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Journal of Science Foundation
January 2018, Vol. 16, No. 1, pp. 13-19 ISSN (Print) 1728-7855
DOI: http://dx.doi.org/10.3329/jsf.v16i1.38174

Original Article

Outdoor Performance Characterization of the Poly-crystalline Silicon Solar Module

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Abstract

The outdoor performance characterization of the poly-crystalline silicon solar PV module was studied. Daily solar illumination data were measured using two pyranometers and analyzed together with the module output power. The present paper reports the temperature dependencies of full-spectrum photovoltaic parameters for poly-crystalline PV module. The measurements were performed under outdoor environment conditions. The most interesting feature that was observed for these devices is that above a cell temperature of 20 ^{0}C the positive temperature coefficient observed for the short-circuit current exceeds in magnitude the negative temperature coefficient that was found for the open-circuit voltage. This means that, unlike the situation for conventional PV module, these cells actually exhibit decrease in efficiency with increasing temperature. *[Journal of Science Foundation 2018;16(1):13-19]*

Keywords: Photovoltaic; temperature coefficient; polycrystalline solar cell; conversion efficiency

[**Reviewed:** 30 July 2017; **Accepted on:** 1 October 2017; **Published on:** 1 January 2018]

1. Introduction

Nowadays, many types of different photovoltaic (PV) modules are commercially available in the market. There are three main types of PV module technology which are monocrystalline silicon, polycrystalline silicon and amorphous silicon thin-film (a-Si TF). More efficient PV modules will lead to smaller PV array installations, generally comes from crystalline silicon with high power generation as well as the conversion efficiency vary up 12.0 to 24.2% (Green et al., 2012). Solar PV systems are also one of the most “democratic” renewable technologies, in that their modular size means that they are within the reach of individuals, co-operatives and small-businesses who want to access their own generation and lock-in electricity prices (Irena 2012). The conversion efficiency of most solar cells decreases as the operating temperature increases, mainly due to a decrease in the optimum output voltage.

PV solar panels are composed of solar cells. A solar cell is an electrical device that converts the energy of light directly into electricity (DC) by the photovoltaic effect. Solar cells created with silicon seem to be the most widely used today, but many companies and scientists have been in the lab trying to concoct a more efficient cell, and ultimately, solar panel system. The basic material used for production of the solar cells is silicon. Solar Cell is a device that converts light directly into DC (direct current) electricity. Solar Cell can be distinguish in three cell types according to the type of crystal i.e., monocrystalline, polycrystalline and

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amorphous. To produce a monocrystalline silicon cell, absolutely pure semiconducting material is necessary. The production of polycrystalline cells is more cost-efficient and it has grain boundaries, randomly oriented, visible on the active surface. There are three main types of solar cells: Monocrystalline, Polycrystalline and thin film or amorphous. Monocrystalline, are formed on the silicon crystal with a homogeneous structure. The basis for the formation of cells are suitable size blocks of silicon. They are cut into a wafer whose thickness is about 0.3 mm. Monocrystalline solar cells achieve the highest levels of performance and life (Breyer and Gerlach, 2011; Wacáawek and Rodziewicz, 2011). Polycrystalline are consisting of many small silicon grain. These solar cells are less efficient than monocrystalline. The production process is easier and have lower price (Wacáawek and Rodziewicz 2011; Rodacki and Kandyba 2000). Amorphous (thin film) are produced through embedding few layers of silicon on the surface of another material, such as a glass. In these solar cells, we cannot distinguish individual cells. Amorphous solar cells are usually used in small devices such as calculators and watches (Klugmann 2008).

In order to elucidate the effect of temperature on poly-Si solar cells, we have measured the temperature dependence of the PV parameters of a number of poly-Si based cells made under outdoor conditions.

All solar module parameters, including short-circuit current, open-circuit voltage, fill factor, efficiency and impact of series and parallel resistances are changed due to changing the light intensity and temperature (Luque and Hegedus 2003). Therefore, it is important to study the effect of the light intensity and temperature on the output performance of the solar module.

Temperature affects how electricity flows through an electrical circuit by changing the speed at which the electrons travel. This is due to an increase in resistance of the circuit that results from an increase in temperature. Likewise, resistance is decreased with decreasing temperatures. In this work, a detailed experimental investigation of module PV parameters with light intensity and temperature were studied.

1.1. *Photovoltaic mechanism in p-n junctions*

When the p-n junction is hit by the light beam, photon with energy greater when semiconductors energy hole generates electron-hole pairs. The newly created electric charge carriers are mostly recombined, which generates heat. The condition for the creation of the photovoltaic phenomenon is to separate these pairs before recombination. This requires a presence of an internal electric field. This strong electric field exists in the p-n junction due to spatial cargo. In this electric field the electrons are moved from p-type to n-type semiconductor and holes are moved from the n-type semiconductor to p-type, resulting in separation of generated electron-hole pairs. Separated minority carriers on the one side of the connector, are becoming majority carriers with limitless lifetime on the other side, thus they create voltage (V_{sc}) and current (I_{sc}) of a solar cell (Green 1981). Current-voltage characteristics of the cell are a graph of the output current of the PV generator as a function of voltage at a given temperature and irradiance.

1.2. *Principles*

The classic definition of the temperature coefficient for a parameter relates to the change in that parameter when only temperature is varied, other factors that might influence the parameter being held constant. Temperature coefficients for I_{sc}, I_{pp}, V_{oc}, V_{pp}, P_{max}, FF, and η can all be determined for given photovoltaic modules.

Regression analysis is used to determine temperature coefficient parameters for I_{sc}, I_{pp}, V_{oc}, V_{pp},P_{max} and FF. The energy conversion efficiency η of modules is defined by:

$$\eta = P_{out}/P_{in} = I_{pp}V_{pp}/P_{in} = FFV_{oc}I_{sc}/P_{in}, \quad (1)$$

where P_{in} is the total radiative input power of all light incident on the cell/module , and P_{out} is the electrical power output of the cell/module. The fill factor, FF is defined by:

$$FF = (I_{pp}*V_{pp}/I_{sc}*V_{oc})*100\% \quad (2)$$

The fill factor measure how square the *I-V* curve. The higher the FF the more power the cell produces. The relation between short-circuit current and open- circuit voltage is given by (Green 1981).

$$I_{sc} = I_0 (e^{qV_{oc}/AkT} - 1) \quad (3)$$

and,

$$V_{oc} = (AkT/q) \ln(I_{sc}/I_0 + 1) \quad (4)$$

where I_{sc} = short circuit current (the current at V = 0. Ideally this is equal to the light generated current (I_L). V_{oc} = open circuit voltage (the voltage at I = 0, V_{oc} depends strongly on the properties of the semiconductor by virtue of its dependence on dark current I_0. k = Boltzmann constant, T = temperature of cell, q = electronic charge, A = diode quality factor of p-n junction. The temperature dependence of V_{oc} is given by (Green M. A. 1981).

$$dV_{oc}/dT = -(E_g/q - V_{oc} + 3kT/q)/T \quad (5)$$

where E_g = band gap energy; and T = Kelvin temperature of cell.

2. Experimental details

At first, PV modules were cooled to lower its temperature to below ambient temperature before experiment (ideally less than 10^0C). The experiments were performed during an approximately half hour period around solar noon on a cloudless, clear day. This ensures that the insolation is constant to within about 1%.The PV module is placed on a stand at normal incidence to the incoming radiation. Two pyranometers (PSP and Li-cor) are placed to the stand, in the same plane as the PV module aperture. Thermocouples were taped to module's rear surface to measure all temperature and rear surface of modules should be make insulated shown in Figure 1. Data were stored in the Campbell data logger. Each cooled module's current-voltage (*I-V*) curve were measured repeatedly using a Daystar *I-V* curve tracer over a range of temperatures, roughly from 10^0C to Stagnation temperature (50^0-75^0C). The area of PV- polycrystalline solar module (SX45) (number of cells =36) was $0.4m^2$.

The following measuring equipment were used to study the photovoltaic parameters in outdoor experiments.

1. I-V curve tracer (A Daystar Corp.)
2. Two calibrated pyranometers (Eppley Corp.PSP and Li-cor)
3. A Solarex Corp.SX45 module (standard references modules)
4. Copper-Constantine thermocouples.
5. Datalogger (A Campbell Scientific Corp.21X) for recording irradiance and temperatures
6. A laptop computer for downloading data from the *I-V* curve tracer and the data logger
7. Polycrystalline PV- module (SX-45)

Figure 1: Outdoor experiment of solar PV module.

For 1000 W/m^2;

I_{sc}^{1000} = I_{sc}/Irradiance*1000; I_{pp}^{1000} = I_{pp}/Irradiance*1000; P_{max}^{1000} = Pmax/Irradiance*1000.

For STC (1000W/m^2,25^{0}C):

I_{sc} (STC) = I_{sc}^{1000} - [α_{Isc} (T_{mod} - 25)]; I_{pp}(STC) =I_{pp}^{1000} - [$\alpha_{(Ipp)}$ (T_{mod} - 25)];

V_{oc}(STC) = V_{oc} - [β_{Voc} (T_{mod} - 25)]; V_{pp}(STC) = V_{pp} -[β_{Vpp} (T_{mod} - 25)] ;

P_{max}(STC) = I_{pp}(STC) *V_{pp}(STC)= $Pmax^{1000}$-[γ (T_{mod} - 25)] ;

Efficiency (η) = (I_{pp} * V_{pp}/Irradiance*Area)*100 % ; Fill factor (FF) = (I_{pp} * V_{pp} /I_{sc} * V_{oc})*100% (King D.L *et al.* 2004).

3. Results and Discussion

Figure 2 and 3 show that the variation of the current and voltage parameters with module temperature. It has been found that current parameters of each module increase with increasing temperature but voltage parameters of each module decrease with increasing temperature. About 9.8% and 12% decrement in V_{oc} and V_{pp}, respectively has been observed. It can be noted from the results that the temperature has a crucial impact on voltage parameters of solar module rather than the current parameters (Radziemska 2003). Figure 4 shows power graphs versus module temperature. It has been found that the power of each module demonstrated a decrease with temperature.

The dependence of fill factor with temperature for each module is shown in Figure 5. It has been found that the fill factor of each module also demonstrated a decrease with temperature increases (Cuce et al., 2013). The dependence of efficiency with temperature for each module is shown in Figure 5. It has been found that the efficiency of each module demonstrated a decrease with temperature (Cuce et al., 2013). Open circuit voltage (V_{OC}) - voltage at the terminals of unloaded (open) PV generator at a given temperature and irradiance, Short circuit current (I_{SC}) - the output current photovoltaic generative at a given temperature and irradiance, PMPP - Point MPP (Maximum Power Point) is a point whose coordinates V_{MPP} x I_{MPP} and form a rectangular shape with the largest possible area under the curve *I-V*. Voltage generated by a single photovoltaic cell depends on the type of material from which it was produced and is about 0.6 V. The output voltage is a weakly dependent on the intensity of the radiation, while the current increases significantly with an increase in radiation intensity (Green 1981; Radziemska 2003). Position of the operating point is strongly dependent on the resistance and radiation. The output voltage depends significantly on the temperature of solar cells: increased results are in a lower working temperature and efficiency (Green 1981).

Because the current and voltage output of a PV panel is affected by changing weather conditions, it is important to characterize the response of the system to these changes so the equipment associated with the PV panel can be sized appropriately. The average operating voltage and current of a PV system is important to consider for safety concerns, equipment capabilities and choices, and minimizing the amount of wire required for construction. Using temperature and solar irradiation data information, engineers and physicists can estimate and design how much energy a PV power plant might generate over its lifetime.

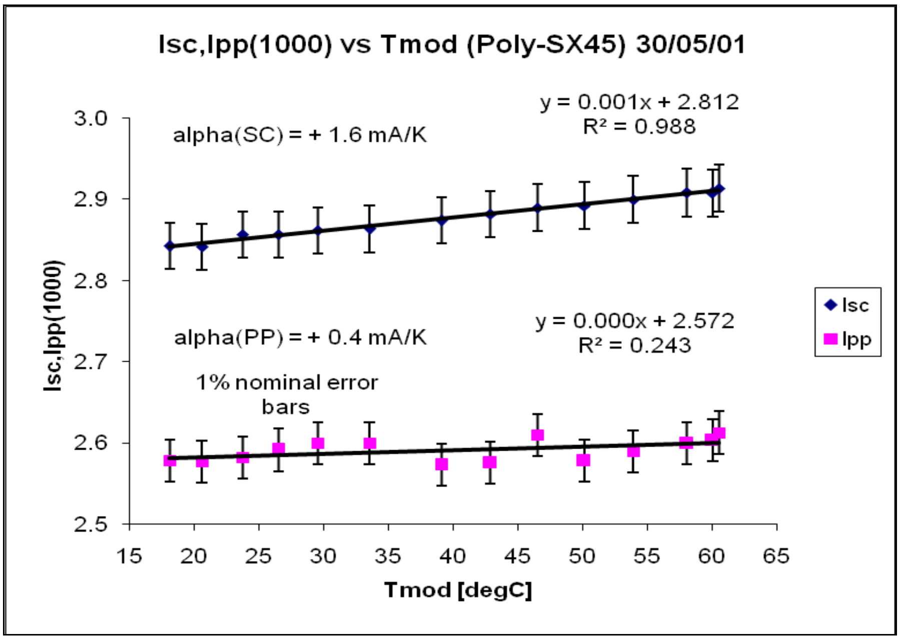

Figure 2: Short circuit and peak current graphs versus module temperature

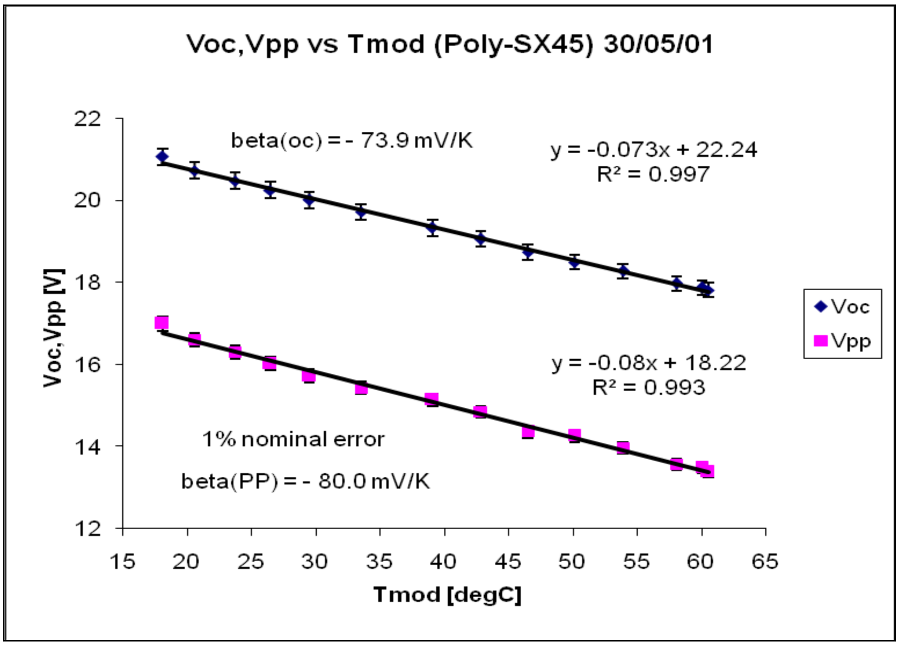

Figure 3: Open circuit and peak volatage graphs versus module temperature

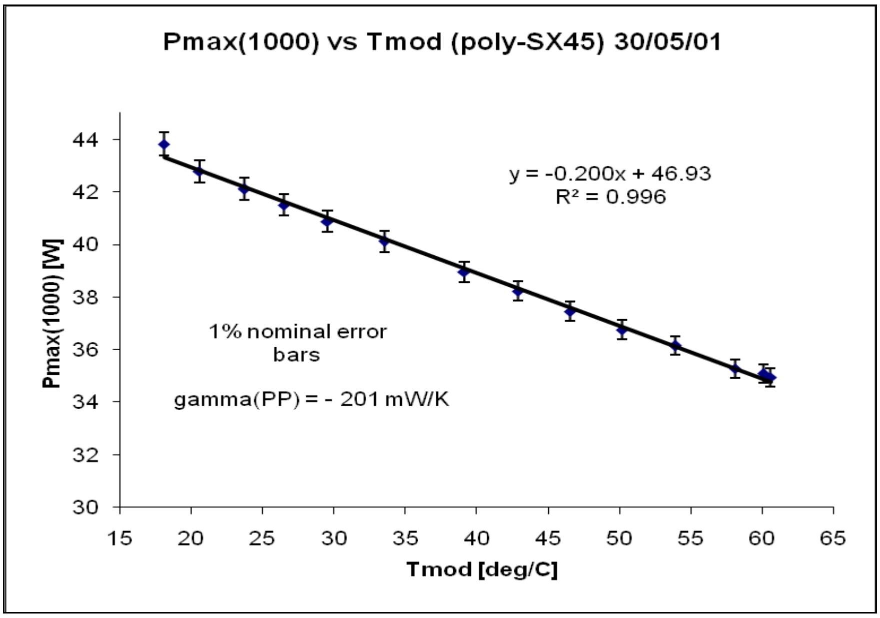

Figure 4: Maximum power graphs versus module temperature

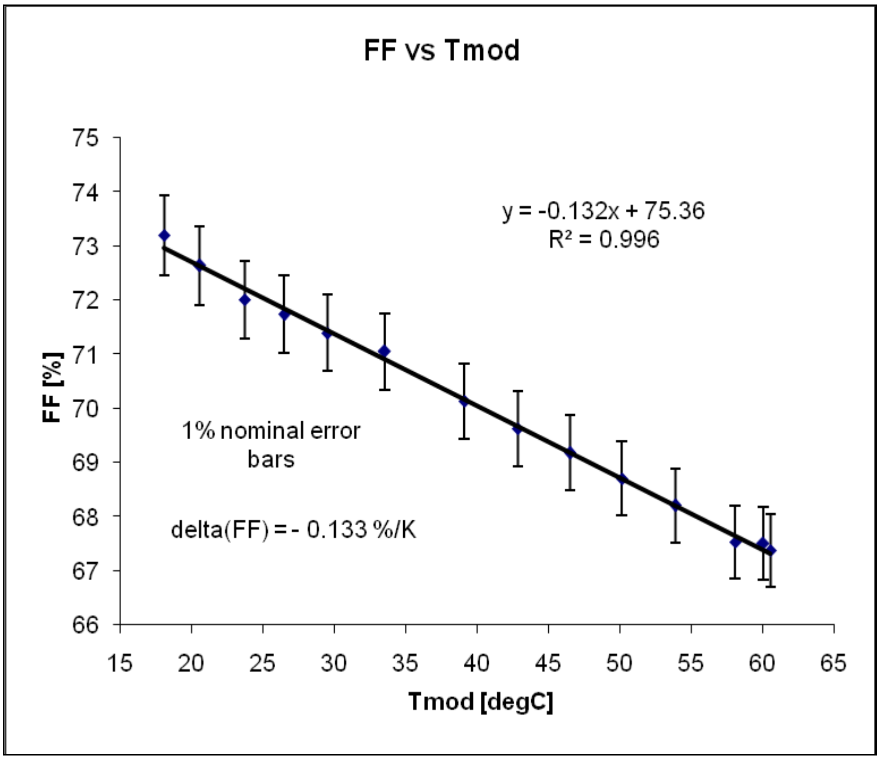

Figure 5: Fill factor graphs versus module temperature

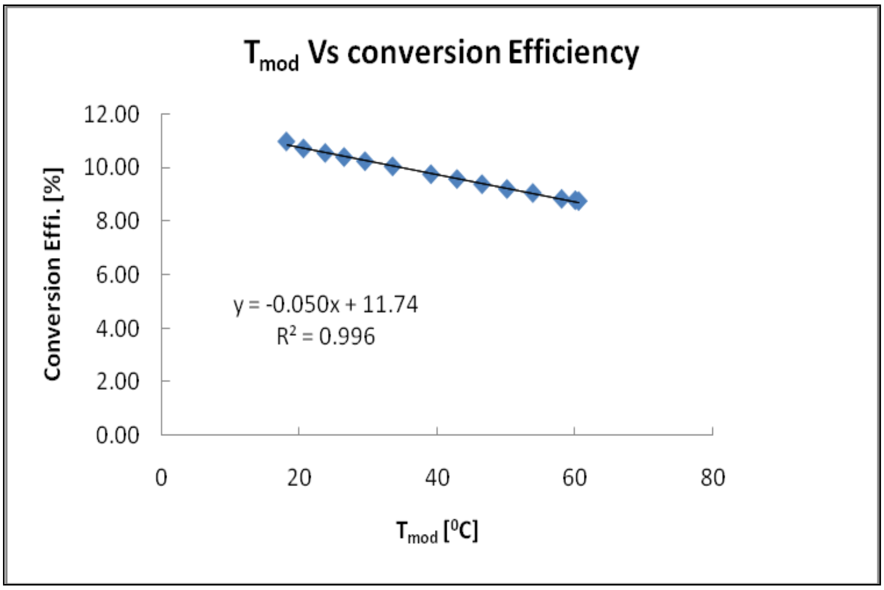

Figure 5: Efficiency graphs versus module temperature of the modules under investigation

4. Conclusion

Outdoor performance characteristics of the multi-crystalline silicon solar module was studied during clean sky with full solar spectrum at the site of Sede-Boqer Campus,Ben-Gurion University, Israel. We observed that module temperature has a dramatic effect on voltage parameters. Open circuit voltage and maximum voltage are decrease with increasing module temperature and short circuit current and maximum current are also increase linearly with increasing light intensity and temperature.

Acknowledgements: The author would like to acknowledge Prof. Dr. David Faiman, Ben-Gurion University, Israel for research guidance and support. Author is also thankful to Bona-Tera foundation, Israel for fellowship.

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