Performance Evaluation of a Mono-Crystalline Photovoltaic Module Under Different Weather and Sky Conditions

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Abstract- The aim of the present study was to assess the suitability of a mono-crystalline photovoltaic module for use in different weather (i.e. cold and warm) and sky (i.e. sunny and partly cloudy) conditions in desert climate in the region of Adrar (0.18 W, 27.82 N), Algeria. Monthly, daily, and hourly performance parameters like performance ratio, efficiency, and output energy were calculated and compared on the basis of one year of data accumulated. The experimental results show that the photovoltaic energy provided during warmer weather conditions is higher than in colder conditions, and the maximum efficiency and performance ratios were observed during weather with low irradiation levels and ambient temperatures. Furthermore, photovoltaic energy production was directly proportional to irradiation, and the module produced 83% more energy in July than November. Moreover, the module had approximately 10.8% and 10.5% higher efficiency and performance ratio values in December than July, respectively. Thus, the photovoltaic module energy production was better under warm climate conditions. However, the efficiency and performance ratio were better under cold climate conditions. Furthermore, after one year of exposition, the maximum power output (P_p) and short-circuit current (I_{sc}) of the module degraded about 3.5% and 0.13%, respectively.

Keywords Photovoltaic module, performance ratio, efficiency, energy.

1. Introduction

The performance of a photovoltaic PV module depends on many physical and meteorological parameters such as the latitude, ambient temperature, wind speed, and solar radiation. Thus, knowledge of the performance of PV systems under real operating conditions is essential for choosing the right product and accurately forecasting the power generation.

Several studies have shown that the performance of different PV technologies depends on the specific climatic conditions of the location. Carr and Pryor [1] studied the energy performance of five different PV technologies and confirmed that thin film technology (a-Si) achieves the best results. The researchers in [2] compared the performance of poly-crystalline and amorphous PV modules and concluded that amorphous modules are the most suitable for tropical climates. Rehman and El-Amin [3] evaluated the performance of poly-crystalline PV modules, indicating that energy efficiency was highly dependent on the module temperature. Ubertini and Desideri [4] studied 15-kWp PV poly-crystalline modules installed on a roof and found that their efficiency decreased by approximately 0.025% for every 1°C increase in temperature. The performance of two PV systems containing 85.05 kWp and 21.6 kWp of CIGS solar cell (copper, indium, gallium and selenium) thin films was analyzed in a 12-month experimental test in [5], and the results indicated that regular weekly cleaning of the PV module optimized the energy production (less than 1.7% loss per week).

This paper presents an analysis of the performance of a mono-crystalline PV module installed under external atmospheric conditions for one year. The performance ratio, efficiency, and energy produced by the PV module (annual, monthly and daily) under different weather conditions (warm and cold) were measured for one year in southern Algeria.

2. Performance Ratio and PV Efficiency

The efficiency (η) and the performance ratio (PR) of a PV module are commonly used to compare the performances of different PV technologies [6]-[7]. The performance ratio is the ratio between the actual energy and the expected energy yield of a site under environmental conditions, defined in Eq. (1), according to IEC standard 61724 [8]:

$$PR = \frac{E \times G_{stc}}{G_T \times P_{max}} \quad (1)$$

The efficiency is the ratio of total energy produced by the PV module to the total solar energy incident on the PV module:

$$\eta = \frac{E}{G_T \times A} \quad (2)$$

where E is the energy produced by the PV module (Wh) over the chosen time interval, i.e., hourly, daily, or monthly; G_T is the incident solar irradiation (Wh/m^2) during the same time interval; P_{max} is the maximum power under standard test conditions (W), measured during the selected time interval; G_{STC} is the solar radiation for standard test conditions (W/m^2); and A is the surface area of the module (m^2).

3. Experimental Results and Discussion

The performance of the PV module in this study was analyzed over three durations (hourly, daily, and monthly) under different sky conditions (sunny and partly cloudy) for two main types of weather (cold and warm). The outdoor exposure tests were conducted from June 2014 to May 2015 within the **R**esearch **U**nit in **R**enewable **E**nergies in the **S**aharan **M**edium (URER-MS), Adrar, Algeria (0.18 W, 27.82 N). A mono-crystalline Technosun SYP80S-M PV module was used and placed under the sun on the roof with 28 degrees tilted angle, opposite the south. Figure 1 show the PV module situated on the roof of the URER-MS. The ambient temperature was extracted from the measurements of the meteorological station of New Energy Algeria (NEAL) also installed on the roof of the URER-MS, at 18 meters of horizontal distance from the installed PV module (Fig.1b).The measurements of meteorological radiation data was performed with a CM11 type Kipp &Zonen pyranometer (last calibrated February 2011) fixed beside the PV module, as shown in Fig.1a. For module temperature measurements, the K-type thermocouple was fixed to the back surface of the PV module in its center. The test interval was set at one minute using a Fluke 2625A datalogger.

Fig. 1. The experimental instruments for outdoor environment.

Note that the results for the month of October 2014 are missing due to equipment maintenance and the module was cleaned every week to prevent module soiling. Table 1 shows the electrical specifications for the module reference conditions.

Table 1. Specifications of the representative module for STC.

Specification	Value
Maximum power P_p (W)	80
Maximum current I_p (A)	4.65
Maximum voltage V_p (V)	17.2
Short circuit current I_{sc} (A)	5
Open circuit voltage V_{oc} (V)	21.6
μ_{Isc} (%/°C)	0.02
μ_{Voc} (%/°C)	0.37
μ_{Pp} (%/°C)	-0.44
A (m^2)	1.195 *0.541

3.1. Hourly performance

This study analyzed the hourly output of the module under different weather conditions. Two principal types of weather (cold and warm) were chosen to show the change in energy production, efficiency, and performance ratio. In terms of sky conditions classification, the hourly clearness index k_t (defined as the ratio of the hourly global solar irradiation and the hourly extraterrestrial solar irradiation on a horizontal surface [9]) is a widely used index since it depends only on global solar irradiance [10]-[11]. The clearness index indicates the level of availability of solar radiation and weather condition at a particular location on the earth's surface [12]. In this work, the k_t values suggested in [13] have been used for the classification of the sky coverage as follows: $0 < k_t \leq 0.2$ for cloudy sky, $0.2 < k_t \leq 0.6$ for partly cloudy sky, $0.6 < k_t \leq 0.75$ for sunny sky and $0.75 < k_t \leq 1$ for very sunny sky.

Table 2 shows information about the five days selected for studying the effect of the weather conditions on the PV module in this section.

Table 2. Classification of days by the types of observed skies

Days	Clearness index k_t	Weather	Skies
03/07/2014	0.5284	Warm	partly cloudy
29/07/2014	0.6513		sunny
05/11/2014	0.2314	Cold	partly cloudy
11/12/2014	0.6861		sunny
07/12/2014	0.6158		sunny

Figures 2 and 3 present the observed daily solar irradiation and the change in ambient temperature measured during the five days of the test, respectively. The hourly energy, performance ratio and efficiency of the PV module during these five days are presented in Figs.4, 5 and 6, respectively.

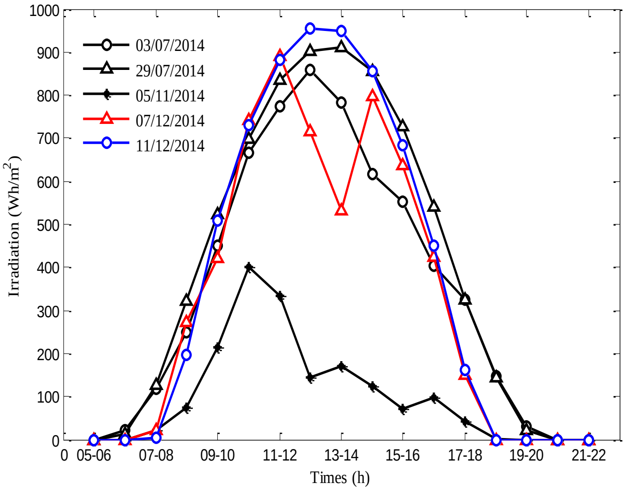

Fig. 2. Hourly irradiation for five days of testing.

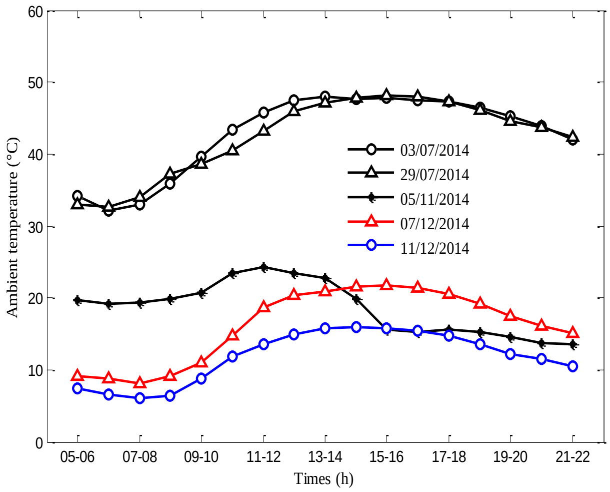

Fig. 3. Hourly ambient temperature for five days of testing.

Figures 5 and 6, show that the module produced a high hourly efficiency and performance ratio during the days with low ambient temperature than the other days.

Generally, the performance ratio and the efficiency were better on cold days, especially at a lower ambient temperature as shown for 05 November and 07-11 December 2014. On the other hand, the low values were observed during warm days, as shown for 03 and 29 July 2014.

Figure 5 shows that the value of the performance ratio was higher than one. These results are possible under high irradiation and low temperatures [14].

In general, the irradiation and ambient temperature are the two most important factors governing the performance parameters of the PV module. To determine the most influential factor for the performance of the PV module, 3 July 2014 and 29 July 2014 were chosen due to their changes in ambient temperature, which are almost the same as those shown in Fig. 3 but with different hourly irradiation fluctuations, as shown in Fig. 2.

Although the fluctuations in the hourly irradiation differ for the two days, there is a similarity between the performance ratio and hourly efficiency achieved by the module on both days. This result shows that the ambient temperature had a greater impact on the performance ratio and efficiency than the hourly irradiation. On the other hand, the hourly irradiation had a greater impact on the value of the energy generation than the ambient temperature.

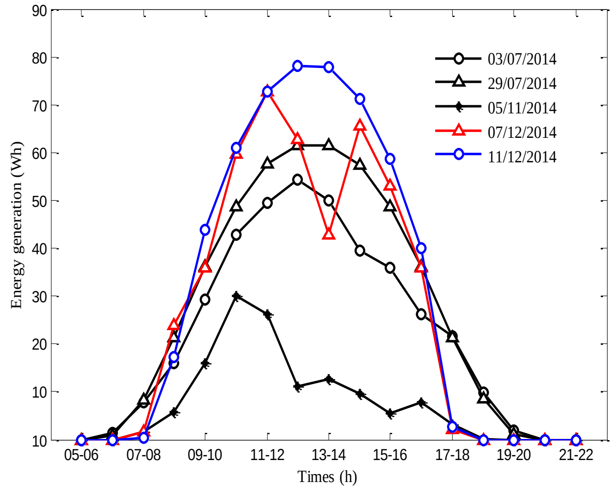

Fig. 4. Hourly energy generation for five days of testing.

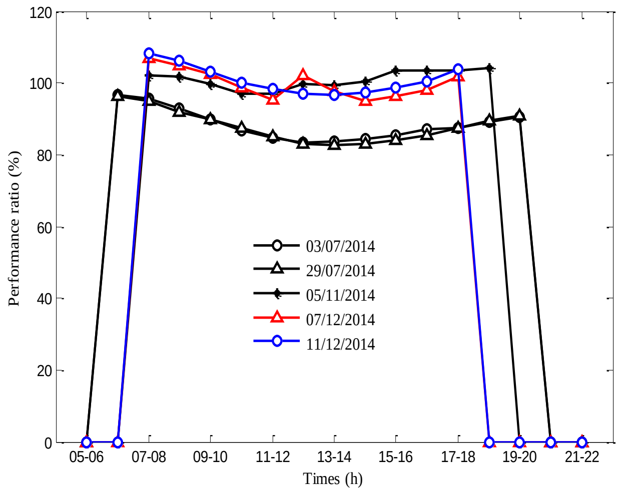

Fig. 5. Hourly performance ratio for five days of testing.

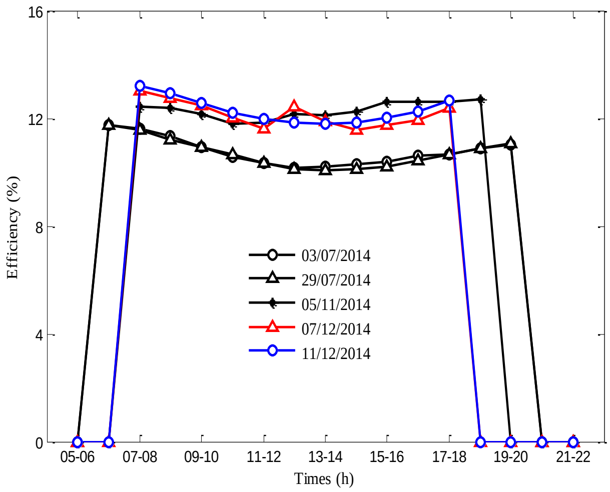

Fig. 6. Hourly daily efficiency for five days of testing.

3.2. *Daily energy performance*

This section presents the results of the comparison between the daily performances of the module for two months, July and December 2014, with different climatic conditions (cold and warm).

The average daily ambient temperature varied between 40.21°C and 44.13°C in July and between 7.24°C and 18.18°C in December. Fig. 7 shows that the difference in the average daily ambient temperature between the two months reached 35°C.

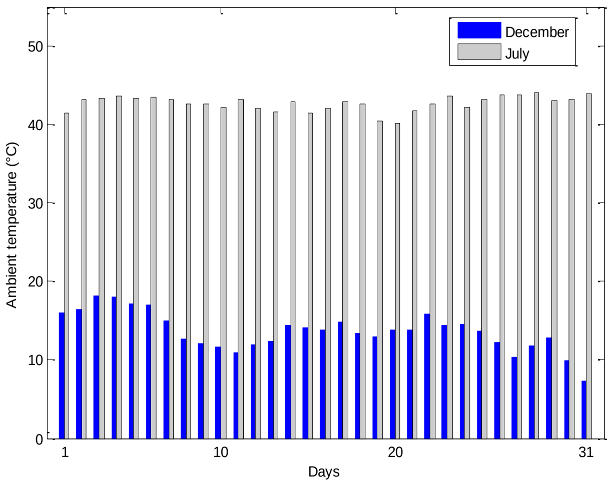

Fig. 7. Daily average ambient temperatures measured during two months.

Figure 8 shows the irradiation and the energy provided by the PV module and Fig. 9 shows the daily performance ratio and efficiency for the each month. As shown in Fig. 8, the daily irradiation varied between 4471Wh/m^2/day and 7523Wh/m^2/day recorded respectively in 14 July and 21 July, while the daily energy generation varied from 313.5Wh on 14 July to 515.8Wh on 21 July.

As reported by previous studies [15]-[16]-[17]-[18], the efficiency and the performance ratio of the PV module were affected by the solar radiation and ambient temperature. As shown in Fig.8, the energy generated during most days of the month of December was greater than the energy generated during the month of July. The irradiation in July increased by 6% compared to December, but this increase is negligible. On the other hand, the average monthly energy, performance ratio, and efficiency are decreased in July compared to those in December about 10.3%, 13.8%, and 14.2%, respectively, due to the higher value of the average ambient temperature which increased by 168.5% in July compared to December. It is clear that the ambient temperature plays an important role in the functioning of the PV module and is inversely proportional with the values of the average monthly energy, performance ratio and efficiency.

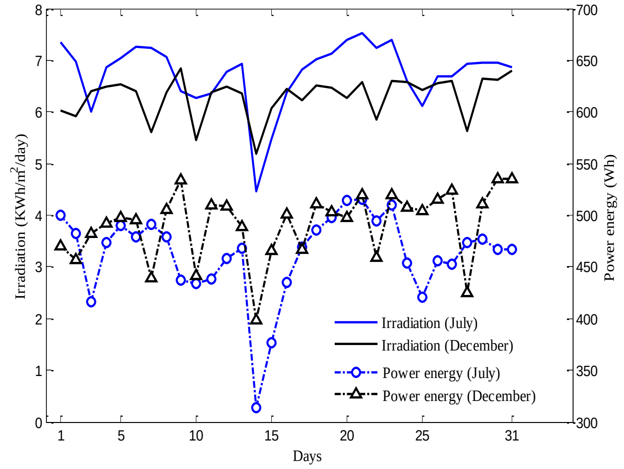

Fig. 8. Daily irradiation and daily energy generation for two months of testing.

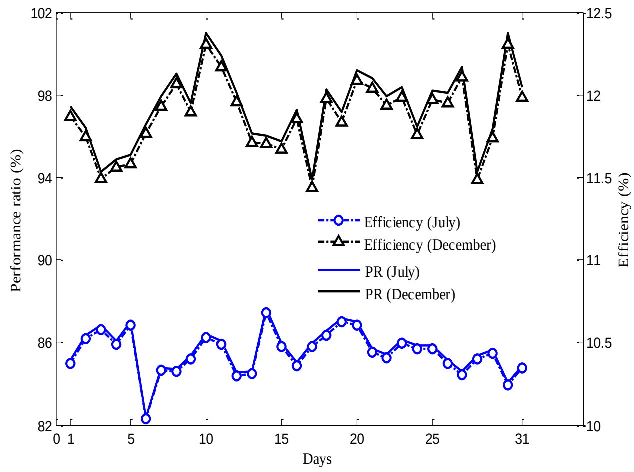

Fig. 9. Daily performance ratio and daily efficiency for the months of July and December.

3.3. Monthly energy performance

The monthly energy, solar irradiation, performance ratio, and efficiency corresponding to June 2014 to May 2015 were determined and are shown in Figs.10 and 11, respectively.

The best performance ratios and efficiencies values were registered in winter (December to March), with averages ranging from about 94.5 to 97.6% and from about 11.5% to 11.9%, respectively, with average daily temperatures ranging from about 15.8°C to 22°C.

In the summer months (June to September), the performance ratios and efficiencies decreased ranging from about 85.6% to 87.7% and from about 10.4% to 10.7%, respectively, while the temperature ranged from about 37.7°C to 43°C. The lower values for the performance ratio and efficiency were aroused by the high temperature.

As previously demonstrated, the irradiation variation had a greater impact on the value of the energy generation than the ambient temperature. In December 2014, the average ambient temperature was equal to that of January 2015 with a different irradiation value, the energy during these two months was different and highest energy-months are the sunniest months. These results indicate that the PV module performed better under cold conditions than warm conditions.

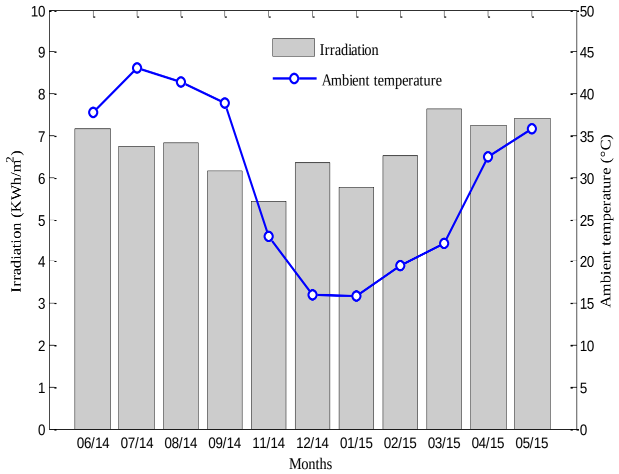

Fig. 10. Average daily irradiation and energy generation.

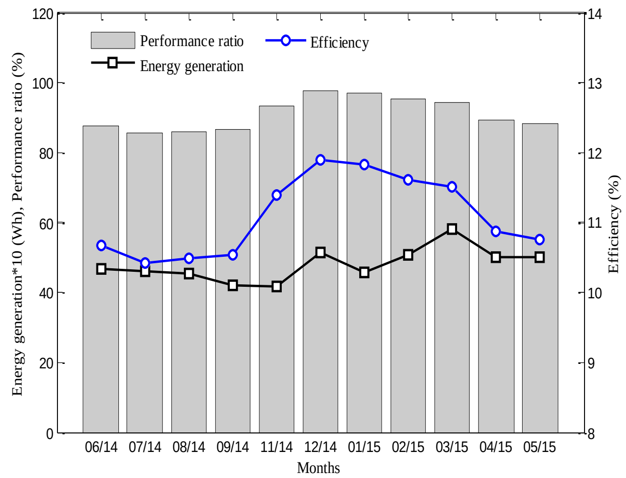

Fig. 11. Average performance ratio and efficiency.

4. Conclusions

The performance of a mono-crystalline PV module was studied during the first year of outdoor operation in southern Algeria. The performance ratio, efficiency and energy generation were measured and analyzed over three durations (i.e., hourly, daily, and monthly) and under different weather conditions (i.e., warm and cold).

The daily energy provided by the PV module was highly dependent on the available sunlight subsequently proportional to the increase in solar radiation. The energy generated during the cold months was higher than during the warmer months.

The minimum average performance ratio and efficiency were observed during warm months like July, when these values measured 85.6% and 10.4%, respectively, while cold weather months such as December exhibited a high performance ratio and efficiency, 97.6% and 11.9%, respectively.

This study showed that, under a desert climate, the PV module generated high energy values and functioned better, but the affected module suffered several modes of degradation, subsequently leading to decreased energy production.

This work is not yet complete. In the future, it is necessary to study comportments and the performance of several types of PV modules with different technologies and from different manufacturers.

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