Impact of Reflectors on Photovoltaic Panel Performance

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ABSTRACT

A photovoltaic panel (PV) is a practical method to produce electrical energy from solar light. The solar conversion efficiency of PV panels is still low, improving it will makes great differs of PV panels used. However, the efficiency of PV panels can be improved in many ways. One of them is to connect reflectors with PV panel. So, the aim of this research is to study the effect of three types flat reflectors (Nickel Chrome reflector; NCR, Aluminum sheet reflector; ASR and reflective glass reflector, RGR) connected with both sides of PV panels at four different tilts angles (30, 45, 60 and 90°) on the intensity of solar radiation falling per different periods of times and to determine the impact and performance of the PV panels output. Generally, the maximum daily average of solar radiation flux incident on the PV panel (from 8:00 to 17:30) was 828.93 W/h/m² for NCR at a reflector angle of 30° (RA30) and the corresponded percentage increment compared to the control panel was 24.98%. Also, at zero shade periods (ZSP) from 10:30 to 13:30, the maximum daily average value of total power was 0.758 kW, which represents 74.61% of the daily total power for NCR at RA90. The highest PV panel temperature was recorded for PV panel with reflectors (Nickel Chrome reflector; NCR, Aluminum sheet reflector; ASR and reflective glass reflector, RGR) connected with both sides of PV panel. So, the aim of this research is to study the effect of three types flat reflectors with cooling technique of PV panel maximum efficiency was 0.85 at 11 o'clock with tilt angle 60° of the concentrating mirror (ALKhatib et al., 2016). The rear reflection enhances a contribution of the collection efficiency to above 95% for the longer wavelengths of the thin film cell. For the wavelengths below 450 nm the collection efficiency drops below 70%, which implies that optimization of the window layer is desired (Bauhuis et al., 2004). One way to reduce the high cost per kWh of electricity is to enhance the performance of PV flat solar panels by implementing a reflector system for these panels, the overall output and efficiency can be improved (Mitchel et al., 2005, Rizk et al., 2002 and Jiménez V., 2004). Reflecting mirrors concentrate the light intensity over the whole surface of the solar panel. Therefore, the output power of solar panel increases (Muhammad et al., 2016). Particularly, it is difficult to create considerable betterment in the performance of the PV solar cell. The efficiency of the solar cell is limited by materials used in solar cell manufacturing. Therefore, increasing the solar radiation received from the sun is the most optimized way to improve the performance of the solar cell (Adel et al., 2016). Experimental results show the efficiency of solar PV panel up to 32% in the case of reflectors without cooling and 52% in the case of reflectors with cooling in the total output power (Radwan et al., 2014). Therefore, increasing the solar radiation received from the sun is the most optimized way to improve the performance of the solar cell (Adel et al., 2016). Experimental results show the efficiency of solar PV panel up to 32% in the case of reflectors without cooling and 52% in the case of reflectors with cooling in the total output power (Radwan et al., 2014). The modified PV panel produced 15% more PV power than one-sun concentration of PV panel. During the experiments the modified PV panel was found heated with maximum operating temperature of 66°C (Palaskar and Deshmukh, 2014).

Keywords: PV Panel, Reflectors, Power, Performance, Solar Radiation

INTRODUCTION

Egypt lies within the subtropical regain with a high potential of solar energy, which can be considered as a reliable energy source throughout the year. The annual average daily global irradiation values are 19.4, 18.67, and 21.78 MJ/m² and for diffuse irradiation they are 6.65, 6.34 and 6.23 MJ/m² for Cairo, Matruh and Aswan, respectively. For the normal incidence beam irradiation the annual average daily values are 24.46 and 16.94 MJ/m² for Aswan and Cairo, respectively (Omran, 2000). The improvement in efficiency production of solar energy system will make big difference in the use of PV panels, reported that the output power of the designed system and its efficiency is increases by increasing the tilt angle of the concentrator. The efficiency limit for an undoped (monocrystalline) Si cell with optimized thickness (110 mm) was calculated to be 29.4% (Richter et al., 2013). The record efficiency for a monocrystalline Si homojunction cell was recently set at 25.1% (Glunz S. W. 2015). Maximum power conversion efficiency of c-Si solar cells is very close to 26.7% (Green et al., 2018). The results showed that the PV solar panel maximum efficiency was 0.85 at 11 o'clock with tilt angle 60° of the concentrating mirror (AliHamadany et al., 2016). A several methods (using solar tracker, cleaning dust from PV panel, cooling technique of panel and using anti-reflecting coating etc.,) have been advanced to get better the efficiency of PV solar panel. These methods can effectively get abeter the efficiency of PV solar panel power generation (Rupali Nazar, 2015). The rear reflection enhances a contribution of the collection

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research is to study the impact of different reflectors types and angles on the intensity of solar radiation falling on PV panel and to declare the resulted changes in PV panel performance.

**MATERIAL AND METHODS**

Four PV panels were placed on the roof of testing and research station for tractors and farm machinery, Alexandria (Latitude 33.74 N and 72.83 E) on a rack facing south with a fixed tilt angle of 31°. Experiments were conducted from 15th May 2018 to 30th June 2018 between 8:00 am and 5:30 pm day time. Global and diffuse radiation on the horizontal surface, temperatures, output of voltage and current of PV panel at corresponding experiment conditions were recorded in 30 minutes of time interval. A PV panel of 150 Watts was used. Its specifications are given in table 1.

**Table 1. PV panel specifications**

<table>
<thead>
<tr>
<th>Item</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>V&lt;sub&gt;oc&lt;/sub&gt;</td>
<td>21.6 V</td>
</tr>
<tr>
<td>I&lt;sub&gt;sc&lt;/sub&gt;</td>
<td>9.25 Amps</td>
</tr>
<tr>
<td>Rated current</td>
<td>8.333 Amps</td>
</tr>
<tr>
<td>Rated voltage</td>
<td>18 V</td>
</tr>
<tr>
<td>Maximum power point(MPP)</td>
<td>150 Watt</td>
</tr>
<tr>
<td>Temperature of PV panel</td>
<td>25 °C</td>
</tr>
<tr>
<td>Area</td>
<td>0.9425 m²</td>
</tr>
<tr>
<td>Max serial fuse</td>
<td>15 Amps</td>
</tr>
<tr>
<td>Temperature coefficient of I&lt;sub&gt;sc&lt;/sub&gt; (%/°C)</td>
<td>+0.06</td>
</tr>
<tr>
<td>Temperature coefficient of V&lt;sub&gt;oc&lt;/sub&gt; (%/°C)</td>
<td>-0.36</td>
</tr>
</tbody>
</table>

Temperatures coefficients of V<sub>oc</sub> and I<sub>sc</sub> were measured using digital sensors at a typical / maximum ± 0.25 °C / ± 0.5 °C, and its range from 0 °C to +1024 °C. In addition, the thermocouples type was MAX6675 and 12-bit design serial K-type.

The following relations were used for the calculation of PV panel efficiency.

\[ \eta_M = \frac{P_{max} \times V_{max}}{G \times A} \] ………………(2)

Increasing power (%) = \frac{P_{ASR-PM} - P_{PM}}{P_{PM}} ………………(3)

Increasing in module efficiency (%) = \frac{\eta_{ASR-PM} - \eta_{PM}}{\eta_{PM}} ………………(4)

Where:
- A = Actual area of PV panel
- \( p_o \) = Output of PV panel
- G = Global solar irradiance
- \( p_{on} \) = Output of PV panel with reflector

A solar power meter (model: SPM-1116SD) was used to measure global solar radiations on the horizontal surface every 30 minutes of time interval. The Arduino-Unu Mega 328 board used with computer software as a device for measuring and recording temperature every 30 minutes during the experimental period. Nine temperature sensors were used (six sensors for panels with reflectors, two sensors for PV panel without reflectors and one sensor for measure ambient temperature). The used temperature sensors were digital sensor at a typical / maximum ± 0.25 °C / ± 0.5 °C, and its range from 0 °C to +1024 °C. In addition, the thermocouples type was MAX6675 and 12-bit design serial K-type.

A DC voltmeter and ammeter were used to measure voltage and current at various loading conditions. Four digital multi-meters (300W) with accuracy of: +1% for DC current and +0.09% for the DC volt was used.

Three types of reflectors were used in this study (Nickel Chrome reflector; NCR, Aluminum sheet reflector; ASR and reflective glass reflector; RGR). The dimensions of the reflectors are 147 cm by 66 cm. Two reflectors of same type were assembled at the longitudinal direction of the PV panel at both sides. Four reflectors angles were used; 30°, 45°, 60° and 90° which represented as follow RAl, RA45, RA60 and RA90 respectively. Fig. 1 shows the reflectors as assembled with the PV panels.

The following equations and procedure were used to calculate the PV panel and PV panel with reflector parameters (Helmy et al. 2014).

The maximum power was calculated using the measured maximum current and the maximum voltage.

\[ p_{max} = I_{max} \times V_{max} \] ………………(1)

The following relation was used for the calculation of PV panel efficiency.

\[ \eta_M = \frac{p_{max}}{G \times A} \] ………………(2)

Increasing power (%) = \frac{P_{ASR-PM} - P_{PM}}{P_{PM}} ………………(3)

Increasing in module efficiency (%) = \frac{\eta_{ASR-PM} - \eta_{PM}}{\eta_{PM}} ………………(4)

Where:
- A = Actual area of PV panel
- \( p_o \) = Output of PV panel
- G = Global solar irradiance
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**RESULTS AND DISCUSSION**

**Reflectors types and tilt angles via the solar radiation flux incident on the PV panels**

The results in Fig. 2 indicated that the solar radiation flux incident on the PV panel recorded on the PV panels with reflectors was a higher compared to the PV panel without reflector. The difference of solar radiation between the three types of reflectors was very small at the day time from 8:00 to 10:00 am and from 15:00 to 17:30 and the maximum solar radiation for the three types of reflectors was recorded from 10:30 am to 14:30.
Fig. (2-A) represents the average solar radiation flux incident on the PV panel at RA 30 for all reflectors types and the control. The daily average total solar radiation at the day time from 8:00 am to 17:30 were 828.93, 778.21 and 707.12 W h/m² for NCR, ASR and RGR respectively, compared with the control which was 663.24 W h/m². The highest increasing percentage of solar radiation received compared with the control was 24.98 % for NCR.

Fig. (2-B) represents the average solar radiation flux incident on the PV panel at RA 45 for all reflectors types. The daily average total solar radiation during the day time from 8:00 am to 17:30 were 813.93, 771.93 and 711.86 W h/m² for NCR, ASR and RGR respectively, compared with the control which was 682.35 W h/m². The highest solar radiation received was by the NCR and it was higher by a value of 19.28 % compared with the control.

Fig. (2-C) represents the average solar radiation flux incident on the PV panels at RA 60 for all reflectors types and the control. The daily average total solar radiation during the day time from 8:00 am to 17:30 were 790.32, 718.08 and 685.73 W h/m² for NCR, ASR and RGR respectively, compared with the control which was 730.63 W h/m². The highest solar radiation values received was by the NCR was 8.17 % compared with the control.

Fig (2-D) represents the average solar radiation flux incident on the PV panel at RA 90 for all studied reflectors types and the control. The daily average total solar radiation during the day time from 8:00 am to 17:30 were 713.49, 636.82 and 631.38 W h/m² for NCR, ASR and RGR respectively, while, the control panel was 749.57 W h/m². In general, the solar radiation flux incident on the PV panel with reflectors decreased compared to the control because both reflectors sides have shade on a large part of the PV panel at the beginning and end of the day (from 8:00 to 10:00 am and from 15:00 to 17:30).

**Reflectors types and tilt angles via daily total power**

The results in Fig. 3 showed the total power of PV panels with reflectors at different tilt angles and the control PV panel during the day time from 8:00 to 17:30. As shown in the results, the maximum daily total power was recorded for the PV panel with NCR compared to the PV panel with ASR and RGR at RA 30, RA 45, RA 60 and RA 90. These results are corresponding with the results of solar radiation flux incident on the surface of the tested panels.
It was also found that, the PV panel with reflectors has a greater total power than the control at different reflector angles except the RA90. This was due to the reflector with RA90 at the beginning and end of the day shades a part of the PV panel. Therefore, the daily total power for the control was more than the total power for the PV panel with reflectors at RA90.

Effect of reflectors types and tilt angles on PV panel temperature

Fig.4 shows the effect of reflectors type and angle on PV panel temperature. The temperature was higher for the PV panels with all reflectors types and at all tilt angles than the control one. The highest PV panel temperature was received for the NCR followed by ASR and the last was RGR at RA90. The highest PV panel temperature values were 52.3, 56.1, 60 and 61.5°C for NCR compared to the control at RA30, RA45, RA60 and RA90 respectively. The results proved that, increasing the PV panel temperature due to the use of reflectors relatively decreased the power obtained.
Reflectors types and tilt angles via total power at zero shade period

Fig. 5 shows the effect of the reflector type and angle on the PV panel total power at the day time from 10:30 am to 13:30 pm which represents a zero shade period (ZSP) compared with the control. The highest value of the total power for the three studied types of reflectors at different angles was for the NCR at the ZSP. The maximum values of total power for the PV panel with NCR, ASR and RGR at RA90 were 0.758, 0.715 and 0.643 kW respectively, compared with the control PV panel (0.563 kW) at ZSP. Also, at ZSP the maximum daily average value of total power which was 0.758 kW represents 74.61 % of the daily total power for NCR at RA90.

![Fig.5. Reflectors types and tilt angles via total power at zero shade periods](image)

Fig.6 results indicated the maximum increase in power during ZSP was recorded for PV panel with NCR compared to the PV panel with ASR and RGR at different angles. The highest percentage increment compared to the control panel in power was 34.76 % for NCR and RA90 during ZSP.

![Fig.6. Reflector types and tilt angles via increasing power at ZSP](image)

Discussion

The discussion of the above results recorded that the values of solar radiation for PV panels with reflectors are mostly higher than the PV panel without reflector. The power gradually increases from morning to noon, however, it starts decreasing in the afternoon. In fact, the highest improvement of PV panel occurs with the reflector during the mid-day, when solar intensity goes higher. So, improvement in this part of the day is more beneficial as compared to morning and afternoon. With fixing the PV panel reflectors at certain angles, sun rays falling on it are not fully reflected on PV panel surface at the period from 8:00 to 10:00 am and from 2:30 to 17:30 and increasing the shading from the reflector on the PV panel surface those makes the modified PV panels performance less than the control PV panel especially with the RA90. To utilize this condition, the reflectors should be tracked from morning to evening continuously along East-West direction beside using a proper reflector type and angle to produce power and maximizing the efficiency more than its rated output. Meanwhile, the life of PV cell will be decreased due to overheating of PV cells and components. Cooling of the modified PV panel is required to increase life of PV cell and PV panel.

CONCLUSION

Several conclusions could be drawn from the investigations of the effect of reflectors types on the performance of PV panels. The use of plane reflector for improving the performance of the PV panel has shown impressive results. Using of plane reflectors are easy in installation, making the usage of solar panel more feasible, inexpensive, reducing the overall cost of electricity generation and improving the performance of the PV panel. Another advantage is increasing the PV panel output power considerably during mid-day. An increase of 20–37 % in solar radiation received on the PV panel was observed with the use of reflectors. A corresponding increase in power output was also recorded. The conversion efficiency seems to be showing considerable increase with the use of different studied reflector types and angles.

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