ESTIMATE OF PHOTOVOLTAIC ENERGY PRODUCTION DURING THE SUNNIEST MONTH IN MAHAJANGA

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ABSTRACT

This work is devoted to estimating the maximum power produced by a directly coupled photovoltaic system and a MPPT controller-controlled photovoltaic system during the sunniest month in Mahajanga. To do this, the study first involves predicting the solar irradiation received on the inclined plane of the photovoltaic module and developing mathematical models for each component of these photovoltaic systems. The results of the Matlab/Simulink simulation clearly show the superiority of the performance obtained by the MPPT-controlled system over that of the directly coupled system regardless of the influence of the site's meteorological parameters.

Keyword : - *Photovoltaic module, MPPT, inclined solar radiation, converter, duty cycle.*

1. INTRODUCTION

The directly coupled system is the most common type of photovoltaic system because it is less expensive and its installation is very simple. It consists of a photovoltaic module, a non-return diode to avoid a return current and a DC-DC charge as shown in Figure 1 below. The MPPT-controlled System consists of a photovoltaic module, a static converter that is controlled by an MPPT control and a DC-DC load. The nature of the static converter depends on the nature of the load. As the load is continuous, the static converter, chopper type Boost was chosen in order to have high voltages. The layout design is shown in Figure 2. The same BP 380 photovoltaic module is used for both systems, in order to observe whether or not there are differences in the value of the power produced.

The objective of this work is to model and simulate on the Matlab software the operation of two types of photovoltaic systems: a photovoltaic system directly connected with a load and a photovoltaic system controlled by MPPT composed of a Photovoltaic module, a DC-DC converter with an MPPT controller and a resistive load. The LIU and JORDAN method is adopted for the estimation of the solar energy received from the photovoltaic module plan. To maintain a permanent supply of a load for climatic variations (irradiation and temperature), two optimization algorithms for maximum power point tracking (MPPT) are adopted: Disruption-Observation method and artificial neural networks.

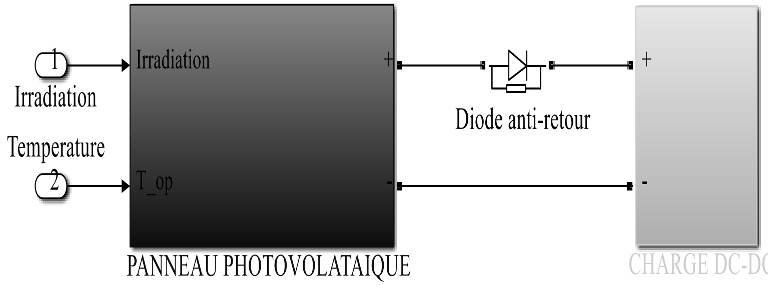

Figure1: Schematic configuration of a directly coupled system.

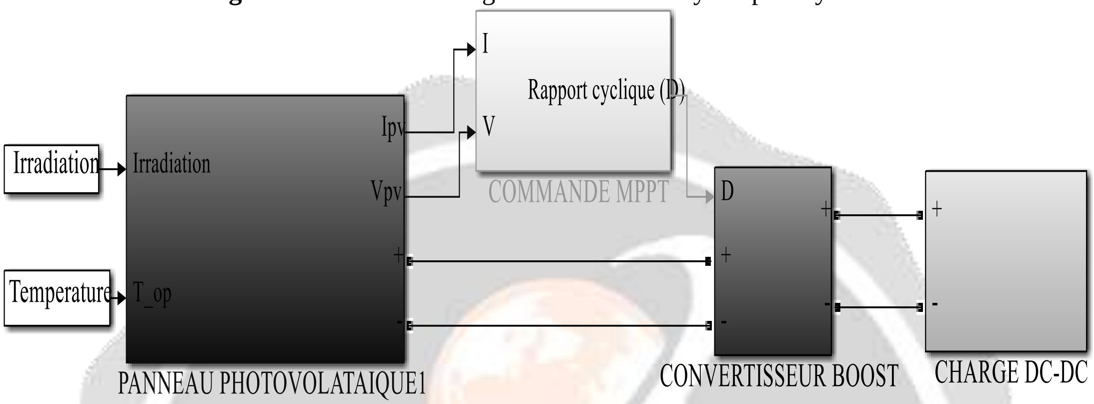

Figure 2 : Schematic configuration of the system controlled by MPPT

2. METHODOLOGIES

2.1 Modelling of global, diffuse and direct irradiations for different inclinations and orientations

The generalized Liu & Jordan relationship gives the global irradiation for different inclinations and orientations and this for a totally clear sky in the following form [1,2]:

$$G = H_d R_b + H_D\left(\frac{1+\cos\beta}{2}\right) + \rho\left(H_d + H_D\right)\left(\frac{1-\cos\beta}{2}\right) \qquad (1)$$

Where, direct irradiation on an inclined plane is expressed by the relationship :

$$G_d = H_d R_b \qquad (2)$$

The inclination factor Rb of the direct radiation is:

$$R_b = \frac{\cos(\phi-\beta).\cos\delta.\cos\omega + \sin(\phi-\beta).\sin\delta}{\cos\phi.\cos\delta.\cos\omega + \sin\phi.\sin\delta} \qquad (3)$$

The following expression represents diffuse irradiation on an inclined plane:

$$G_d = H_d \times \left(\frac{1+\cos\beta}{2}\right) \qquad (4)$$

On the other hand, the irradiation reflected on the inclined plane can be expressed by the following relationship:

$$G_{ref} = \rho \times \left(H_d + H_D\right) \times \left(\frac{1-\cos\beta}{2}\right) \qquad (5)$$

2.2 Modelling the photovoltaic generator

The term GPV refers to the PV module or panel. A photovoltaic module is the association of PV cells in parallel and/or in series consisting of NS number of cells connected in series and NP number of cells connected in parallel. For the GPV model, the two-diode 7P model of a PV cell is adopted since it is relatively close to the actual model[3,4,5]. This model is represented by Figure 3 below.

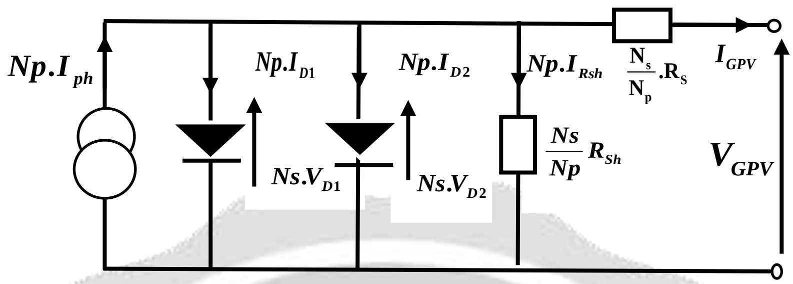

Figure 3 : Diagram of the equivalent circuit of a GPV

Using the equivalent GPV scheme, the necessary equation giving the characteristics of the GPV is described as follows:

$$I_{GPV} = N_p I_{Ph} - N_p I_{o1}(T_m)\times\left[\exp\left(\frac{q(V_{GPV}+I_{GPV}R_{Gs})}{n_1 N_s K T_m}\right)-1\right] \qquad (6)$$

$$-N_p I_{o2}(T_m)\times\left[\exp\left(\frac{q(V_{GPV}+I_{GPV}R_{Gs})}{n_2 N_s K T_m}\right)-1\right]-\frac{V_{GPV}+I_{GPV}R_{Gs}}{R_{Gp}}$$

Schokley's equation gives us the expressions of the current flowing through the diodes :

$$I_{d1} = I_{o1}(T_c)\times\left[\exp\left(\frac{V_{d1}}{n_1 V_t}\right)-1\right] ;\ I_{d2} = I_{o2}(T_c)\times\left[\exp\left(\frac{V_{d2}}{n_2 V_t}\right)-1\right] \qquad (7)$$

With

$$I_{PH} = \left[I_{cc} + k_i\left(T_c - T_{ref}\right)\right]\times\frac{G}{G_{re}f} ;\ T_m = T_a + G\times\left(\frac{NOCT-20}{800}\right) \qquad (8)$$

:

$$I_{01}(T_m) = I_{o1}(T_{ref})\times\left(\frac{T_c}{T_{ref}}\right)^{(3/n_1)}\times\exp\left[\frac{qEg_o}{n_1 K}\left(\frac{1}{T_{ref}}-\frac{1}{T_c}\right)\right] \qquad (9)$$

$$I_{02}(T_m) = I_{o2}(T_{ref})\times\left(\frac{T_c}{T_{ref}}\right)^{(3/n_1)}\times\exp\left[\frac{qEg_o}{n_2 K}\left(\frac{1}{T_{ref}}-\frac{1}{T_c}\right)\right] \qquad (10)$$

$$I_{o1}(T_{ref}) = \frac{I_{cc}}{\left[\exp\left(\frac{qV_{co}}{Kn_1 T_{ref}}\right)-1\right]} ;\ I_{o2}(T_{ref}) = \frac{I_{cc}}{\left[\exp\left(\frac{qV_{co}}{Kn_2 T_{ref}}\right)-1\right]} \qquad (11)$$

2.3. Modeling of the booster converter

It is a Boost converter is a power converter with a DC output voltage higher than its DC input voltage[6]. This converter consists of four components: a capacitance (Cp), an inductance (L), the parallel resistance and a MOSFET transistor switch. From a circuit point of view, the chopper appears as a quadrupole figure 4. The modeling of the parallel chopper is obtained by applying fundamental laws governing the operation of the system.

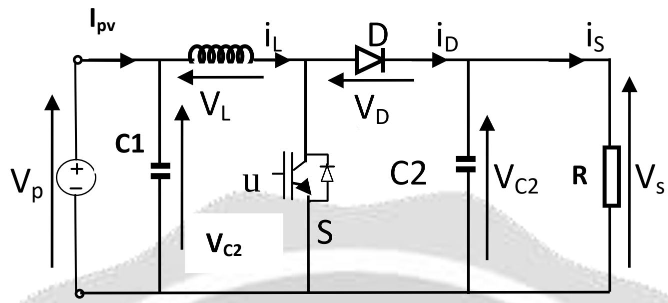

Figure 4 : Converter (DC/DC) voltage booster

The application of Kirchhoff's laws on the equivalent circuits of the booster converter of both operating phases (passing transistor and blocked transistor) gives the approximate model of the booster converter (relationship 12). The electrical output quantities (Vs and Is) in the booster converter are linked to those of the inputs (Vpv and Ipv) according to the duty cycle α of the signal that controls the converter switch by the equation system (13). The output resistance of the PV panel (Rpv) as a function of α and Rs and the duty cycle is written as a function of the resistances Rpv and Rs (relationship 14).

$$\begin{cases} I_L = I_{pv} - C_1 \dfrac{dV_{pv}(t)}{dt} \\ I_s = (1-\alpha) I_L - C_2 \dfrac{dV_{pv}(t)}{dt} \\ V_{pv}(t) = L \dfrac{dI_L}{dt} = (1-\alpha) V_s \end{cases} \qquad (12)$$

$$\begin{cases} V_s = \dfrac{V_{pv}}{(1-\alpha)} \\ I_s = (1-\alpha) I_{pv} \end{cases} \quad (13); \qquad \begin{cases} R_{pv} = \dfrac{V_{pv}}{I_{pv}} = R_s (1-\alpha)^2 \\ \alpha = 1 - \sqrt{\dfrac{R_{pv}}{R_s}} \end{cases} \quad (14)$$

The α report checks the inequality 0<α<1, the converter only plays the role of an elevator if the load Rs fulfils the following condition: the resistance at the output of the Boost (the resistance of the load) must be higher than the resistance of the photovoltaic panel.Rs>Rpv. Under optimal conditions and for a given load Rs, the internal resistance of the panel (Rpv=Ropt) and the duty cycle (α = αopt) therefore comply with the equation :

$$R_{opt} = \left(1-\alpha_{opt}\right)^2 R_s \qquad (15)$$

The mathematical expression of the inductance and capacitor of the Boost chopper:

$$L = \frac{V_{co}}{4 \times \Delta I \times f} \quad ; \quad C = \frac{V_{co}}{32 \times L \times \Delta V_s \times f^2} \qquad (16)$$

Avec ΔI est l'ondulation de courant dans l'inductance et ΔV_s est l'ondulation de la tension de sortie du condensateur.

2.4. Search for the Maximum Power Point (MPPT)

To maintain a permanent supply of the load for climatic variations (irradiation and temperature), the optimization algorithm for maximum power point tracking (MPPT) adopted is the P&O, Perturbe and Observe method[7]. The Perturbation and Observation control principle is to generate disturbances by reducing or increasing the duty cycle and to observe the effect on the power delivered by the GPV.

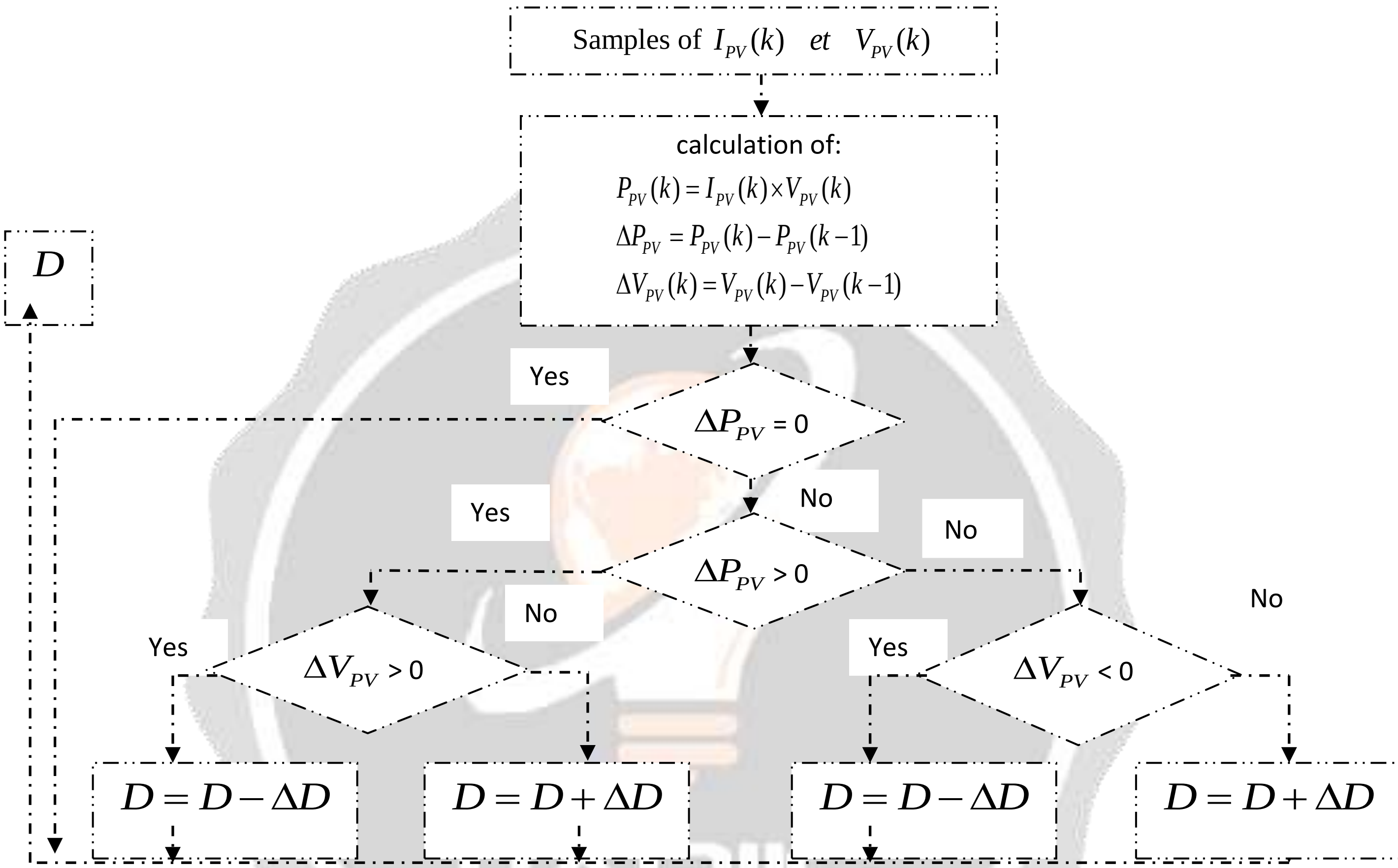

Figure 5 : Disruption and observation algorithm

3. RESULTS AND DISCUSSIONS

3.1- Geographical data of the Mahajanga site

The study area for our two types of systems is Mahajanga I province. The Mahajanga site, located in the northwestern region of Madagascar, is characterized by meteorological data according to Table 1.

Table1: Geographical coordinates of the Mahajanga site

Latitude (°)	Longitude (°)	Altitude (m)	Reference meridian (°)	Ground albedo	DEL
15°40'Sud	46°21'Est	22m	40°	0 ,35	0 ,9h

3.2- Characteristics of the adopted photovoltaic panel

The electrical characteristics of the 80 W BP solar 380 photovoltaic module under standard conditions (1000 W.m-2, optical mass: AM 1.5, cell temperature: 25 °C) are given in Table 2 below:

Table 2: Typical Electrical Characteristics.

Parameters	Values
Max. power (Pmax)	80 W
Minimum guaranteed Pmax	76 W
Voltage at Pmax (Vmp)	17.6 V
Current at Pmax (Imp)	4.5 A
Short-circuit current (Icc)	4.8 A
Circuit-open voltage (Vco)	22.1 V
Temperature coefficient of Icc (Ki)	(0.065±0.015)%/K
Temperature coefficient of Vco (Kv)	-(0.36±0.05) %/K
Power temperature coefficient	-(0.5±0.05)%/K
NOCT (Air 20°C, Sunshine 800W/m2, wind speed 1m/s)	47±2°C
Number of cells in series/parallel	36/1

3.3. Simulink simulation of the directly coupled system and MPPT-controlled system

Simulation of these two systems is performed using Simulink. Indeed, simulation on Simulink makes it easy to obtain a graphical environment for the development of block diagrams by dragging and dropping, complete integration with the MATLAB environment, customization of the block library and adaptation to continuous time, discrete time and hybrid systems. In the system simulation controlled by MPPT, the determination of the inductance and capacitor values of the Boost converter is determined using a script file. Thus, to start the simulation of the system controlled by MPPT, you must first run this script file before running the simulation.

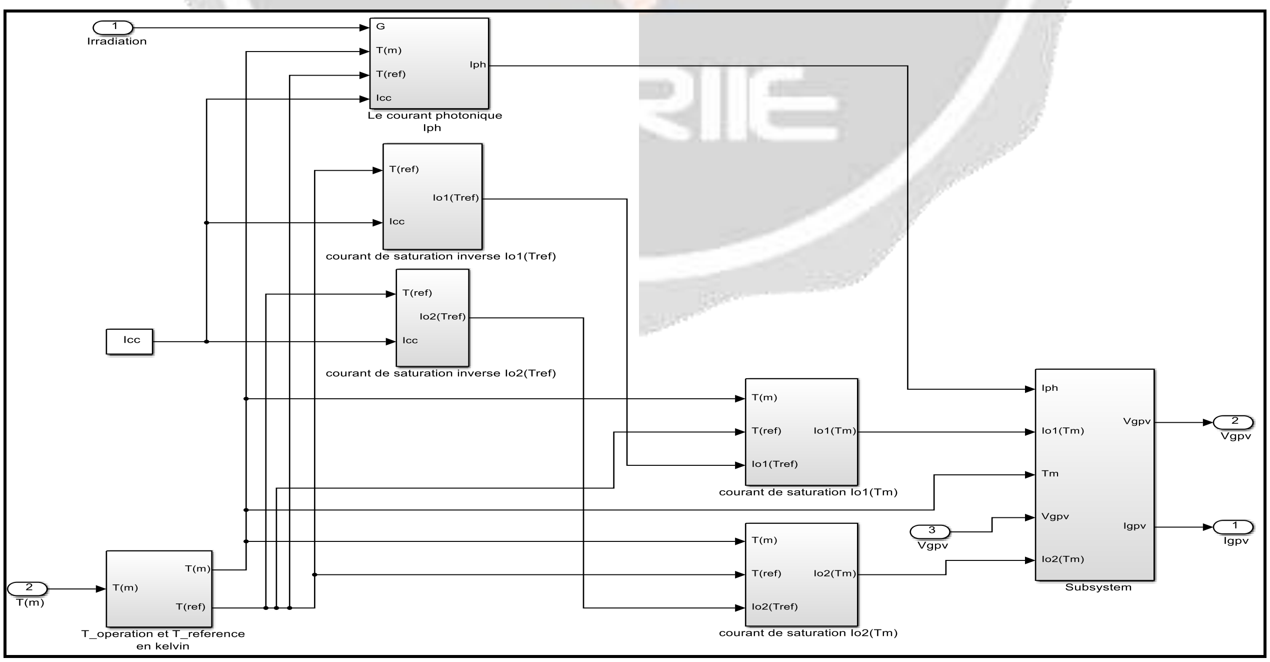

Figure 6 : Block diagram of a PV module for the two diode model

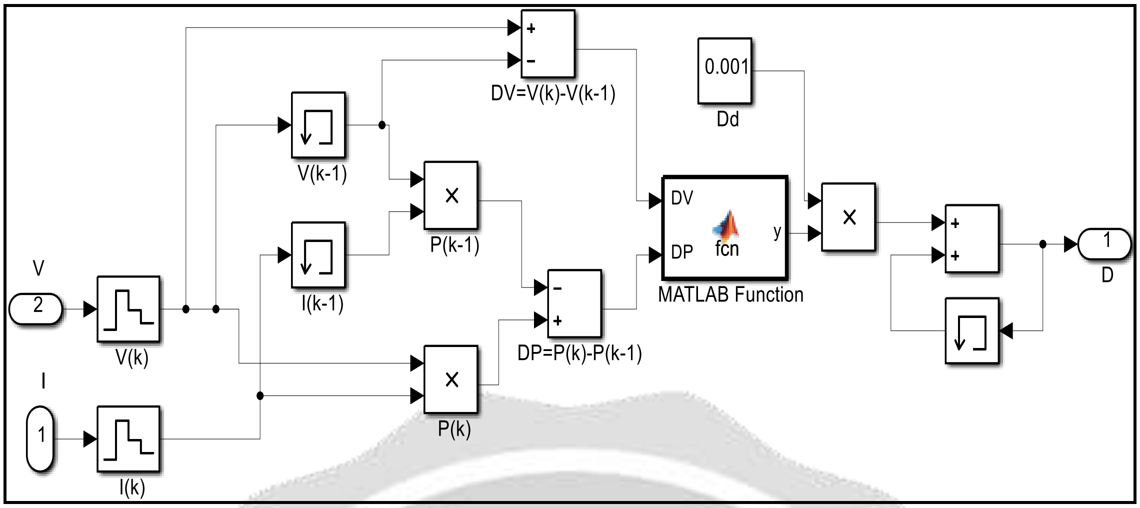

Figure 7 : Block diagram of the P&O algorithm in Simulink.

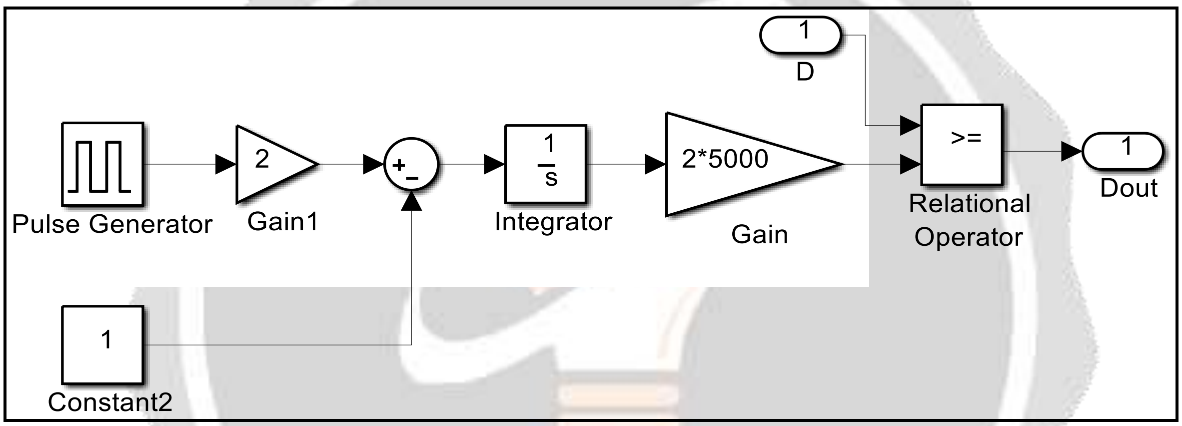

Figure 8 : Block diagram of the PWM signal that will control the Mosfet switch

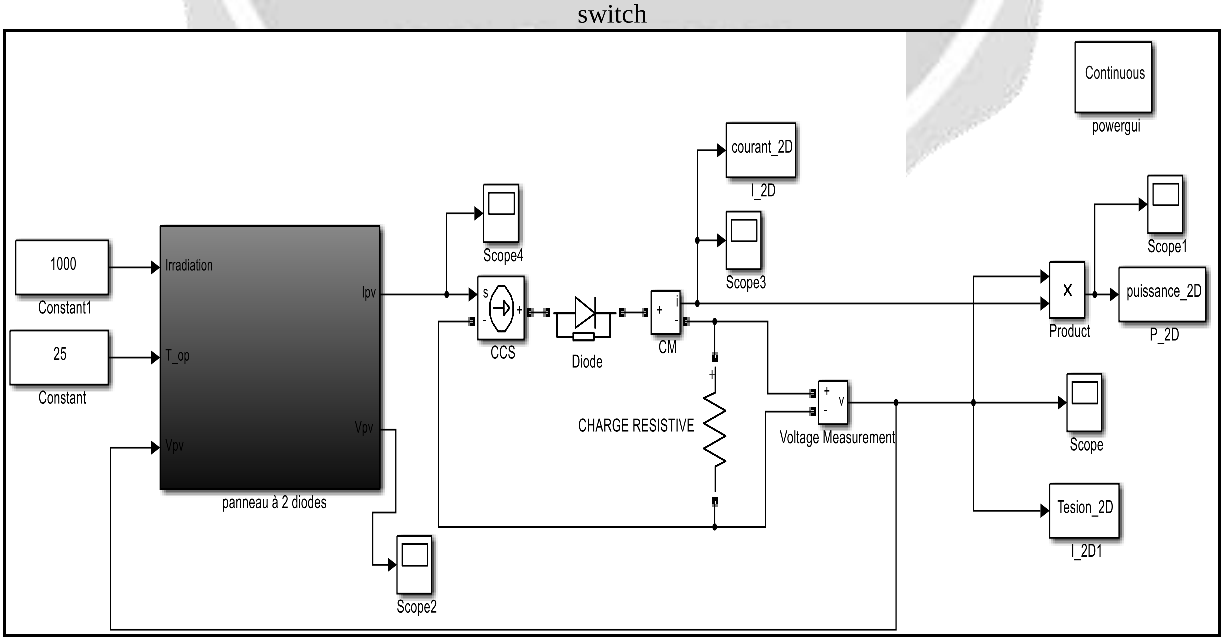

Figure 9 : Simulation of the directly coupled system

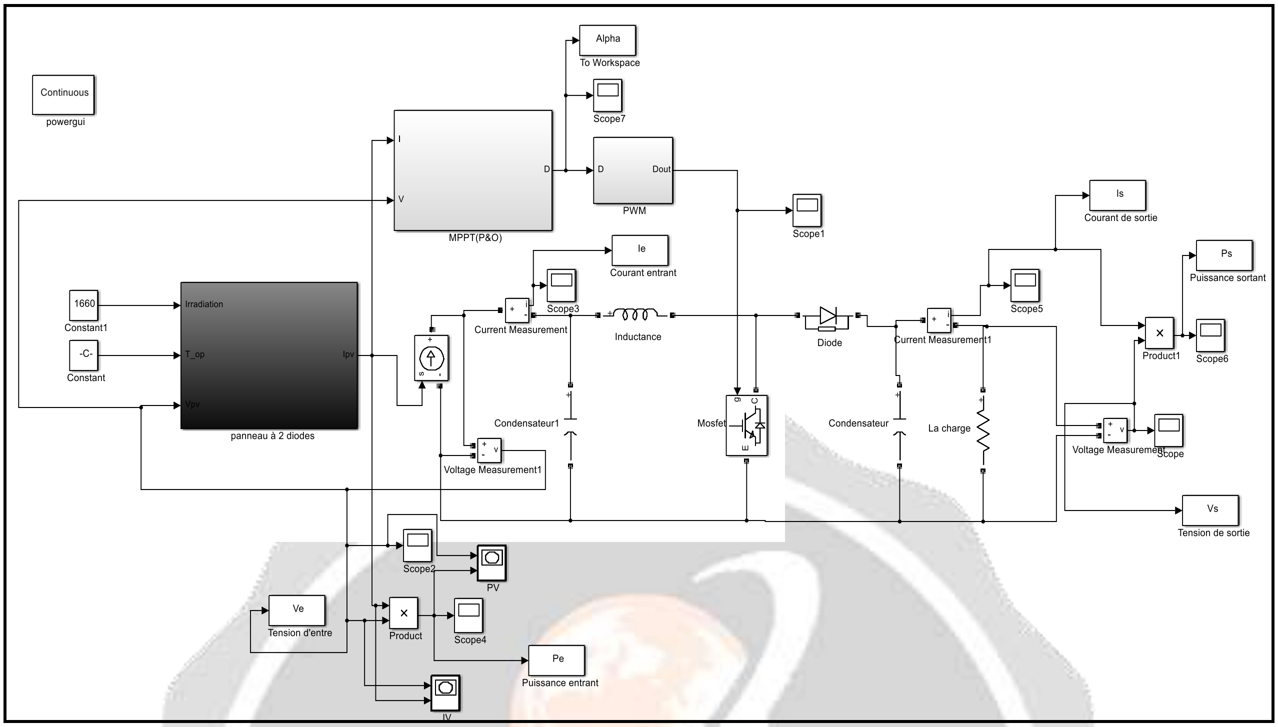

Figure 10 : Simulation of the system controlled by MPPT in Matlab/Simulink.

3.4. Simulation of inclined global solar irradiation

Figure 11 shows the monthly average of the global solar irradiation per hour for the Mahajanga site during the year 2015, the irradiation is minimal in June, generally in winter, and almost maximal during the summer period, especially in October and November. The year 2015 was chosen because it is the sunniest year in Mahajanga since 2000 to 2018. We took the data from the global solar irradiation of the last three months of 2015, namely October, November and December, to perform the simulation. Table 3 below is a summary table that gives us the monthly irradiation, module temperature, current, voltage and maximum power provided by our module during these last three months of the year 2015.

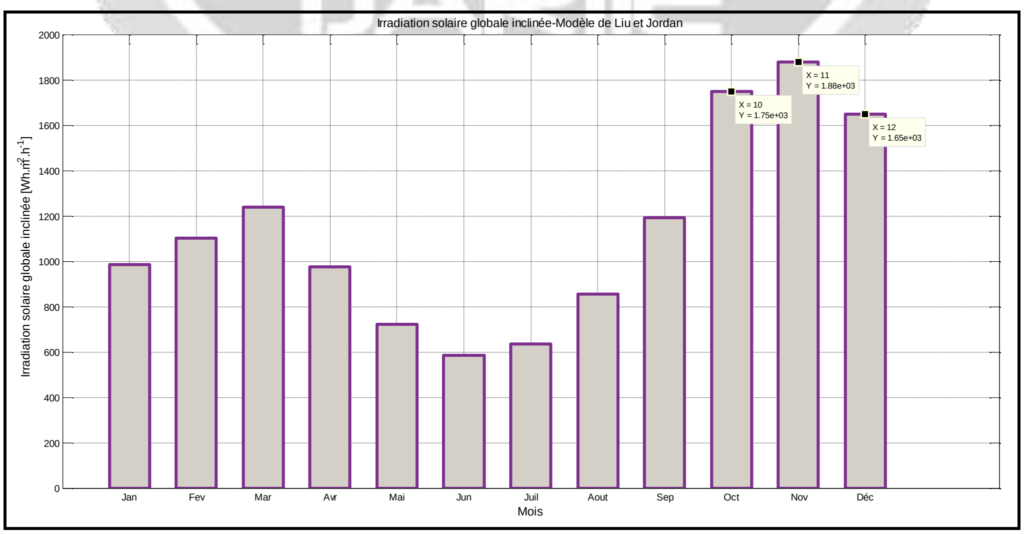

Figure 11 : Monthly average of the global solar irradiation per hour inclined

Table 3: Irradiation values, module temperature, voltage, current and maximum power supplied by the module during the last three months of 2015

	Irradiation (W.m-2)	Module temperature (°C)	Maximum voltage supplied by the module (V)	Maximum current supplied by the module (A)	Maximum power supplied by the module (W)
October	1750	87.46	9.547	7.388	70.53
November	1880	92.1	7.793	9.194	71.64
Décember	1660	84.925	9.901	6.95	68.82

3.5. Simulation of the influence of climatic conditions on the PV module

The curves in Figure 12 show respectively the influence of solar irradiation for a constant temperature (Tm=25°C) and the temperature for a fixed irradiation of 1000W/m2 on curves I(V), P(I) and P(V). Solar irradiation and the temperature inside the panel have a great influence on the production of current and voltage: the higher the solar irradiation, the higher the current supplied by the module, the lower the temperature of the module, the better the voltage supplied by the panel.

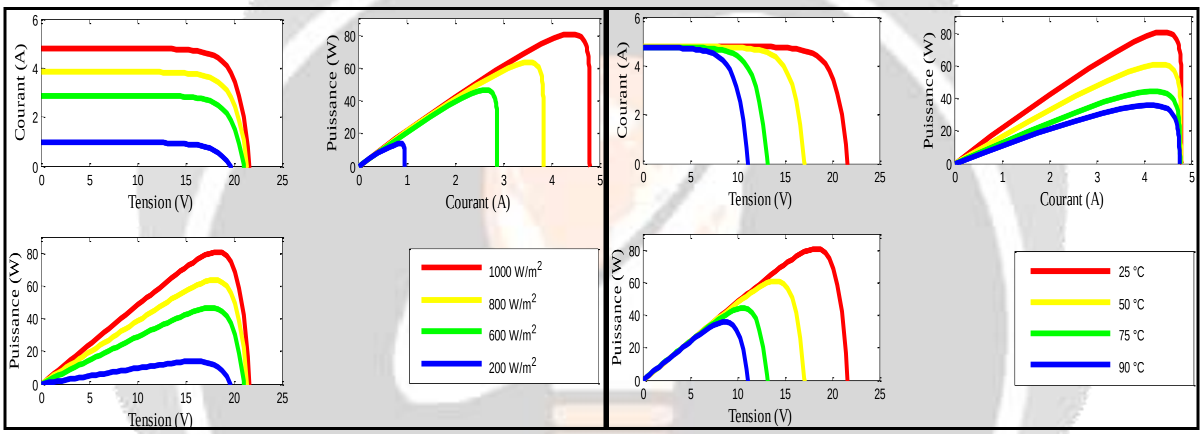

Figure 12 : Influence of solar irradiation and temperature variation on curves I(V), P(I) and P(V).

3.6. Simulation of the temporal evolution of power

In the following, we have taken a resistive load of 5.1502 ohms which corresponds to 4 bulbs of 12 V, 7 W each bet in parallel. The curves in Figure 13 below show the time evolution of the electrical quantities (V, I and P) supplied to the resistive load coupled directly to the PV panel during the last three months of 2015. We note that the power transferred to the load by the panel for each month varies from 26.66 W, 24.46 W and 27.83 W. However, the panel in each month provides a power of 70.53 W, 71.64 W and 68.82 W, according to the results of Table 3. These results prove that the power supplied by the panel is not fully transferred to the load. And that there is an average power loss of 44.01 W. In conclusion, the directly coupled system does not work at its maximum point. The curves in Figure 14 illustrate the time evolution of the average electrical quantities (Voltage, Current and Power) entering and leaving the Boost converter connected to the same resistive load of 5.1502 ohms for the last three months of the year 2015 in Mahajanga. When the Boost converter is interposed between the PV module and the resistive load, the power supplied to the load for the last three months of the system controlled by MPPT is: 67.89 W, 69.18 W and 66.28 W. We find that on average, the difference between the power supplied by the module and that supplied to the load is 2.56 W. In addition, the output voltage of the Boost converter is always higher than that of the input. Thus, we can see that the presence of the Boost converter associated with the MPPT control perfectly fulfils its role of adaptation between the source and the load. Thus, the MPPT-controlled system operates at its maximum power point for each month by fully transferring the power supplied by the panel to the load.

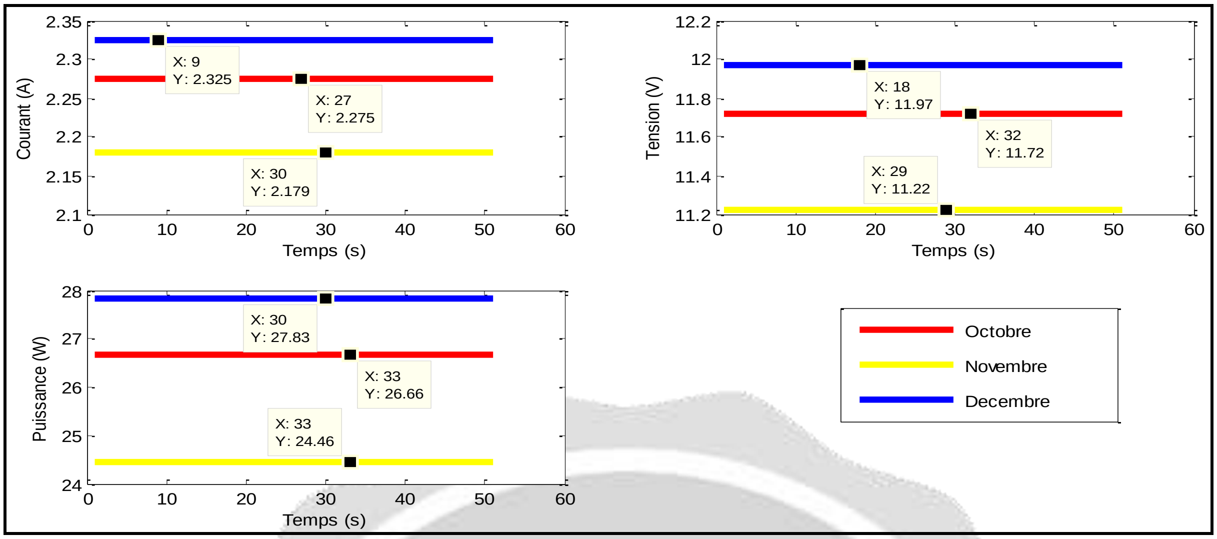

Figure 13: Time evolution of the power provided by the system directly coupled to the load for the last three sunny months of the Mahajanga site

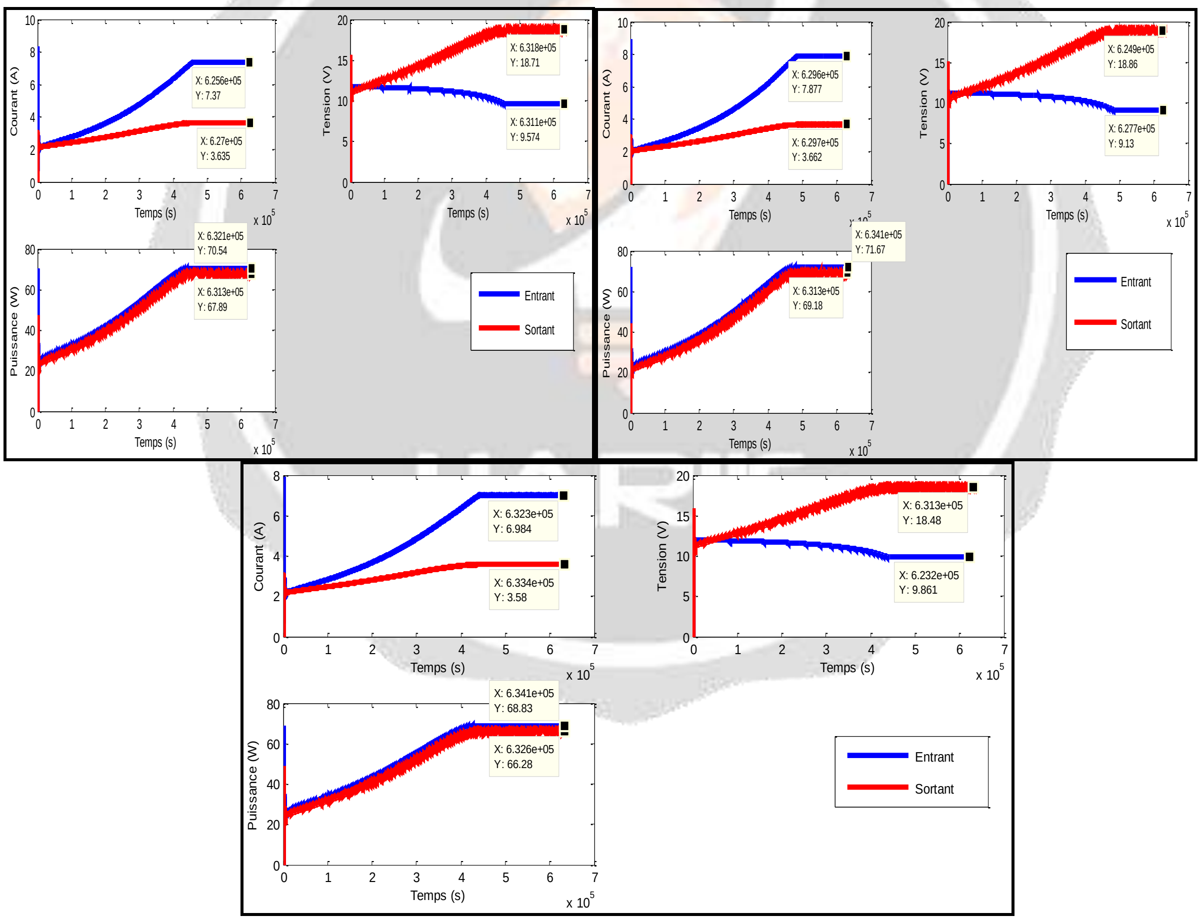

Figure 14 : Time evolution of the currents, voltages and powers entering and leaving the Boost chopper for the months of October, November and December of the system controlled by MPPT.

3.7. Simulation of the influence of the resistive load

In Figure 15 below, the resistive load is varied by 5 ohms, 10 ohms ,20 ohms and 30 ohms to see the influence of the variation in load on the electrical quantities: the voltage, current and power supplied by the PV module on the two system configurations for the month of November in Mahajanga. For the directly coupled system, the higher the value of the resistive load increases, the higher the voltage supplied by the panel increases and tends towards the value of the open circuit voltage; while the current supplied by the panel decreases. Similarly, the power supplied to the load decreases with the increase in the value of the load. This shows that the variation of the load has a great influence on the power supplied to the load for a directly coupled system.
In the case of the MPPT controlled system, for a resistive load variation of 5 ohms, 10 ohms ,20 ohms and 30 ohms, a fixed irradiation and a fixed temperature, the system provides the load with a power that is constant, on average 69.46 W. Thus, it is found that a load variation has no influence on the power supplied to the load because of the MPPT control which ensures the correct duty cycle so that the system can operate at its maximum power point.

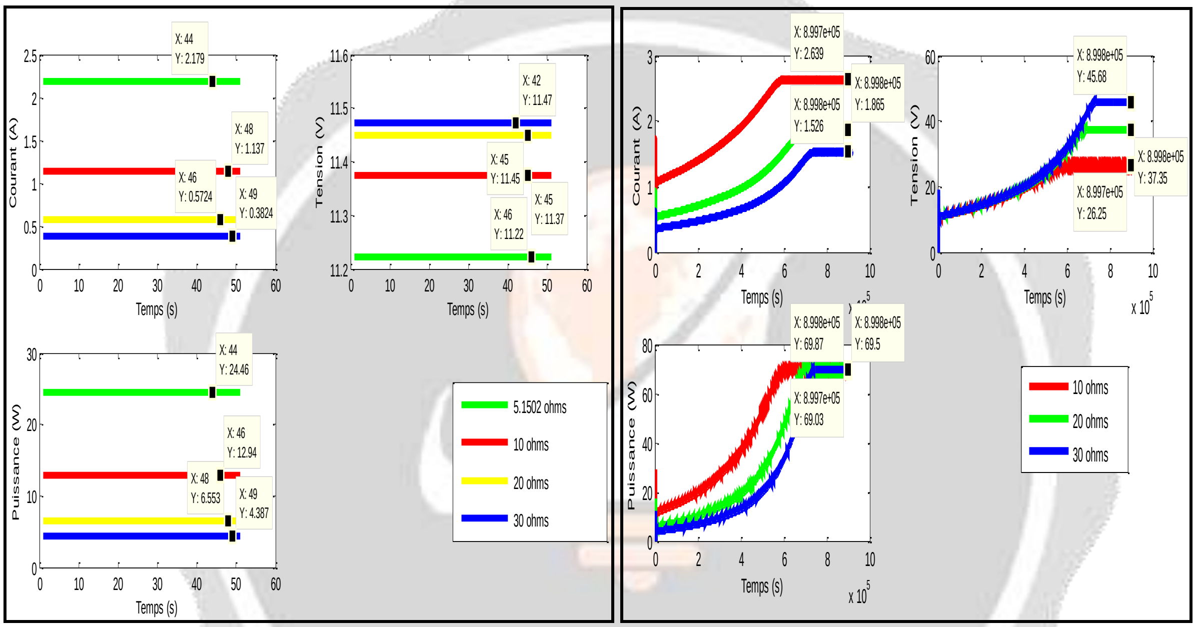

Figure 15 : Influence of the variation in load on the voltage, current and power supplied by the module of the directly coupled system (left) and the system controlled by MPPT (right).

Taking the month of November, which offers the highest irradiation in Mahajanga for the year 2015, at 1880 W/m2, i.e. a power on the panel of 1220.55 W and a panel temperature of 85°C, the comparative study shows the differences between a directly coupled system and a system controlled by MPPT.
Table 4 below specifies that for a load variation, it is the MPPT-controlled photovoltaic system that provides us with maximum power production for the panel. In addition, this power provided by the module is almost equal to that provided to the load. The converter controlled by MPPT used, ensures its role of adaptation between the panel and the load. Either the efficiency of our converter, which is the ratio between the output power of the converter (PS) and the power supplied by the module (PPV), is approximately equal to 96%.

Table 4: Estimate of the power produced by a directly coupled system and that controlled by MPPT for the sunniest month in Mahajanga.

Systems	r_{ch} (ohms)	V_{PV} (V)	I_{PV} (A)	P_{PV} (w)	V_{boost} (V)	I_{boost} (A)	P_{boost} (w)	R_{boost} (%)	R_{syst} (%)
Direct torque system	*5.15*	11.22	2.179	24.46	-	-	-	-	2
	10	11.37	1.137	12.94	-	-	-	-	1
	20	11.45	0.57	6.55	-	-	-	-	0.53
	30	11.47	0.38	4.38					0.35
Controlled system	*5.15*	9.13	7.87	71.67	18.86	3.66	69.06	96.35	5.6
	10	9.131	7.84	71.67	26.25	2.63	69.27	96.65	5.6
	20	9.102	7.87	71.67	37.35	1.86	69.35	96.76	5.6
	30	9.105	7.87	71.67	45.68	1.52	69.70	97.25	5.7

4. GENERAL CONCLUSION

In this work, a comparative study between a directly coupled system and a MPPT-controlled system based on Mahajanga meteorological data was conducted to estimate the maximum power produced during the summer months of Mahajanga city. Simulation results have shown that the directly coupled system offers a very low efficiency of around 2.48%. Indeed, for a given irradiation, a given temperature and a fixed load value, the power supplied to the load is far below that which the panel can supply. And for an increase in load, the power supplied by the panel is very low in front of the MPPT-controlled system. The MPPT-controlled system offers a slightly higher efficiency than the directly coupled system. The power supplied by the panel is almost totally transferred to the load. This proves that the Boost converter associated with the MPPT control performs its role of adapting between source and load with efficiency, it can give a high voltage at the output of the converter compared to that of the input.

5.REFERENCES

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