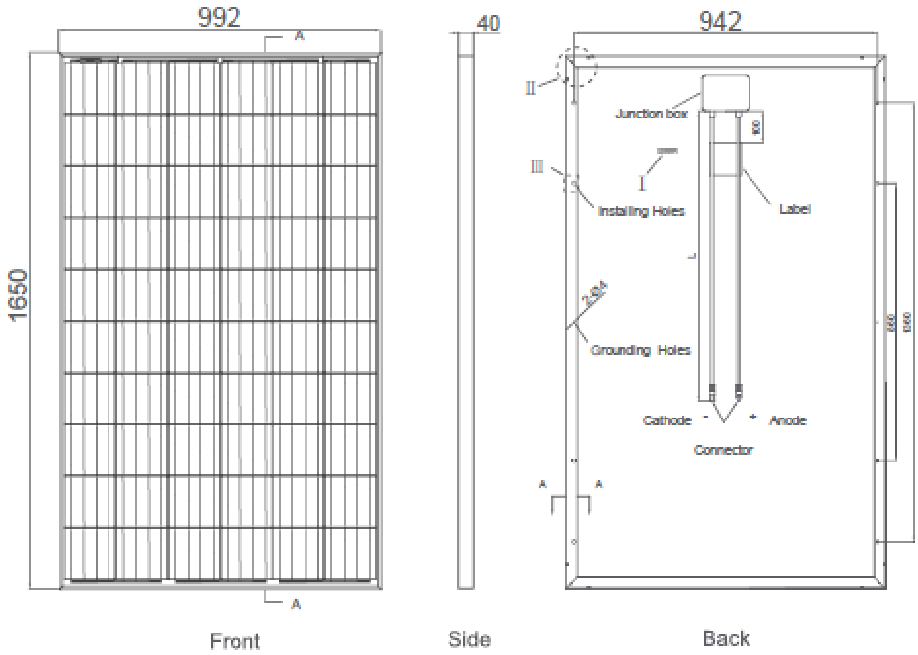
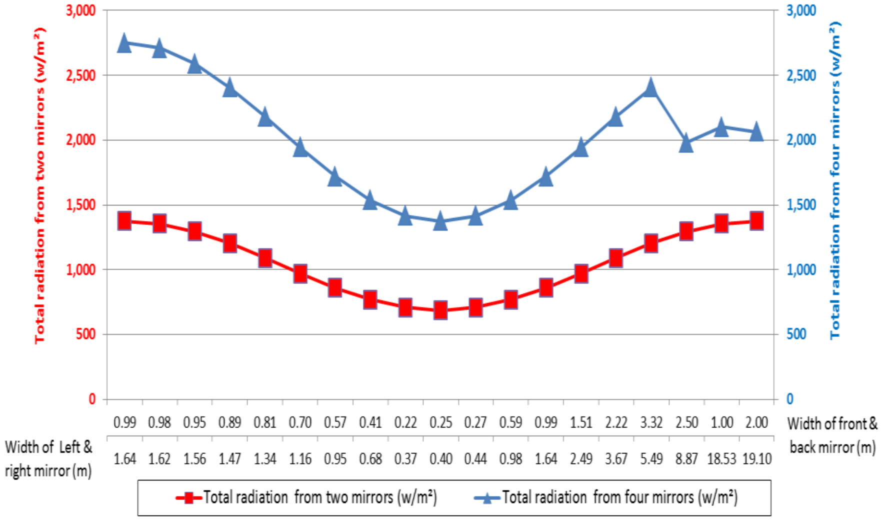


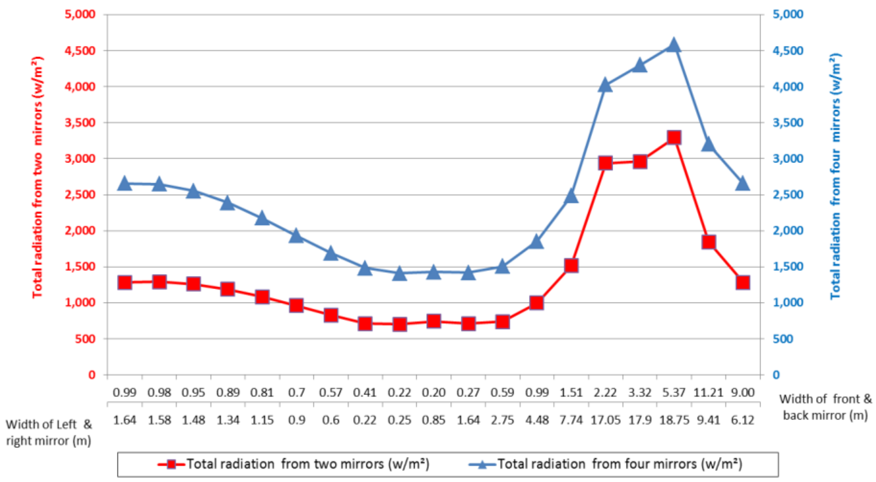
Fig. 7. Dimension of PV module system

The process of receiving solar radiation rays in a PV module system combined with two reflecting mirrors and four reflecting mirrors is carried out based on the angle of incidence of solar radiation (ϑ_M), which is divided into several angles including 0°, 15°, 30°, 45°, 60°, and 75° which can be shown in Figure 8. Based on Figure 8 it can be explained that the increasing the total amount of reflective mirror used in the PV module system, the more the sun's rays are obtained by the PV module system (this condition occurs the amount of solar radiation at four pieces of reflecting mirror are double compared to two reflecting mirrors). The amount of solar radiation increased significantly from 687.59 W/m^2 to 1375.17 W/m^2 with the geometry of the left and right sides of the photovoltaic mirror's surface of 0.4 m; and the width of the rear and front surface of the photovoltaic surface of 0.25 m, and the angle of the reflector mirror of 45° and the incident angle of sunlight by 0°. The magnitude of solar radiation increased significantly from 712.7 W/m^2 to 1480.72 W/m^2 with the geometry side of the left-side mirror width and right of the photovoltaic surface at 0.22 m; and the width of the rear and front surface of the photovoltaic mirror of 0.41 m, and the angle of the reflector mirror of 35° and the incident angle of sunlight of 15°.

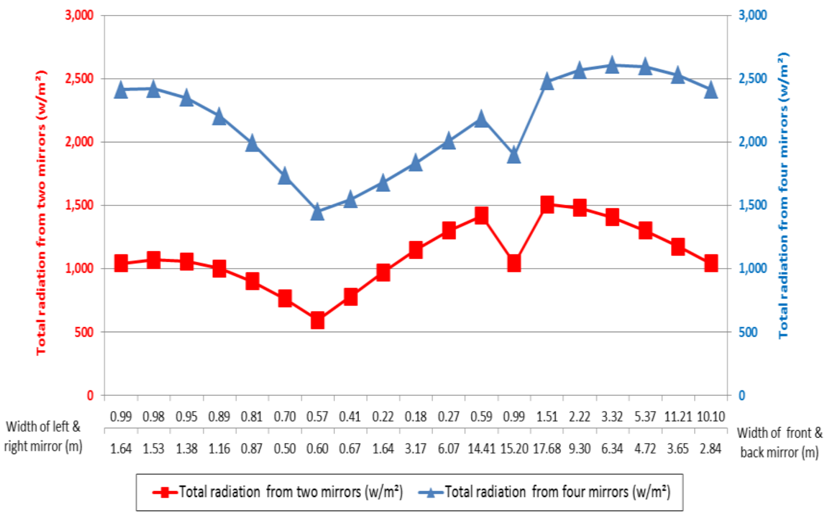
The amount of solar radiation increased significantly from 595.47 W/m^2 to 1454.95 W/m^2 with the geometry of the left and right sides of the photovoltaic mirror's surface of 0.6 m; and the width of the rear and front surface of the photovoltaic mirror of 0.57 m, and the angle of the reflector mirror of 35° and the angle of incident of sunlight of 30°. The magnitude of solar radiation increased significantly from 576.72 W/m^2 to 1667.8 W/m^2 with the geometrical side of the left-side mirror width and right of the photovoltaic surface at 0.34 m; and the width of the rear and front surface of the photovoltaic mirror of 0.81 m, and the angle of the reflector mirror of 20° and the angle of incident of sunlight by 45°. The magnitude of solar radiation increased significantly from 429.74 W/m^2 to 1724.48 W/m^2 with the geometrical side of the left-side mirror width and right of the photovoltaic surface of 0.83 m; and the width of the rear and front surface of the photovoltaic mirror of 0.95 m, and the angle of the reflector mirror of 10° and the angle of incident of sunlight of 60°. Consideration of the reception angle of the incident of sunlight and the angle of the reflector mirror results in the amount of solar radiation from the angle of sunlight of 75° unacceptable This is due to the magnitude of the angle of the sun's rays to be captured by the reflecting mirror beyond the receiving limit so that the amount of solar radiation reflected to the PV module system is not optimal. This condition indicates that the PV module system that is used to capture solar radiation in environmental conditions in Libya has a system of receiving solar radiation with four reflective mirror conditions in the incident angle of sunlight from 0° to 60°, with the angle of the reflecting mirror receiver between 10° up to 45°. The small angle of the reflecting mirror receiver causes the area of the reflecting mirror area to receive solar radiation to increase so that the amount of solar radiation received becomes higher. This is also proportional to the increase in the efficiency of the PV module system in the combination of four reflecting mirrors, for which the efficiency data can be shown in Table 2.



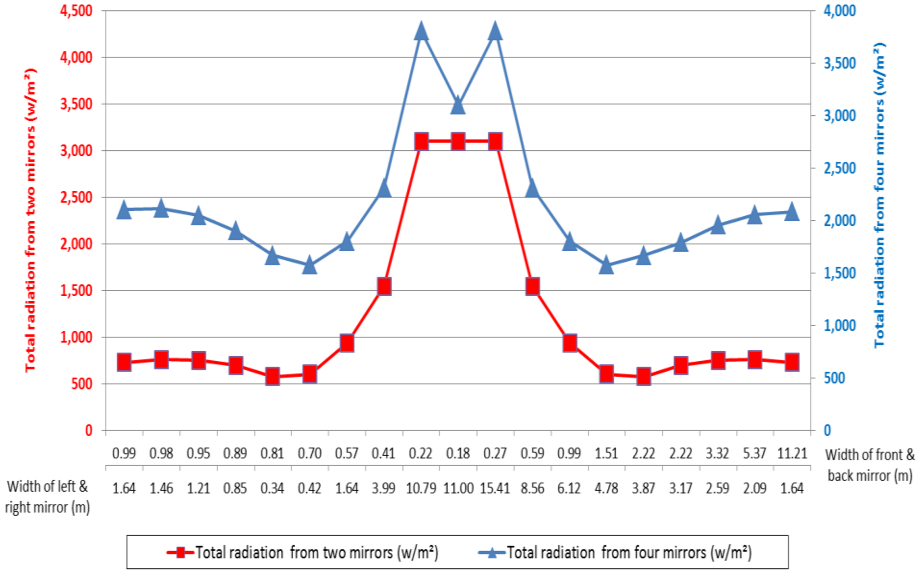
(a)



(b)



(c)



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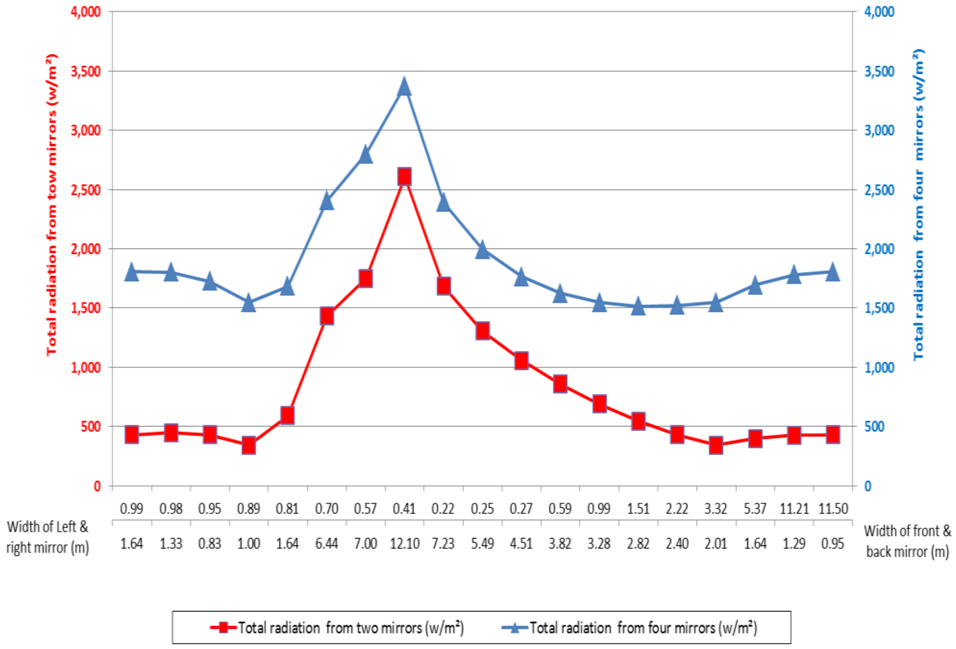

(e)

Fig. 8. The comparison of the magnitude of solar radiation received by two reflecting mirrors (red) and four reflecting mirrors (blue) in the incident angle of solar radiation by (a) 0° (b) 15° (c) 30° (d) 45° and (e) 60°

Table 2. The efficiency of the PV module system in the different of the incidence angle of solar radiation

Incidence Angle (°)	Area of PV Module (m^2)	Intensity of Solar Radiation (W/m^2)	Maximum Power (W)	Power of open circuit (W)	Efficiency of PV Module (%)
0	1.62	1375.17	270.12	353.28	6.05
15	1.62	1480.72	270.12	353.28	6.26
30	1.62	1454.95	270.12	353.28	6.86
45	1.62	1667.80	270.12	353.28	9.25
60	1.62	1724.48	270.12	353.28	9.22
75	1.62	-	270.12	353.28	-

Based on Table 2 explained that increasing the incidence angle of sunlight can increase the efficiency of a PV module. This occurs due to the increase in the reception of the solar irradiance along with the area of the reflecting mirrors that distributes the solar light irradiance to the PV module. The decrease in the efficiency of the PV module occurs at the incidence angle reaching the angle of 60° and the angle of 75°, this is because the fall of solar light irradiance to the surface of the reflecting mirrors becomes refracted and is exposed to other areas.

4 Conclusion

The results can be concluded that the utilization of a combination of reflecting mirror in a PV module system is able to increase the magnitude of solar radiation for the electric energy conversion process when compared to traditional systems without using a combination of reflecting mirror technology. The magnitude of solar radiation increases based on parameters of the angle of incidence of sunlight, the angle of the reflecting mirror, and the geometrical dimensions of the reflecting mirror. The increase in the reception of solar radiation occurs along with the decrease in the angle of the reflecting mirror and the increase in the sun's angle of view. This is due to the low angle of the reflecting mirror, thereby increasing the dimensions of the area of the mirror to receive the magnitude of solar radiation to be reflected in the PV module system. The best conditions occur in the PV module system with a combination of four reflecting mirrors with a solar angle of 60° and a reflecting mirror angle of 10°, which is capable of receiving solar radiation of 1724.48 W/m^2. An increase in the angle of incidence of solar radiation by 75°, is unacceptable because the angle of the reflecting mirror in the reception of sunlight radiation is not able to be suitable with the conditions of the maximum radiation solar reception.

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