International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 03, March-2017

Matlab/Simulink and Experimental Studies of Shading Effect on a Photovoltaic Array

Mourad Talbi[1]
[1]Laboratoire de Nanomatériaux et des Systèmes pour les Energies Renouvelables
Center of Researches and technologies of energy of Borj Cedria
Tunis, Tunisia

Nawel Mensia[2], [1]Fehri Krout, [2]Radhouane Chtourou
[2]Laboratoire Photovoltaïque
Center of Researches and technologies of energy of Borj Cedria
Tunis, Tunisia

***Abstract*—Photovoltaic systems are vulnerable to the change of climatic conditions (temperature and irradiance). They cause a declination in power generation efficiency and reliability. The variation is commonly caused by uniform and non-uniform partial shading. The aim of this paper is to present the non-uniform partial shading impact on the performances of a photovoltaic generator. Hence, a theoretical modeling of a generator composed of two series photovoltaic panels, is presented. The first part provides literature review with mathematical model. The second section offers details of the simulation analysis under diverse partial shading conditions.**

***Keywords*— Photovoltaic systems, Shading, PV panels, (P-V) characteristic, (I-V) characteristic.**

I. INTRODUCTION

The quick renewable development, green and clean energy technologies play a very important role in clean application particularly in electric power generation. Energy produced from renewable resources including wind, biofuels, sun and others is named renewable energy [1]. The most popular form of renewable energy is solar energy. It provides electric energy directly by employing PV modules then MPP Tracker (MPPT) is used in order to maximize the efficiency of the PV system. The PV system has a single MPP at the peak values of current and voltage [2]. The power yield of PV modules is a function of different weather conditions including temperature [3], solar irradiance [4] and partial shading [2]. In this paper we will be interested in a model of a PV Module containing 36 solar cells. This model was proposed by Sanjay Lodwal and presented in matworks [5] and we have made one modification on it by introducing the technique of the series resistance proposed in [6]. After this modification we connect in series two modified models and we study the effect of partial shading on one of them. Section 2 is dedicated to present the equivalent circuit to a PV cell. The effect of Partial Shading on a PV cell is explained in section 3. Matlab/Simulink numerical simulation of one PV module exposed to different shading effects is presented in section 4. Finally, the conclusion is given in Section 5.

II. PHOTOVOLTAIC EQUIVALENT MODEL

The PV array consists of solar cell stacks. Solar cell transforms light into electricity. In figure 1, is displayed a solar cell equivalent circuit. It is simply consists of a photo current (IPH), a diode, a shunt or parallel resistor (RSH) and an internal resistor (RS). The current at the terminal of the solar cell is expressed as follows [2]:

$$I = I_{PH} - I_S\left[exp\left(q\,\frac{(V+IR_S)}{KT_C A}\right)-1\right] - \frac{V+IR_S}{R_{SH}} \qquad (1)$$

With I_S is the saturation current, K is the constant of Boltzmann, A is an ideal factor and T_c is the Kelvin temperature.

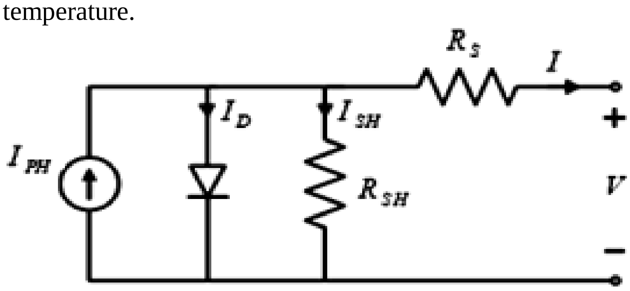

Figure 1. Equivalent circuit of a PV cell.

In a simple representation of a PV cell, series resistance, $R_S = 0$ and shunt resistance $R_{SH} = \infty$ [7]. This ideal case is practically impossible; though, many research works aim to reduce the effect of both the shunt and series resistances. Common PV cell yields below $2W$ at $0.5V$, which is significantly low. For larger output power values, a PV array is employed. It is it is constituted of a number of modules which are connected in series and parallel arrangements. Each of these modules is constituted of of PV cells connected in parallel and series. PV modules are simulated employing either physically using SimPowerSystems toolbox or mathematically using math function. Generally, the mathematical approach is easier to use than the physical model. On the contrary to physical model, in the mathematical one, to have a series-parallel combination for a PV cells, there is no need for block diagram repetition [7, 8]. Consequently in [7], was built the system that depends on mathematical modeling.

III. EFFECTS OF PARTIAL SHADING ON PV

The functioning of a photovoltaic array is impacted by solar irradiance, temperature and shading and array configuration. Often, the PV arrays get shadowed, partially or

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 03, March-2017

wholly, by towers, trees, utility and telephone poles, adjacent buildings and the moving clouds. The situation is of special interest in case of big PV installations such as those used in distributed power generation systems. Under partly shaded conditions, the photovoltaic characteristics get more complex with more than one peak. Yet it is very crucial to understand and predict them in order to draw out the maximum possible power. Here, we present a MATLAB-based modeling and simulation scheme desirable for studying the $P - V$ and $I - V$ characteristics of a photovoltaic array.

In this section is described the procedure used to simulate the $I - V$ and $P - V$ characteristics of a partially shaded PV array. It is of importance to understand how the shading pattern and the PV array structure are defined in MATLAB using the proposed scheme. The PV array is configured as a combination of six series of PV modules connected in three parallel connections. Each set of PV modules operate under different solar radiations and different cell temperatures. The first set is under solar radiation of $800\ W/m^2$ and cell temperature of $750°_C$, the second set is under solar radiation of $600\ W/m^2$ and cell temperature of $250°_C$ and the third set is under solar radiation of $700\ W/m^2$ and cell temperature of $500°_C$. Based on these conditions the simulations illustrating the PV characteristics is shown in Figure 2 with three different multiple peaks. The maximum peak is called as global peak and the remaining two peaks are named as the local peaks.

The PV output power is affected by different factors such as partial shading [9], solar insolation, temperature and the configuration of the PV arrays. In [7] Khaled Matter et al., discussed the effect of several shading condition on the PV arrays that may occur due to presence of trees, buildings and clouds [10, 11]. The power-Voltage (P-V) characteristic curves of the PV system with full insolation exhibits nonlinearity with one MPP [6]. This complexity increases with changing insolation conditions [2, 6]. Under conditions of partial shading, some of the PV cells which collect even irradiance, will work with maximum efficiency. In the series structure, a uniform current is passing in each cell. Consequently, the cells experience shading run in reverse biasing to yield equal current leading to the decrease in the MPP value. To solve this problem, a bypass diode is connected to selected cells in the series configuration [9]. The addition of bypass diodes modifies the array characteristics. Under partial shading conditions and in the presence of the bypass diodes, many local MPP emerge. The bypass diodes produce a short circuit around the shaded cells permitting the current produced from unshaded cells to flow; consequently, the array current and heating losses are reduced [9-12].

IV. MATLAB/SIMULINK NUMERICAL SIMULATION OF ONE PV ARRAY EXPOSED TO DIFFERENT SHADING EFFECTS

In this paper, we used a Matlab simulink for investigating the characteristics curves of a PV array subject to diverse shading circumstances. This PV array is as previously mentioned constitutes of two PV modules connected in series. Each of them is a model of PV module contains 36 solar cells. This PV array is presented in Figure 2.

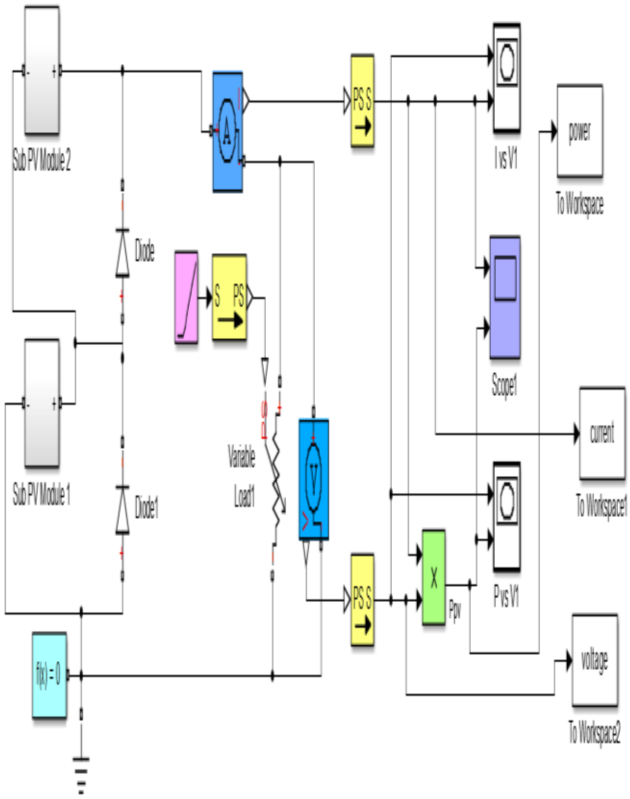

Figure 2. The Simulation block diagram of the PV array experiencing different shading conditions.

Where the Sub PV Module 1 or 2 is illustrated in Figure 3 with $I_r(W/m^2)$ designates the Irradiation. For the partial shading of the Sub PV Module 2, we have chosen I_r equal to 500 W/m^2 while it is equals to 1000 W/m^2 for the Sub PV Module 2.

The model of those solar cells can be determined by choosing all the parameters existent in the block parameters of each solar cell. These block parameters are in number of 5 and are listed in Table 1.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 03, March-2017

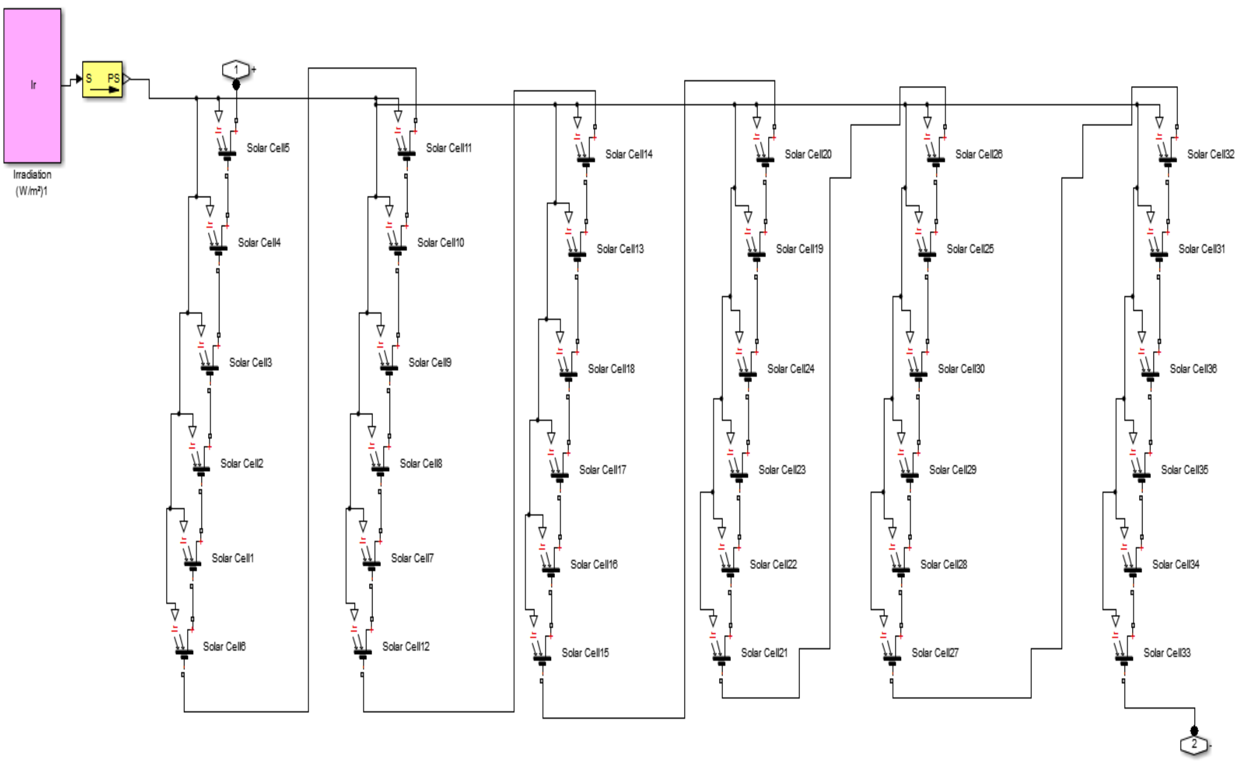

Figure 3. The Sub PV Module 1 or 2 contains 36 solar cells connected in series.

The model of those solar cells can be determined by choosing all the parameters existent in the block parameters of each solar cell. These block parameters are in number of 5 and are listed in Table 1.

TABLE 1. THE BLOCK PARAMETERS OF EACH SOLAR CELL

Parameter	Value
Short-Circuit Current: Isc	8.9 A
Open-circuit voltage: Voc	22.75V
Quality factor: n	1.2
Series resistance: Rs	0.0125
Irradiance: I_r	Its value is variable

We have used in this work the computation procedure of the series resistance described in [12] in order to compute R_s for each solar cell. This procedure is summarized as follow [12]:

$$R_S = \frac{0.575}{N_S} - \frac{1}{Xv} \tag{2}$$

Where N_S is the number of PV cells connected in series and in this work, it is equals to 36. The quantity X_v is expressed as follow:

$$X_V = (q \cdot \mathrm{I0\_T1}/(\mathrm{n} \cdot \mathrm{k} \cdot \mathrm{T1})) \cdot \exp\left(\frac{\mathrm{q{\cdot}Voc\_T1}}{\mathrm{n{\cdot}k{\cdot}T1}}\right) \tag{3}$$

Where $Voc\_T1 = \frac{Voc(T1)}{N_s}$ with $Voc(T1)$ is the voltage in open circuit and in this work is equals to 22.75. the current $I0\_T1$ is expressed as follow:

$$I0\_T1 = \frac{I_{SC}(T1)}{exp\left(\frac{q{\cdot}Voc\_T1}{n{\cdot}k{\cdot}T_1}\right)-1} \tag{4}$$

and $T1$ is the temperature in Kelvin and is expressed as follow:

$$T1 = 25 + 273.15 \tag{5}$$

The constant k is the Boltzmann constant and is equals to $1.38 \cdot 10^{-23} J/K$ and q is the electron charge and is equals to $1.602 \times 10^{-19} C$. The factor n is the Quality factor and is equals to 1.2 (Table 1).

Figures 4 to 13 illustrated the $I - V$ and $P - V$ characteristics in the following cases:

- $I_{r_1} = 1000\ W/m^2, I_{r_2} = 1000\ W/m^2$,
- $I_{r_1} = 1000\ W/m^2, I_{r_2} = 750\ W/m^2$ (partial shading),

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 03, March-2017

- $I_{r_1} = 1000\ W/m^2, I_{r_2} = 500\ W/m^2$ (partial shading),
- $I_{r_1} = 1000\ W/m^2, I_{r_2} = 250\ W/m^2$ (partial shading),
- $I_{r_1} = 1000\ W/m^2, I_{r_2} = 151\ W/m^2$ (partial shading).

Where I_{r_1} is the irradiance of the Sub PV Module 1 and I_{r_2} is the irradiance of the Sub PV Module 2.

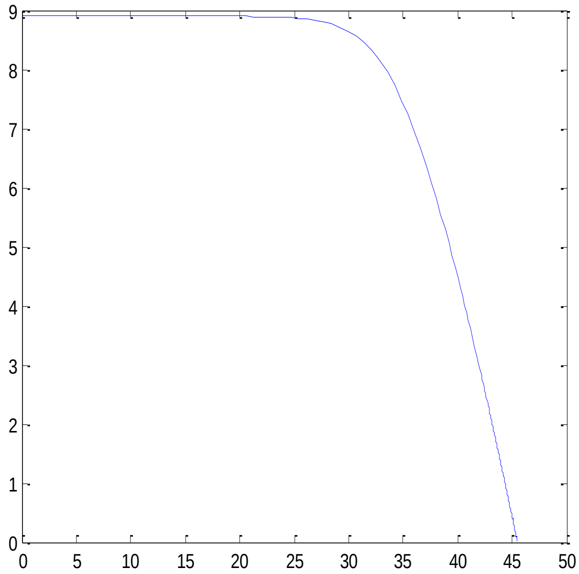

Figure 4. $I - V$ characteristic in the case:
$I_{r_1} = 1000\ W/m^2, I_{r_2} = 1000\ W/m^2$
(without shading).

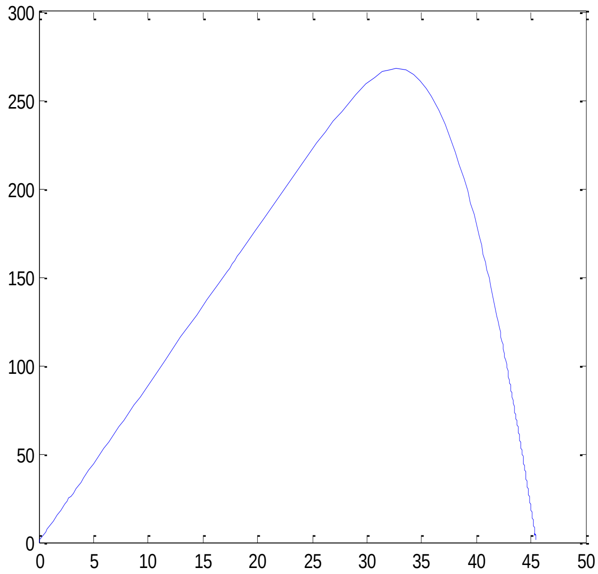

Figure 5. P-V characteristic in the case:
$I_{r_1} = 1000\ W/m^2, I_{r_2} = 1000\ W/m^2$
(without shading).

For maximum irradiances Ir_1 and Ir_2 equal to 1000W/m² (Figures 4 and 5) and a constant ambient temperature (25°C), the maximum PV power reaches approximately $267.8\ W$. The corresponding voltage and current are, respectively, $32.68\ V$ and $8.19\ A$.

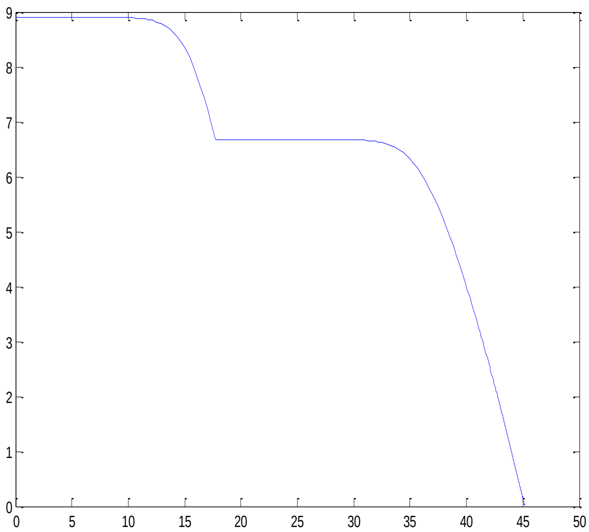

Figure 6. $I - V$ characteristic in the case of partial shading:
$I_{r_1} = 750\ W/m^2, I_{r_2} = 1000\ W/m^2$

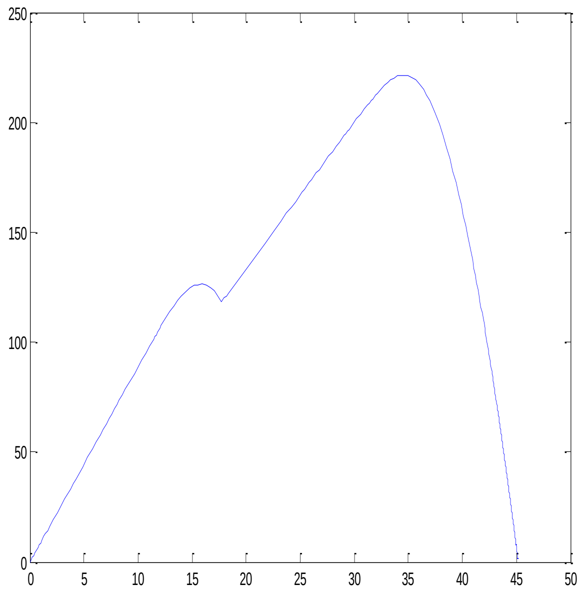

Figure 7. $P - V$ characteristic in the case of partial shading:
$I_{r_1} = 750\ W/m^2, I_{r_2} = 1000\ W/m^2$

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 03, March-2017

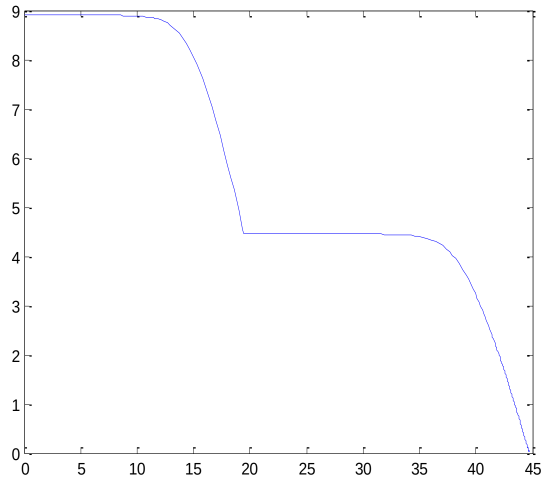

Figure 8. $I - V$ Characteristic in the case of partial shading: $I_{r_1} = 500\ W/m^2, I_{r_2} = 1000\ W/m^2$ (partial shading).

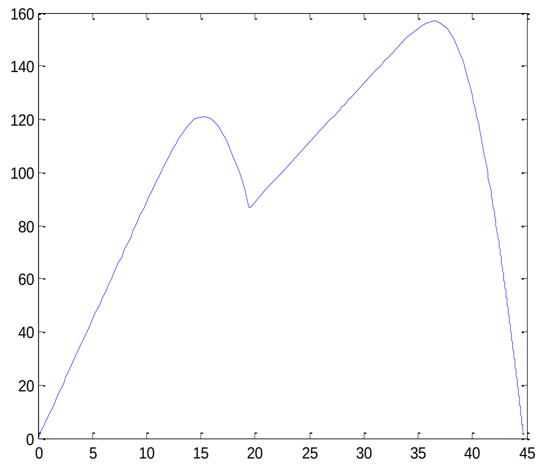

Figure 9. $I - V$ Characteristic in the case of partial shading: $I_{r_1} = 500\ W/m^2, I_{r_2} = 1000\ W/m^2$

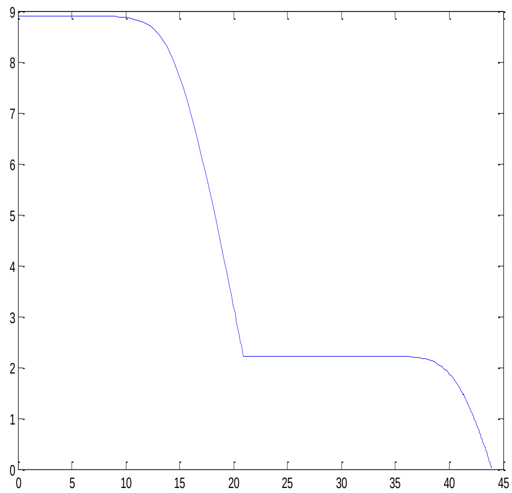

Figure 10. $I - V$ characteristic in the case of partial shading: $I_{r_1} = 250\ W/m^2, I_{r_2} = 1000\ W/m^2$

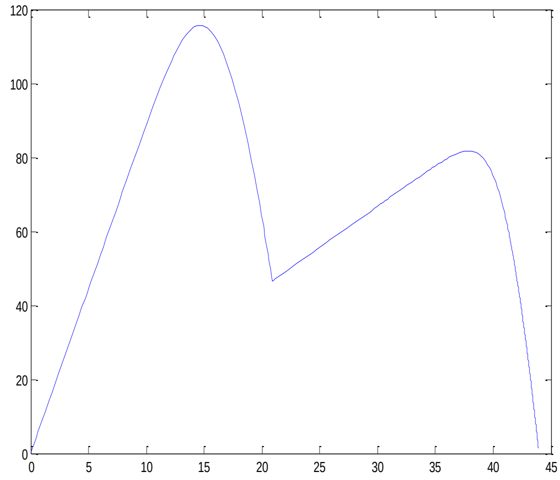

Figure 11. $P - V$ characteristic in the case of partial shading: $I_{r_1} = 250\ W/m^2, I_{r_2} = 1000\ W/m^2$

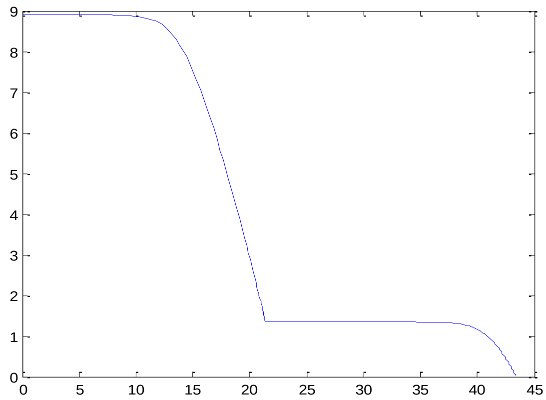

Figure 12. $I - V$ characteristic in the case of partial shading: $I_{r_1} = 151\ W/m^2, I_{r_2} = 1000\ W/m^2$

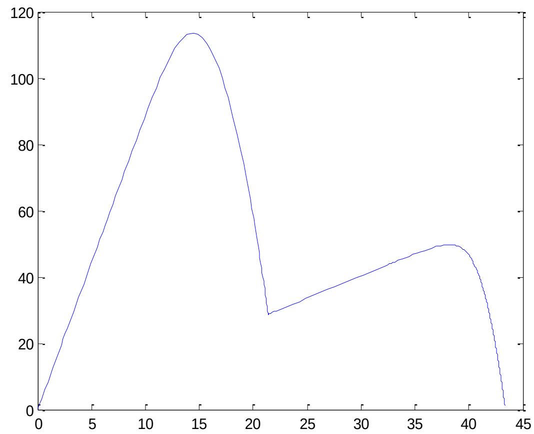

Figure 13. $P - V$ characteristic in the case of partial shading: $I_{r_1} = 151\ W/m^2, I_{r_2} = 1000\ W/m^2$

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 03, March-2017

The obtained results show that the maximum PV power is affected by the partial shading. Two local peaks appear on the P-V and I-V characteristics. These peaks vary with the level of the partial shading. During partial shading, each module is exposed to different irradiances. Thus, each panel has its own maximum (peak) power. Figures 6 to 13 presents the output (I-V and P-V) curves of the PV generator composed of two panels. It shows, for various Ir1, the array characteristics exhibiting two power peaks, for each case of level partial shading.

V. CONCLUSION

This paper presents a study of a partial shading impact on the PV panel characteristics. We demonstrate that partial shading results a substantial degradation in the output power causing global and local maximum peaks in the P-V characteristic curves. For this reason, appropriately rated bypass diodes are commonly employed to preserve solar array power. Moreover, the use of a maximum power point tracking algorithm to extract the global PV power is not an efficient solution. We suggest a unified controller which makes each panel to operate at its maximum power.

REFERENCES

[1] Report issued by IEA,"Renewable Energy into Mainstream," SITTARD: The Netherlands, Oct. (2002).

[2] C. S. Chin, P. Neelakantan, S. S. Yang, B. L. Chua, K. K. Teo,"Effect of Partially Shaded Conditions on Photovoltaic Array's Maximum Power Point Tracking," International Journal of Simulation Systems, Science & Technology (IJSSST), vol. 12, no. 3, pp. 52-59, (2011).

[3] C. S. Chin, P. Neelakantan, H. P. Yoong, K. K. Teo,"Fuzzy logic based MPPT for phorovoltic modules influenced by solar irradiance and cell temperature," Proceedings of 13th international conference on computer modeling and simulation, Cambridge, United Kingdom, pp. 376-381,(2011).

[4] E. K. Syafanuddin and T. Hiyama, "Polar coordinate fuzzy controller based real-time maximum-power point control of photovoltaic system," Renewable Energy, vol. 34, no. 12, pp. 2597-2606, (2009).

[5] https://www.mathworks.com/matlabcentral/fileexchange/49068-simulink-model-of-photovoltaic-module

[6] Francisco M. González-Longatt, ‘‘Model of Photovoltaic Module in Matlab,’’ 2DO CONGRESO IBEROAMERICANO DE ESTUDIANTES DE INGENIERÍA ELÉCTRICA, ELECTRÓNICA Y COMPUTACIÓN (II CIBELEC 2005).

[7] Khaled Matter, Hala J. El-Khozondar, Rifa J. El-Khozondar, Teuvo Suntio, ‘‘Matlab/Simulink Modeling to study the effect of partially shaded condition on Photovoltaic array's Maximum Power Point,’’ International Research Journal of Engineering and Technology, Volume: 02 Issue: 02, May-2015 (IRJET), pp. 697-703.

[8] S. Said, A. Massoud, M. Benammar, S. Ahmed, "A Matlab/Simulink-Based Photovoltaic Array Model Employing SimPowerSystems Toolbox," Journal of Energy and Power Engineering, vol. 6, pp. 1965-19756, (2012).

[9] Y. J. Wang and P. C. Hsu, "Analytical modeling of partial shading and different orientation of photovoltaic modules," IET Renewable Power Generation, vol. 4, no. 3, pp. 272–282, (2009).

[10] M. Seyedmahmoudian, S. Mekhilef, R. Rahmani, R. Yusof , E. T. Renani, "Analytical Modeling of Partially Shaded Photovoltaic Systems," Energies, vol. 6, pp. 128-144, (2013), doi:10.3390/en6010128.

[11] H. Patel and V. Agarwal, "MATLAB-Based Modeling to Study the Effects of Partial Shading on PV Array Characteristics," IEEE Transactions on Energy Conversion, vol. 23, no. 1, pp. 302- 310, (2008).

[12] Y. H. Ji, D. Y. Jung, C. Y. Won, B. K. Lee, J. W. Kim,"Maximum Power Point Tracking Method for PV Array under Partially Shaded Condition," Proceeding of Energy Conversion Congress and Exposition (ECCE 2009), IEEE, pp. 307-312, Sept. (2009).