

Study, modeling and simulation of photovoltaic panels under uniform and nonuniform illumination conditions

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Résumé - Dans ce travail, on a étudié le comportement des panneaux photovoltaïques dans le cas d'un éclairage homogène sur toute la surface du module, et le cas de la non homogénéité de l'éclairage, c'est-à-dire l'ombrage. Pour cela un groupe des panneaux PV de type UDT50 ont été modélisé et simulé sous environnement Matlab/Simulink pour discuter et comparer les caractéristiques externes dans les deux situations du travail étudiées. Les résultats de simulation obtenus montrent bien l'effet de la non homogénéité de l'éclairage dans une installation photovoltaïque, ce qui nécessite des précautions particulières afin de garantir le maximum de puissance possible dans toutes les conditions.

Abstract - In this work we studied the behavior of the photovoltaic panels in a uniform and non uniform illumination conditions on the module surface. For this a group of UDT50 PV panels was modeled and simulated under Matlab/Simulink environment toward discuss and compare the external characteristics in the two studied situations. The simulation results obtained shows well the effect of the shadow in a photovoltaic installation, which requires particular precautions in order to guarantee the maximum power possible under all operation conditions.

Keywords: Photovoltaic panels – PV - external characteristic - Global Maximum Power Point Tracking (GMPPT) - Local Maximum Power Point Tracking (GMPPT) - Uniform and nonuniform illumination conditions.

1. INTRODUCTION

With highly increasing demand for energy and limiting problems related to conventional fossil fuel energy sources like global greenhouse effect, clean electricity production using renewable sources such as solar energy has become popular [1].

The power generated from the PV module mainly depends on solar irradiance and temperature. In the first approximation for the output power of a module is to be proportional to the irradiance of sunlight under uniform insolation conditions [2].

With the appearance of the structure of PV power generation system and the complication of atmospheric conditions especially partial shadow, the output characteristic of PV arrays is affected obviously [3].

This paper built the model of PV array based on Matlab/Simulink and research on the output characteristics of PV modules under uniform and nonuniform illumination. The simulation results will benefit the optimizing of PV array structure and control.

2. PHOTOVOLTAIC PANEL MODEL

The widely known photovoltaic cell electrical equivalent circuit [4] (Fig. 1), an equivalent model for a more powerful PVG made of an ($N_s \times N_p$) array of PV cells, is

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established [5, 6]:

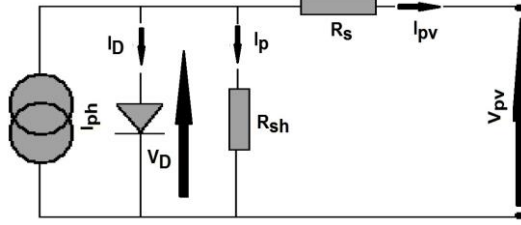


Fig. 1: Simple model of the photovoltaic cells

$$I_{pv} = I_{ph} - I_D - I_p \quad (1)$$

I_D expression being deduced from the semi-conductor diode theory, the above relation may be detailed as,

$$I_{pv} = I_{ph} - I_0 \left(\exp \left(\frac{V_{pv} + R_s \cdot I_{pv}}{nKT/q} \right) - 1 \right) - \frac{V_{pv} + R_s \cdot I_{pv}}{R_{sh}} \quad (2)$$

Where, I_{ph} is the light generated current (A), I_0 the PV cell saturation current (A), q , the electron charge ($q = 1.96 \times 10^{-19}$ C), k , the Boltzmann constant ($k = 1.38 \times 10^{-23}$ J/K), n the cell ideality factor, T the cell temperature. R_{sh} and R_s are pure parasitic resistances characterizing respectively parallel current leakage and series connecting circuit.

In general, for a PVG involving an array of N_s cells connected in series and N_p in parallel, its output voltage current relation may be deduced from the basic cell equation (2) as follows [5, 6]:

$$I_{pv} = N_p \cdot I_{ph} - N_p \cdot I_0 \left(\exp \left(\frac{q \cdot (V_{pv} + N_s/N_p \cdot R_s \cdot I_{pv})}{nKT N_s} \right) - 1 \right) - \frac{V_{pv} + N_s/N_p \cdot R_s \cdot I_{pv}}{N_s/N_p \cdot R_{sh}} \quad (3)$$

From (2), an already temperature dependence of the cell external characteristic is established. Furthermore, all the cell parameters (I_0 , n , R_{sh} and R_s), are equally temperature related. However, semiconductor diode theory, suggests that the most significant temperature effect comes from the reverse saturation current I_0 . Variation of its value $I_0(T)$ with working temperature T , is usually evaluated relatively to its evaluated value $I_0(T_r)$ at a reference temperature T_r [4].

$$\frac{I_0(T)}{I_0(T_r)} = \left(\frac{T}{T_r} \right)^3 \cdot \exp \left(\frac{q \cdot E_g}{n \cdot K} \left(\frac{1}{T_r} - \frac{1}{T} \right) \right) \quad (4)$$

Where, E_g is the cell material band gap, supposed here no temperature dependant, and k is the Boltzmann constant.

The value of saturation current $I_0(T_r)$, may be evaluated through the open circuit voltage $V_{oc}(T_r)$ and the short circuit current $I_{sc}(T_r)$ deduced from (2).

$$I_0(T_r) = \frac{I_{sc}(T_r)}{\left(e^{\frac{qV_{oc}(T_r)}{nkT}} - 1 \right)} \tag{5}$$

The equation of the illumination current brought back to the reference conditions ($G_r = 1000 \text{ W/m}^2$, $T_r = 25 \text{ }^\circ\text{C}$) is given as follows,

$$I_{ph} = \left(I_{cc} \cdot \frac{G}{G_r} + I_t \cdot (T - T_r) \right) \tag{6}$$

I_t , Temperature coefficient of short-circuit current; G_r , The reference illumination; G , The actually illumination.

3. UNIFORM ILLUMINATIONS CONDITIONS

3.1 Photovoltaic panel Simulink model

The adopted modules are a 52 W_c mono crystalline silicon (UDTS50) (Figure 2 and **Table 1**). Starting from the standard given data, typical corresponding values of the ideality factor n and the energy gap E_g , the diode saturation current I_0 has been evaluated from (5), for a standard temperature T_0 ($25 \text{ }^\circ\text{C}$).

The available information at this stage is sufficient to build a first model of the module with realistic values of R_{sh} and R_s) which are kept as fine tuning parameters.

This is to adjust the external characteristics of the model in such a way that they correspond as nearly as possible at those of the adopted module [4].The adopted model in this work is shown in figure 3.



Fig. 2: UDTs photovoltaic panels

Table 1: UDTs panel characteristic

Standard illumination, $G \text{ (W/m}^2\text{)}$	1000
Standard temperature, $T \text{ (}^\circ\text{C)}$	25
Short-circuit current, $I_{cc} \text{ (A)}$	3.43
Open circuit voltage $V_{co} \text{ (V)}$	21.28
Optimal voltage, $V_{opt} \text{ (V)}$	16.65
Maximum power, $P_{max} \text{ (W)}$	52.66
Form factor (%)	72
Output (%)	11
Series resistor, $R_s \text{ (}\Omega\text{)}$	0.4
Cell surface, $S, \text{ (cm}^2\text{)}$	10×10
Number of the cell	36

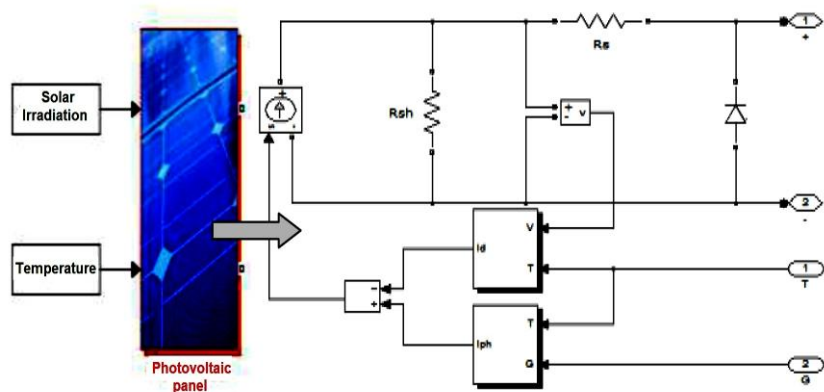
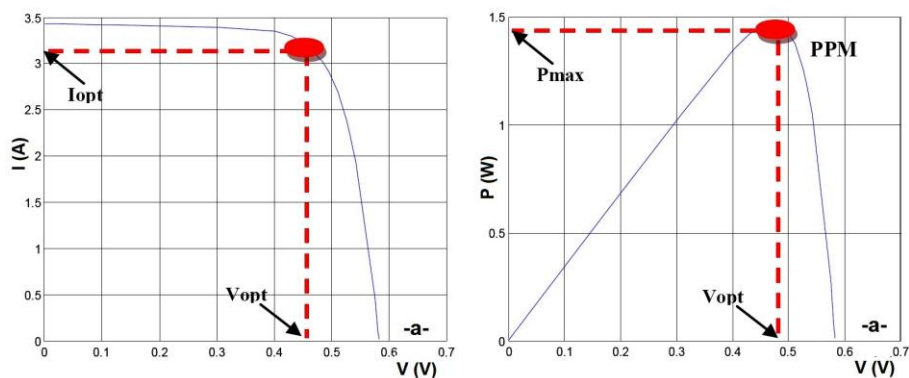


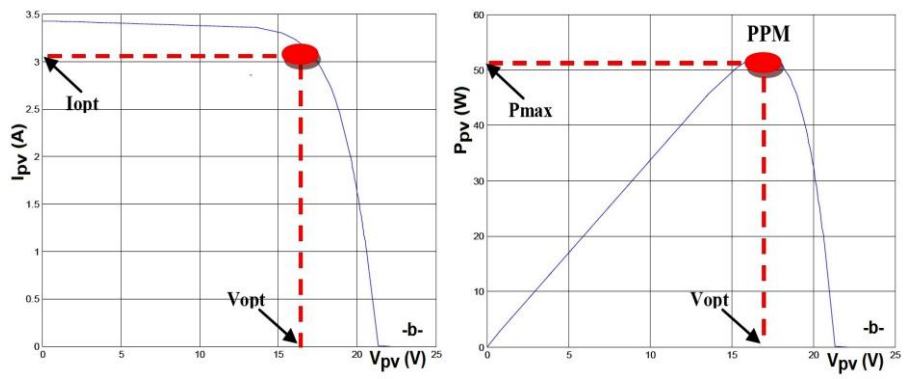
Fig. 3: Structure of the PVG Simulink model.

3.2 Simulation results

The external reference characteristics of the photovoltaic cell and module are established using the identified perturbation inputs (solar illumination, temperature) as parameters in standards conditions are shown in figure 4.



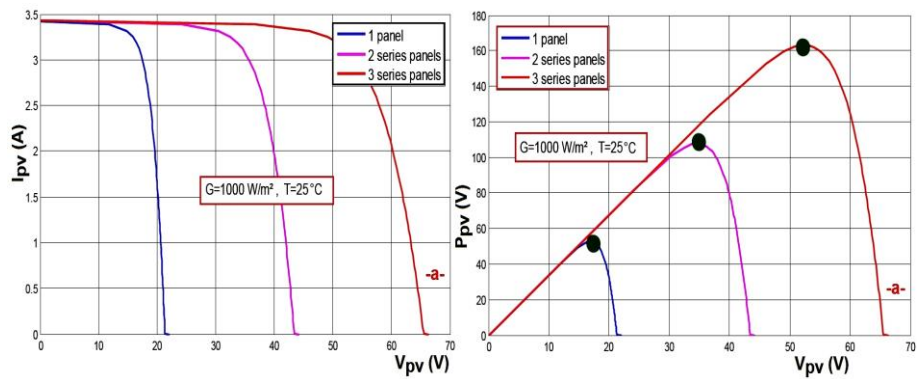
a. Cell external characteristic



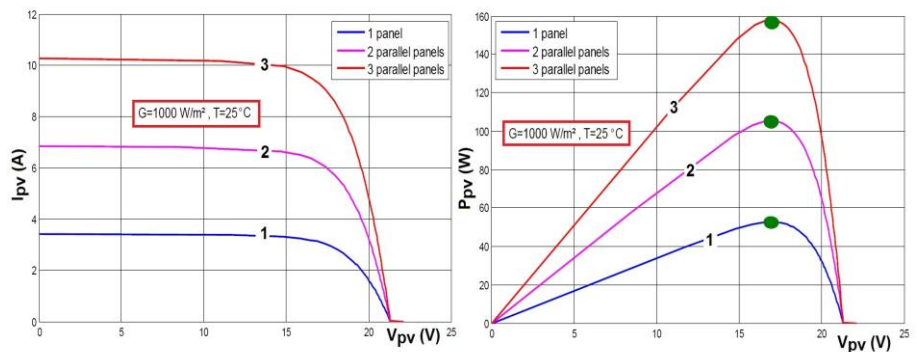
b. Panel external characteristic

Fig. 4: External characteristic of the photovoltaic cell and panel.

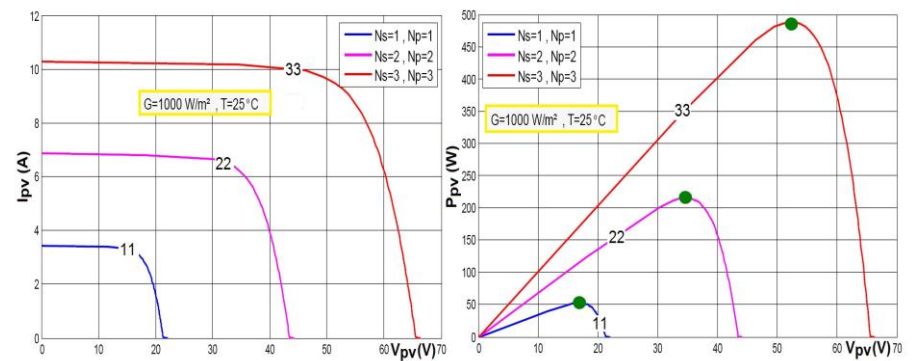
Photovoltaic modules are the basic elements of any photovoltaic system. They can be connected in series to increase the voltage and in parallel to amplify the current, or in series and parallel to increase both. The results obtained in this case are given in the figure 5.



a. Series connection



b. Parallel connection



c. Series and parallel connection

Fig. 5: Photovoltaic panels association

In order to make the PV model completely studied, the dependence of the model on temperature and solar irradiance has to be simulated. The results obtained are given in figure 6 and figure 7.

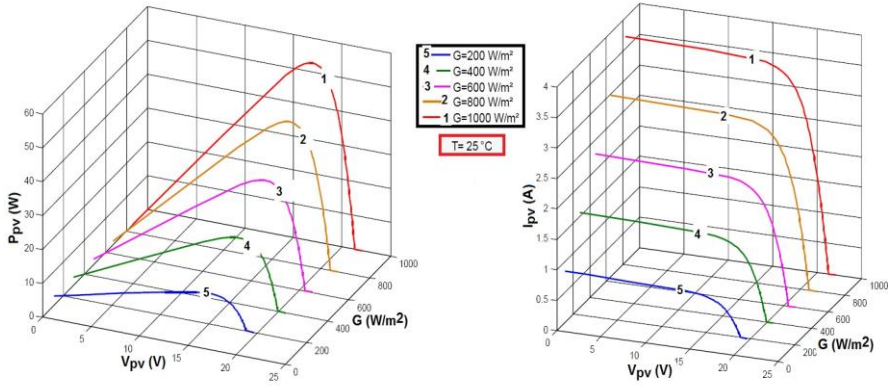


Fig. 6: PVG (current-voltage) and (power-voltage) characteristics for different solar irradiances

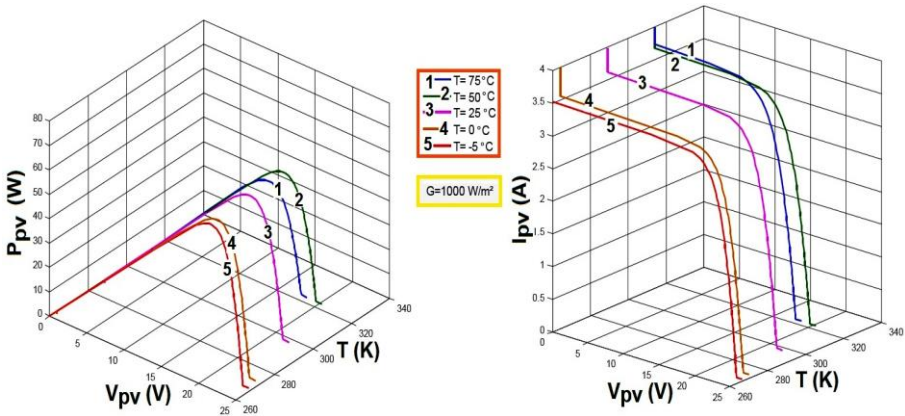


Fig. 7: PVG (current-voltage) and (power-voltage) characteristics for different temperatures

4. NONUNIFORM ILLUMINATIONS CONDITIONS

In many real cases, unfortunately the PV array does not receive a uniform irradiation. Non-uniform irradiation may occur because of the shadow of clouds, the trees, booms, chimneys, nearby ^{houses}, or the shadow of one PV ^{array} on the other, etc. The PV array operates under PSC (partially shaded conditions) when the mentioned conditions have occurred. Hence this creates multiple local maxima points and one global maximum point (the real maximum power point) on the power-voltage (P-V) curve of the PV array [2, 7, 8].

The interconnection of cells having identical characteristics is actually a purely theoretical study, because each cell in a system has its own characteristic. These

differences in characteristics are commonly called Mismatch. We will define two types of Mismatch's here The structural Mismatch and functional mismatch).

The origin of the structural mismatch rises owing to the fact that two identical cells (even technology, even manufacturing process, even manufacturer, even series) subjected to same operating conditions will have different characteristics. This type of mismatch will be not studied in this work.

The functional mismatch due to operating conditions of different photovoltaic cells (shades partial, not hot...). These losses can be very significant [9].

A series PV array contains several PV modules connected in series. Output characteristic of a series PV array depends on the irradiation level of each module. When part of the series PV array is shaded, the shaded modules will not be able to produce as much current as the unshaded modules.

On the other hand, the same amount of current must flow through all parts that are connected in series. Thus, if one of the modules is shaded, the maximum output current of all other modules is limited to the short circuit current of the minimum irradiated module.

For the output current less than the shaded cell, the extra amount of current in the unshaded cells flows through cells diode and forward biases them. For current more than shaded cell, the shaded cells reverse biased and act as series loads and dissipate power. The dissipated power causes hot spots and damages the whole module. In order to prevent this effect, the Bypass diodes are widely used in solar power to bypass shaded cells [1].

In the next section we presented the effect of the partial shading condition in different combination of a photovoltaic system, the simulation results obtained explain clearly the functionality of the module under PSC, in order to make the necessary precaution before dimensioned and installed any photovoltaic systems.

4.1 Two series connected photovoltaic panels

The first test is to connect two photovoltaic panels (UDTS50) in series with two Bypass diode in parallel, and non- return diode, the first photovoltaic panel is making in normal illumination condition; in contrary the second is making in a various partial shading condition like shown in figure 8.

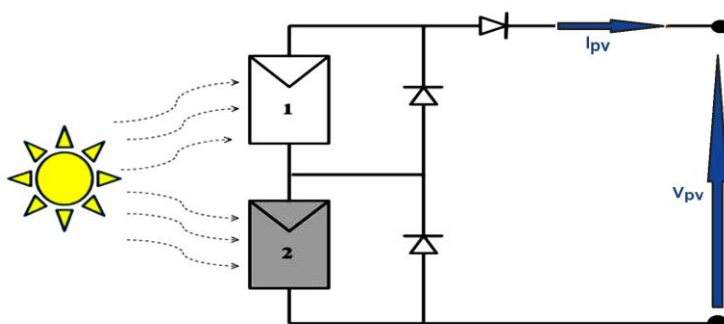


Fig. 8: Two series photovoltaic panels connected

The external characteristics obtained in standard conditions with constant shading rate of 50 % are given in figure 9.

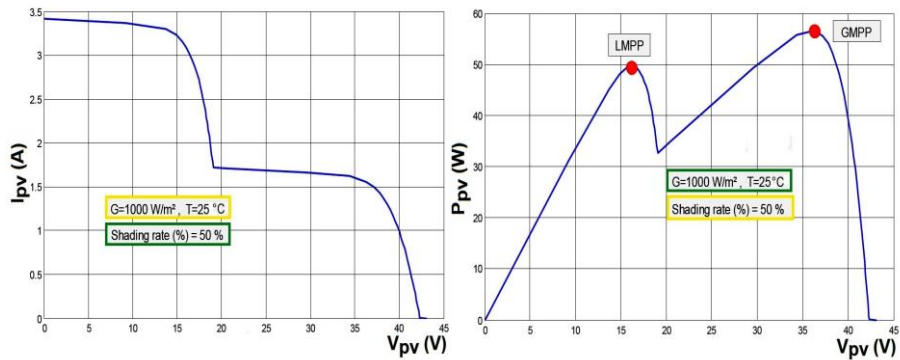


Fig. 9: External characteristic of two series photovoltaic panels

The main results obtained for a standard condition ($G=1000\text{ W/m}^2$, $T=25\text{ }^\circ\text{C}$) with various shading rate (%), and constant shading rate (%) with variable solar illuminations are shown in figure 10 and figure 11.

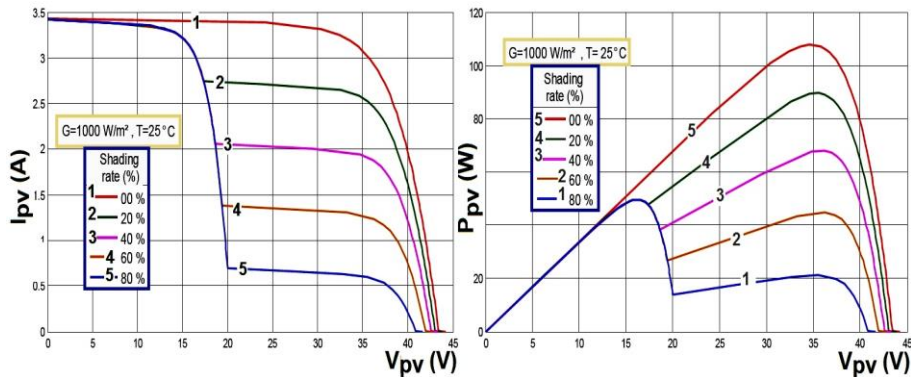


Fig. 10: External characteristic of two series photovoltaic panels for different values of shading rate (%) and standard conditions ($G=1000\text{ W/m}^2$, $T=25\text{ }^\circ\text{C}$).

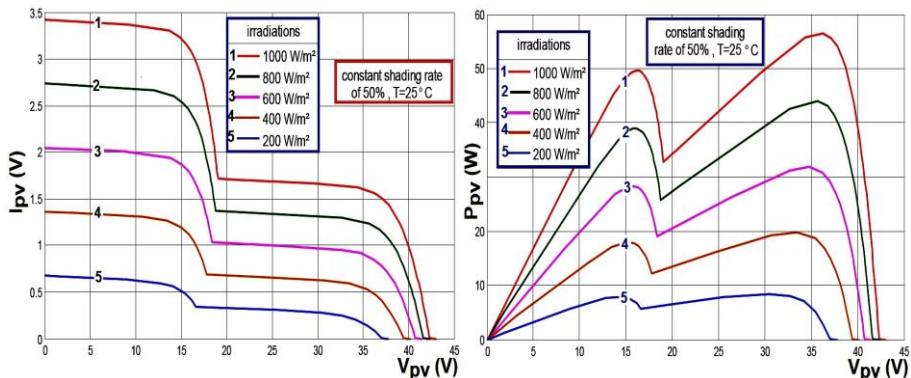


Fig. 11: External characteristic of two series photovoltaic panels for different values of illumination and constant shading rate of 50 %, $T=25\text{ }^\circ\text{C}$

4.2 Three series connected photovoltaic panels

For this test we connect three photovoltaic panels (UDTS50) in series with three By-pass diode in parallel, and non- return diode, such the previous assembly, the first photovoltaic panel is making in normal illumination condition; but the second and the third are making in a various partial shading condition like shown in figure 12.

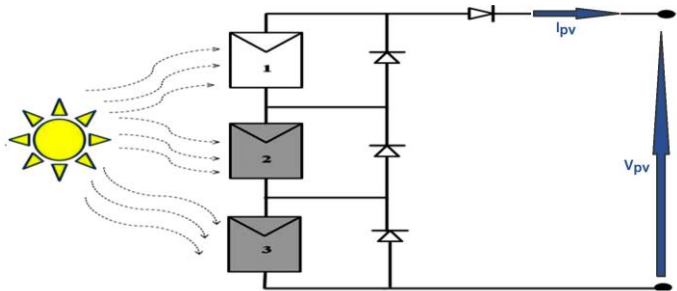


Fig. 12: Three series photovoltaic panels connected

The external characteristics obtained in standard conditions with constant shading rate of (00%, 60%, 40%) are given in figure 13.

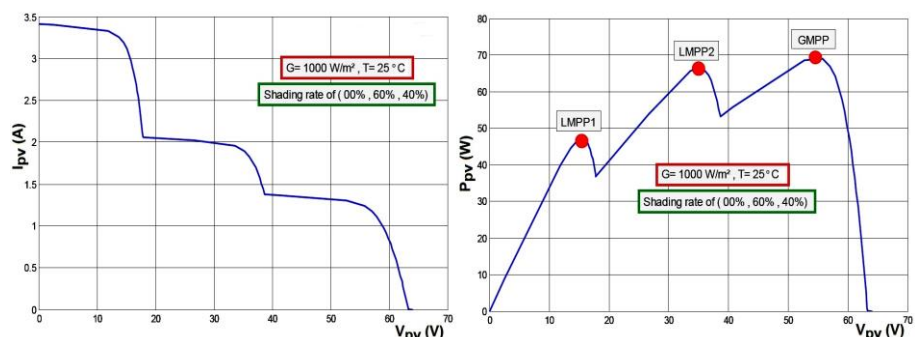


Fig. 13: External characteristic of three series photovoltaic panels

The main results obtained for a standard condition ($G=1000 \text{ W/m}^2$, $T=25^\circ\text{C}$) with various shading rate (%) in the second and the third photovoltaic panels, and contrarily are shown in figure 14 and figure 15.

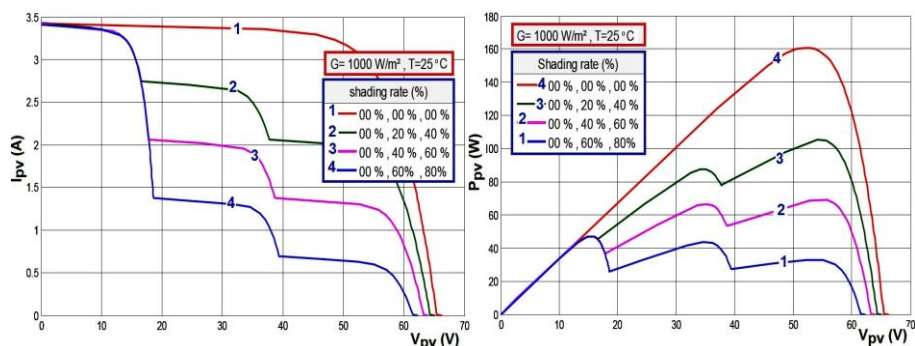


Fig. 14: External characteristic of two series photovoltaic panels for different values of shading rate (%) and standard conditions ($G=1000 \text{ W/m}^2$, $T=25^\circ\text{C}$)

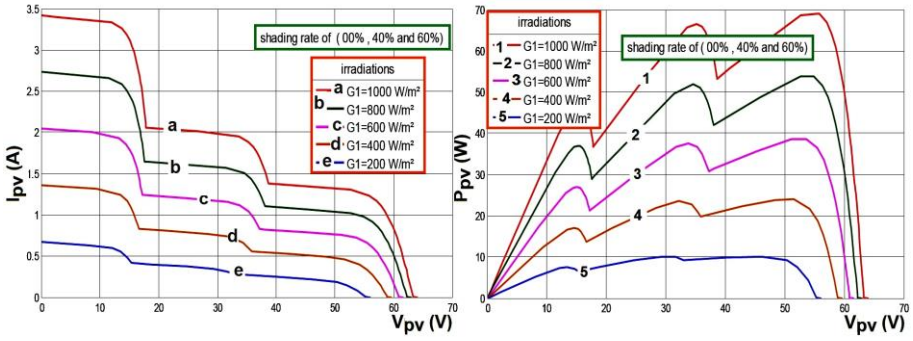


Fig. 15: External characteristic of two series photovoltaic panels for different values of illumination and constant shading rate of 50 %, $T=25^{\circ}\text{C}$.

4.3 Photovoltaic station

To study the effect of the non uniform illumination condition on a photovoltaic field, we assembled 20 panels of the type UDT550 in series and in parallel ($N_s=10$, $N_p=2$), then we applies the shade to the 5 panels in series which are in the same branch as shows figure 16.

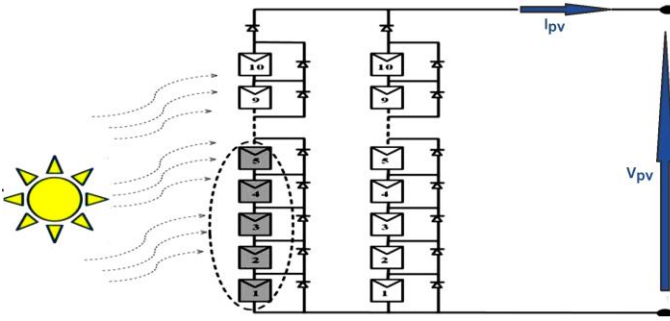


Fig. 16: Photovoltaic filed

The main results obtained for a standard condition ($G=1000\text{ W/m}^2$, $T=25^{\circ}\text{C}$) with various shading rate (%), and contrarily are shown in figure 17 and figure 18.

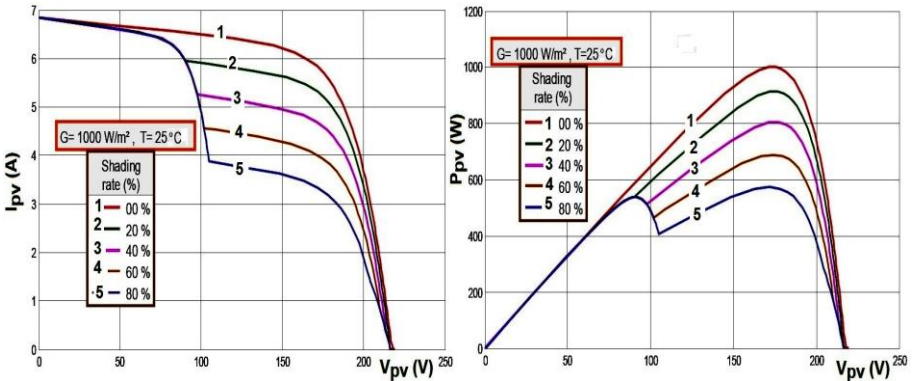


Fig. 17: External characteristic of photovoltaic filed for different values of shading rate (%) and standard conditions ($G=1000\text{ W/m}^2$, $T=25^{\circ}\text{C}$)

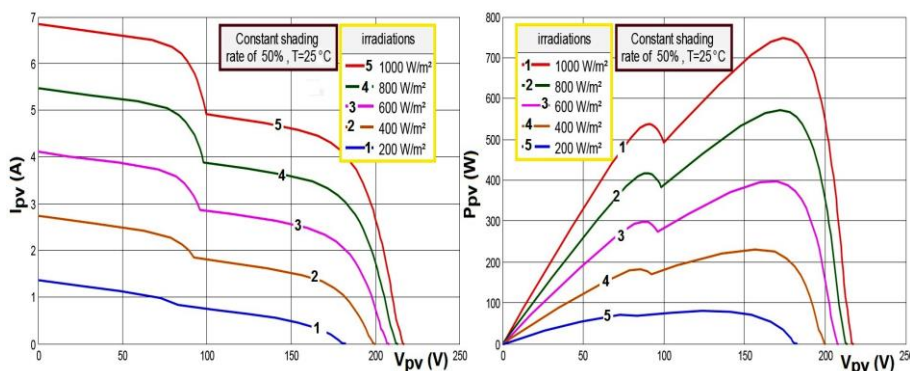


Fig. 18: External characteristic of photovoltaic filed for different values of illumination and constant shading rate of 50 %, $T=25^{\circ}\text{C}$

Clearly, it is available to get the following rules: under the conditions of partial shadows, P-V characteristic curves have multiple peak points.

The external characteristic of two series connection panels under non uniform illumination condition has deformed compared with the typical curve, in this case there are two maximum power points (the local MPP and the global MPP). So for optimizing the photovoltaic power produced it is necessary to adopt a special control for ensuring the global point.

For the connection of three series panels, which two panels are affected by partial shading, there are three maximum power points (the first local maximum power point, the second local maximum power point and the third is a global point), the PV system in this case is necessary to employ in the global point for any conditions.

The effect of the nonuniform illumination condition for a PV system becomes very significant in the case of a means and high photovoltaic field power. For that the preceding study covers also the case of an assembly of 20 panels, in which 15 subjected to the conditions standards and 5 are shaded.

The simulation results watches which the external characteristic of the installation is modified, we also obtained two point of maximum power (LMMP, and GMMP), thus the total maximum power in normal condition is higher than the two power founded in shading condition for various illuminations. As a result the shade situation makes it possible to decrease the maximum power produced by photovoltaic installation what requires a detailed attention such as:

- 1- Relatively avoid the appearance of this event, by an adequate choice of the places where install the PV system, which does not produce a nonuniform illumination effect in the production phase.

- 2- Decrease this effect to the maximum by the adaptation of special control which always seeks the global maximum power point.

5. CONCLUSION

This research paper presents a detailed analysis of the impact of irradiance variations caused by partial shading on PV system. Primarily, system has been modeled by circuit simulation. Then simulations have been performed using Matlab/Simulink under varying shading levels. The following conclusions can be drawn:

- Shading results a substantial degradation in the output power causing global and local maximum peaks in the ($P_{pv} - V_{pv}$) characteristic curve.
- Power generation capability of the unshaded series connected cells is limited due to the heavily shaded cell which can potentially cause failure of the entire array. Thus, appropriately rated bypass diodes are commonly employed to minimize hot-spot heating and to preserve solar array power.
- Array configurations and shading patterns decide the magnitude of the global maximum power. Therefore, conventional MPPT techniques cannot precisely locate maximum power point.

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