# Characterization and modelling of the optimal performances of the marketed photovoltaic panels.

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**Abstract:** In this paper, we have presented the results of the characterization and the fine modelling of the electric characteristics current-voltage and power-voltage of the photovoltaic (PV) panels. We have analyzed the electric parameters of PV cells and the optimal electric quantities of PV panels (voltage and power) according to the meteorological conditions (Temperature, solar irradiation). The obtained results show that the diode parameters of the PV cells depend on solar irradiation: the saturation current increases with solar irradiation. This induces a decrease of the optimal voltage with solar irradiation: when the solar irradiation varies from 300W/m$^2$ to 900W/m$^2$, the optimal voltage decreases by 11 %. These results are confirmed by the measures of the manual regulation of the maximum power point (MPP) during one day. Also, we have analysed qualitatively the performances of the associated panels in parallels and in series.

**Keywords**: Cells and Photovoltaic panels, electric characterization, fine modelling of the electric characteristics, Pspice simulator, maximum power point (PPM).

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## I. Introduction

In the field of photovoltaic energies the fine modelling of the electric operation of the photovoltaic (PV) panels is essential [1-4]. This will make it possible on one hand to qualify the technological process of realization of PV cells, and on the other hand to analyze optimal operation as well as the ageing of PV panels. This last study is necessary in order to conceive and to realize adequate PV systems allowing the continuation of the Maximum Power Point (PPM) [4-11].

In the literature few results relate to the characterization and fine modelling of the optimal electric quantities (voltage, current and power) of PV panels as a function of the meteorological conditions (solar radiation, temperature,…). Generally, one finds a disagreement between the authors who use different cells and photovoltaic panels. D. Shmilovitz [12] considered, for a given temperature that the optimal voltage increases with solar radiation. In another work, B. J Huang et al [13], showed on modules PV of the type MSX60, for a given temperature, a behaviour of the optimal voltage which depends on solar radiation: when solar radiation is lower (superior) than 150 W/m$^2$ the optimal voltage increases (decreases) with solar radiation.

In order to clear up the behaviour of the optimal electric quantities of modules PV as a function of the solar radiation, we propose in this work to characterize modules PV of the type SP75 (in silicon single-crystal) and to model in a fine way in the Ppsice simulator the behaviour of the optimal electric quantities as a function of the solar radiation. More particularly we study the electric model, the Maximum Power Point (MPP) and the ageing of PV panels.

## II. Results and discussions

### II.1. Symbolization of PV cell

We have symbolized in Pspice the electric diagram of the PV generator formed of 36 cells in series (Figure 1). As shown in the figure 1, a PV cell is formed by the generator of current ICC (short-circuit current), the diode (D), the shunt resistance ($R_{Sh}$), and series resistance ($R_S$). The current of the diode depends on the technological parameters (dimensions of the PN junction, doping, mobility of the carriers…) and of the (T) temperature according to the expression:

$$I_D = I_S(T) \bullet \exp(-\frac{q \bullet V_D}{K_B \bullet T}) \qquad (1)$$

Where:

$V_D$: voltage at diode terminals,

$I_S$ (T) : saturation current,

q : charge of the free electron,

$K_B$ : Boltzmann constant.

From the comparison of the results of simulations to those provided by the manufacturer, we have deduced the various parameters from the diode and PV cell ($R_S$ and $R_{Sh}$), and dependence of the short-circuit current ($I_{CC}$) with solar radiation (Le (W/m$^2$)):

$$I_{CC} = 0.00481 * Le - 0.0125 \qquad (2)$$

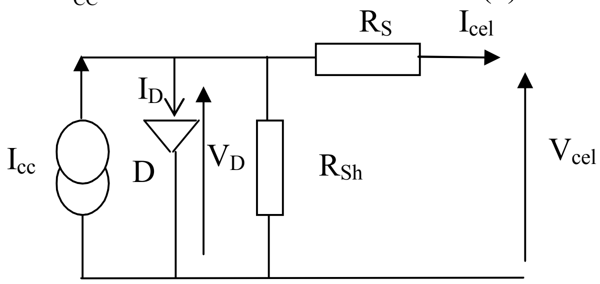



**Figure 1:** Electric diagram of a Photovoltaic cell.

## II.2. Electric characterizations and modeling of PV panels

### *II.2.1. Experimental procedures*

The PV panels (or modules) which were the subject of our experimental study are represented on (figure2). A panel consists of 36 cells single-crystal, and can provide under the standard conditions of test (solar radiation of 1000 W/m$^2$, temperature of 25°C, spectrum AM1.5) a power of 75 W and a current of 4.41 under voltage of 17.2 V. These panels and conceived PV systems are characterized starting from the measuring equipments set up at the laboratory (Figure 3).

**Figure 2**: Photovoltaic panels SP75 installed with the Faculty of Science of Oujda.

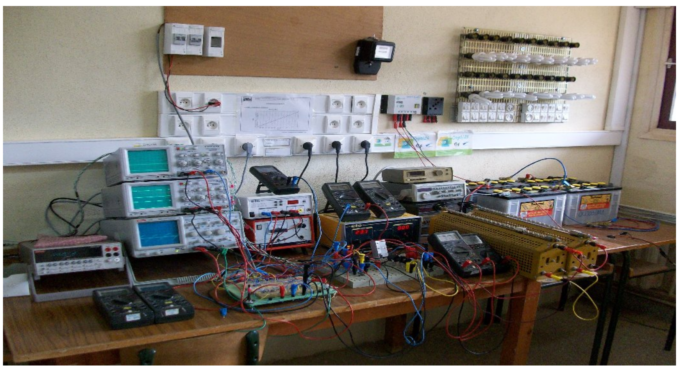


**Figure 3**: Measuring equipments set up to characterize the photovoltaic panels and systems.

### *II.2.2. Characterizations and electric modeling of the modules*

We have characterized the module during one day when the intensity of solar radiation varies from 300 W/m$^2$ to 900 W/m$^2$ and the temperature is around of 22°C - 25°C. On figure 4 we have represented the typical characteristics voltages-current and power-voltage obtained. On the same figure we have represented the characteristics simulated in Pspice by fixing the parameters of the diode (current of saturations…) who allows having a good agreement between the experiment and simulation. From the characteristics of figure 4 we have represented on figures 5 and 6, the variations of the saturations ($I_S$) current of the diode (D) and the optimal ($V_{opt}$) voltage of the panel as a function of solar radiation. It appears that for this temperature 20-25°C:

- The current (log (Is)) increase linearly with solar radiation.
- The optimal (Vopt) voltage decreases linearly with solar radiation. When solar radiation varies from 300 to 900 W/m$^2$, the optimal voltage varies from 14.8 V to 13.2 V (a decreasing of 11%). The comparison between these results with those already published in the literature, show on one hand that the values of the parameters of the cell are different to those fixed at the time of the modelling of the characteristics voltage provided by the manufacturer (Is=$10^{-10}$A and Vopt =17.2 V), and on the other hand that the strong dependence of these parameters (Is, Vopt…) with solar radiation. The most of works of the literature one supposes that the saturation current of the diode and the Vopt voltage depend very little on solar radiation. By taking account of these assumptions, we have shown in Pspice that when the solar radiation varies from 1.000 W/m$^2$ to 500 W/m$^2$ the Vopt voltage undergoes a light decreasing (< to 2%). When the solar radiation is around of 300 W/m$^2$, this decreasing can reach 5%. In our work and starting from the modelling of the characteristics voltage we have deduced a different behavior: when the solar radiation decreases the Vopt voltage increases in a considerable way. Consequently, when the regulation of the power provided by PV panels starting from MPPT command, it necessary to take into account of this strong dependence with solar radiation. In order to validate the whole of these results obtained in this paragraph, We have analyzed in the following paragraph, the manual regulation of the power provided by the panel as well as the modelling of the electric performances obtained (Vopt, Iopt, Popt,…) according to solar radiation.

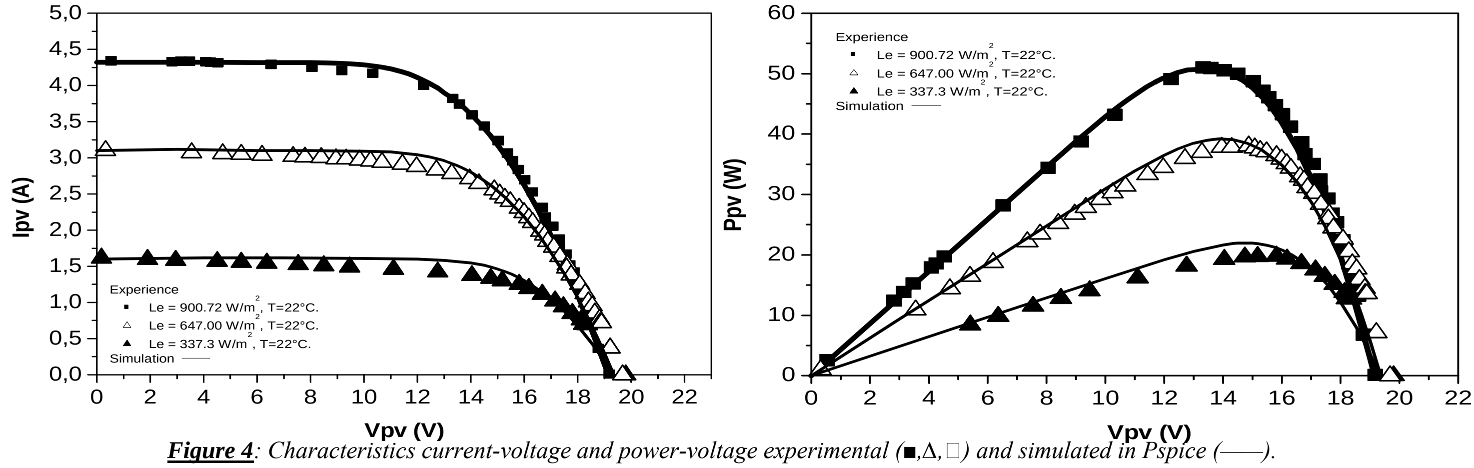



***Figure 4***: *Characteristics current-voltage and power-voltage experimental (■,Δ,□) and simulated in Pspice (——).*

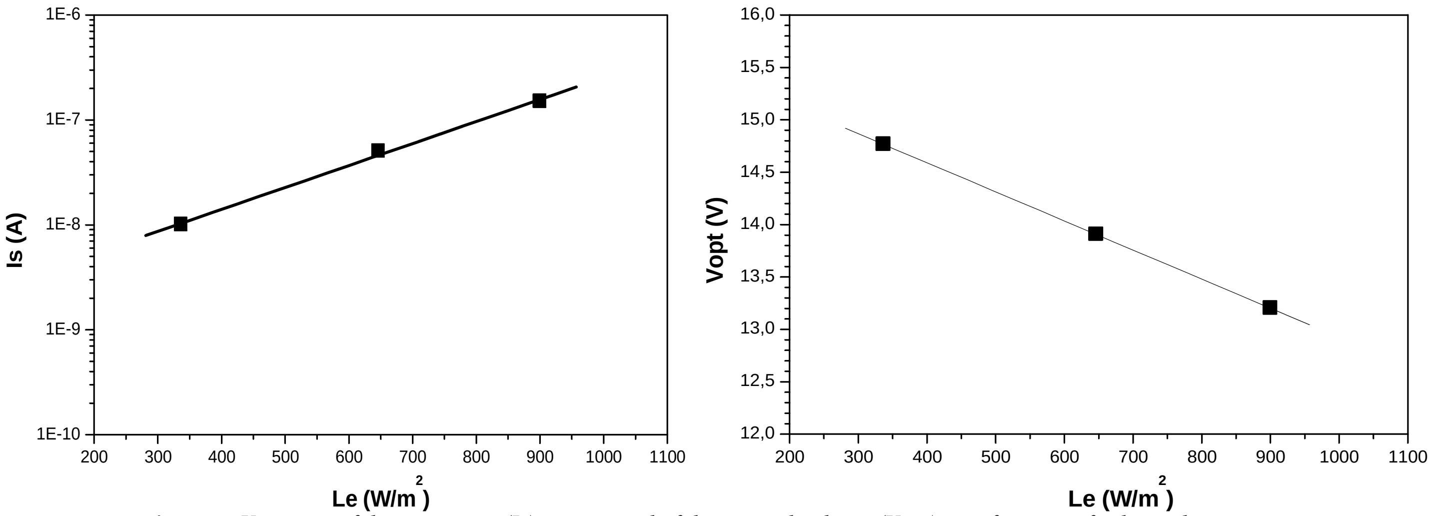



***Figure 5***: *Variation of the saturation (Is) current and of the optimal voltage (Vopt) as a function of solar radiation.*

### *II.2.3. Modelling of the regulation of the power provided by PV panels*

In order to validate the results obtained in the preceding paragraph, we manually controlled the power provided by PV panel starting from the system of figure 6. This system is formed by:

- a PV panel,
- A Boost converter dimensioned for that works at a normal rate continuous at a frequency (f=1/T) of 10 Hz [2, 4, 5, 9-11],
- Resistive load of 50 Ω,
- Command formed by an oscillator which generates saw tooth of signal of frequency 10 kHz, a comparator and generator of a continuous and variable voltage. The comparison between saw tooth of signal and the continuous voltage generates a square signal of variable duty cycle (α).

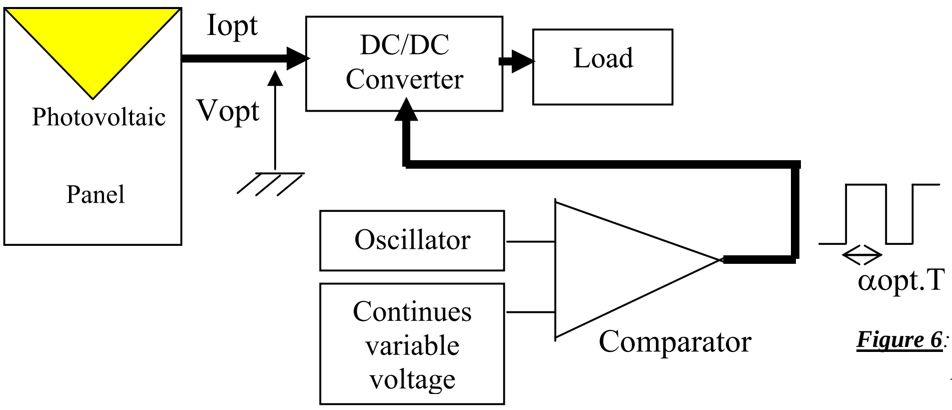



***Figure 6***: *Manual regulation of the power provided by PV panel.*

By varying the duty cycle (α), we have analyzed the regulation of the optimum power provided by the panel during one day when the temperature is of 20°C-25°C and solar radiation varying from 250 W/m$^2$ to 900 W/m$^2$. The optimal electric characteristics obtained (Vopt, Iopt and Popt) are represented on figure 7. On the same characteristics, we have deferred the characteristics simulated in Pspice as a function of solar radiation and of the temperature (paragraph II.2.2).

It should be noted that with the courses of our manual regulation, the equipment of measurement we have to control the maximum power of the PV panel around of Vopt voltage which varies in a range of voltage of 0.8 V. The curves of figure 7, allow for effect of this range on the Iopt current and the Popt power.

The whole of the results obtained in this paragraph shows that when the temperature varies from 20 to 25 °C the experimental results are very close to those simulated. We notice clearly, the dependence of the Vopt voltage with solar radiation: when solar radiation increases, the Vopt voltage decreases. These results validate those found in the preceding paragraph. Consequently, when the regulation of the operation of PV panels by MPPT command it is necessary to take account of the variation of the optimal voltage Vopt with solar radiation.

To make sure of the good performance of DC/DC converter, we have represented on figure 8, the values of the optimal duty cycle ($\alpha_{opt}$) of the signal which control the switch of the converter as well as the efficiency of the converter as a function of solar radiation. On the same curves we represented the values obtained in the Pspice simulator. It appears a good agreement between the experiment and simulation; this shows the good performance of the system of (figure 6).

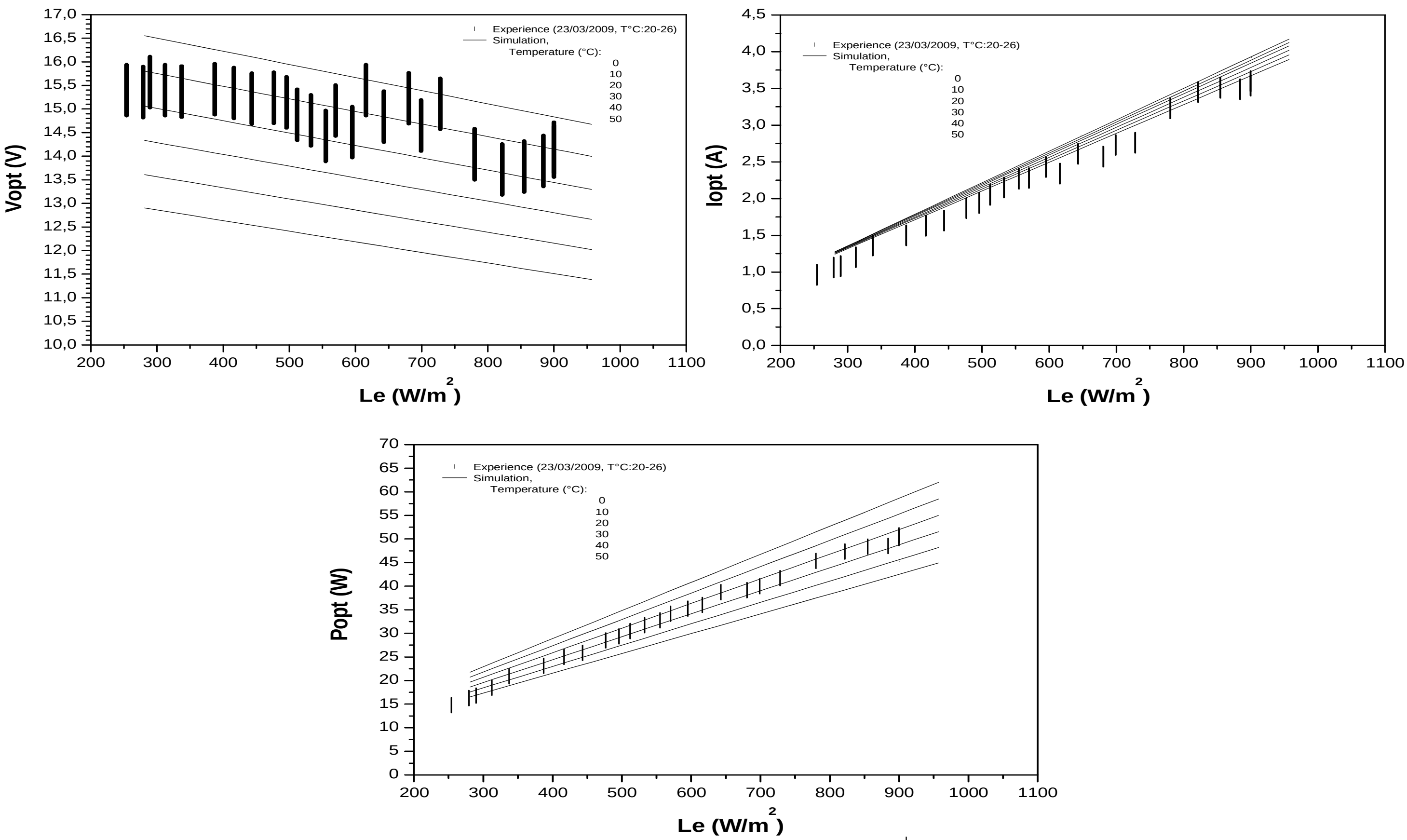



***Figure 7***: *Optimal electric quantities (Vopt, Iopt et Popt)* experimental ( | ) *and simulated in Pspice (——).*

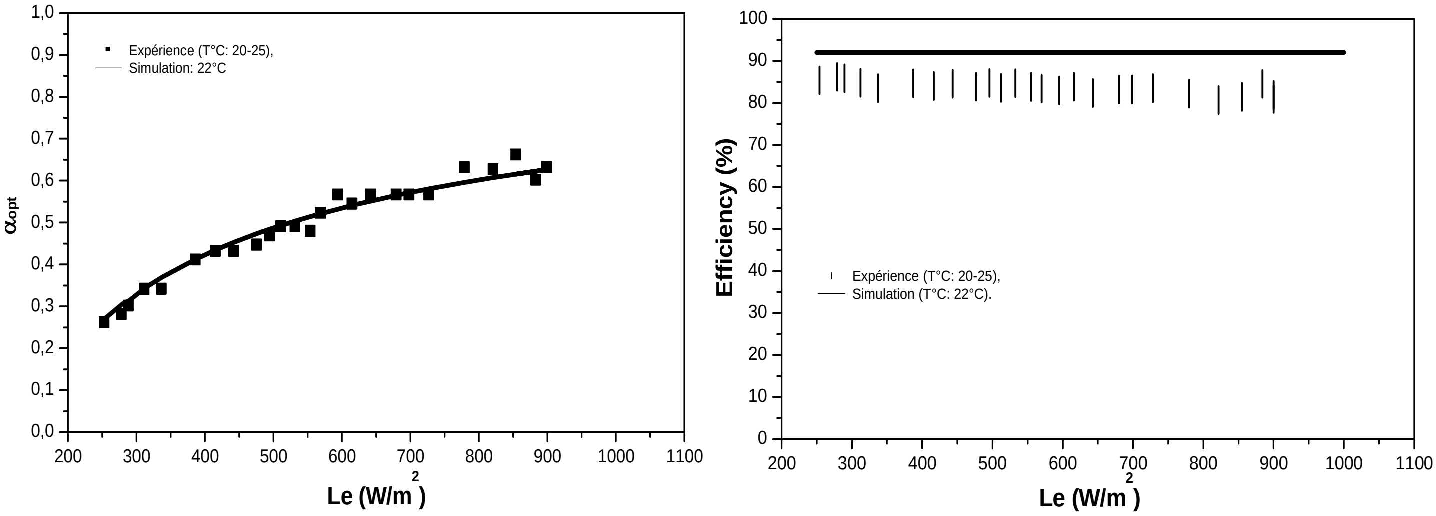



***Figure 8**: Duty cycle and optimal efficiency experimental (■, |) and simulated in Pspice (—).*

### *II.2.4. analyzes the operation of the panels in parallel and in series*

In a PV installation the panels are associated in parallel and in series. In such an installation in parallel or in series, it is essential to know the optimal behavior of a panel. In our case, we have analyzed the characteristics power-voltage of two or three panels associated either in parallel or in series. The results obtained are represented on figure 9. It appears that the optimum power is clearly important when the association of the panels in series: in the case of the association of two panels in series, the improvement can reach 8%. However, the association of the panels in parallel induced the losses of the performances of the panels: in the case of two panels in parallel the losses of the power is around of 3% for a solar radiation of 950 $W/m^2$. In the case of the association in parallels and in series, the losses and improvements are important for low solar radiation (300 $W/m^2$).

In order to deduce the behaviour of one panel when the panels are associated in parallel or in series, we have deduced from the characteristics of figure 9 the characteristics power-voltage of one panel (Figure 10). It appears that short-circuit current ($I_{CC}$) of a panel is not affected by the association of the panels and the optimal voltage Vopt of one panel follows the variations analyzed in II.2.3.

Since the short-circuit current is not affected by the association of the panels, we have attributed the various behaviors obtained to the leakage current of the PV cells diode: association in series (parallels) of the PV panels decreases (favoured) the leakage current of the diode,

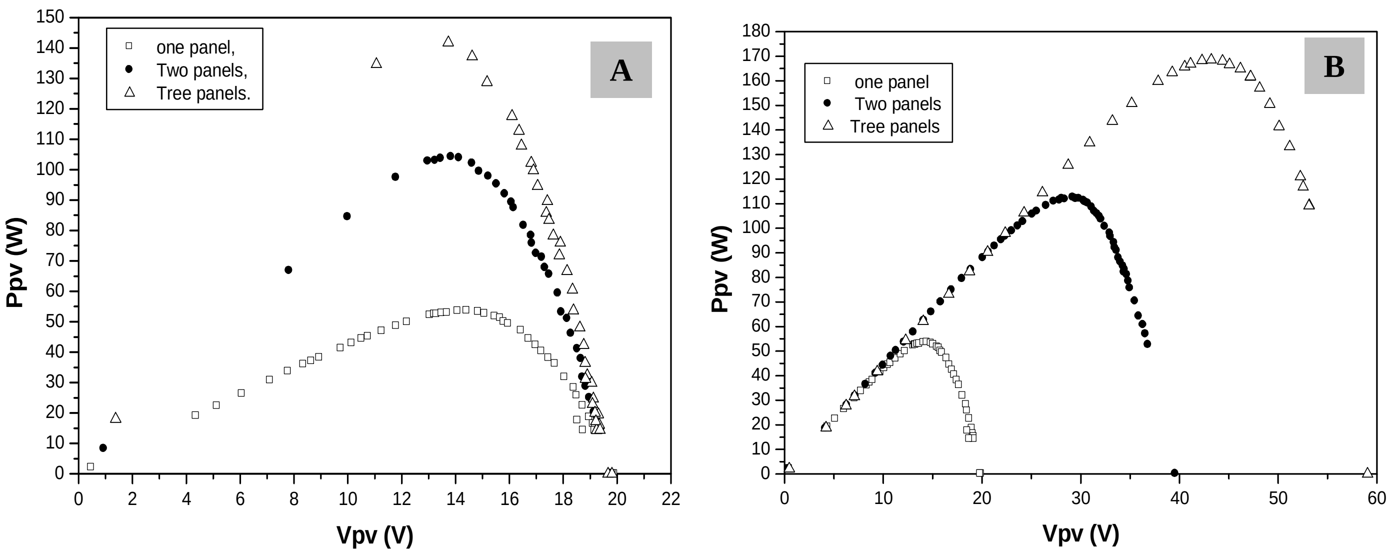
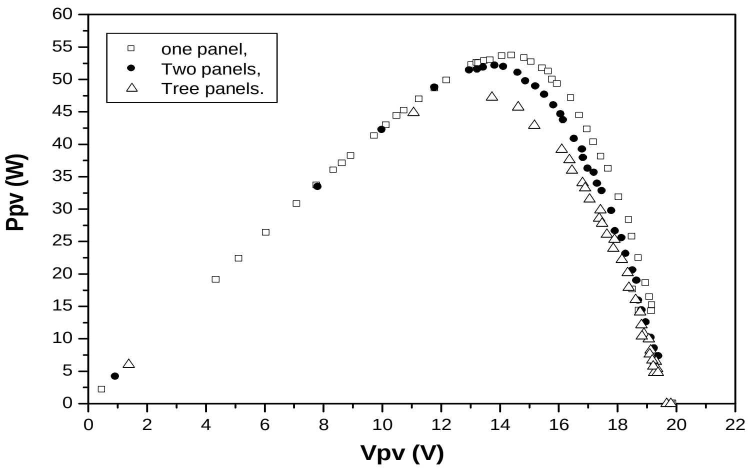



**Figure 9**: Characteristics experimental current-voltages and power-voltage of a panel, two and three panels assembled in parallel (A) and in series (B). T: 22-25°C. Le= 917 $W/m^2$.



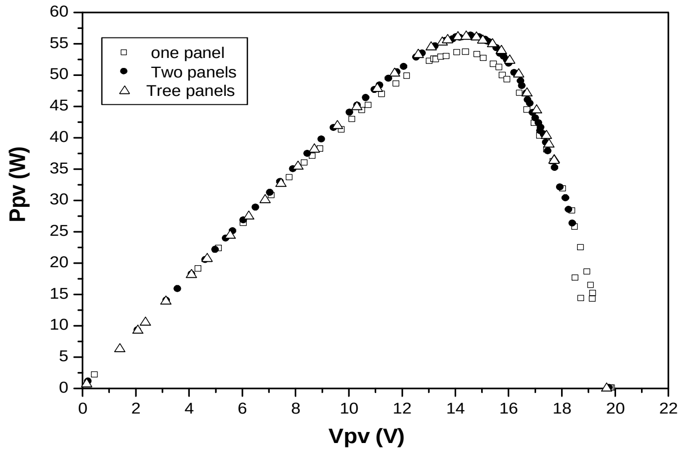




**Figure 10**: Characteristics experimental current-voltages and power-voltage of a panel, deduced from the characteristics of figure 9.

# III. Conclusion

In this work we have analyzed in Pspice and characterized the electric operation of the photovoltaic (PV) panel. The results obtained show that the symbolization of PV panel in Pspice simulator makes it possible to determine the optimal electric operation of PV panel as a function of the meteorological conditions (solar radiation, temperature…). The model of the panels depends on the solar radiation. When the solar radiation varies, from 300 W/m$^2$ to 1000 W/m$^2$, the saturation current of the diode of PV cell increases of one decade. By taking into account of these variations, the optimal voltage Vopt of PV panels varies from 14.8 V to 13 V. These results show well the decreasing of the optimal voltage with the solar radiation.

Also, we have analysed qualitatively the performances of the associated panels in parallels and in series. We have deduced that the association in parallels (series) induced the losses (improvements) of the performances of the PV panels. These losses and increase are important for low solar radiation (300 W/m$^2$). We have attributed qualitatively the losses and the improvements of the electric power of the PV panels to the leakages current of the PV cells diodes: the increase (decrease) of the leakage favours the losses (improvements) of electric performances.

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