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Experimental analysis of solar intensity on photovoltaic in hot and humid weather conditions

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Abstract— Photovoltaic (PV) technology becomes worldwide spread and always improves its output and costs. However, as these PV modules are exposed to outdoor conditions, it is highly influenced by weather parameters. The recent study was conducted to evaluate the effect of solar radiation on the PV module in hot and humid weather in Sohar-Oman. Two PV modules connected in series were used to assess the impact of the local wind in this area. The results indicated that the wind effect was insignificant on the modules temperature for the tested period. Most of the study results were similar to the findings of many researchers concerning voltage drop with increasing temperature, and high current value, and a significant reduction of the power due to the rise in air temperature. However, in this study, we used the concept of solar air temperature and studied its effect on the panels' temperature. The results reveal that solar air temperature worked as heating source starting from 8 AM till about 5 PM in winter and 7 PM in summer, and as a cooling source after the mentioned times. The high relative humidity distinguishing the tested area Sohar caused a reduction in the solar radiation intensity which reflected in lower solar air temperature.

Keywords- solar intensity, PV back temperature, solar air temperature, relative humidity.

1 Introduction

PV is a device that converts sunlight into electricity directly and commonly known as "solar cells". Solar cells connect in series and parallel to increase voltage and current and produce PV module. The power available from one module is insufficient for supplying power to many loads. Many PV modules can be connected in parallel, series, or both so as to form a PV array to increase either output current and/or voltage. The simple example is the solar cell powered, small calculators. The large size and more complicated PV systems provide a significant portion of the electricity for cities. PV is the most promising means of maintaining our intensive energy standard of living while not contributing to global warming and pollution.

Weather conditions influence PV module voltage and power production changes; it is important to distinguish the system responds to these changes, and, therefore, they can be associated with the design and preparation of PV module size and proper equipment. The design and the right numbers for the PV system dispel safety concerns, and raise the capabilities of the equipment and reduce the amount of wiring required to the system, and thus reduce the costs of its establishment. Engineers estimated the amount of energy that can be produced through the use of weather data as temperature, wind speed, solar radiation intensity, and relative humidity [1].

Oman located within the red solar belt; this area is characterized with one of the highest solar radiation in the world. The high solar intensity levels are followed by heat, where the solar modules are directed to stand to face this radiation [2]. The incident radiation is divided into two parts; the first part used to generate electricity in the photovoltaic cell while the second part used to raise its temperature [3]. All the research trials show higher PV cell temperatures linked with the rising of the solar radiation intensity. Solar module optimally operates in particular weather conditions called standard test conditions STC, which were identified by manufacturers and engineers at a temperature of 25°C, the solar radiation intensity of 1000 W/m², the air mass = 1.5, and relative humidity of 45% [4]. However, these circumstances do not fit in most regions across the world. As the weather is constantly changing, the greater part of the solar cells does not work under ideal conditions [5]. Many external influences determine the efficiency of PV energy conversion, including light reflectivity on the cell surface, which varies from one type to another. There is also the angle at which the solar radiation is falling on the cell [6], [7]. There is another important factor affecting the efficiency of the PV system which is the wavelength of the falling radiation, as the effectiveness of energy conversion changed with the changes in the spectrum of the sun's rays [8], [9]. Also, an important factor is the cell temperature, which depends on several factors, including ambient air temperature, solar intensity, and local wind speed [10], [11]. Even if all these influences stay constants, the conversion efficiency remains dependent on light intensity [12], [13].

The cell displays for intense solar radiation and high temperature for a long time reflected on its performance and efficiency, which will be lower than those measured in STC. Many researchers investigated the PV cell efficiency in variable geographic locations; weather in urban areas, rural areas, or deserts [14]. All these studies took the importance of the differences in the solar radiation intensity into account as an important cause of the performance and efficiency of the PV cell.

The estimation of the selected site solar resources is facilitated by the availability of the data of the solar radiation intensity. The provision of the solar intensity, temperature, and the local wind speed data become a way to assess the performance of PV modules taking into account the many interference effects that affect the PV modules performance anywhere [15].

Singh [16] investigated the impact of temperature on the performance of solar modules in the temperature range from 0° to 250° theoretically. The study concluded that increasing temperature increased the current and reduced the voltage and fill factor. Radziemska [17] studied the effect of temperature and wavelength on the performance of PV cell adding a copper plate working as a heat sink for the generated heat by radiation. The results showed a decrease in cell power with about (0.65%/K) when the cell temperature is raised 80°C. Makrides

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et al. [18] analyzed the effect of temperature on the various photovoltaic technologies in Cyprus. The results showed that the power losses varied depending on the type of the solar cell. The average loss of power due to temperature rise is 8 % for monocrystalline silicon, and9% for the multi- crystalline silicon while the thin-film and the other technologies the power loss was 5%.

Hamrouni [19] investigated the effect of solar radiation and ambient temperature on the performance of a pumping system consists of a PV generator, transformer DC-DC, DC-AC inverter and submersible pump. The investigations were carried out in Tunisia, and the results of the study showed that the rise in ambient temperature cause low performance of the pump system and is associated with a significant increase in the solar beam. The study concluded that the reduction in the maximum efficiency occurred in the middle of the day when the intensity of the solar radiation is at its maximum.

Kazem et al. [20], [21] investigated the effect of solar radiation on the PV systems in Oman. Different configurations have been designed, tested and evaluated in term of technical and economic criteria. The authors claimed that even with the negative impact of high temperature on the PV performance but the high solar radiation, long day and peak hours in promising to invest in PV systems in Oman.

In this study, the weather conditions of solar radiation, ambient air temperature, the PV cell temperature, relative humidity, and wind speed data from the city of Sohar-Oman for a full year starting from 1-9-2014 and ending at 31-8-2015 has been measured and recorded. The study investigated the influences of the solar radiation intensity and the rest variables on the efficiency of the cell in three different systems. These PV systems are standalone, grid connected and tracking systems.

1.1 Solar potential in the tested area (Sohar-Oman)

Oman lies between latitude and longitude and 59 40 E, and 16 40 N, respectively, so the intensity of solar radiation across the country is relatively high. Oman is characterized by a scalding climate, and reaches maximum temperatures sometimes as high as 50°C in the summer season, from May to September. In coastal areas of Oman, which stretches to the length of 2300 km, the climate is humid while the desert areas remain dry [5]. Most of the land is a desert in Sohar has a high degree of clarity throughout the year, and most of the solar radiation is the direct one. The average is up to 5.197 kWh/m^2/day. Many valuable research studies have shown, based on the measurement of the solar intensity and the other different weather conditions, that PV production systems will have a promising future in Oman.

2 Experimental Setup

Three PV systems of 1.68 kW standalone, 1.4 kW grid-connected and 0.28 kW tracking were installed at the Renewable Energy Laboratory in Sohar University. Table 1 illustrates the PV module specifications; the life of the module is 25 years. Each system consists of two modules connected in series to come up with 36 V DC. Also, a different number of modules connected in parallel to produce the power rating of the three systems. The first and second systems (standalone and grid connected) fixed on the roof of the lab with 27° inclination facing south and on the same height. The third system (tracking) also fixed with the same tilt angle for comparison with 2-meter height from the lab roof floor with the same orientation. The idea of setting up the third system was to study the local wind effect on the module temperature, and then the performance of the PV system. Fig. 1 shows a capture for the three installed systems. In this study, the stand alone and the tracking system were used.

Table 1
Specifications of the proposed system

PV module(Kyocera KD140GH-2PU)	
PV module rated power	140 Wp
Maximum voltage	17.7
Maximum current	7.91
Open circuit voltage	22.1
Short circuit current	8.68
PV module Efficiency	13.9%
Temperature coefficient of Vo.c	-0.36 %/k
Temperature coefficient of Is.c	0.06 %/k
Inverter	1.7 kW,1 kW, 0.3kW
AC voltage	220-260
Inverter Efficiency	94.1%

Fig. 1. Capture for the tested PV systems

In this research, the climate data was measured for a full year for the period from 01/09/2014 until 08/31/2015. In these data, the intensity of solar radiation, diffuse solar radiation, relative humidity, ambient temperature, the speed of the local winds, were measured. Measurements were conducted per seconds to get the most accurate data, and to facilitate the statistic process and to use this information in the study; these data were treated in a computer program to calculate the average for per-minute and then every per-hour. The last one was used to investigate the effects of weather variables on the PV performance.

For this purpose, the WE300 - Rugged solar radiation transmitter detector (4-20 ma), Range: 0 to 1500 W/m2; spectral response: 400 to 1100 nm; 22.5 m cable, was used to measure the solar radiation intensity. A WE710 PV Panel backside surface temperature sensor type 100Ohm, platinum class an RTD, Output: 4-20 ma, (-50°C to +85°C) was used to measure the panels temperatures. This device has an accuracy of ±0.25°C, and wires length was 22.5 m cable. A WE700 + WE770 air temperature sensor with solar shield temperature sensor type: precision RTD, has an output: 4-20 ma, range: -50°C to +50°C, 22.5 m cable, was used to measure the ambient temperature. A REAM-Data Acquisition System of 16 Analogue Channels (4-20mA , 0-5V ,0-10V and 0-24V) NISE 104–Computer Dual Core Atom D2550 1.86GHz, 2GB RAM, 32GB SSD, 17" IP65 1024 x 768 Touch Screen with Software: DART (Data Acquisition Real Time) was used to measured and record variables on the renewable energy lab computer for 24 hours a day and 365 days.

3 Results and Discussions

The weather conditions in Oman, in general, divided into two seasons, cold and hot. The cold season, which is called winter season, expands from 15 December to 15 February. The hot season, summer season, extends for the rest of the year. However, the period from first of May to the end of September lives the highest ambient temperatures. In this study, and as we have recorded the variables mentioned above for whole one year. Two periods were selected to introduce the harshest climate conditions in the tested area.

Fig. 2 shows the ambient temperature for both periods distributed on the daytime. The summer climate temperatures are not very high in the desert areas of Oman, because of the high relative humidity in Sohar. The high humidity increases the heat absorption from the solar radiation.

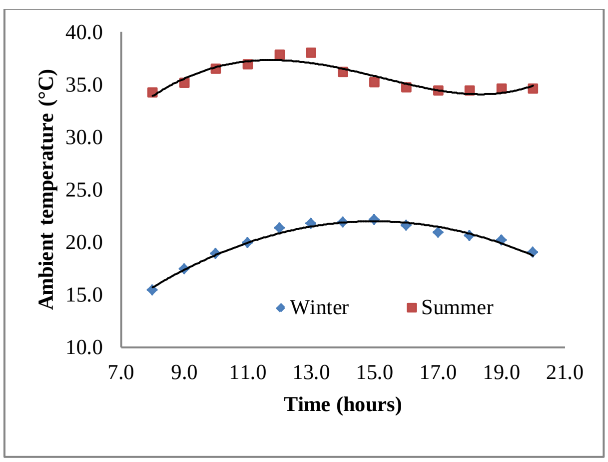

Fig. 2. Ambient air temperature distribution with time for winter and summer

Fig. 3 represents the recorded solar intensity for the two seasons. The figure shows the significant differences between the solar intensity which increase in summer with about 101.6% compared to winter.

Fig. 4 manifests the back panel temperature for the first module which was fixed on the lab roof. The panels temperatures increased highly compared to its temperatures in winter; the increments were 97.64%.

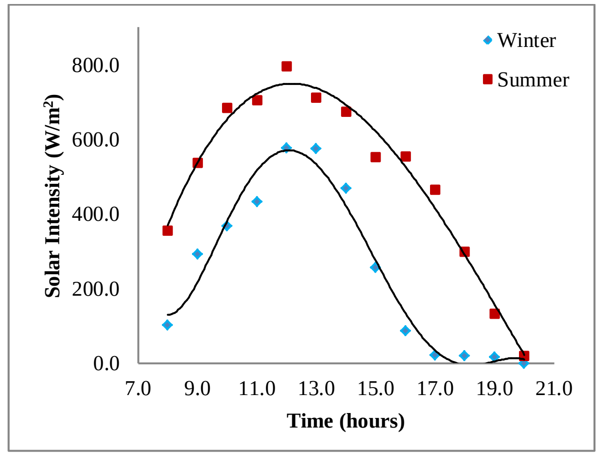

Fig. 3. Solar radiation intensity temperature distribution with time for winter and summer

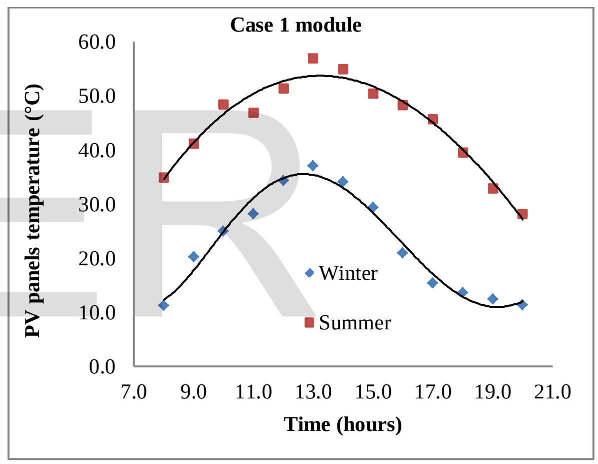

Fig. 4. Case 1 module temperature distribution with time for winter and summer

Fig. 5 declares the back panel's temperature for the second module which was fixed two meters higher than the first system to find out the cooling effect of the local wind on the system. When the results indicated in Fig. 4 were compared to Fig. 5 results the following was shown:

1- In winter, an insignificant reduction in the back panel's temperatures equals to 1.9%.

2- In summer, an insignificant decrease in the back panel's temperatures equals to 2.8%.

The expression of these results as it is insignificant because the impact of the temperature reduction rate on the productivity of the system is limited, when the high cost of structure and maintenance for the second case is considered, compared to the first instance. After the recorded conditions improved that there are no beneficial changes between the two tested modules, the study will focus on the first module. Fig. 6 represents the output voltage from the first module distributed on the

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daytime for winter and summer. The results show that winter's voltages are higher than summer ones with 483%. These findings are compatible with all the researchers in this field. In summer the module currents become higher than winter, as Fig. 7 indicates. The current in summer was higher than that in winter with about 46.7%, which confirms the other researches in this field also.

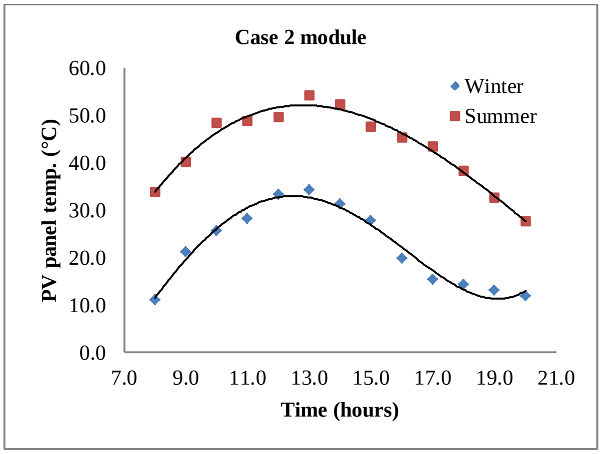

Fig. 5. Case 2 module temperature distribution with time for winter and summer

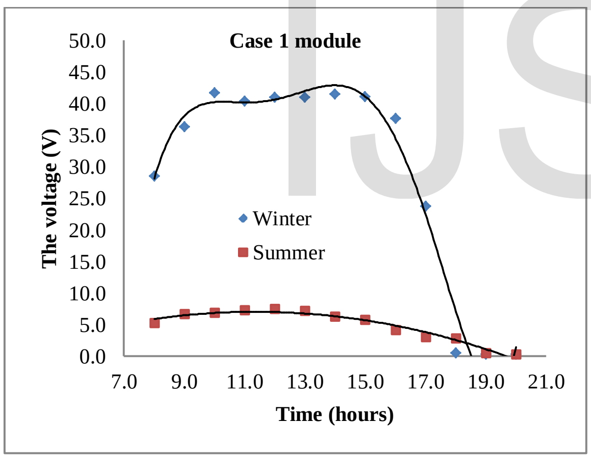

Fig. 6. Case 1 module voltage distribution with time for winter and summer

Finally, the power generated by the system in winter is higher than those caused by summer, as Fig. 8 represents. The power difference was 71.1% for the benefit of winter. This result doesn't vary much from other researches in this field. However, most of these articles referred the degradation in PV module cause to the high ambient temperature in summer. In this work, we took another variable worth to mention although of its importance which is the solar air heat.

The influence of the sun on the surface of any external wall causing heating and warming the surface of the wall to a higher degree than the outside ambient air temperature. The amount of the heating effect of the sun depends on:

1. The site (width line), the time of day, the date (summer or winter).
2. The surface color.
3. The direction of the wall facing the sun (north, south, east …etc).

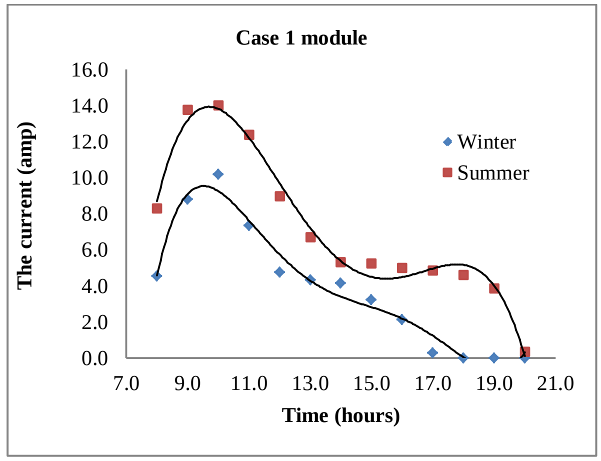

Fig. 7. Case 1 module current distribution with time for winter and summer

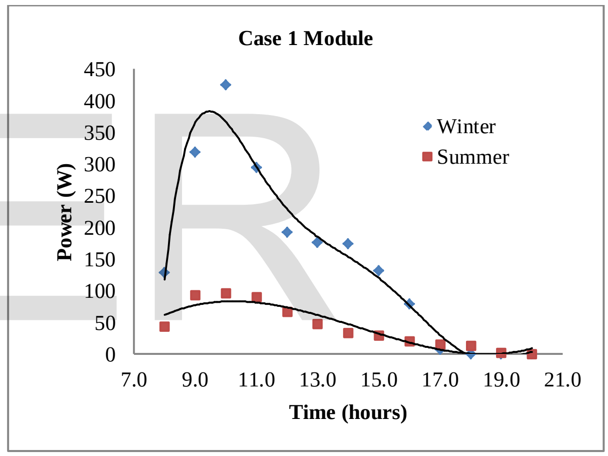

Fig. 8. Case 1 module power distribution with time for winter and summer

The solar radiations with the ambient temperatures are causing a new degree of the external environment, which is calculated and called the solar air temperature.

The solar air temperature for a dark wall facing the West will be higher than the ambient air temperature up to 56°C, and for a white wall, the surface will be higher only at 28°C.

The solar air temperature equation is calculated by the equation:

$$t_e = t_o + \frac{\alpha I_t}{h_o} - \varepsilon \Delta R / h_o \qquad (1)$$

Where:

T_o = the outdoor air temperature.

h_o = the surface heat transfer coefficient usually taken as 17 W / m².°C

α = the solar energy absorption coefficient from the surface.

It = the total solar radiation on the surface.

For the horizontal surfaces these are a correction factor represented by (ε ΔR/ho) which is usually equivalent to 4K, and for vertical surfaces R usually is taken as 0. Since the surrounding areas have a temperature degree higher than the temperature of the ambient air temperature, and thus the solar air temperature compensates for the low level of effective sky temperature. The above equation is used to calculate the solar air temperatures for all sites and times on condition of the availability of the ambient air temperatures and direct solar radiation data.

Figs 9 and 10 represent the variations in the ambient temperature, the panel temperature, and the solar air temperature for winter (Fig. 9) and summer (Fig. 10). Both figures gave some immediate indications which are:

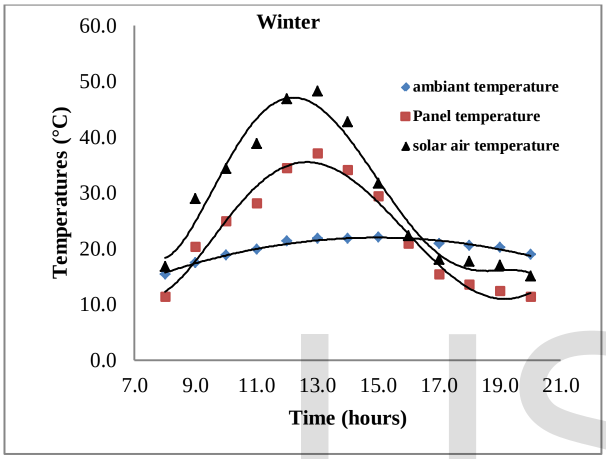

Fig. 9. ambient, panels, and solar air temperature distribution with time for winter

1- The panel temperature is higher than the ambient temperature starting from 8 AM till 5 PM in winter. In summer, this period was elongated for about 7 PM. After this time, the panel temperature became lower than the ambient temperature.

2- The solar air temperature was higher than both the ambient and the panel temperature. According to the thermodynamic zero- law, the heat moves from higher temperature body to the lower one. This means that the solar air temperature is the major influential parameter impacts the panel temperature, and hence its performance.

3- The solar air temperature peak in winter occurred at 1 PM while in summer happened at 12 AM. The panel maximum temperature lagged in the two cases with about one hour from solar air temperature. This time, lag is natural, as the panel needs time to absorb the heat from the air by conduction, convection, and radiation, and then needs time to transfer this heat from the front surface to the back surface where the temperature sensors were fixed.

4- The two figures clarifies that the solar air temperature in the last three hours for winter and one hour for the summer has a cooling effect on the panel, as it was lower than the ambient temperatures.

5- Ref. [22] clarified that the high relative humidity in the tested area of Sohar is a major factor affecting the PV modules performance in this area. The recent results confirm what the reference conclusions. The very high relative humidity in this area absorbs a significant portion of the incident radiation which reflects on lower solar air temperature.

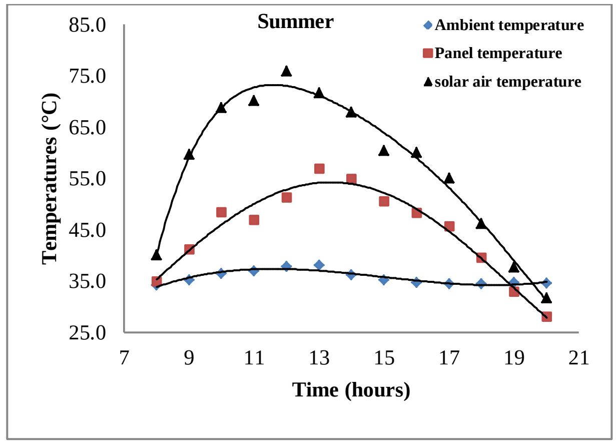

Fig. 10. ambient, panels, and solar air temperature distribution with time for summer

4 Conclusions

In this article, the effect of solar radiation on the PV module was studied. Two modules consist of two panels connected in series were used to evaluate the correlation between the local wind cooling effect and the solar intensity. The results indicated that the wind effect was insignificant on the modules temperature for the tested period. Also, the study results were similar to the findings of many researchers regarding voltage drop with increasing temperature, and high current value, and a significant reduction of the power due to the air temperature increase. In this study, the solar air temperature was introduced as the dominant effect on the panels' temperature, where it worked as heating source starting from 8 AM till about 5 PM in winter and 7 PM in summer. Besides, it worked as a cooling source after the mentioned times. The high relative humidity distinguishing the tested area Sohar cause a reduction in the solar radiation intensity which reflected in lower solar air temperature .

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