Practical Evaluation of Solar Irradiance Effect on PV Performance

Majid Shahatha Salim[a]; Jassim Mohammed Najim[b]; Salih Mohammed Salih[c],*

[a]College of Science, University of Anbar, Ramadi, Iraq.
[b]Assistant professor. PhD. College of Science, University of Anbar, Ramadi, Iraq.
[c]PhD. Renewable Energy Research Center, University of Anbar, Ramadi, Iraq.
*Corresponding author.

Abstract

The sun radiation has very important effect on the performance of photovoltaic (PV) solar modules due to its variation from time to time. In this paper, the performance of Solara®-130 PV module will be evaluated practically by using the solar model tester (SMT). The existing SMT can generate variable solar irradiance from 100 w/m^2 up to 1050w/m^2. The I-V and P-V curves are plotted automatically via software controlling program on the SMT. Different parameters are obtained from the SMT like: V_{OC}, I_{SC}, V_{pm}, I_{pm}, R_s, R_{sh} and fill factor. The results can be used for plotting the relation between the solar irradiances (G) and the corresponding short circuit currents (I_{SC}), then the relation between G-I can be used for measuring the solar irradiance based on the short circuit current in that curve, which means instead of using the PV module for generating electricity, it can be used for measuring the sun radiation instead of using the Pyranometer device.

Key words: Solar model tester; Solara®-130; Pyranometer; Solar irradiance; RERC

INTRODUCTION

An enormous interest to utilize renewable sources of energy such as solar energy has been increased in the resent years due to the massive consumption and exhaustion of fossil fuel. Photovoltaic power is an established technology and has recently experienced rapid growth over the last ten years (Xiao, Ozog, & Dunford, 2007). A solar cell basically is made by a p-n semiconductor junction and when exposed to light, a dc current is generated. PVs offer several advantages such as: high reliability, low maintenance cost, no environmental pollution, and absence of noise (Patel, 2008). Solar energy accounts for most of the usable renewable energy on earth, solar energy falls on the surface of the earth at a rate of 120 petawatts. This means all the solar energy received from the sun in one days can satisfied the whole world's demand for more than 20 years (Review and comparison., 2011). The amount of sunlight received by any surface on earth will depend on several factors including; geographical location, season, local landscape, time of the day and local weather. The light's angle of incidence on a given surface will depend on the orientation since the Earth's surface is round and the intensity will depend on the distance that the light has to travel to reach the respective surface. The radiation received by a surface will have two components one which is direct and will depend on the distance the rays travel (air mass) while the other component is called diffuse radiation (Gwinyai, 2008). Solar energy systems have emerged as a viable source of renewable energy over the past two or three decades, and are now widely used for a variety of industrial and domestic applications. Such systems are based on a solar collector, designed to collect the sun's energy and to convert it into either electrical power or thermal energy. The literature contains many studies regarding the use of solar collectors to implement such applications as light fixtures, window covering systems, cookers, and other applications (Adams & Day, 1876; Chapin, Fuller,

& Pearson, 1954; Carlson & Wronski, 1976). In fact, nowadays, solar PV provides around 4800GW. Between 2004 and 2009, grid connected PV capacity reached 21GW and was increasing at an annual average rate of 60% (Renewable Energy Policy., 2010).

Arjyadhara, Ali, & Chitralekha (2013) analyzed the overall performance of solar cell with varying irradiance, temperature and fill factor. They give an idea about how the solar cell performance changes with the change in mentioned parameters in reality and their results are shown by conducting a number of experiments.

To maximize the energy collected by a given photovoltaic system, Tina, Arcidiacono, & Gagliano (2013) proposed a system for tracking the solar position. The system consists of a structure of nine photodiodes. A suitable analysis of the output signals calculates the azimuth and solar height angles, which are related to the direction of maximum solar irradiance. The authors developed a hardware and software for a prototype system, which they called it as a SoliSector. Outdoor. Experimental results regarding testing and calibration of the proposed system are given in this reference.

The performances of Solara®-130 and Sunworth®-100 solar modules are evaluated using a single diode equivalent circuit in addition to the evaluation of these modules based on solar module tester (SMT) (Salih, Salih, Hasan, & Bedaiawi, 2012). Different parameters are analyzed like: temperature, diode ideality factor, series resistance, and solar irradiance level. The results of the PV characteristics curves are compared with the parameters from the manufacturing companies for each model.

1. DEFINITIONS OF PV PARAMETERS

The performance of PV module is derived from I-V and P-V characteristic curves measured under standard test condition (T = 25 ^{o}C, G = 1000 W/m^2, AM = 1.5). The solar module tester SMT provided standard testing for the following parameters: V_{oc}, V_{mp}, I_{sc}, I_{mp}, FF, P_{max}, and Temperature. PV Modules are rated at two voltage levels: the first is called "Open Circuit Voltage (V_{oc})". The voltage output of the module is measured with the module disconnected from any load. V_{mp} is the voltage at which the module puts out the most power. I_{sc} is the short-circuit current which represents the amount of current that the PV module supplies into a dead short. I_{mp} is the current at maximum power point and represents the Amperes delivered by the module at its maximum power point. P_{max} (W) is the maximum power and it is equal to Amperes times Volts. Every module has a specific point on its power curve where the product of Amps times Volts yields the greatest wattage. This is the MPP, and the module's wattage output is rated at this point's voltage and current. In order to find the module's MPP, the flash test takes data over the entire range of voltage and current. This

way the wattage for each current and voltage data point can be calculated. By doing this it can be find the MPP in the sea of current versus voltage data. FF (%) is defined as the maximum power produced (at MPP) divided by the product of I_{sc} and V_{oc}. One can see that the FF will always be less than 1. Due to the difficulties in measuring conversion efficiency quickly, it is common to measure the fill factor instead.

2. I-V AND P-V CHARACTERISTIC CURVES WITH VARIABLE IRRADIANCE

During the real calculation of PV model power under the sun radiation effect, it is very important to know at which solar power irradiance (W/m^2) the calculations are done. That is because the solar power radiation varies from time to time. At the same time, the tilt of PV panel is of important to get the maximum power, and the values in the name plate at the back of each panel are measured at standard test conditions in the made companies (i.e., V_{OC}, I_{SC}, V_{mp}, I_{mp}, ^{o}C = 25, G = 1000 W/m^2). It is able to get the standard solar irradiance (1000W/m^2) practically by moving the solar panel left-right-up-down (tilt angle) until the Voc. and I_{SC}. read by meter device match the values in the name plate. But if the values are different, then it means the solar irradiance is less or more than 1000W/m^2. The solar irradiance is varying within assigned period and thus variation can give different results from the same PV module. This unstability of solar radiation can be solved by using the solar module tester (SMT) which has constant solar irradiance within testing time period, and hence this will lead to exact o/p power of PV module. So, it can plot the relation between the irradiance (G) and the short circuit current (I_{SC}) by varying the simulated solar radiation and measuring the corresponding short circuit current at different radiation. The existing solar model simulator, "exists in renewable energy research center (RERC) university of Anbar" can be used to do such function by varying the flashing irradiance on the PV module under test, then registering the corresponding I_{SC}. and V_{OC}. that can be gotten from the solar model tester software. The step will be repeated at different values of solar radiation power, and finally the relation between G-I and G-V curves can be plotted. The G-I curve will be used for the module under test for calculating the solar radiation power at any location by using the tested PV module (a Solara®130W module is used in this test) instead of using the Pyranometer for such test which may not exist in most places. Also this model can be used for install the solar cell systems at required angle by simply moving it by hands according to the G-I curve to get the optimum installation angle of PV system. The technical specification of Solara®-130 PV module used in this paper is given in Table 1. Figure 1 shows the I-V and P-V curves for Solara®-130 PV model at an irradiance of 373.54w/

m^2. From this figure the $I_{SC} = 3.251$ A. and $V_{OC} = 20.885$ V. The other values of I_{SC}. and V_{OC}. for different values of solar irradiance are shown in Figure 2 to Figure 7. The value of G, I_{SC}, V_{OC}. R_S, and FF are given in Table 2.

Table 1
Specification of Solara®-130 PV Model

Parameter	Solara®-130 (Germany)
V_{max} (Volt)	17.8
I_{max} (Ampere)	7.3
V_{OC} (Volt)	21.7
I_{SC} (Ampere)	8.18
P_{out} (Watt)	130

From Figure 1, the output power is 53.7 W when the sun irradiance is 375.54 w/m^2, the output power increases as the sun radiation increases. The standard output power for this panel is 130W and it is obtained at standard solar radiation of 1000W/m^2 as shown in Figure 6. From the given curves it can be seen that the short circuit and the peak current values are increases as the sun radiation increases. The other important factor can be discriminated which is the resistance in parallel for the whole panel decreases as the output power or sun radiation increases.
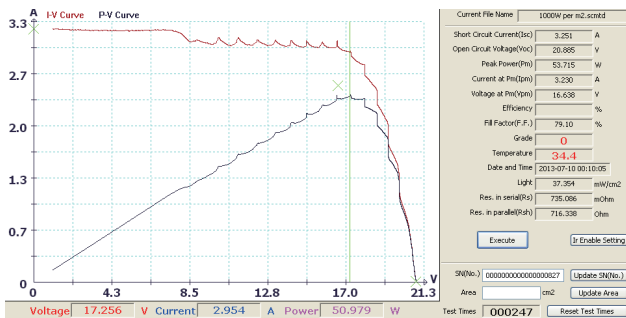

Figure 1
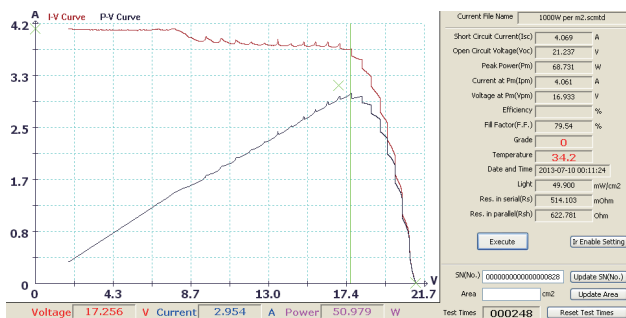I-V and P-V Characteristics of (Solara®-130) **Model at G = 373.54 w/m²**

Figure 2
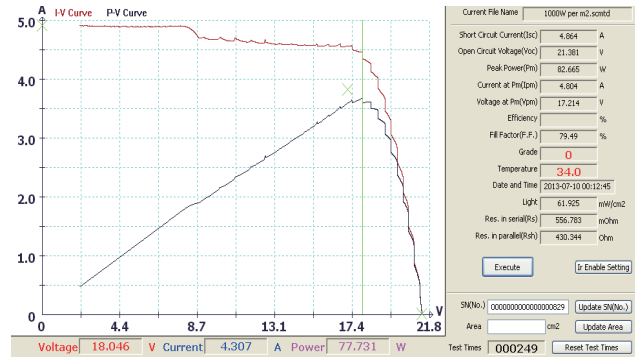I-V and P-V Characteristics of (Solara®-130) **Model at G = 499 w/m²**

Figure 3
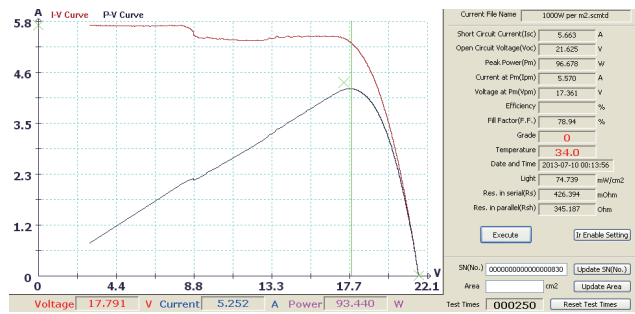I-V and P-V Characteristics of (Solara®-130) **Model at G = 619.25 w/m²**

Figure 4
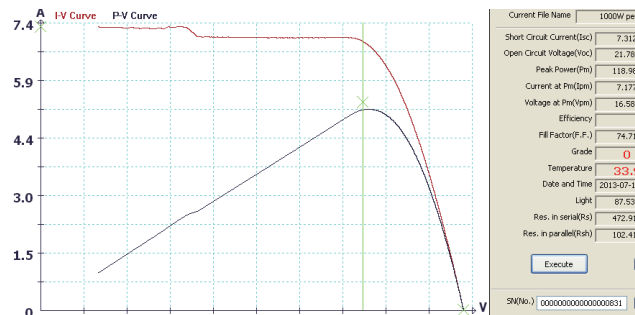I-V and P-V Characteristics of (Solara®-130) **Model at G = 747.39 w/m²**

Figure 5
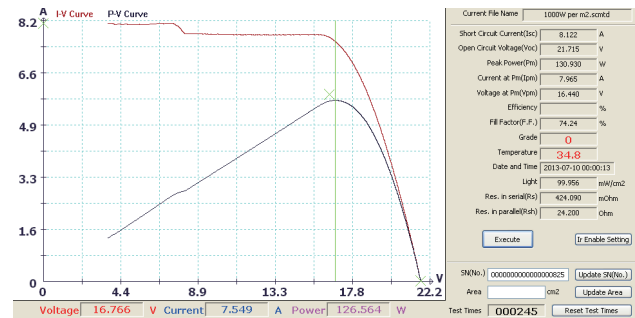I-V and P-V Characteristics of (Solara®-130) **Model at G = 875.36 w/m²**

Figure 6
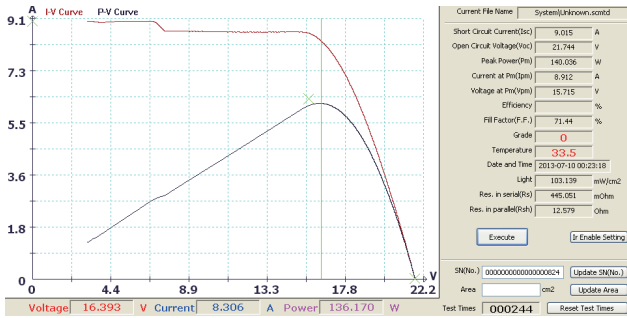I-V and P-V Characteristics of (Solara®-130) **Model at G = 999.56 w/m²**

Figure 7
I-V and P-V Characteristics of (Solara®130) **Model at G = 1031.39 w/m²**

Figure 8 illustrates the relation between the solar irradiance and the short circuit current of the tested module (i.e. Solara®130). It can be seen that the module current increases as the solar irradiance increases. The relation between them approximately linear with small amending is done on curve to get a smooth one (i.e. curve fitting). This curve is of important, because the PV modules convert the sun radiation into electricity, so one can think if it possible to use such module for measuring the sun radiation by reverses order. In reverse order way, it can be used the short circuit current taken from the module for measuring the sun radiation based on the plotted curve in Figure 8. for example if the module subjected to a sun radiation at a certain angle, then the user can only read the short circuit current by amper meter device and intersect the current value vertically until it intersects with the G-I curve, at this case the intersection point on y-axis represents the sun radiation. This method is simpler and less costs than the method based on sun radiation meter (Pyranometer). The only thing is to plot the relation between G-I curve for the panel required to be used for testing.

Table 2
Short Circuit Current and Open Circuit Voltage at Different Irradiances

Irradiance (W/m²)	I_{SC} (A)	V_{OC} (V)	I_{pm} (A)	V_{pm} (V)	FF	Resistance in serial R_s (mΩ)	Resistance in parallel R_{sh} (Ω)	Power (w)
373.54	3.251	20.885	3.23	16.638	79.1	735	716	53.71
499	4.069	21.237	4.061	16.933	79.54	514	622	68.73
619.25	4.864	21.381	4.804	17.214	79.4	556	430	82.66
747.93	5.663	21.625	5.57	17.361	78.94	426	345	96.67
875.63	7.312	21.783	7.177	16.58	74.71	472	102	118.9
999.56	8.122	21.715	7.965	16.44	74.24	424	24.2	130.9
1031.39	9.015	21.744	8.912	15.715	71.44	445	12.5	140.0

Figure 8
G-I Curve for Solara®-130 PV Module Based on Solar Module Tester
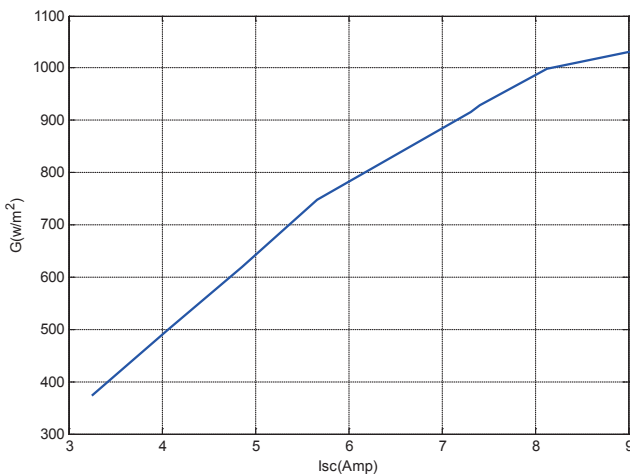

Figure 9
G-I_{pm}, I_{SC} Curves for Solara®-130 PV Module Based on Solar Module Tester

Figure 9 shows the relation between the sun radiation versus the short and maximum currents (I_{SC}, I_{pm}). From this figure, the output currents increase as the sun radiation increases. The short circuit current has more values than short circuit currents. The multiplication of I_{pm} by V_{pm} in Table 2 gives the output peak power of module (P_m).
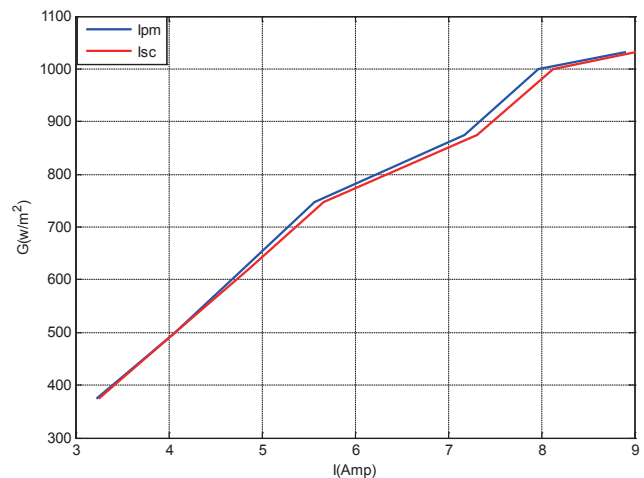
Figure 10 shows the relation between the sun irradiance (G) and the shunt resistance (R_{sh}) for the connection of cells in the PV panel. Form this curve the resistance decreases as the sun radiation increases. The last Figure 11 presents the relation between the sun radiation and the output maximum power. It is clear

that the output power of module increases as the sun irradiance increases. The relation between the simulated sun radiation and the output power is approximately linear. The maximum power of module at $G = 1000$ W/m^2 is 130W which matches the power of module on the name plate of it from the manufacturing company.
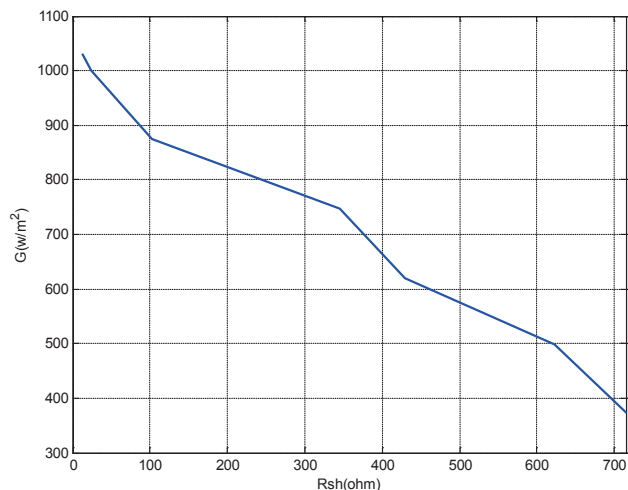

Figure 10
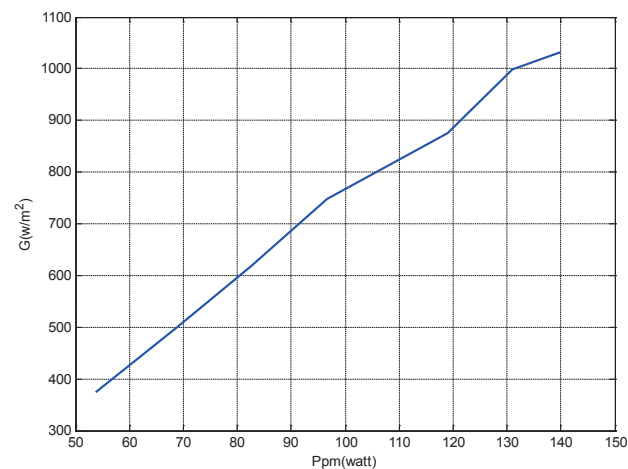**G-R$_{sh}$ Curve for Solara®-130 PV Module Based on Solar Module Tester**

Figure 11
G-P$_{pm}$ Curve for Solara®-130 PV Module Based on Solar Module Tester

CONCLUSION

A practical simulation of sun radiation effect on the output performance of photovoltaic module was introduced in this paper. The results show that the sun radiation plays an important rule on the output of photovoltaic module. A solar module tester was used for generating different values of solar irradiance. The output of PV module increases as the simulated sun radiation increases. The PV module can be used for measuring the sun radiation based on G-I curve introduced in this paper. Different parameters were extracted automatically by using the solar module tester and they played an important rule for evaluating the PV module.

REFERENCES

Adams, W. G., & Day, R. E. (1876). The action of light on selenium. *Proc. Roy. Soc. London Ser. A* , p.113.

Arjyadhara, P., Ali, S. M., & Chitralekha, J. (2013). Analysis of solar PV cell performance with changing irradiance and temperature. *International Journal Of Engineering and Computer Science*, *2*(1), 214-220.

Carlson, D. E., & Wronski, C. R. (1976). Amorphous silicon solar cell. *Applied Physics*, *28*, 671.

Chapin, D. M., Fuller, C. S., & Pearson, G. L. (1954). A new silicon p-n junction photocell for converting solar radiation into electrical power. *Journal of Applied Physics*, *25*, 676-677.

Gwinyai, D. (2008). *Modeling of photovoltaic systems* (Unpublished master's thesis). The Ohio State University.

Patel, H. (2008). Maximum power point tracking scheme for PV systems operating under partially shaded conditions. *IEEE Transactions on Industrial Electronics*, *55*(4), pp.1689-1698.

Renewable Energy Policy Network for the 21st Century (REN21). (2010). Renewable 2010 global status report. Deutsche Gesellschaftfür Technische Zusammenarbeit (GTZ) GmbH, 19.

Review and comparison of different solar energy technologies. (2011, August). Global Energy Network Institute. Retrieved from http:// www.geni.org /globalenergy.

Salih, S. M., Salih, F. F., Hasan, M. L., & Bedaiawi, M. Y. (2012). Performance evaluation of photovoltaic models based on a solar model tester. *I. J. Information Technology and Computer Science*, (7), 1-10.

Tina, G. M., Arcidiacono, F., & Gagliano, A. (2013). Intelligent sun-tracking system based on multiple photodiode sensors for maximization of photovoltaic energy production. *Mathematics and Computers in Simulation*, *91*, 16-28.

Xiao, W., Ozog, N., & Dunford, W. G. (2007). Topology study of photovoltaic interface for maximum power point tracking. *IEEE Transactions on Industrial Electronics*, *54*(3), pp.1696-1704.