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A comparative analysis of long-term field test of monocrystalline and polycrystalline PV power generation in semi-arid climate conditions

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ABSTRACT

Two different, commercially available photovoltaic modules, monocrystalline and polycrystalline, have been monitored outdoors in the semi-arid area of Iran, over a complete year.
The values of power output, specific energy yield, normalized power output, efficiency and performance ratio of each module have been analyzed and linked to the climatic characteristics of the site.
The result indicates that despite the similar behavior of both PV modules with instantaneous irradiance, the monthly behavior of the modules is different, which is due to different light absorbing and thermal characteristics of each panel. The monthly average module efficiency of monocrystalline module has a gradual decreasing trend in the months with a higher ambient temperature, while polycrystalline module shows an inverse behavior. The results of monthly performance ratio have also shown that the performance of monocrystalline module decreases with increasing monthly ambient temperature.
Monitoring the gross performance of both PV modules shows that the monocrystalline module performed better both regarding maximum efficiency and overall specific energy yield, and was found to be more efficient at this site. This work offers are also useful as a comparison for investigating the productivity of solar plants in different areas with climatic characteristics similar to the semi-arid region of Iran.

Introduction

In recent years, solar energy has become an increasingly important source of renewable energy and it is expected to expand in the near future. It is more important in the middle-east countries where the level of solar radiation is considerably high and it could be as an alternative energy source under conditions that low cost and user-friendly technologies are employed.

One of the finest ways to harness the solar power is photovoltaic technology which is currently being investigated to convert most efficiently the sunlight to electricity.

The performance and efficiency of photovoltaic modules are affected by several factors such as the kind of technology used, the light spectrum, solar irradiance and ambient temperature, humidity and wind (Rahman et al., 2015; Makrides et al., 2012; Daniela et al., 2015). The aging and degradation of photovoltaic modules is also dependent on climatic and environmental conditions (Dubey et al., 2014; Tamizh Mani Mani and Kuitche, 2013).

Independently of the production technology, the most popular type of PV panels are monocrystalline (c-Si), polycrystalline (pc-Si) and amorphous, which are made by connecting photo-electric modules in series and/or in parallel. The energy conversion coefficients for these elements are 12–15, 11–14 and 6–7 accordingly (Zagorska et al., 2012), so mono-crystalline and poly-crystalline panels have begun to be employed commercially and are more widely used in PV panels.

Different researches and scientists have worked on the performance evaluation of photovoltaic system under different climates.

Congedo et al. (2013) focused on the performance of the monocrystalline PV according to the climate characteristics in Southeastern Italy. Their experiments offered a tool to estimate the performances of installed plants with climatic characteristics similar to Southeastern Italy.

Eduardo et al. (2015) experimentally study the performance of monocrystalline and polycrystalline photovoltaic panels for their particular application of water pumping system in Cascavel, Brazil; as for their system with complete pumping, the monocrystalline system presented an average global efficiency of 4.27%, whereas the polycrystalline system showed global efficiency of 5.00%.

Midtgard et al. (2010) Evaluated and compared the performance of three PV modules (monocrystalline, polycrystalline, and triple junction

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Nomenclature

η	efficiency (%)
G	global solar irradiance (kW/m^2)
H	incident solar radiation (kW/m^2)
P_0	PV rated power (kW)
P	instantaneous AC power (W)
$P_{max(STC)}$	maximum power output (W) of panel at standard test conditions
η_P	normalize power output efficiency (%)
PR	performance ratio
PV_A	surface area (m^2)
E_m	the total monthly energy produced by a PV system
γ_m	the monthly average specific energy
N	the number of measuring points for the day
Δt	the time interval of the measurement (min)
M	the number of measured days with complete data sets
η_m	the monthly average efficiency
T	temperature
D_{time}	the duration of the measurements in a day (min)

Subscripts

a	ambient
c	solar module
sys	system
STC	standard test conditions

amorphous silicon) in the climate the site of Norway Eduardo et al. (2015). They concluded that monocrystalline module was better in terms of module efficiency and overall power production.

Another research has been done by Abdelkader et al. (2010) on the behavior of two types of solar panels which are the monocrystalline and polycrystalline and their behavior is measured in Jordan. He has concluded that the efficiencies of the monocrystalline and polycrystalline were very close to each other, but the monocrystalline had a higher efficiency than the polycrystalline.

Jacques et al. (2013) tested monocrystalline solar panels in France, while controlling the ambient temperature and the wind speed. They compared their experimental results with a MATLAB/SIMULINK thermal model for a monocrystalline cell under the same conditions and they obtained consistent relations.

All the above-mentioned studies either focuses on the test results of the efficiency of the different types of solar panels for particular days or in some cases during some months of a year.

The test result of long-term overall performance of monocrystalline and polycrystalline with the evaluation of PV panel performance, according to the irradiance and ambient temperature in semi-arid climate condition is very rare.

The aim of the present study is to evaluate the performance of the most commercially available PV modules (monocrystalline and polycrystalline) in Iran; the country in the middle-east with wide regions in semi-arid climate conditions and huge potentials for harvesting the solar power.

In addition, this study will provide a recommendation for the PV system designer to choose the panels suitable for different areas in the Middle East countries according to the environmental characteristics in this area.

The whole paper is organized as follows: Climate data analysis section focuses on the climate data analysis of the region of the study. Experimental setup and methodology section presents the experimental setup and methodology. Analysis procedure and results are mentioned in Data analysis section and Conclusion section summarizes the relevant conclusions.

Climate data analysis

Fig. 1 illustrates the average annual radiation in Iran and shows its huge potential of harvesting solar energy of Iran. The sun is shining around 2800 h in a year with the average global radiance more than 2000 kWh/m^2. The solar radiation data, displayed in Fig. 1, shows that the solar irradiance in the southern part of Iran, in particular in arid and semi-arid regions, is higher and consequently has more potential for harvesting the solar energy (http://solargis.info/doc/_pics/freemaps/1000px/ghi/SolarGIS-Solar-map-Iran-en.png).

The location of the measuring city is presented in Fig. 1; Rafsanjan City, in the southeast of Iran, is characterized by a semi-arid climatic conditions. The analysis of the testing period, is useful to obtain a general trend of the climatic variation.

In the following, the climate data of Rafsanjan were analyzed in terms of solar radiation, sunshine time, temperature, humidity and wind speed during 12 months of 2014. Fig. 2 shows the solar radiation and sunshine time of Rafsanjan; according to the meteorological data, the average value of the global radiation ranges between 2.8 kWh/m^2 per day in winter months and 7.5 kWh/m^2 per day in summer months for a horizontal surface (http://www.suna.org.ir).

Fig. 3 shows the maximum, minimum and average temperatures collected in 2014. The warmest month is July, characterized by the average value equal to 36.5 °C, whereas the minimum average value is equal to 4.8 °C in January.

The monthly average wind speed of the testing period, is reported in Fig. 4. This parameter is important to estimate the productivity the PV module due to its effect on cooling the PV module by heat convection. The monthly average values of the wind speed of 2014 is in the range 1.7–4.48 m/s.

Moreover, another climatic variable which would effect on the productivity of the PV module is the monthly average humidity (Rahman et al., 2015). The recorded data shows that the humidity is in the low values during the whole year; the humidity values are generally below 25% and can reach 40% in the cold months (Fig. 5). This low range of humidity is typical for the semi-arid regions and does not vary dramatically.

Experimental setup and methodology

Location of study

The experiments have been carried out in solar site of Vali-e-Asr university of Rafsanjan.

The two tested panels were installed on the same stand-alone frames in a similar inclination angle of PV modules (Fig. 6). Based on the location of Rafsanjan city (30.40° N, 55.99° E), the PV modules were placed on a south facing structure at a fixed tilt angle of 34° with the horizontal plane; this angle is near the yearly optimum tilt angle of Rafsanjan, which yields the maximum annual incident solar radiation.

Test systems

Such a PV system consists of PV arrays, data acquisition and monitoring system, and DC to AC inverter. Power generated in the stand alone PV unit can be supplied for a corresponding load. Therefore the solar PV panels are simultaneously converting solar radiation into electricity.

The power monitoring system, includes Sunny Web Box and Sunny Sensor Box, which is interfaced with a data acquisition board. The output of electric current and voltage was measured by the block in a certain period of time and recorded in an SMA sunny web box. The amount of irradiation, the module's temperature, the output current and power generation, daily energy production and total energy production were measured and recorded simultaneously.

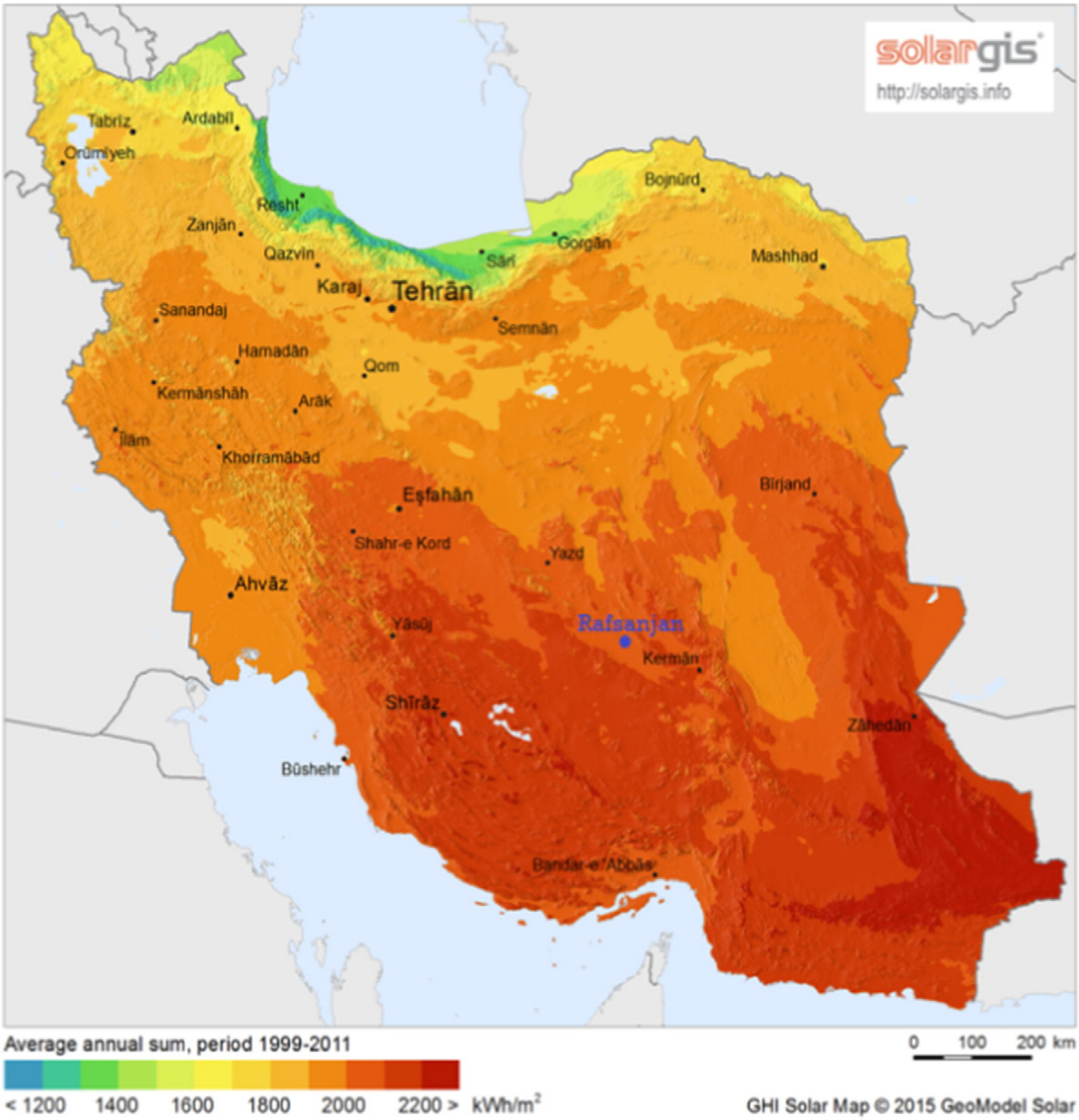

Fig. 1. The average annual radiation of Iran (http://solargis.info/doc/_pics/freemaps/1000px/ghi/SolarGIS-Solar-map-Iran-en.png).

The global solar irradiance was measured using a Pyranometer Kipp & Zonen. Fig. 7 illustrates the schematic diagram of the data monitoring system.

Monocrystalline and polycrystalline PV systems, consisting of five and six panels respectively, startup simultaneously at 6:30 AM and off at 6:30 PM, for almost all days of a year. Table 1 shows the technical specifications and physical dimensions of PV modules used in this investigation.

Data analysis

The data of the solar irradiance, ambient temperature and module temperature covers about 359 days of the year 2014. The single monthly value of each parameter, has been calculated according to the monthly average value of the daily recorded integrals.

Since the given photovoltaic devices operate simultaneously in an actual environment in varying irradiance, weather and climate conditions during the year, our experiments offer a tool to estimate the performances of the given plants with climatic characteristics of semi-arid regions, which leads to a comprehensive evaluation of their performance according to the dependent climatic variables.

Simple evaluation of key data

Power output and efficiency versus irradiance

The most important environmental parameter, influencing the performance of the PV modules, is the irradiance. Since each type of the PV modules used in this study has a different rated power, the output power of PV modules has been normalized with their output power at STC, as presented in formula (1) (Azhar and Abdul, 2012).

Normalized Power Output Efficiency:

$$\eta_P = \frac{P}{P_{\max(\mathrm{STC})}} \times 100\% \qquad (1)$$

In other words, the normalized power output shows how much power is actually generated in each solar irradiance over the installed capacity of the modules.

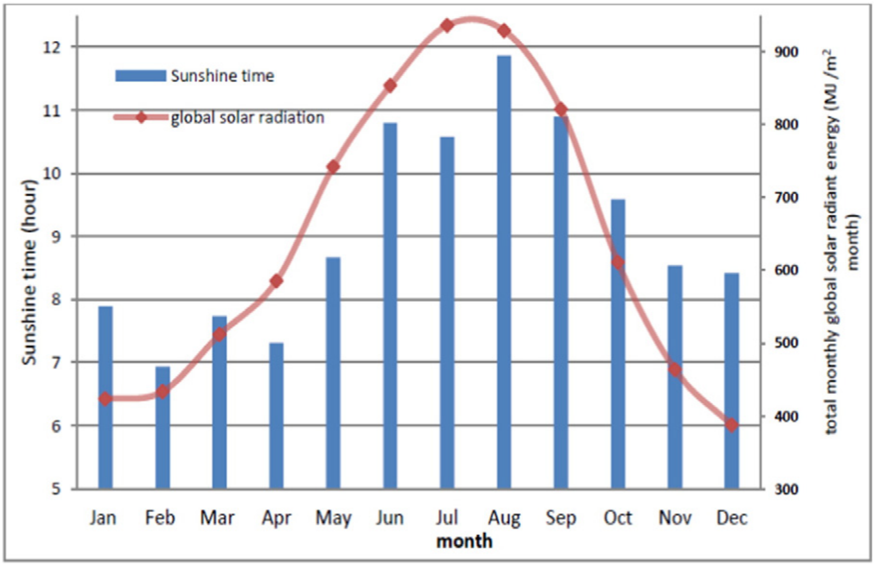

Fig. 2. The monthly values of sunshine time and global radiation in 2014.

Fig. 8 illustrates the normalized power output of the modules versus the measured direct radiation. It is possible to observe that both modules have a similar trend which their normalized power output increases linearly with the solar irradiance with R^2 coefficient around 0.979 and 0.967 for monocrystalline and polycrystalline modules respectively; the data are selected for five random days of each month.

However, the outdoor investigation of the influencing solar irradiance on the power output of PV module, is complicated and commonly leads to many scatter recordings of PV modules. The main difficulties in the assessment of solar irradiance effects arise from the fact that the irradiance is associated with other factors that also affect the performance

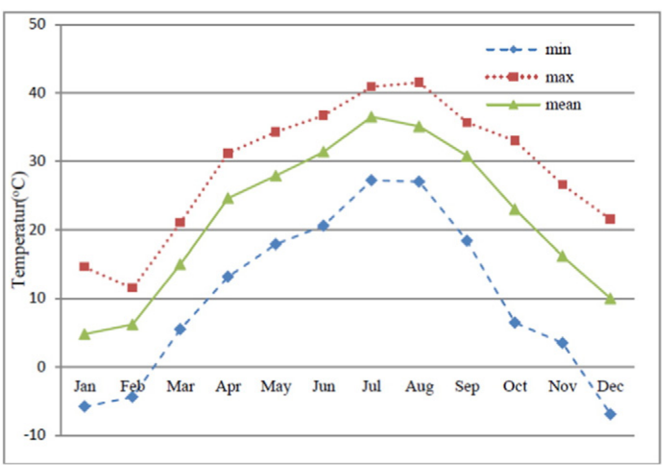

Fig. 3. Maximum, minimum and average of the monthly ambient temperature in 2014.

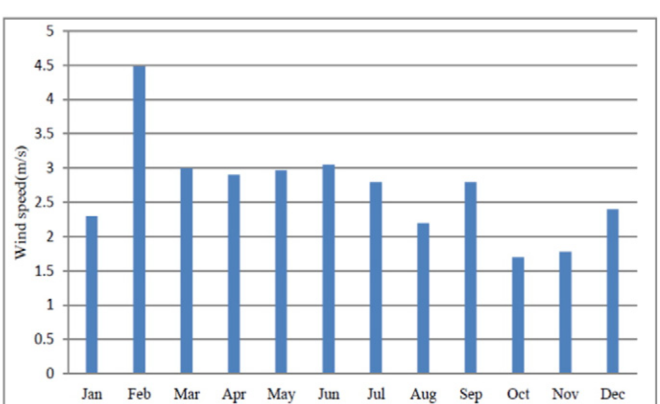

Fig. 4. Monthly average wind speed in 2014.

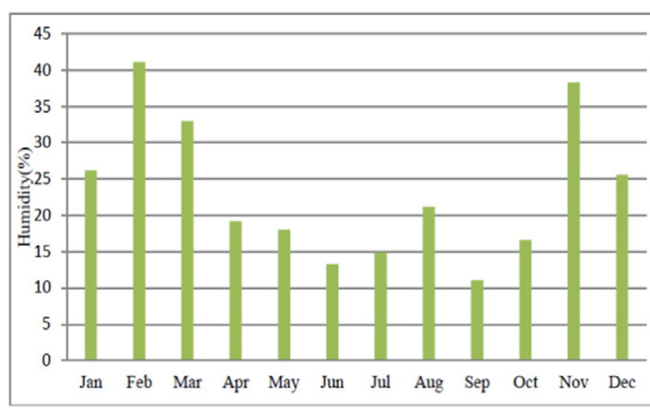

Fig. 5. Average humidity in 2014.

Fig. 6. Solar power plant at Vali-e-Asr University of Rafsanjan.

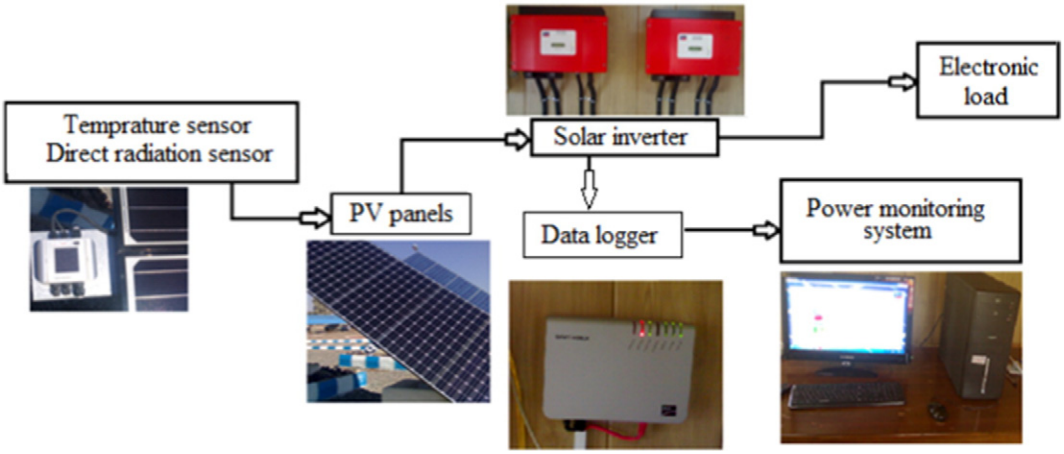

Fig. 7. The schematic diagram of the data monitoring system.

of PV. These factors include clear sky, or diffuse irradiance due to cloudy conditions, low irradiance due to early morning or late afternoon, variations of the panel temperature, spectral and angle of incidence effects (Makridis et al., 2012).

Nevertheless, two different kinds of PV modules, even with the same rated power, will not provide the same output power. This is because the different thermal characteristics and solar cell physic of the PV modules lead the different output power.

Hence, for the comparison purpose, the module efficiency, describing the ability of a panel to convert sunlight into usable energy, is used. The module efficiency, represented in formula (2), is the ratio of the measured power output to the incident solar power input on the active area of the module.

$$\eta = \frac{P}{PV_A.H} \times 100\% \tag{2}$$

This is not shown in Fig. 8, but can be seen in Fig. 9, where the module efficiency of both modules is plotted versus irradiance.

Many of the recordings at moderate irradiance are striking since they give much lower efficiency than normal. There was a systematic shade that appeared on the modules due to the utility pole, which cast a shadow on the modules as the rising sun moved from east towards the west. The utility pole can be seen in Fig. 6.

Some other points with high efficiency, especially during low irradiance, represent distorted data; most of them are probably due to the movement of the cloud, which the intermittent cloud covered sky causes a temporary drop in the global and incident irradiance, while the instantaneous power output does not drop as quickly as the measured direct radiation dose. In the heavily overcast sky days and intermittent cloud covered sky days, the PV module efficiency presents an irregular profile (Congedo et al., 2013).

Another reason for the scattering results of the efficiency is due to the variation of the ambient temperature during the testing period; ambient temperature and consequently module temperature have significant influence on the performance of the modules (Soualmi et al., 2014).

Temperature analysis

The ambient temperature is an important factor in the efficiency of the PV modules, because the temperature of PV module depends directly on the internal and external heat transfer coefficients which are affected mainly by the ambient temperature and irradiance (Bai et al., 2016).

To isolate the temperature effect on the performance of the PV module, the module efficiency is considered for some working conditions during which, the solar radiation is kept constant ($G = 800 \pm 10\ W/m^2$) and the ambient temperature varies.

As illustrated in Fig. 10, the measured data confirm that in the working conditions with a fixed irradiation, the efficiency of both PV modules, decreases when the ambient temperature rises; similar behavior has been seen in the work of Amrouche et al. (2013).

However, the efficiency of the polycrystalline modules inclines in a less rate than one of monocrystalline; as the ambient temperature increases from 5 °C to 35 °C, the monocrystalline and polycrystalline

Table 1
The technical specifications of PV modules.

Type	Mono-crystalline silicon	Poly-crystalline silicon
Module dimensions (mm × mm)	1632 × 986	1649 × 993
Maximum power	250 W	215 W
Maximum power voltage (Vmpp)	29.9 V	28.9 V
Maximum power current (Impp)	8.37 A	7.46 A
Open circuit voltage (Voc)	37.1	35.8
Short circuit current (Isc)	8.76 A	8.1 A
Maximum system voltage	1000 V	1000 V
Maximum series fuse	15 A	15 A
Maximum load	5400 pa	5400 pa

Electrical Nominal Value at STC (1000 W/m^2, AM 1.5 Spectrum, Cell Temperature 25 °C).

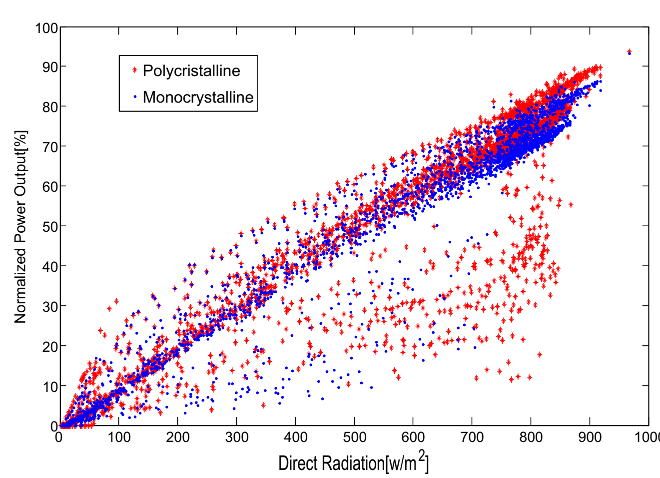

Fig. 8. Scattering plot of normalized power output efficiency of monocrystalline and polycrystalline modules versus direct solar radiations.

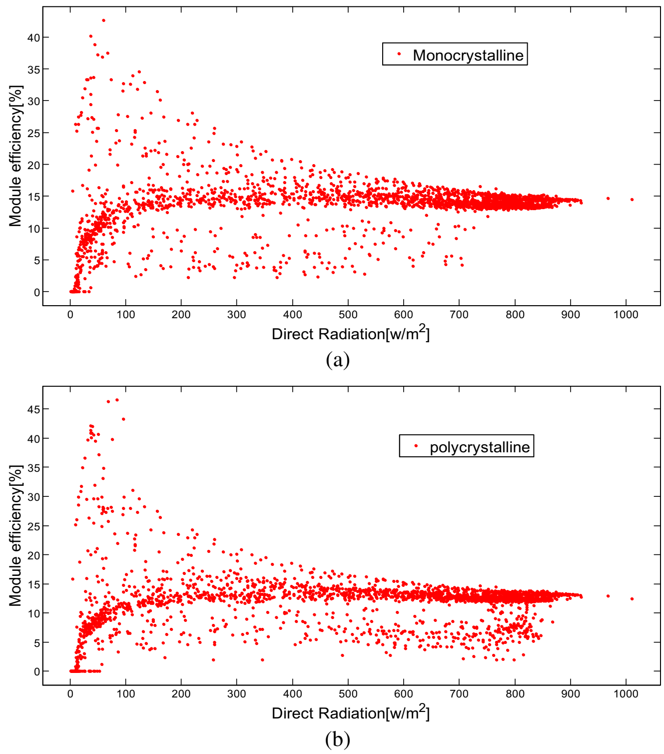

Fig. 9. Module efficiency vs. direct irradiance; (a) Monocrystalline (b) Polycrystalline.

module efficiencies decrease 10.9% (fill in actual efficiencies of roughly 14.9% to 13.4%) and 11.6% (again, fill in values at 5 °C and 35 °C, which look like about 13.5% and 12.2%), respectively.

The operating temperature of a solar module (T_c) above ambient (T_a) is often roughly assumed to be a linear function of the irradiance incident on the module (G_i), as shown in Eq. (3).

$$T_c = T_a + C_i G \tag{3}$$

Fig. 11 shows the relation between the ambient temperature, module's temperature and the intensity of solar radiation. We notice that, as expected, the relationship between temperature difference ($T_c - T_a$) and the irradiance is linear in both modules; the proportionality factor C_t in our experiments is about 0.031 °C/W/m^2 for both modules, while this factor is typically in the range between 0.027 and 0.032 °C/(W/m^2) (Midtgard et al., 2010).

To see the effect of the ambient temperature on the efficiency of the modules, the data of two days, with different ambient temperature, are

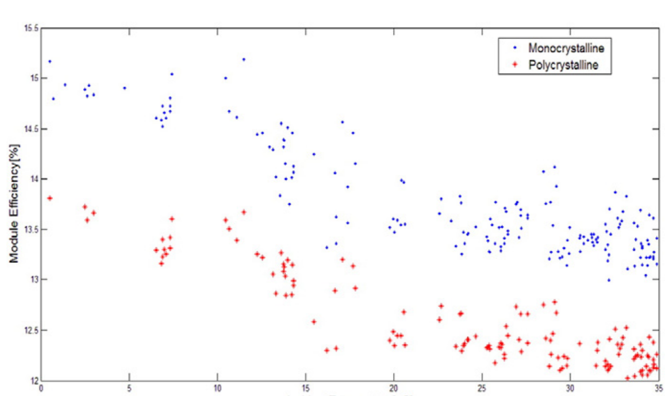

Fig. 10. The module efficiency versus the ambient temperature of the selected data with global radiation of 800 ± 10 W/m^2.

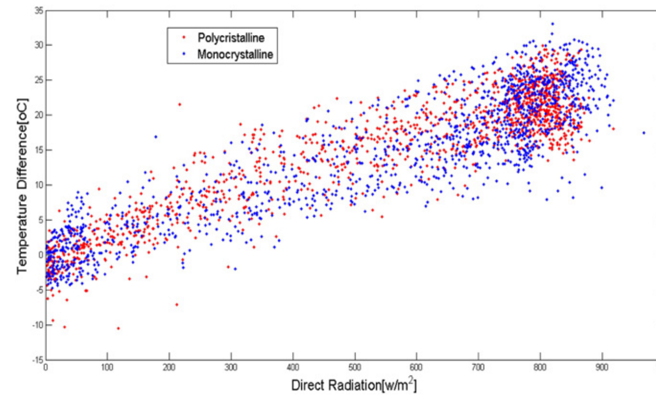

Fig. 11. Difference between the measured module temperature of monocrystalline and polycrystalline and ambient temperatures (Tc −°Ta) versus irradiance.

presented; in Fig. 12a the hourly instant values of the module efficiency of PV modules are shown for the 5th December 2014; then, Fig. 12b refers to the 11th June 2014. The first day was a cold weather with cloudy sky; the second day, instead, characterized by a hot summer day with a clear-sky. Table 2 presents the values of average ambient temperature (T_a), average temperature of the panel (T_c), average wind speed and humidity for these days.

The figures show that on both days, the module efficiency of the monocrystalline is generally more than the polycrystalline module. However, on the hot day, the efficiency of the monocrystalline module is near polycrystalline module, while during the cold day (Fig. 12.a), they show greater difference. Also, at times with high solar irradiance, the efficiency of both modules decreases, confirming that PV efficiency

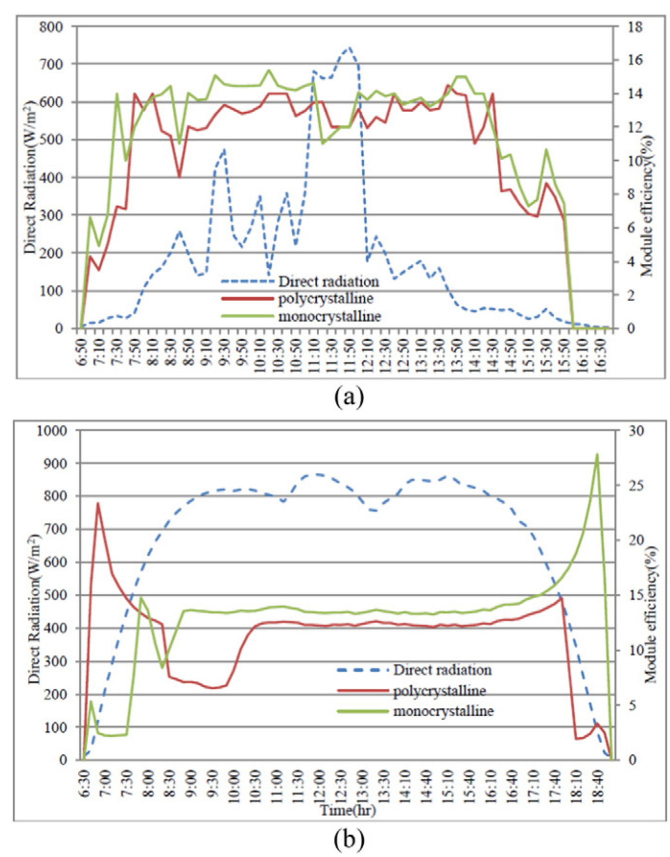

Fig. 12. Hourly variation of module efficiency during (a) 5th December and (b) 11th June 2014.

Table 2
Weather conditions for the 11th June and the 5th December 2014.

	11/06/2014	05/12/214
Sky conditions	Clear	Cloudy
Average ambient temperature (°C)	32.2	11.8
Average temperature of the panel(°C)	48.1	29.5
Wind speed (m/s)	2.9	3.4
Humidity (%)	12	26

decreases as module temperature increases. Tiba and Beltrao (2012) also have seen similar behavior in high irradiance conditions.

Performance analysis of the PV during the year

For analyzing the overall performance of the PV system, the values of specific energy yield, monthly efficiency and the monthly performance ratio of both PV modules, were calculated and compared over the whole monitoring period.

Energy output analysis

In this section, the monthly energy yields of the modules, is characterized and evaluated based on the monthly average specific energy (kWh/kWp), which is defined as the total monthly energy produced by a PV system (E_m in kWh), divided to the PV rated power (P_0 in kWp). The monthly average specific energy is calculated by the following Eq. (4):

$$\Upsilon_m = \frac{E_m}{P_0} \tag{4}$$

Fig. 14 shows the specific energies for both modules over the target period.

As expected, the summer months, June and July, appear to have the highest sunshine (Fig. 13), which leads to the best specific energy, while for the both modules, the least amount of specific energy is produced during the darkest winter months, November–February.

By comparing the results, it is also possible to observe that in non-summer months, the monocrystalline module has a significantly higher specific energy than the polycrystalline module, while during the summer months, this value for the polycrystalline module is higher.

The values of specific energy of both modules increase from February to June, and decrease in the successive months with a peak difference of about 0.84 kWh/kWp-day and 0.51 kWh/kWp-day for polycrystalline and monocrystalline modules, respectively.

For the monocrystalline module it ranges from the highest value (168.15 kWh/kWp) in July to the lowest (115.54 kWh/kWp) in December, whereas for the polycrystalline module, the maximum value (168.21 kWh/kWp) is in June and the minimum one (95.77 kWh/kWp) is January.

The dependence of monthly energy yield (Y_f) against solar irradiance (monthly average of daily global solar irradiation) for monocrystalline and polycrystalline, is represented in Fig. 14, which shows that in the low range of solar radiance (winter), the energy yield of monocrystalline module is significantly higher than polycrystalline, while with increasing solar irradiance (spring and autumn), the difference of specific energy of the modules is decreasing, and finally in the high range of irradiance (summer), the energy yield of polycrystalline module reaches slightly higher than monocrystalline.

Module efficiency analysis

To give an estimate of the monthly averaged efficiency of the PV modules, the instantaneous efficiency of the panels is averaged over the testing days from 06:30 a.m. until 06:30 p.m. with the interval time of 5 min. Then the daily averaged value of all available testing day with complete dataset, are summed for each given month, thereafter the obtained value is divided by the number of days. The final value gives the estimate of the average monthly efficiency by the PV modules during each given month. However, for the months with incomplete data sets, the monthly averaged values of the efficiency are calculated according to the recorded data of the available days with the assumption that the recordings are representative for the full month. This is expressed also in Eq. (5).

$$\eta_m = \frac{1}{M} \sum_j^M \sum_j^N \frac{\eta * \Delta t}{D_{time}} \tag{5}$$

η_m is the monthly average efficiency, M is the number of measured days in a month with complete datasets, N is the number of measuring points in a testing day, Δt is the time interval of the measurement, and D_{time} is the duration of the measurements in the given testing day.

Fig. 15 shows the monthly average PV system efficiency over the monitored period, which is obtained according to Eq. (5). The highest efficiency is calculated in December (15.2%) for monocrystalline module, while the lowest one is evident in November (11.44%) for polycrystalline.

It is evident that during the cold months, the monocrystalline module has a significantly higher efficiency than the polycrystalline module which is near the efficiency found at 1000 W/m^2 in the summer without temperature adjustment. This could be due to colder weather in the non-summer seasons.

While for the polycrystalline module, the overall efficiency is significantly lower than the non-temperature adjusted efficiencies found at 1000 W/m^2 during the non-summer.

In other words, with increasing irradiance and ambient temperature, the efficiency of the monocrystalline module decreases, while polycrystalline shows an inverse behavior. Indeed, it means that, in the hot weather with abundant irradiance, the polycrystalline is more efficient than monocrystalline due to their different light absorbing and thermal characteristics of each kind of panels (Bashir et al., 2014).

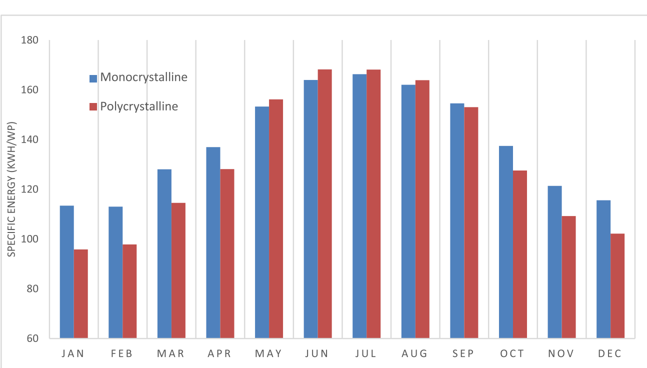

Fig. 13. Monthly total energy generated over the monitored period.

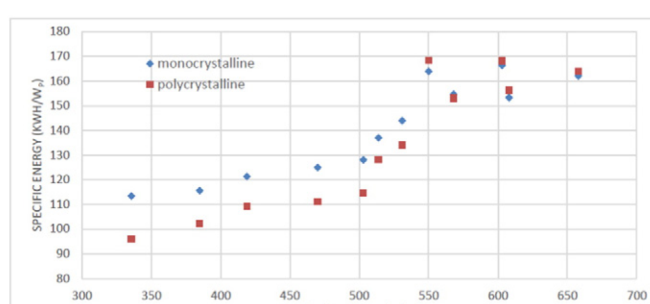

Fig. 14. Monthly final yield against monthly average of daily global solar irradiation.

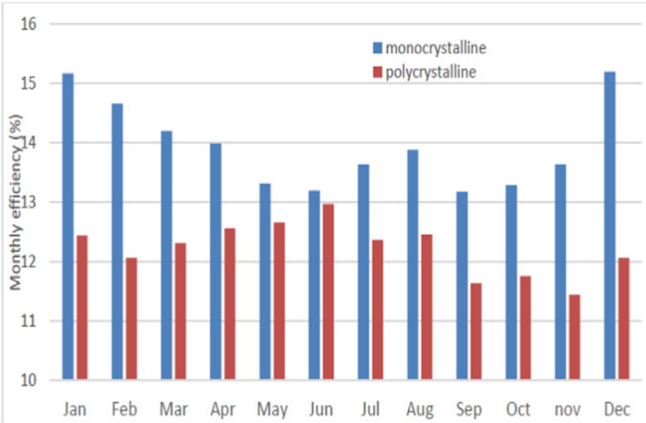

Fig. 15. Monthly module efficiency over the monitored period.

The same results are presented in Table 3; the overall efficiencies over the year for both modules, are shown in the last row. These results indicate that the monocrystalline module performed better than the polycrystalline module over the whole target period.

Performance ratio analysis

Since the actual electrical characteristics of the PV panels are different from the reference STC characteristics, the PR is calculated to evaluate the performance of the PV modules. Indeed, PR, defined as the ratio between the real energy production and the product energy at STC, is a useful way to quantify the overall effect of losses due to different environmental and operational factors such as spectrum, module mismatch, optical reflection, module temperature, and wind speed. Therefore, it indicates the percentage of energy really available after deducting energy losses. PR is largely independent of the location of a PV plant and the incident solar irradiation on the PV. The instantaneous performance ratio is estimated by Eq. (6).

$$PR = \frac{\eta_{sys}}{\eta_{STC}} \tag{6}$$

Where: $\eta_{sys} = \frac{P}{PV_A.H}$ and $\eta_{STC} = \frac{P_{STC}}{PV_A.G_{STC}}$.

The monthly averaged values of the PR are calculated according to the assumption expressed also for monthly averaged values of the efficiency (Eq. (5)).

The values of PR, illustrated in Fig. 16, show the monthly performance ratio of both modules over the testing period. In regard to the monthly irradiance (Fig. 2) it concluded that the polycrystalline module yields better PR at months with abundant irradiance, while becomes less than monocrystalline modules at winter-months, which is due to their different light absorbing characteristics, also found by Bashir et al. (2014).

In June, the monocrystalline module has the lowest PR (83%) corresponding to the highest solar irradiance, while this value for polycrystalline module is the highest (97%).

Table 3
Variations in the monthly module efficiency during the year 2014.

Month	Monocrystalline Monthly module efficiency (%)	Polycrystalline
Jan	15.17	12.44
Feb	14.66	12.07
Mar	14.2	12.32
Apr	13.99	12.56
May	13.32	12.66
Jun	13.2	12.97
Jul	13.64	12.37
Aug	13.88	12.46
Sep	13.18	11.64
Oct	13.29	11.76
Nov	13.64	11.44
Dec	15.2	12.07
Total	13.95	12.23

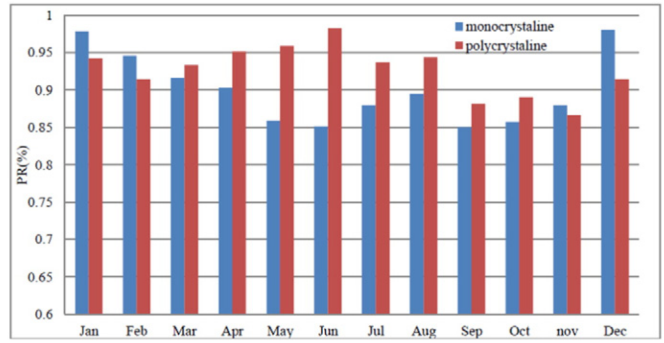

Fig. 16. Monthly performance ratio over the monitored period.

Conclusion

A performance test of two different commercially available PV, monocrystalline and polycrystalline, panels has been carried out in this paper. This test was conducted during the year 2014 in an outdoor environment in southeastern of Iran. This site is characterized by semi-arid climate conditions; hot and dry summer and relatively cold winter; the humidity values are generally below 25% and can reach 40% in cold months.

Input power has been calculated based on the measured solar radiation, and the output power of the panels is calculated from the measured values of generated current and voltage. Beside the input and output of the PV panels, the environmental data were recorded to correlate with the performance of the tested PV panels.

In particular the dependency of module performance on solar irradiance and ambient temperature has been underlined through the recordings over a year.

As expected, the power output of both modules increases with the irradiance, while their efficiency, during the moderate irradiance, is the highest in the selected days. The monthly average efficiency of monocrystalline module varies between the highest values to about 15.2% in December and the lowest to about 13.2% in June, while these values for polycrystalline module is 12.97% in June and 11.44% in November respectively.

The comparison of the module efficiency indicates that despite similar behavior of both PV modules with instantaneous irradiance, the monthly average module efficiency of monocrystalline module has a gradual decreasing trend in the months with higher solar irradiance and temperature, while polycrystalline module shows an inverse behavior.

Like monthly average efficiency, monthly PR of monocrystalline module decreases through the summer-months, which has higher solar irradiance and temperature, but the polycrystalline module yields higher monthly PR in the winter months.

The temperature measurements further enabled us to evaluate the effect of ambient temperature on the performance of the PV modules at the actual operating conditions, which findings of performance ratio indicate that due to the different light absorbing and thermal characteristic of each PV module, in the summer months with high temperature, polycrystalline module performs higher PR than monocrystalline, however, in non-summer months, even with similar irradiance, monocrystalline module yields higher PR.

Hence it is concluded that under semi-arid climate conditions of Iran, polycrystalline solar module is more suitable to be used in the summer months, while monocrystalline module is more efficient in the non-summer months.

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