International Journal of Engineering

Journal Homepage: www.ije.ir

Analysis of Temperature Effect on a Crystalline Silicon Photovoltaic Module Performance

S. M. Salih*[a], Y. Kh. Jabur[a], L. A. Kadhim[b]

[a] *University of Anbar, Renewable Energy Research Centre, Iraq*
[b] *University of Baghdad, Al-Khwarizmi College of Engineering, Iraq*

P A P E R I N F O

Paper history:
Received 13 December2014
Received in revised form 24 December 2015
Accepted 24 December 2015

Keywords:
Photovoltaics
Temperature Effect
Mathematical Model
Solar module tester
Renewable energy

A B S T R A C T

In this paper, the effect of the cell-temperature on the performance of photovoltaic (PV) module is evaluated. The evaluation is based on a mathematical module (single diode equivalent circuit) and practically based on solar module tester (SMT). Solara®130W PV crystalline silicon module was used in this simulation. The SMT is able to supply a constant irradiance level (1000W/m^2) or any other desired value during the test (100 -1200W/m^2). The evaluation results showed that the output power of PV reduces by about 0.48W as the temperature of the module surface increases by one degree Celsius.

doi: *10.5829/idosi.ije.2016.29.05b.17*

1. INTRODUCTION

In the last decades, the photovoltaic (PV) energy is considered for power generation among all the renewable sources. This has resulted in lowering of greenhouse gases emissions. The generated power from photovoltaic is considered the ideal resource for distributed generation systems, which are located at or near to the load point [1].

The operating temperature of PV module is one of the most important parameters for the evaluation of long term performance of PV systems, as it modifies the power output and system efficiency. The temperature effect varies with characteristics of module encapsulating material, configuration, and installation and operating point of module, dissipation and thermal absorption properties, PV cells types, and climatic conditions at the installed location, such as solar irradiation level, ambient temperature and wind speed [2-5].

*Corresponding Author's Email: : *dr_salih_moh@yahoo.com* (Salih Mohammed Salih)

The output of PV Photovoltaic module or efficiency is usually inversely proportional to the operating temperature of the cell. There are two factors playing the conflicting role of the output power of PV modules. Firstly, if the temperature increases, the band gap of the intrinsic semiconductor shrinks, the open circuit voltage (V_{OC}) decreases. Secondly, as the temperature increases more, the band gap of the inherent semiconductor shrinks, this results in more absorption of incident energy. A greater percentage of the incident light has sufficient power to raise charge carriers from the valence band to the conduction band. If the photocurrent is large, then it will increase the I_{SC} at an existing solar insolation. The temperature coefficient of PV cells will have a positive effect on short circuit current. The theoretical maximum power would be raised due to this effect [2, 6-9]. Consequently, if the solar radiation level is fixed, increasing temperature leads to decreased V_{OC} and slightly increased the I_{SC}, eventually it reduces the power output [8].

So, it is important to lower the operating temperature of modules but with high irradiance. Since, the temperature of cells is very difficult to measure in most applications, because the cells are firmly enclosed for

Please cite this article as: Salih Mohammed Salih, Younus Khalaf Jabur, Laith Awda Kadhim, Analysis of Temperature Effect on a Crystalline Silicon Photovoltaic Module Performance, International Journal of Engineering (IJE), TRANSACTIONS B: Applications Vol. 29, No. 05, (May 2016) 722-727

moisture protection. Therefore, in most cases, the back side temperature of a PV module is commonly measured. However, in this paper the PV cells temperatures are measured in front of the panel by using an infrared thermometer. This will give more accurate results than measuring the temperature at the back of the panel.

2. MODELLING THE SOLAR CELL

A simple equivalent circuit of a solar cell can be represented by a current source connected in parallel with a diode and series resistance, the combination is shown in Figure 1. The output of the current source is proportional to the falling light on the cell (photocurrent I_L). The solar cell is not considered as an active device during the dark period, and it works as a diode, i.e., a p-n junction. The output current or voltage is zero. However, if it is connected to an external supply, it generates a current I_d called diode (D) current or dark current. The *I*–*V* characteristics of the cell will be determined by such diode [10, 11].

The next step will determine the *I*–*V* characteristics of the solar cell with single-diode and series resistance [12]:

$$I = I_L - I_0\left(e^{\frac{q(V+I*Rs)}{nkT}} - 1\right) \tag{1}$$

The recurrent equation is used to determine the output current as a function of the terminal voltage under the same irradiance and temperature for p-n junction. The Newton–Raphson method is a simple iterative technique and can be used for fast convergence of both positive and negative currents [10-11]. The *PV* short circuit current I_{sc} is given by:

$$I_{sc} = I = I_L - I_0\left(e^{\frac{q(Rs*Isc)}{nkT}} - 1\right) \quad for\ V = 0 \tag{2}$$

If the series resistance is very small and negligible, then

$$I_{sc} = I = I_L \tag{3}$$

So, Equation (3) is used as a good approximation of Equation (2). The open circuit voltage (V_{oc}) is given by:

$$V = V_{oc} = \frac{nkT}{q}\ln\left(1 + \frac{I_{sc}}{I_0}\right) \quad for\ I = 0 \tag{4}$$

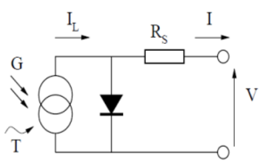

Figure 1. Equivalent circuit of a solar cell.

The *PV* output power of cell is given by:

$$P = V\left[I_{sc} - I_0\left(e^{\frac{q(v+I*Rs)}{nkT}} - 1\right)\right] \tag{5}$$

The *I*–*V* output of a solar cell in the dark has an exponential characteristic which is similar to the feature of a diode. The photons with energy greater than the band gap energy of the semiconductor, when exposed to light, are absorbed and create an electron-hole pair. Under the influence of the internal electric fields of the p-n junction these carriers are swept apart, and generate a current proportional to the incident radiation. When a cell is short-circuited, the current flows in the external circuit; when open-circuited, the current is shunted internally by the intrinsic p-n junction diode. Therefore, the characteristics of this diode set the open circuit voltage characteristics of the cell [12].

In this paper, a Solara®130W PV module is chosen for modeling due to its suitability in the traditional applications. The module provides 130W as a maximum power, and has 36 series-connected polycrystalline silicon cells. The technical specifications are given in Table 1. The model characteristics with variable temperature are evaluated by Matlab software. The program can calculate the current *I* using typical electrical parameters of the module (I_{sc} and V_{oc}), variable voltage, P_{max} and temperature (*T*). The non-linearity of the characteristic curves can be solved by the numerical methods which are related to the next equations.

$$K_0 = \frac{I_{sc\_}T_1 - I_{sc\_}T_1}{T_2 - T_1} \tag{6}$$

$$I_{L\_}T_1 = I_{sc\_}T_1 * G \tag{7}$$

$$I_L = I_{L\_}T_1 + K_0 \times (Tak - T_1) \tag{8}$$

$$I_{0\_}T_1 = \frac{I_{sc\_}T_1}{e^{\frac{q \times V_{oc\_}T_1}{nkT_1}} - 1} \tag{9}$$

$$I_0 = I_{0\_}T_1 * \left(\frac{Tak}{T_1}\right)^{\left(\frac{3}{n}\right)} * e^{\frac{-q*V_g}{nk} * \left(\frac{1}{Tak} - \frac{1}{T_1}\right)} \tag{10}$$

$$Xv = \frac{I_{0\_}T_1 * q}{nkT_1} * e^{\frac{q*V_{oc\_}T_1}{nkT_1}} \tag{11}$$

$$\frac{dV}{dI - Voc} = \frac{-1.15}{2*Ns} \tag{12}$$

$$Rs = \frac{-dv}{dI\_Voc} - \frac{1}{Xv} \tag{13}$$

$$Vt\_Ta = \frac{nkTak}{q} \tag{14}$$

$$Ia = Ia - \frac{\left(I_L - Ia - I_0 * \left(e^{\frac{Vc+Ia*Rs}{Vt\_Ta}} - 1\right)\right)}{-1 - \left(I_0 * \left(e^{\frac{Vc+Ia*Rs}{Vt\_Ta}} - 1\right) * \frac{Rs}{Vt\_Ta}\right)} \tag{15}$$

where:
I_L is the photo generated current (A);
I is the net cell current (A);
I_o is the reverse saturation current of diode (A);
q is the electron charge ($1.602\text{x}10^{-19}$C);
V is the cell output voltage (V);
R_s is the resistance inside the cell (Q);
n is the diode ideality factor (takes value between 1 and 2);
k is the Boltzmann's constant ($1.381\text{x}10^{-23}$J/K);
T is the cell temperature in Kelvin (K);
T_1 is the cell temperature at the Standard Test Condition (STC), given as 25°C or 298K;
$I_{sc(T1)}$ is the short circuit current (A) at T_1;
K_o is the temperature coefficient of I_{sc} (%/^{o}C);
G is the irradiance (W/m^2);
$V_{oc(T1)}$ is the open circuit voltage of the cell at T_1 (V).

3. SOLAR MODULE TESTER

In general, there are three types of simulators which are:

1. Simulator with constant light source (Heat load, cooling, and high-power consumption).
2. Simulators with a Pulsed light source (No heating of the sample, fast measurement and no temperature leveling).
3. Simulators with a pulsed light and decaying (can measure quickly at different irradiation levels. Measurement of series resistance, high peak irradiance easily reached).

The third module which already exists in renewable energy research center (RERC) is used for determining the *I-V*, and *P-V* characteristic curves for the model. The module can test the Mono-Si, Poly-Si or a-Si PV module. A Slar Module Tester (SMT) (module type: GSMT, class-AAA) can extract the most *PV* characteristics. All parameters can be automatically calculated via SMT with the aid of a scmt #286 DAQ-2010 software, the parameters of PV module are: I_{sc}, V_{oc}, P_{max}, V_{max}, I_{max}, FF, T, R_s, R_{sh} and the efficiency [13].

4. SIMULATION RESULTS

The *I-V* and *P-V* characteristics of Solara®-130W PV model with variable T are calculated using SMT and Matlab software in this section.

TABLE 1. Technical specifications of Solara®-130W PV model

Parameter	Solara®-130W (Germany)
V_{max} (V)	17.8
I_{max} (A)	7.3
V_{oc} (V)	21.7
I_{sc} (A)	8.18
P_{out} (W)	130

The technical specifications for Solara®-130W PV model is given in Table 1. The temperature of a PV module significantly affects its performance. The PV module power output reduces as the temperature increases; even the temperature is not significant as the duration and intensity of sunlight. The PV module temperature also affects its efficiency. In general, the temperature coefficient of a crystalline silicon PV module is 0.45 to 0.5% per Celsius degree increase in temperature[1,2]. The first CdTe PV modules have a temperature coefficient of 0.25% per degree Celsius, which leads to half the incremental power loss compared to conventional PV modules[14-16]. Varying the temperature will increase the voltage drop while it does not significantly affect the current developed.

The dominant effect of increased cell temperature is the linear decrease of the open circuit voltage, making the cell less efficient. The voltage output from the PV array decreases but the current output increases slightly with respect to the voltage. Consequently, the power output from the PV array decreases.

The influence of the cell temperature on the *I–V* characteristics based on a mathematical model given in Section 2 is illustrated in Figure 2. The effect of temperature variation (0, 25, 40, and 70 ^{0}C) on the *I–V* characteristics at a constant irradiance of G = 1 sun and diode ideality factor of n = 1.2 is shown. The figure shows that when temperature increases, the output power decreases. At 25^{o}C, the output power is 117W, and then it decreases to 96.5W at 70^{o}C. The temperature variation effect is equal to the variation of to temperature, which is:

$\Delta p/\Delta t=(117-96.5)/(70-25)=0.45$W/degree

Figures 3-7 illustrate the temperature effect on module output power based on SMT. Maximum power of the module is 130W at 25^{o}C. As the temperature increases, the module output power decreases. The temperature used in these curves represents the cells temperature during the test. The temperature is measured by the Infrared thermometer after heating the module surface by exposing it to the sun radiation. To get accurate results, the temperature is measured before and after the test with taking into consideration the decreasing of temperature when the module is inside the testing room. In this case, the exact flashing time of SMT relative to the temperature readings before and after test is also considered. The temperature reduces by about two degrees after the test in reference to the initial value before the test, and the test takes less than two minutes (includes connecting the PV panel, registering

---

1. Yingli Solar 2011, YGE 285 Series Datasheet, 1.: http://www.yinglisolar.com/assets/uploads/products/downloads/2013_YGE_72_lr.pdf

2. Photovoltaic Efficiency-Inherent and System,: http://www.solar-facts.com/panels/panel-efficiency.php.

the standard parameters of PV, correct the measured values and three flashing times are done for each test).

The output power is 130W at 25^{o}C, and then it decreases to 113.17W at 60^{o}C. The temperature variation effect on the output power is:

$\Delta p/\Delta t=(130-113.17)/(60-25)=0.48$W/degree

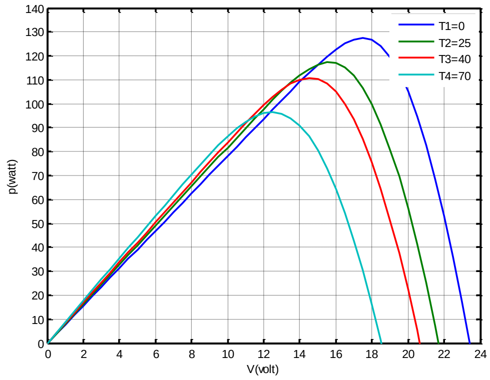

Figure 2. *P–V* characteristic with temperature variation based on a mathematical model.

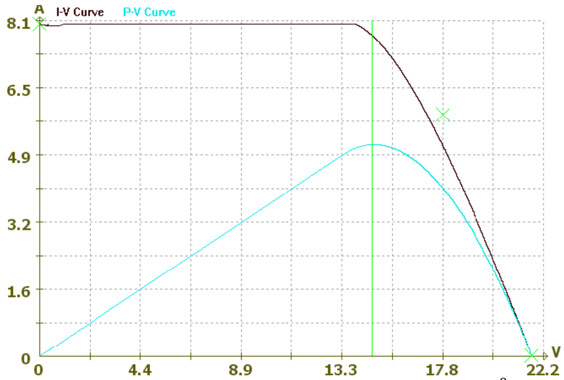

Figure 3. *I–V* and *P–V* characteristic curves at t=25 ^{0}C based on SMT, o/p=130W

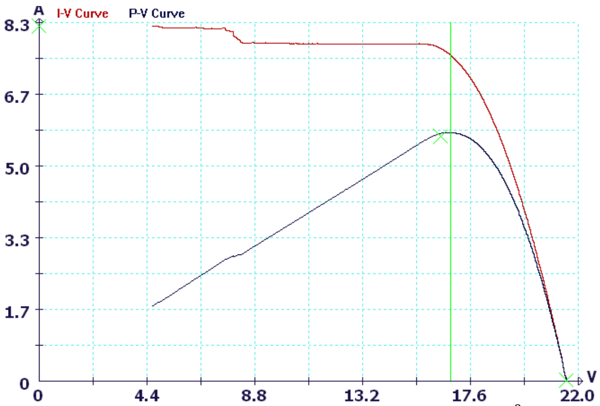

Figure 4. *I–V* and *P–V* characteristic curves at t=36 ^{0}C based on SMT, o/p=124.47W.

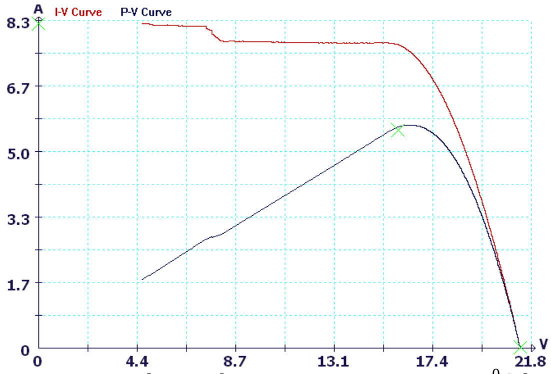

Figure 5. *I–V* and *P–V* characteristic curves at t=44 ^{0}C based on SMT, o/p=120. 7W.

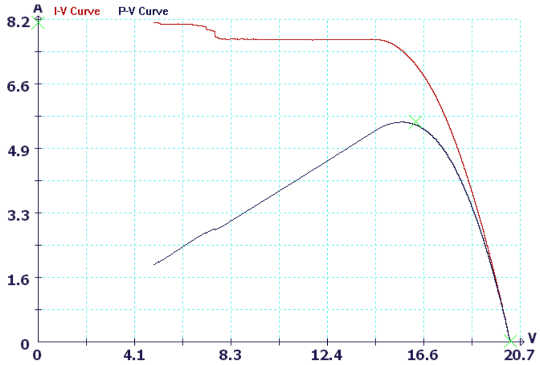

Figure 6. I–V and P–V characteristic curves at t=54 0C based on SMT, o/p=115.9W.

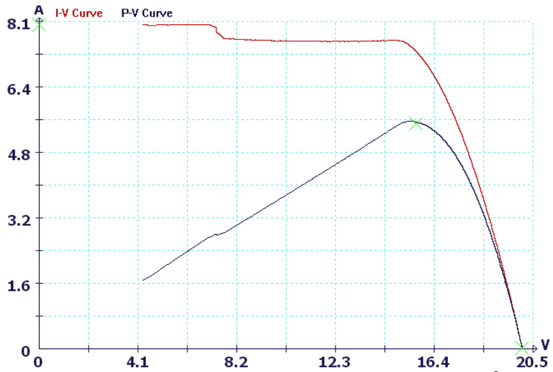

Figure 7. *I–V* and *P–V* characteristic curves at t=60 ^{0}C based on SMT, o/p=113.17W.

Figure 8 summarizes the temperature effect on the output power performance based on Figures 3-7. From this curve it is seen that the power decreases approximately linearly as the temperature of the cells increase. The ambient temperatures in Iraq are more than 40^{o}C for most days in June and July, especially from 12:00pm to 6:00pm which lead to having a direct adverse effect on PV performance. The temperatures with global, direct, diffuse, and total solar irradiances for June-2014 are plotted in Figure 9.

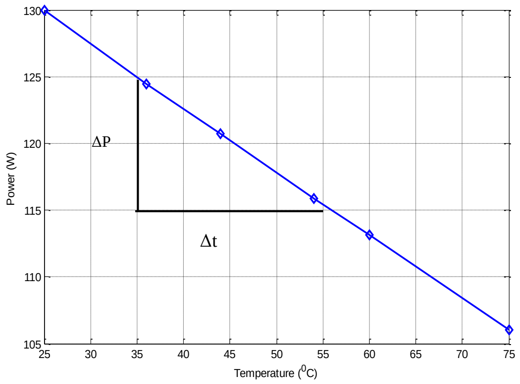

Figure 8. Temperature effect on the output power for Solara® 130W based on SMT.

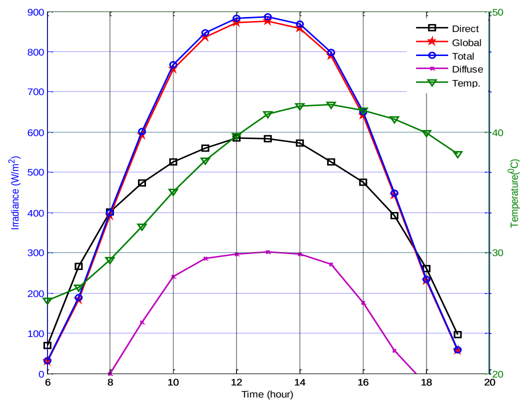

Figure 9. Hourly average irradiance for June-2014 in Ramadi City-Iraq.

From this figure, a small difference in the amplitudes between the total and global solar irradiance. The little difference is coming from the fact that the sun approaches to be vertical (90^o) in the summer months of June, July and August. Although the solar irradiance is high in Iraq, but the temperature is also high which reduces the cells efficiency and lifetime. So, it is important to analyze weather parameters (temperature, dust, solar irradiance, humidity, shading, etc.) in the intended installation site in order to optimize the output power from PV before installing the system.

5. CONCLUSION

A practical evaluation of PV was conducted with the aid of solar module tester. The output power of PV module was tested at different temperatures of panel surface. The results are compared with the effect of temperature on PV performance based on simulation module with the aid of Matlab software. The results showed that temperature can have a significant impact on PV output. The output power is reduced by 0.48w for each 1^{o}C increasing in the panel surface temperature. Therefore, it is important to decrease the temperature of PV modules (by using water spraying technique or another method) which leads to increase in the output power of PV in addition to its lifetime.

6. REFERENCES

1. Kishor, N., Mohanty, S.R., Villalva, M. and Ruppert, E., "Simulation of pv array output power for modified pv cell model", in Proc. IEEE International Conference on Power and Energy (PECon), Page (s). Vol., No. Issue, (2010), 533-538.
2. Jakhrani, A.Q., Othman, A.-K., Rigit, A.R.H. and Samo, S.R., "Determination and comparison of different photovoltaic module temperature models for kuching, sarawak", in Clean Energy and Technology (CET), 2011 IEEE First Conference on, IEEE. Vol., No. Issue, (2011), 231-236.
3. García, M.A. and Balenzategui, J., "Estimation of photovoltaic module yearly temperature and performance based on nominal operation cell temperature calculations", ***Renewable energy***, Vol. 29, No. 12, (2004), 1997-2010.
4. Trinuruk, P., Sorapipatana, C. and Chenvidhya, D., "Estimating operating cell temperature of bipv modules in thailand", ***Renewable energy***, Vol. 34, No. 11, (2009), 2515-2523.
5. Grunow, P., Lust, S., Sauter, D., Hoffmann, V., Beneking, C., Litzenburger, B. and Podlowski, L., "Weak light performance and annual yields of pv modules and systems as a result of the basic parameter set of industrial solar cells", in 19th European Photovoltaic Solar Energy Conference. (2004), 2190-2193.
6. Huang, B., Yang, P., Lin, Y., Lin, B., Chen, H., Lai, R. and Cheng, J., "Solar cell junction temperature measurement of pv module", ***Solar Energy***, Vol. 85, No. 2, (2011), 388-392.
7. Skoplaki, E. and Palyvos, J., "Operating temperature of photovoltaic modules: A survey of pertinent correlations", ***Renewable energy***, Vol. 34, No. 1, (2009), 23-29.
8. Hasan, M.A. and Sumathy, K., "Photovoltaic thermal module concepts and their performance analysis: A review", ***Renewable and Sustainable Energy Reviews***, Vol. 14, No. 7, (2010), 1845-1859.
9. Duffie J. A., and Bechman W. A., "*Solar Engineering of Thermal Processes"*, 3rd Edition, John Wiley & Sons, Inc. (2006).
10. Salih, S.M., Salih, F.F., Hasan, M.L. and Bedaiawi, M.Y., "Performance evaluation of photovoltaic models based on a solar model tester", ***International Journal of Information Technology and Computer Science (IJITCS)***, Vol. 4, No. 7, (2012), 1-10.
11. Taha, M.Q., Eesse, Q.H. and Salih, S.M., "Mathematical modeling of different photovoltaic modules", ***Journal of telecommunications***, Vol. 11, No. 2, (2011), 59-64.
12. Walker, G.R., "Evaluating mppt converter topologies using a matlab pv model", ***AUPEC 2000: Innovation for Secure Power***, Vol. 1, No., (2000), 138-143.
13. Salih M. S., Mustafa H. S., Ahmed S. A., "Simulation of shading effect on photovoltaic modules based on solar module tester", Joint International Conference on Nanoscience, Engineering and Management (Bond21),(2013), 19-21
14. Pan, L., "Analysis of photovoltaic module resistance characteristics", ***International Journal of Engineering-Transactions B: Applications***, Vol. 26, No. 11, (2013), 1369-1376.

15. Maity, S., Bhunia, C. and Sahuc, P., "Experimental study of some effective surface parameters of crystalline silicon solar cell for getting better performance", ***International Journal of Engineering-Transactions A: Basics***, Vol. 28, No. 1, (2014), 81-87.

16. Dhassa A. D., Natarajana E. And Lakshmi P., " An investigation of temperature effects on solar photovoltaic cells and modules" ***International Journal of Engineering IJE***, Vol. 27, No. 11, (2014), 1713-1722.

Analysis of Temperature Effect on a Crystalline Silicon Photovoltaic Module Performance

S. M. Salih[a], Y. Kh. Jabur[a], L. A. Kadhim[b]

[a] *University of Anbar, Renewable Energy Research Centre, Iraq*
[b] *University of Baghdad, Al-Khwarizmi College of Engineering, Iraq*

P A P E R I N F O

Paper history:
Received 13 December2014
Received in revised form 24 December 2015
Accepted 24 December 2015

Keywords:
Photovoltaics
Temperature Effect
Mathematical Model
Solar module tester
Renewable energy

چکیده

در این مقاله اثر دمای سلول بر عملکرد ماژول فتوولتائیک (PV) ارزیابی شده است. ارزیابی بر روی یک ماژول ریاضی بر اساس (مدار معادل دیود تکی) و عملاً بر اساس ماژول تستر خورشیدی (SMT) انجام شده است. در این شبیه سازی ماژول سیلیکون کریستالی Solara®130W PV مورد استفاده قرار گرفته است.(SMT) قادر به تامین سطح تابش ثابت ($1000W/m^2$) و یا هر مقدار دیگر مورد نظر در طول آزمون (100 -$1200W/m^2$) است. نتایج بررسی نشان داد که افزایش یک درجه سانتیگراد دمای سطح ماژول توان خروجی PV را به میزان 0.48W کاهش می دهد.

***doi**: 10.5829/idosi.ije.2016.29.05b.17*