ARPN Journal of Engineering and Applied Sciences
©2006-2021 Asian Research Publishing Network (ARPN). All rights reserved.

www.arpnjournals.com

PERFORMANCE OF THE PV MODULE UNDER DIFFERENT SHADING PATTERNS

E. T. El Shenawy[1], O. N. A. Esmail[2], Adel A. Elbaset[3] and Hesham F. A. Hamed[3]
[1]Department of Solar Energy, National Research Centre, El Behooth St., Dokki, Giza, Egypt
[2]Faculty of Engineering, Al-Azhar University, Qena, Egypt
[3]Faculty of Engineering, Minia University, Minia, Egypt
E-Mail: essamahame@hotmail.com

ABSTRACT

Generation of the electrical energy based on photovoltaic (PV) technology has been increased over the world due to either the continuous reduction in the traditional energy sources in addition to the pollution problems related to their usage, or the clean nature and safe usage of the PV technology. Also, PV systems can generate clean electricity in the site of using without any transmission which can be considered cost effective than other generation systems. The performance of the PV system is highly affected by the amount of solar radiation incident on it. Completely or partially shaded PV systems can affect its output. The PV system can be shaded by trees, buildings, dust, incorrect system configuration or other obstacles. The present paper studies the effect of the partial shading on the performance of a thin film PV module under climatic conditions of Cairo, Egypt. This effect was measured and evaluated according to practical measurement of the characteristic curves such as current-voltage and power-voltage for two identical PV modules (with and without shading) placed at the same time on one mechanical structure for comparison. The measurements have been carried out for the following shading patterns; half cell (bottom, middle and top of the PV module); complete cell; and two adjacent cells. For all shading patterns, the shapes of the I-V and P-V curves were changed and had more than one maximum power point. This problem can inversely affect the system in case of using traditional maximum power point trackers. Also, the output power from the module decreased according to the incomplete solar radiation reaching the PV module due to shadow patterns. The power loss due shading was 7%, 22% and 41% for shading of half-cell, one cell and two adjacent cells of the PV module, respectively.

Keywords: I-V measurements, PV module characteristics, PV module power loss, PV module shading.

1. INTRODUCTION

Growing attention to global warming and pollution effects over the worlds help the renewable energies such as solar or wind to be used in wide range of applications. The PV systems can generate electrical energy without pollution or global warming and can be modular and silent with almost maintenance free [1, 2]. The PV technology can be used in generating electrical energy for many applications such as stand-alone or grid-tied systems. In all of these systems, the PV power can be ranged from some hundreds of watts in small applications and remote residential systems, to some megawatts such as in high solar PV farms. Also, the PV system can be stationary or fixed at optimum orientation and tilt angle to receive as much as possible solar radiation all time, or tracked the sun using solar tracking system to follow the sun beam either in the daily or seasonally movements of the sun [3].

Although, the power-voltage (P-V) curve and current-voltage (I-V) characteristic of the solar PV module represented in module parameters such as open circuit voltage, short circuit current and maximum power point are affected by many factors like ambient and module surface temperature, air velocity, module surface maintenance and system arrangement it mainly depend on the amount of solar energy received by the module [4]. The amount of daily solar energy received by any solar system in kWh/day depends on the geographical site, system orientation, tilt angle, system arrangement, amount of dust covering the surface of the system and shading. Complete or partial shading of the PV system can come from adjacent buildings, trees, clouds and incorrect system configuration [5]. Since any PV module consists of electrically connected number of series and/or parallel solar cells, shading any part of the PV module causes some or all of the module cells to be less or nonilluminated, which causes energy loss from the module than that of the module rated and distorted the regular shape of the nonlinear characteristic I-V curve of the module, which arise more than one peak power point for the I-V curve and make the tracking of the maximum power point more difficult [6]. Also, shading one or more of solar cells in one module causes a negative voltage to be applied on these cells. If the cells have no protection from the negative voltage such as using bypass diodes, cells breakdown can appear and leads to all module failure. Consequently, one bypass diode can be connected with each chain of cells in the PV module to protect the module from failure due shading of their sells [7].

As power of the PV module is rated at standard illumination of 1000 W/m^2 and surface temperature of 25^{o}C, the output of the module reduces with the reduction of the solar intensity than the standard value. Shading of some cells in the PV module reduces the output from these cells with respect to their neighbors that makes the protection diodes to bypass these cells for module protection against hot-spot results from cells overheating and loses a percentage of the module power according to the percentage of the shading cells. Lua *et al.*, [8] studied the shading effect on the performance of one PV module

©2006-2021 Asian Research Publishing Network (ARPN). All rights reserved.

connected of 72 cells. The module has three parallel lines with three bypass diodes, one for each line. Each line consists of a chain of 24 cells electrically connected in series. They reported that shading one cell of any line reduce the module output by the third.

Due to the shading problems in protection and energy losses, it must be carefully avoided and studied well in the design, arrangement and installation of the PV systems. Different models are carried out to study the shading effect in terms of corresponding losses calculation with different shading patterns [9-12]. In all of these shading theoretical models different input data must be required concerning the system under consideration either PV model, array or system. The required data concerns the configuration of the model, numbers of series/parallel cells, number bypass diodes, electrical connection and the nature of shading. Due to the nonlinear nature of the PV module curves (I-V and P-V), it can be solved numerically by applying the shading on the suggested cells and calculate the behavior on the overall module or system under consideration [13]. Although the simulation of the shading patterns with the nonlinear behavior of the PV systems especially with large number of solar cells and modules is not easy and need a large number of input data, these models can give efficient information about the overall energy losses due to shading for different PV systems [14].

Another way to estimate the shading losses in the PV systems using software packages such as PVSYST [15] and simplified model that represented by Dolara *et al.*, [16]. These simplified models can be used with an acceptable error comparing to the practical measurement of the shading losses to avoid the difficulties resulted from dealing with non-liner models of the PV systems [17]. Rodrigo *et al.*, [18] improved the previous model based on an empirical equation to introduce more accurate one. The new model gives more accurate results in estimating of the shading losses then the previous one but it still has some deviations in estimating the shading instantaneous losses. The authors reported that the Root Mean Square deviation between the practical measurements of the shading power losses by the system and the predicted by the improved model is about 26%.

In this work, the performances and the energy losses from a thin film PV module is practically measure under different shading patterns according to the climatic condition of Cairo, Egypt (Lat. 30° 2' 38" North, Long. 31° 14' 9" East). The shading patterns are; shading of half-cell, shading of one-cell, shading of two-cells in the PV module. The performance of the PV module is evaluated by measuring a different I-V and P-V characteristics under different operating solar radiation levels with the suggested different shading patterns.

2. PV MODULE

The PV module (Figure-1) is a thin film type with rated power of 22 W at Standard Test conditions (STC, 1000 W/m^2 of solar radiation and surface temperature of 25^{o}C). Table-1 shows the electrical characteristics of the PV module. The PV module is installed facing south on a fixed steel structure tilted at 30^o with horizontal to ensure optimum inclination angle according to the geographical location of Cairo, Egypt.

Figure-1. PV module.

Table-1. Electrical characteristics of the PV module.

Item	Specifications
Type	Thin film
Module power	22 W
Open circuit voltage	22 V
Short circuit current	1.8 A
Operating voltage	15.6 V
Operating current	1.4 A

3. MEASURING CIRCUIT AND SHADOW PATTERNS

To investigate the performance loss of the PV module under partial shadow, a series of partial shadow patterns are applied to the PV module at different operating solar radiation levels. The partial shadow patterns are arranged as follows;

- Partial shadow for a half cell in the bottom of the PV module.
- Partial shadow for a half cell in the middle of the PV module.
- Partial shadow for a half cell in the top of the PV module.
- Partial shadow for one cell of the PV module.
- Partial shadow for two cells of the PV module.

©2006-2021 Asian Research Publishing Network (ARPN). All rights reserved.

In each of these shadow patterns, the I-V and P-V measurements are taken simultaneously for two identical PV modules; one facing to the sun without shading and the other is partially shaded, for comparison the effect in the same operating conditions. The two PV modules are put in the same tilted surface with the same inclined angle.

The I-V and P-V measurements of the PV module under the specified partial shadow patterns are taken by using the simple and accurate I-V measuring circuit of photovoltaic modules based on an electronic load as shown in Figure-2 [19].

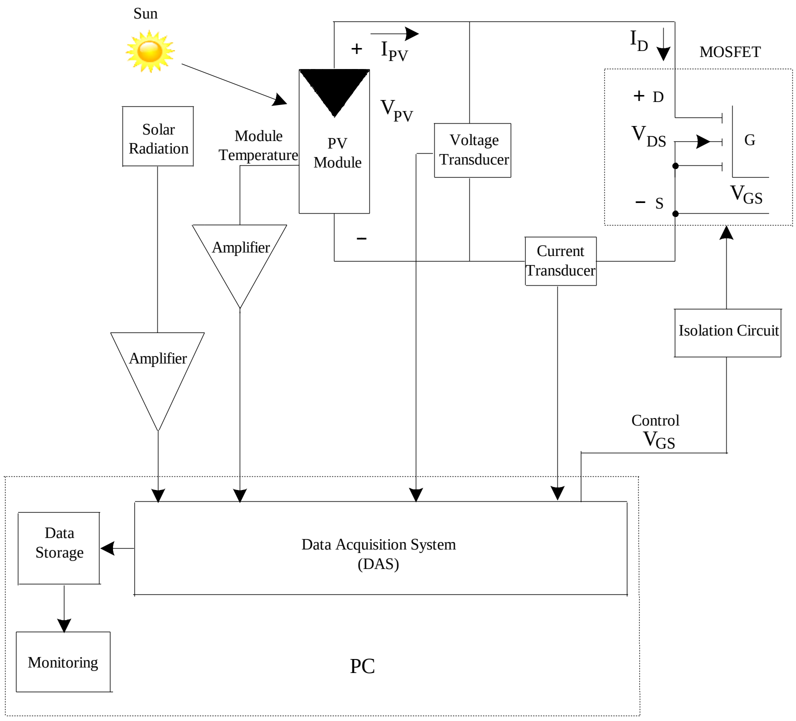

Figure-2. Block diagram of the electronic circuit for tracing I-V characteristic [19].

As shown in Figure-2, the tracking of the PV module I-V and P-V curves is via electronic load using 520 W, N-type Metal Oxide Semiconductor Field Effect Transistor (MOSFET) with the required different sensors and transducers as well as the amplification and isolation circuits. Table-2 shows the electrical parameters of the electronic load.

Table-2. Electrical parameters of the electronic load.

Item	Specifications
Rated power	520 W
Operating voltage	500 V
Operating current	48 A
Operating temperature	Up to 150 °C

For each shadow patterns, the following electrical and physical parameters are measured and stored using the measuring circuit and data acquisition system shown in Figure-2 [19, 20] for both modules at the same time under climates of Cairo, Egypt;

- Incident solar radiation using a Kipp-Zonen type pyranometer mounted at the same structure parallel to the PV module.
- The PV module surface temperature was recorded by the measuring circuit via K-type thermocouple placed at the center of the back surface of the PV module.
- The PV module voltage can be tracked via a bipolar voltage transducer, while the current can be measured by the shown appropriate current transducer.

4. RESULT AND DISCUSSIONS

According to the shown shadow patterns, and the measured data from both PV modules (with and without shadow), the effect of partial shadow can be explained from the following results and discussions.

Figures 3, 4 show the effect of partial shadow for a half cell in the bottom of the PV module on I-V and P-V characteristics of the PV module at solar radiation level of 975 W/m^2, respectively. From the figures, it is clear that the effect of half-cell shaded directly affecting the power delivered by the PV module and the shape of the I-V curve has changed specially at the maximum power point. The

ARPN Journal of Engineering and Applied Sciences
©2006-2021 Asian Research Publishing Network (ARPN). All rights reserved.

loss of the PV module output power due to partial shadow of the half-cell is about 7 %.

The same effect can be shown at any half-cell of the PV module; bottom, middle or top, as shown in Figures 5, 6 that represent I-V and P-V characteristics of the PV module for a bottom, middle and top half cell shaded (975 W/m^2), respectively.

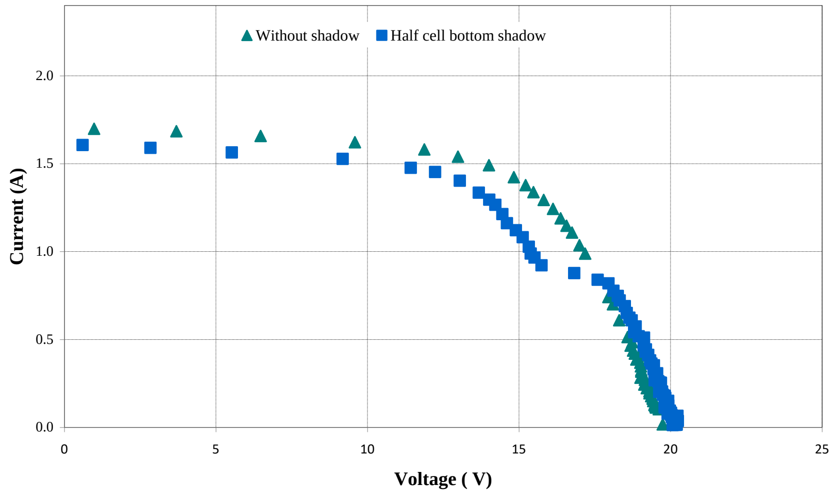

Figure-3. I-V characteristics of the PV module for a bottom half cell shaded.

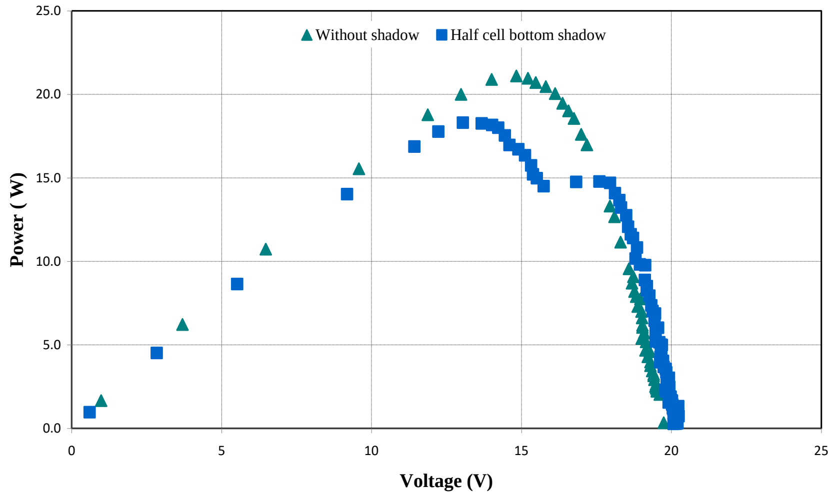

Figure-4. P-V characteristics of the PV module for a bottom half cell shaded.

ARPN Journal of Engineering and Applied Sciences
©2006-2021 Asian Research Publishing Network (ARPN). All rights reserved.

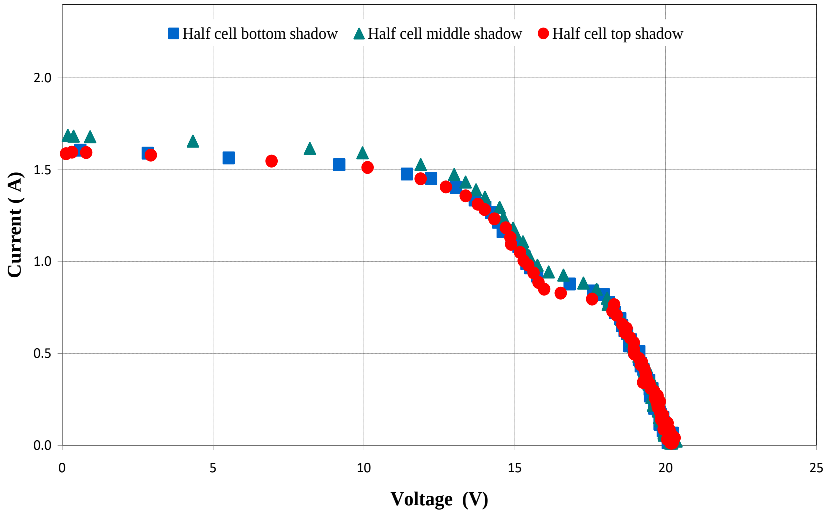

Figure-5. I-V characteristics of the PV module for a bottom, middle and top half cell shaded.

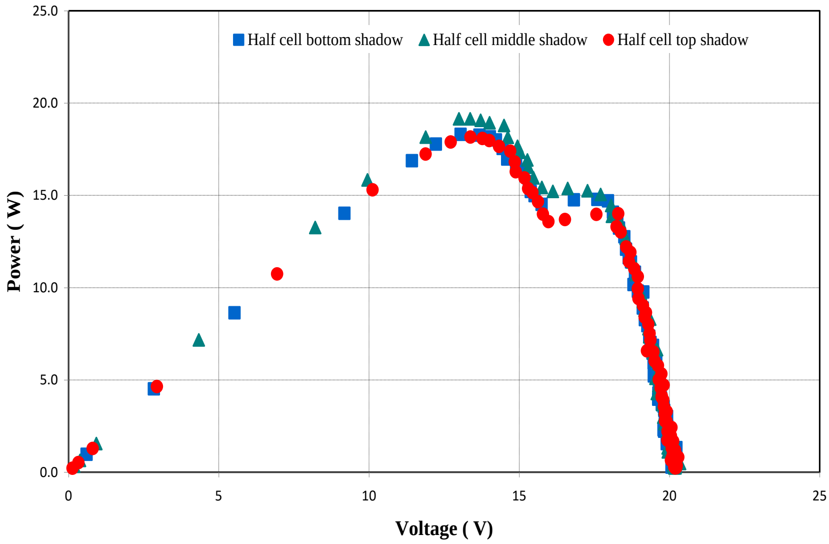

Figure-6. P-V characteristics of the PV module for a bottom, middle and top half-cell shaded.

Figures 7, 8 show the effect of partial shadow for one and two adjacent cells of the PV module, respectively. From the figures it is clear that the same effect on the shape of the I-V and P-V curves as in case of half-cell shaded. It is clear that shading more cells (two-cells) results in more power losses than that of one-cell. The resultant power losses are 22 % and 41% for shading one and two cells, respectively. Also, the open circuit voltage was highly affected in case of shaded two adjacent solar cells of the PV module (Figure-8).

The effect of partial shadow (for half-cell, one cell and two cells) on the performance of the PV module can be summarized in Figures 9, 10, respectively. It can be seen from the previous I-V and P-V curves of the PV module appear many optimal points in irregular shadow, which cause a big problem in case of using Maximum Power Point Tracking (MPPT) in the PV system. Traditional MPPT control algorithm is no longer available, new MPPT control algorithm must be studied in case of irregular shading that may affecting on the PV installation.

ARPN Journal of Engineering and Applied Sciences
©2006-2021 Asian Research Publishing Network (ARPN). All rights reserved.

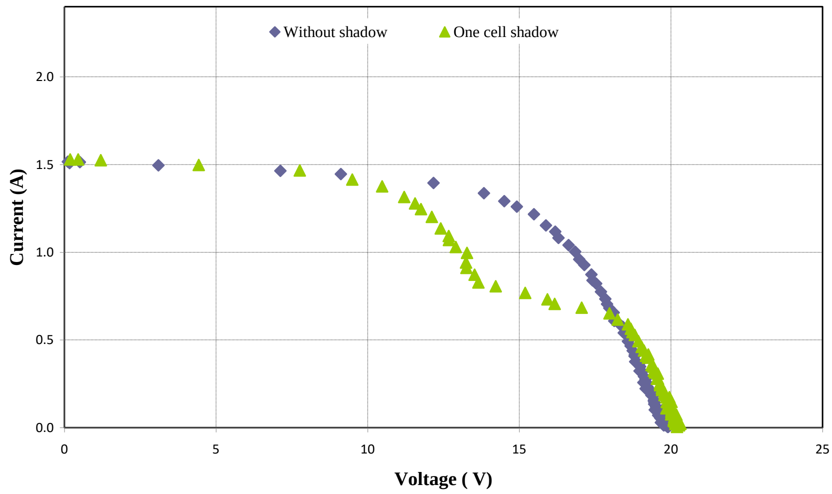

Figure-7. I-V characteristics of the PV module for one cell shaded.

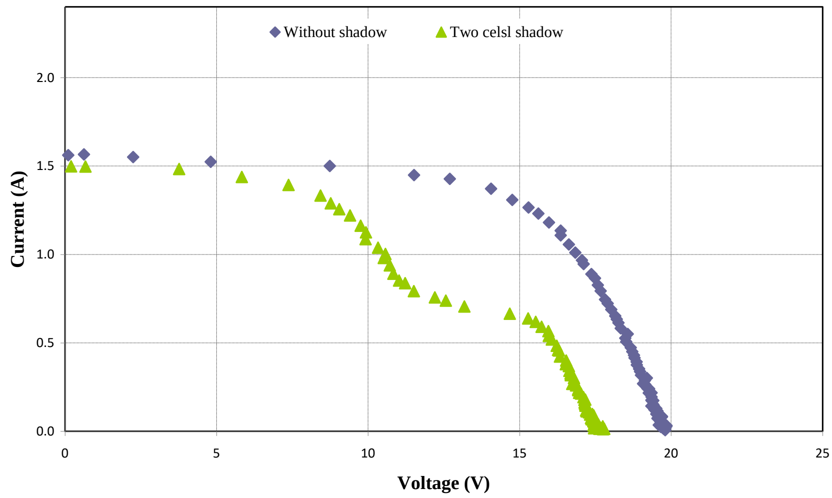

Figure-8. I-V characteristics of the PV module for two cells shaded.

The PV module used in this study (Figure-1) is connected of 22 series identical solar cells, thus the series cells should have the same current if they were illuminated at the same irradiation level. Once the cell or part of the cell has shaded, its current will be decreased by a certain amount according to the nature of shading, and the current of the shaded cell will be less than that of the illuminated ones. Without bypass diodes, the difference between the two currents will pass through the shaded cells leading the shaded cells to be heated causing hot spots, which will reduce the module life time over the long term. To avoid these hot spots, standard bypass diodes are used inside the PV modules to bypass the current if it's increased above a certain limit. When there is shading cells of the modules, the bypass diode becomes forward bias (due to higher current in the illuminated paths than that of the shaded ones) and bypass the higher current far from the shaded paths to ensure full protection for the shaded paths from heat circulation. Consequently, the module power has reduced below its rated due to the bypassed cells. It must be noted that practically it's difficult and not economically to put bypass diode for each series cell, but at least it is used for each parallel path in the module configuration.

ARPN Journal of Engineering and Applied Sciences
©2006-2021 Asian Research Publishing Network (ARPN). All rights reserved.

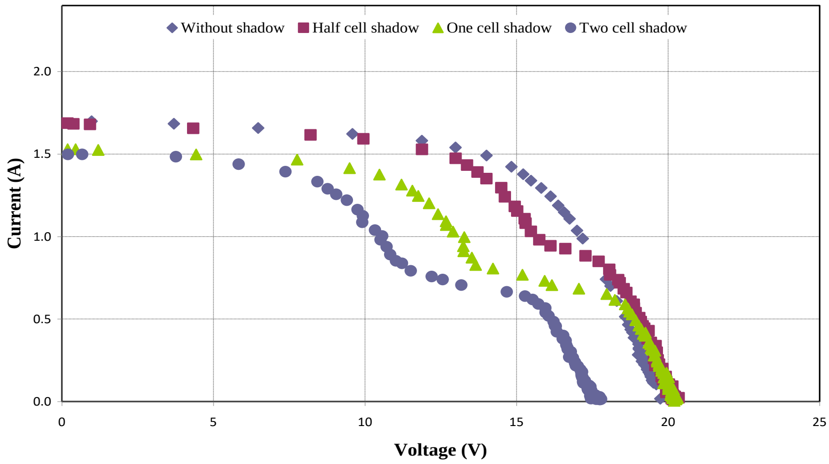

Figure-9. I-V characteristics of the PV module for half-cell, one cell and two cells shaded.

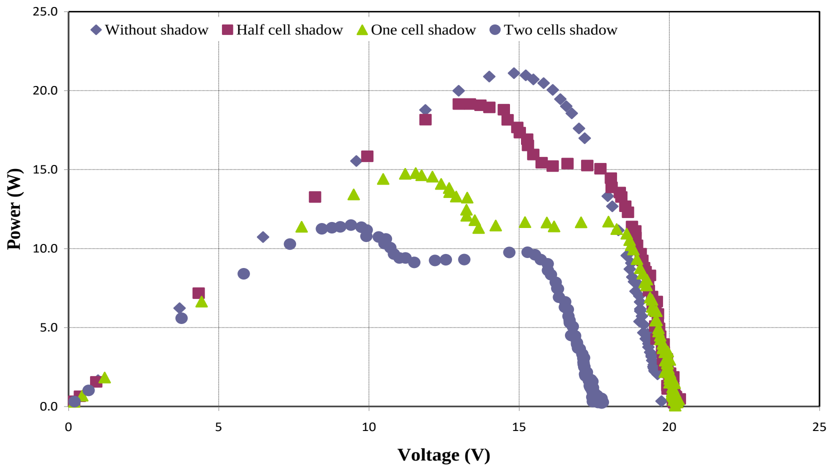

Figure-10. P-V characteristics of the PV module of half-cell, one cell and two cells shaded.

5. CONCLUSIONS

The effect of partial shading on the performance of a thin film PV module was investigated practically through the direct measurement of the I-V and P-V curves of the PV module under different partial shading patterns. The partial shading patterns are; half-cell shaded in bottom, middle and top of the PV module, also for one and two cells. For accurate measurements, two identical modules (with and without shading) are placed at the same time on one mechanical structure for measurements. For all shading patterns, the shapes of the I-V and P-V curves are changed and have more than one maximum power point. This problem can inversely affect the system in case of using traditional maximum power point trackers. Also, the power losses due shading are 7%, 22% and 41% for shaded half-cell, one cell and two adjacent cells of the PV module, respectively.

REFERENCES

[1] H. Hanifi, M. pander, B. Jaeckel, J. Schneider, A. Bakhtiari and W. Maier. 2019. A novel electrical approach to protect PV modules under various partial shading situations. Solar Energy. 193: 814-819.

[2] M. Baka, P. Manganiello, D. Soudris and F. Catthoor. 2019. A cost-benefit analysis for reconfigurable PV modules under shading. Solar Energy. 193: 814-819.

[3] L. Fialho, R. Melicio, V. M. F. Mendes, J. Figueiredo and X. Collares-Pereira. 2014. Effect of shading on series solar modules: simulation and experimental results. Procedia Technology. 17: 295-302.

[4] I. H. Mahammed, A. H. Arab, S. berrah, Y. Bakelli, M. Khennene, S. H. Oudjana, A. Fezzani and L. Zaghba. 2017. Outdoor study of partial shading

©2006-2021 Asian Research Publishing Network (ARPN). All rights reserved.

effects on different PV modules technologies. Energy Procedia. 141: 81-85.

[5] H. Patel and V. Agarwal. 2008. MATLAB-based modeling to study the effects of partial shading on PV array characteristics. IEEE Transactions Energy Conversion. 23: 302-310.

[6] A. Woyte, J. Nijs and R. Belmans. 2003. Partial shadowing of photovoltaic arrays with different system configurations: literature review and field test results. Solar Energy. 74: 217-250.

[7] V. Quaschning and R. Hanitsch. 1995. Numerical simulation of photovoltaic generators with shaded cells. Int. Proc. 30th Universities Power Engineering Conference, London, UK. pp. 583-589.

[8] F. Lua, S. Guoa, T. M. Walsha and A. G. Aberlea. 2013. Improved PV module performance under partial shading conditions. Energy Procedia. 33: 248-255.

[9] M. C. Alonso-Garcı´a and J. M. Ruiz. 2006. Analysis and modeling the reverse characteristic of photovoltaic cells. Solar Energy Materials and Solar Cells. 90: 1105-1120.

[10] K. Brecl, and M. Topi. 2011. Self-shading losses of fixed free-standing PV arrays. Renewable Energy. 36: 3211-3216.

[11] E. Karatepe, M. Boztepe and M. Colak. 2007. Development of a suitable model for characterizing photovoltaic arrays with shaded solar cells. Solar Energy. 81: 977-992.

[12] S. Silvestre and A. Chouder. 2008. Effects of shadowing on photovoltaic module performance. Progress in Photovoltaics. Research and Applications. 16: 141-149.

[13] G. Blaesser and D. Munro. 1995. Guidelines for the assessment of photovoltaic plants. document C: initial and periodic tests on photovoltaic plants. Joint Research Centre of the European Communities, Ispra Establishment, Report EUR 16340 EN, Ispra, Italy.

[14] Y. Wang, D. Wang and Y. Liu. 2017. Study on Comprehensive Energy-saving of Shading and Photovoltaics of Roof Added PV Module. Energy Procedia. 132: 598-603.

[15] PVSYST V5.62, software for photovoltaic system. University of Geneva. http://www.pvsyst.-com/en (accessed 19.12.12), Institute of Environmental Sciences (ISE), 2012.

[16] A. Dolara, G. C. Lazaroiu, S. Leva, and G. Manzolini. 2013. Experimental investigation of partial shading scenarios on PV (photovoltaic) modules. Energy. 55: 466-475.

[17] F. Martinez-Moreno, J. Munoz and E. Lorenzo. 2010. Experimental model to estimate shading losses on PV arrays. Solar Energy Materials and Solar Cells. 94: 2298-2303.

[18] P. Rodrigo, E. F. Ferna´ndez, F. Almonacid and P. J. Pe´rez-Higueras. 2013. A simple accurate model for the calculation of shading power losses in photovoltaic generators. Solar Energy. 93: 322-333.

[19] E. T. El Shenawy, O. N. A. Esmail, Adel A. Elbaset and Hesham F. A. Hamed. 2014. Simple and accurate I-V measuring circuit for photovoltaic applications. International Journal of Engineering Research & Technology. 3(6): 1141-1147.

[20] O. N. A. Esmail, E. T. El Shenawy, Adel A. Elbaset and Hesham F. A. Hamed. 2013. Design and practical implementation of a data acquisition system for photovoltaic applications. Journal of Applied Sciences Research. 9(8): 4856-4866.