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The Temperature Effect on Solar Photovoltaic Module Efficiency

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Abstract

The solar photovoltaic (PV) system generates both electrical and thermal energy from solar radiation. In this paper, an attempt has been made for evaluating the effect of temperature on the energy and power conversion efficiency of a solar PV module installed at Karabuk province in Turkey. Using the first law of thermodynamics, energy analysis was performed and the variation of maximum power point was observed during the PV conversion process. The operating and electrical parameters of a PV array include PV module temperature, overall heat loss coefficient, open-circuit voltage, short-circuit current, fill factor, etc. were experimentally determined for a week of November, 2015. The experimental data are used for the calculation of the energy and power conversion efficiencies of the PV systems. Energy efficiency is seen to vary between 13% and 21% during the week. In contrast, power conversion efficiency is lower for electricity generation using the considered PV module, ranging from 8% to 16%. It is observed that the PV module temperature has a great effect on both the energy and power conversion efficiency. Besides, these efficiencies can be improved if the heat can be removed from the PV module surface. It was concluded that the energy losses increased with increasing module temperature.

Key words: Temperature effect, PV module performance, energy and power conversion efficiency

1. Introduction

Energy has always become a crucial factor for continuity of human life. Despite the increasing energy demand due to improved living standards all over the world, reducing dependence on foreign energy is therefore essential. For this purpose, developing installed electricity capacity with power generation technologies that are environmentally friendly and have high energy efficiency is needed.

The solar power is affordable, inexhaustible and clean source of energy. Employing solar energy therefore brings enormous benefits considering enhance sustainability, decrease pollution and limiting global warming. It is not only a powerful option to reduce environmental concerns; it provides also an indigenous solution for diminishing use of fossil fuels and keeping clean power generation prices lower [1].

The solar photovoltaic (PV) cell is an electrical device that converts the energy of light into direct-current electricity using semiconducting materials that exhibit the photovoltaic effect, which is called physical and chemical phenomenon. The working principle of cell starts with the absorption of light in which the electrons present in the valence band are being excited and become free. Thus, photons whose energy is equal to or greater than the band gap in

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semiconductor materials used in making cell constitute electron hole pairs or excitons at first. As the second step involves the separation of charge carriers of opposite types in the cell, separating extraction of those carriers to an external circuit takes place in the last phase. Consequently, PV cells as working a semiconductor diode convert carrying sunlight energy into directly electricity by utilizing internal photochemical reactions. [2].

Like all other semiconductor devices, solar cells are sensitive to temperature. Increases in temperature reduce the band gap of a semiconductor, thereby effecting most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. Lower energy is therefore needed to break the bond. In the bond model of a semiconductor band gap, reduction in the bond energy also reduces the band gap. Therefore, increasing the temperature reduces the band gap.

Considering previous studies in literature, it is seen that the efficiency of photovoltaic solar cells decreases with an increase of temperature, this decrease is determined first of all by the drop of open circuit cell voltage [3], therefore an efficient performance of PV cells in conditions, for example, of concentrated sunlight, demands cooling. The earlier theoretical studies [4] have shown that this decrease is inevitable, but the actual temperature coefficient of the efficiency depends on the carrier transport mechanism, and in different cases (ideal current or recombination one) could differ by several times; the effects of recombination normally enhance the efficiency variation with temperature. Numerous subsequent studies [5, 6, 7] presented results of measurements and calculations of the temperature coefficients of solar cells parameters in different approximations. Therefore, since solar PV modules are consisted of solar cells, they are also affected by their operating temperature, which is primarily a product of the ambient air temperature as well as the level of sunlight.[8].

For energy efficiency of solar modules, experimental studies also exist. A field experiment in the United Kingdom revealed a drop of 1.1% of peak output for every increase in degrees Celsius of a home solar PV module once the module reached 42 degrees Celsius [9]. Laboratory experiments at the Rivers State University of Science and Technology at Port Harcourt, Nigeria in 2008 found similar results; solar module energy production dropped off steadily once the module temperature reached 44 degrees Celsius. The temperatures of the solar panels tested were, on average, about 20 degrees Celsius higher than the ambient air temperature [10]. Accordingly, the drop-off in efficiency begins at about 30 to 33 degrees Celsius. Here, temperatures frequently reached during summer daytime hours in temperate climates, and often exceeded in equatorial nations.

2. System Description

In this experimental study, a silicon based polycrystalline solar PV module was performed throughout November in Karabuk province in Turkey. In order to carry out efficiency analysis, a PV system was installed on the top of the Engineering Faculty, Karabuk University, Karabuk, Turkey. There are 72 polycrystalline PV panels as seen in Fig. 1. Each has a rated power output of 130 Watt-peak (Wp) with a rated voltage of 21,9 V. The specific features and dimensions of each PV module have been given in Table 1. Here, the module properties have been presented in standard test conditions including 1000 W/m2 global solar radiation, 1,5 AM and 25 ^{o}C ambient temperature.

Figure 1. The installed PV system

Table 1. The panel properties within standard test conditions

IBC PolySol 130 GC		Technical Data
Nominal peak power	W_p	130.0
Nominal voltage	V	18.0
Nominal current	A	7.23
Open circuit voltage	V	21.9
Short-circuit current	A	7.9
Temperature coefficient of I_{sc}	%/K	+0.05
Temperature coefficient of V_{OC}	mV/K	-78.8
Temperature coefficient of P_{max}	%/K	-0.46
Power conversion efficiency	%	12.94
Power Tolerance	%	±2.5
Fill Factor (FF)	-	75.22
Number of cell	-	36
Length	mm	1500
Width	mm	670
Height	mm	42
Weight	kg	12.0
Effective Area	m^2	0.8649

To perform analysis, measurements on a PV module have been carried out between 9 am to 17 pm in a 30 minute intervals during November. For defining and evaluating energy efficiency rates, electrical parameters of the module e.g. nominal current-voltage, open circuit voltage and short-circuit current have been measured. Besides, atmospheric parameters such as global solar radiation, the ambient and panel temperature as well as wind speed have been recorded since environmental conditions affect the real working performance the module.

For measuring parameters mentioned above, some instruments have been utilized. For instance, the panel backside temperature measurement is performed with the calibrated digital thermocouple and thus, the temperature data has been provided to be taken in the middle of the module. These measurement instruments are clearly listed in Table 2.

Table 2. Parameter list and measurement instruments

Parameter	Notation	Instrument
Module temperature	T_{cell}	Lascar EL-USB-TC-LCD digital thermocouple
Ambient temperature	T_{amb}	Thomas traceable digital thermometer
Solar radiation	S_T	MS-410 Pyranometer
Wind velocity	ϑ_{wind}	Delta OHM HD2303 digital anemometer
Open circuit voltage	V_{oc}	50 Ω wire-wound rheostat
Short-circuit current	I_{sc}	50 Ω wire-wound rheostat
Nominal voltage	V_{max}	UNI-T UT61B digital multimeter
Nominal current	I_{max}	MY-68 digital multimeter

3. Energy Analysis

The energy of a photovoltaic system depends on two major components namely electrical and thermal (heat radiated by the solar rays). While the electricity is generated by photovoltaic effect the photovoltaic cells also get heated due to the thermal energy present in the solar radiation. Since the thermal energy available on the photovoltaic surface is not utilized for useful purpose and hence called as heat loss to the ambient [11]. Considering the above said components, energy output of the photovoltaic system may be defined as

$$\dot{E}n_{out} = \dot{E}n_{electrical} + \dot{E}n_{thermal} = V_{oc}I_{sc} + \dot{Q} \quad (1)$$

Here, $\dot{Q}$ denotes the available thermal energy and can be represented as

$$\dot{Q} = h_{ca}A(T_{cell} - T_{ambient}) \quad (2)$$

The convective (and radiative) heat transfer coefficient (hca) from photovoltaic cell to the ambient, can be calculated by considering wind velocity (v), density of the air and the surrounding (ambient) conditions given as [12].

$$h_{ca} = 5{,}7 + 3{,}8 * v \quad (3)$$

Considering Eqs. (1)–(4), the energy efficiency of a PV system can be defined as the ratio of the output energy of the system (i.e., electrical and thermal energy) to the input energy (i.e., solar energy) received on the photovoltaic surface and can be given as

$$\eta_{energy} = \frac{\dot{E}n_{out}}{\dot{E}n_{in}} = \frac{V_{oc}I_{sc} + \dot{Q}}{S_T A} \quad (4)$$

For solar cells, efficiency measures the ability to convert solar energy into electrical energy. The electrical power output is the product of the voltage and the current from the photovoltaic device. Therefore, η_{pce} can be defined as the ratio of actual electrical output and input solar energy incident on the PV surface area as follows:

$$\eta_{pce} = \frac{\dot{E}_{max}}{S_T A} = \frac{V_{max} I_{max}}{S_T A} \quad (5)$$

This efficiency is also called actual electrical efficiency and can be defined in terms of fill factor (FF) given as

$$\eta_{pce} = \frac{FF V_{oc} I_{sc}}{S_T A} \quad (6)$$

4. Results and Discussion

The temperature effect on the PV performance has been discussed and analysed. The analysis results are given in following figures. Figure 2 illustrates the variation of the energy and power conversion efficiencies depending on the PV module temperature throughout 1st of November. Since module temperature increases from 19,2 oC to 39 oC between 09:00 am to 12:30 pm, η_{pce} values decrease from %15,3 to %12,3, while η_{energy} rates also fall down from %20 to %16,3. For after 12:30 pm, there is an opposite case where η_{pce} raises up to %14,7 and η_{energy} reaches %19,2 at 17:00 pm, respectively. In this case, it is seen that η_{pce} and η_{energy} ratios have indicated a parallel variation during in 1st of November. Same situation applies to the other days. Figure 3 gives the variation of efficiencies in 10th of November, while 20th and 30th of November have been seen in Figure 4 and Figure 5 respectively.

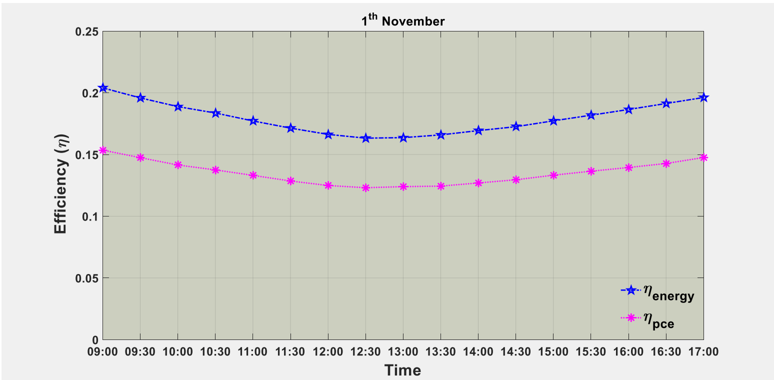

Figure 2. The variation of energy and power conversion efficiency in 1st of November

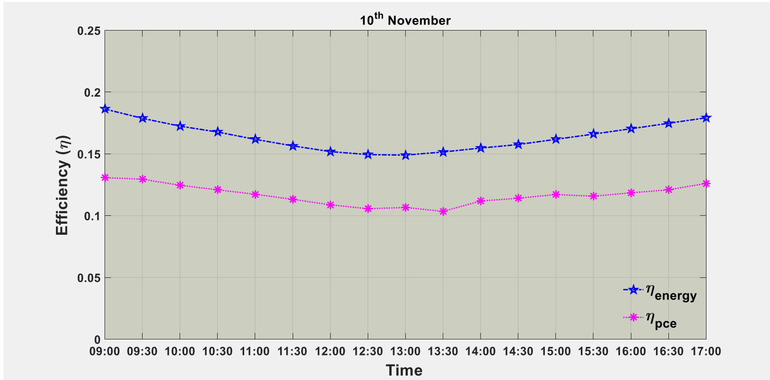

Figure 3. The variation of energy and power conversion efficiency in 10th of November

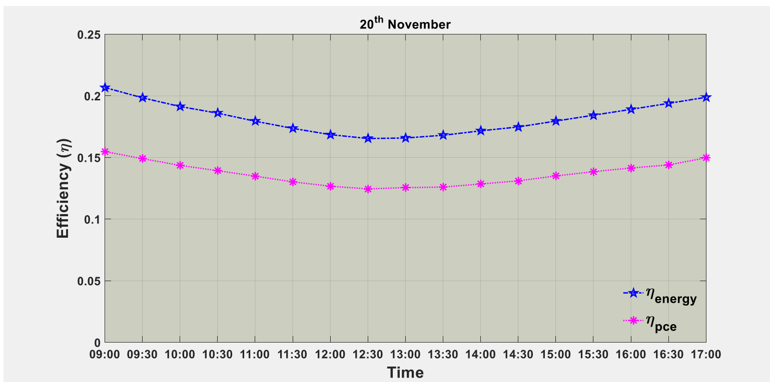

Figure 4. The variation of energy and power conversion efficiency 20th of November

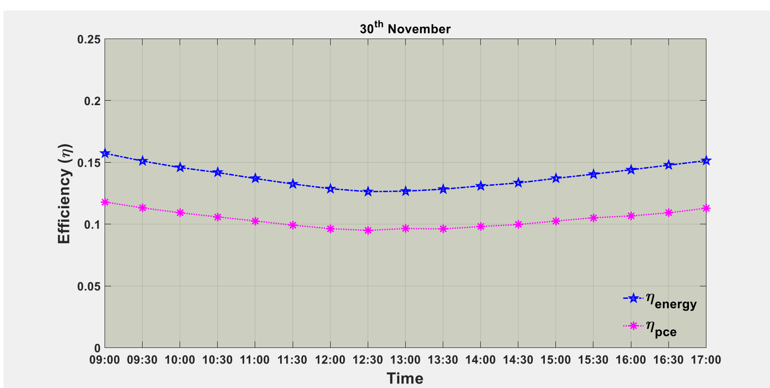

Figure 5. The variation of energy and power conversion efficiency in 30th of November

5. Conclusion

In this study, one of the main factors that affect the PV efficiency has been obtained. By this experimental study, it is understood that the high temperature values have a negative effect on the PV performance, particularly, after 32-33 degrees Celsius since there is a sharp drop in both energy and power conversion efficiencies at this level due to the degradation of semiconductor materials that produce electricity thanks to the thermophysical nature of them. However, here, it is worth to note that there are more than a parameter influencing the PV performance and the integration of these parameter gives more accurate results on the power output and efficiency drops. It can be also said that temperature and other environmental factors can reduce efficiency and cause lower the PV module's energy output, however, the factor of the length and strength of sunlight received should be also examined in terms of power production and efficiency variations.

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