Study, Simulation and Analogical Realization of the Loop of Current MPPT for the Photovoltaic Panels

S. Boukebbous and M.Khelif

Abstract—**in this paper, one of the indirect approaches for tracking the maximum power point (MPPT) was used, it is the method of control per loop of current which was the subject of a detailed study and whose performances were evaluated in a rigorous and complete way. On the basis of lesson released on this level, a qualitative experimental validation of the adopted approach was also realized.**

Index Terms— **Photovoltaic panels, PVG, PV, Maximum Power Point Tracking (MPPT), battery.**

I. INTRODUCTION

WITH the decrease of conventional energy sources and the growing problem of environmental pollution, the research and utilization about the renewable energy, such as solar energy, wind energy as so on, has been concerned with more and more attention [1].

A photovoltaic (PV) array converts sunlight into electricity. The voltage and current available at the terminals of the PV array may directly feed small loads such as lighting systems and DC motors. More sophisticated applications require electronic converters to process the electricity from the array. These converters may be used to regulate the voltage and current at the load, to control the power flow in grid-connected systems and mainly to track the maximum power point (MPP) of the array [2].

The characteristic of the photovoltaic arrays is nonlinear, so in order to obtain the maximum power, we need to track and control it. In this work we proposed an indirect approach method (MPPT with loop of current), when the performance of it has evaluated in rigorous situation. In this way, we can increase the power generation of photovoltaic system and reduce the power cost.

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II. PVG MODEL AND SIMULATION RESULTS

Starting from the widely known photovoltaic cell electrical equivalent circuit [1] (Fig.1), an equivalent model for a more powerful PVG made of an (N_s x N_p) array of PV cells, is established [3,4]:

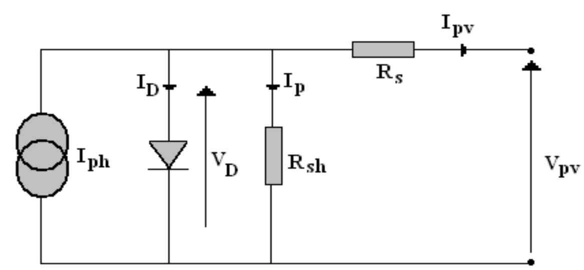


Fig.1.Simple model of the photovoltaic cells.

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

I_D expression being deduced from the semiconductor diode theory, the above relation may be detailed as:

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

Where, I_{ph} is the light generated current (A), I_o the PV cell saturation current (A), q the electron charge (q = 1, 6 10^{-19} C), K the Boltzmann constant (k = 1, 38 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 [3,4]:

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

From equation 2, an already temperature dependence of the cell external characteristic is established. Furthermore, all the cell parameters (I_o, n, R_s and R_{sh}), are equally temperature related. However, semiconductor diode theory, suggests that the most significant temperature effect comes from the reverse saturation current I_o. Variation of its value I_o (T) with working temperature T, is usually evaluated relatively to its evaluated value I_o (T_r) at a reference temperature T_r [5].

$$\frac{I_0(T)}{I_0(T_r)} = \left(\frac{T}{T_r}\right)^3 . \exp[\frac{q\,E_g}{nK}\left(\frac{1}{T_r}-\frac{1}{T}\right)] \qquad (4)$$

Where: Eg is the cell material band gap, supposed here no temperature dependent, and k is the Boltzmann constant.
The value of saturation current Io (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).

$$I_0(T_r) = \frac{I_{sc}(T_r)}{(e^{\frac{q\,V_{oc}(T_r)}{nKT}}-1)} \qquad (5)$$

The equation of the illumination current brought back to the reference conditions (G_r = 1000W/m², T_r =25C°) is given as follows:

$$I_{ph} = [I_{cc}\frac{G}{G_r} + I_t(T-T_r)] \qquad (6)$$

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

The model of the PVG precedents is implemented in environment Matlab/Simulink as indicates the (Fig.2).

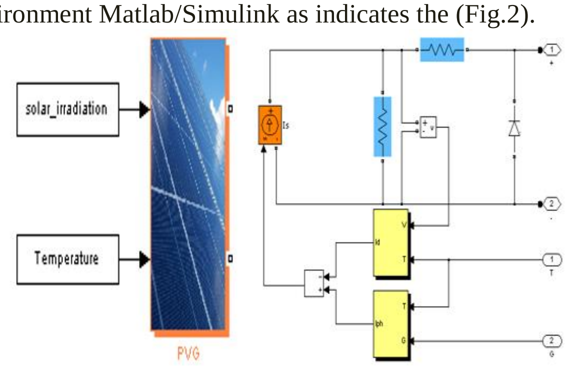


Fig. 2.Structure of the PVG Simulink model.

The main external reference characteristics of the PVG are established using the identified perturbation inputs (solar illumination, temperature) as parameters (Fig.4, 5).

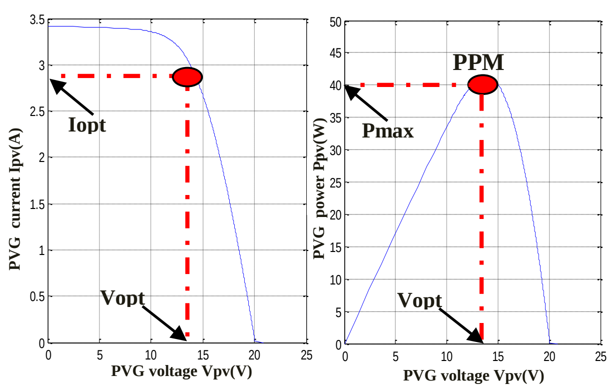


Fig. 3.PVG (current- voltage) and (power- voltage) characteristic for standards conditions.

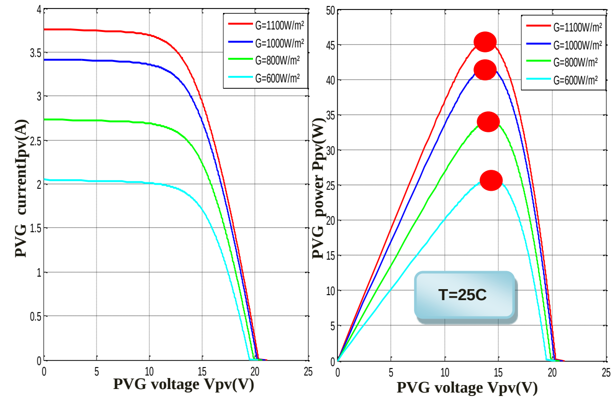


Fig. 4.PVG (current- voltage) and (power- voltage) characteristic for different solar illuminations.

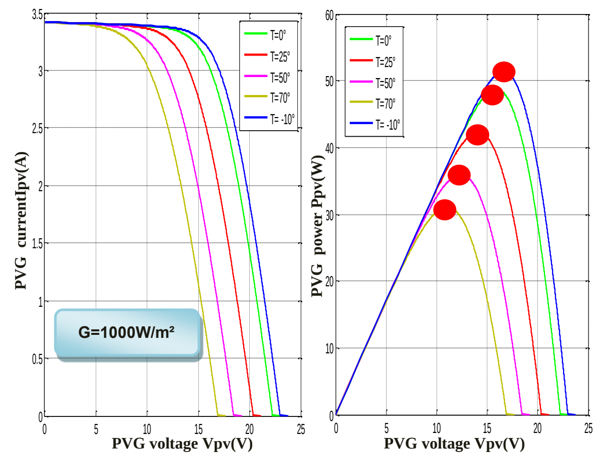


Fig. 5.PVG (current- voltage) and (power- voltage) characteristic for different temperatures.

III. MPPT WITH LOOP OF CURRENT

Due to its nonlinear external current–voltage characteristic, the PVG maximum power output varies with its operating point. The latter being equally load related, this occurs even for a given solar irradiation and temperature. In this case only a unique load value may ensure the optimum operating point in terms of maximum power extraction from the PVG, which output voltage and current are then at their respective optimal values (V_{opt}, I_{opt}). Generally, all the inputs defining the optimum operating point of the PVG (Solar irradiation, temperature and load, shading being a particular situation), are imposed. However, it is known in power DC electrical circuits, that a switching DC-DC electronic power converter may be an efficient impedance adaptor tool. Hence, it may be used to adjust the equivalent load impedance to the needed value for PVG optimal operating point, whatever are the solar irradiance, temperature and eventually shading rate [5].

The techniques making it possible to automate and optimize the procedure in question are subdivided in two great classes according to whether the approach is direct or indirect. In our work we used one of indirect methods known as MPPT with loop of current.

This Method is based on the mathematical model developed by Borowy and Salameh in 1996 using the equivalent diagram of a photovoltaic cell with only diode (Fig.1), To calculate the coordinates of the optimum point (V_{opt}, I_{opt}) in the presence of the operating conditions, the optimum current is given as follows [6].

$$I_{opt} = I_{cc}\left\{1-\left[C_1 exp\left(\frac{V_{opt}}{C_2 V_{co}}\right)-1\right]\right\}+\Delta I (7)$$

I_{cc}: the short circuit current of the module (A).
V_{co}: the open circuit voltage of the module (V).
ΔI:is determined by the difference in temperature and the solar irradiation.
C_1 and C_2 are parameters which can be calculated such as follows:

$$C_1 = (1-\frac{I_{mp}}{I_{cc}})\exp(-\frac{V_{mp}}{C_2 V_{co}}) \qquad (8)$$

$$C_2 = \frac{\frac{V_{mp}}{V_{co}}-1}{\ln(1-\frac{I_{mp}}{I_{cc}})} \qquad (9)$$

$$\Delta I = \alpha_o(\frac{G}{G_r})\Delta T + (\frac{G}{G_r}-1)I_{cc}, \Delta T = T - T_r \qquad (10)$$

V_{mp}, I_{mp}: The maximum voltage and current of the module under standards conditions.
α_o: Coefficient of the current according to temperature (A/C).
G_r, T_r: illumination and temperature at standards conditions ($1000W/m^2$, 25C°).

IV. CHARACTERISATION TESTS

To characterize photovoltaic panels, it is necessary to trace its external characteristics for various illuminations and temperatures, the (Fig.6) represents the photovoltaic panels and the assembly used for this test [7,8].

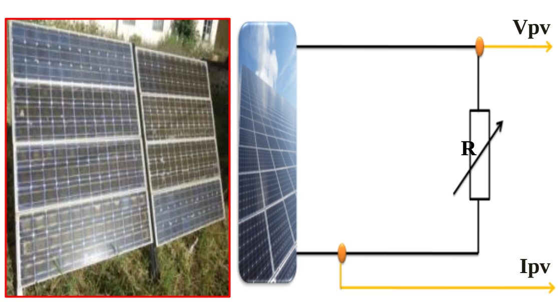


Fig. 6.UDTS50 Photovoltaic panels and assembly used to trace the external characteristic of the panels.

In this test we used a variable resistor like load of the panel. Thus for each values of the latter a current and voltage are measured for a constant illumination and temperature. The external characteristics obtained are given in (Fig.7).

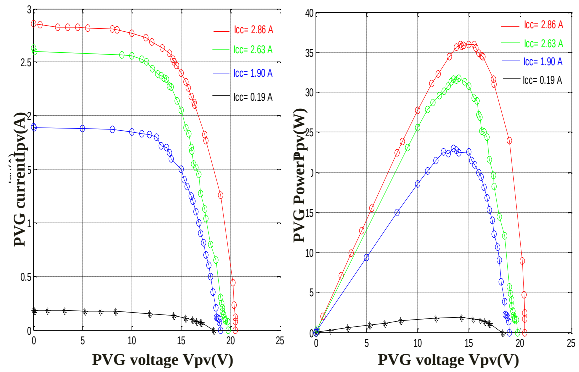


Fig. 7. External characteristic of photovoltaic panel for various illumination and temperature = 26 C°.

The network of the curve obtained previously makes it possible to validate our model as indicates (Fig.8).

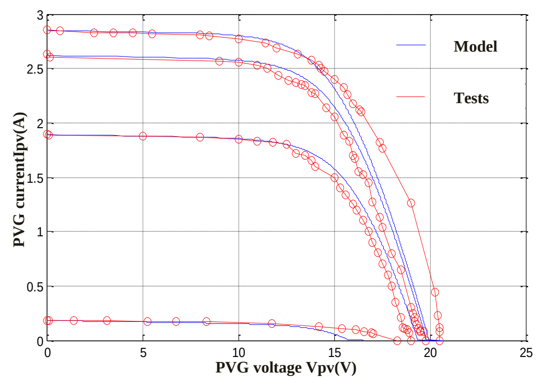


Fig. 8.Validation of our model using the curve previously obtained.

Moreover, these tests also make it possible to obtained the relation between the optimal and the short-circuit current using the real and the model of the photovoltaic panel (Fig.9).

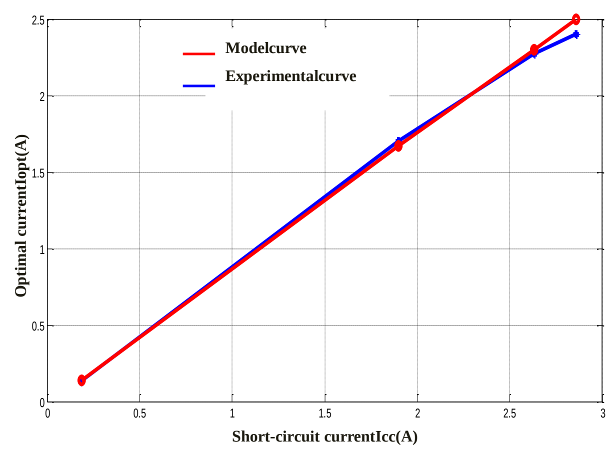


Fig. 9.Variation of the optimal current according to short-circuit current.

The (Fig.9) show that the two curves are almost identical what confirms the reliability of our model, and the relation between the optimal current and that of short-circuit is linear of form: $I_{opt} = A\,I_{cc} + B$.

So the equation (7) becomes:

$$I_{opt} = AI_{cc} + B \quad (11)$$

When: A, B are constants.

From the (Fig.9) we can determinate the two constant A and B, when A is the slope of the curve. The relation between these two curves is given follows:

$$I_{opt} = 0.821 I_{cc} + 0.0034 \quad (12)$$

V. THE LOOP OF CURRENT MPPTTECHNIQUE DESIGN ANDSIMULATION RESULTS

The control circuit of the boost converter is given as follows (Fig.10):

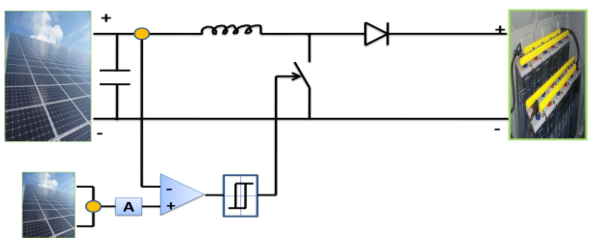


Fig. 10.Control circuit of the boost converter.

For simplify the control we neglected constant B in the equation (11), therefore the expression becomes a linear relation which passes by the origin.

The obtained current I_{opt} will be compared with the PVG current I_{pv}, the result enters in the hysteresis regulator which makes it possible thereafter to fix the panel current in a band ΔI around $I_{opt} = I_{ref}$.

In simulation we used a PVG of Pmax = 42W (V_{opt}=14.8V, I_{opt}=2.8A), and an electrochemical storage systems (2 battery (12V 150Ah) in series).

The simulation results are given in (Fig. (11 to 15)).

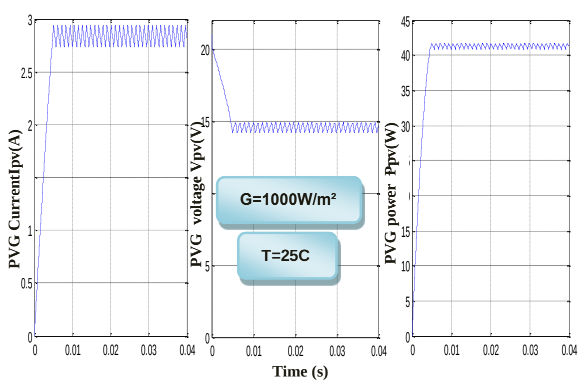


Fig. 11.Variation of the current, the voltage and PVG power for a constant illumination and temperature.

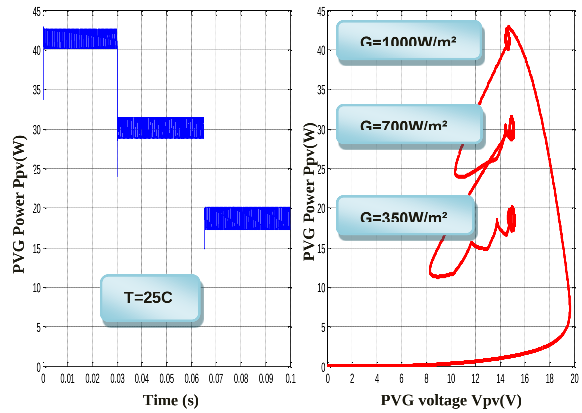


Fig. 12. Variation of the PVG power for a constant temperature and variable illuminations.

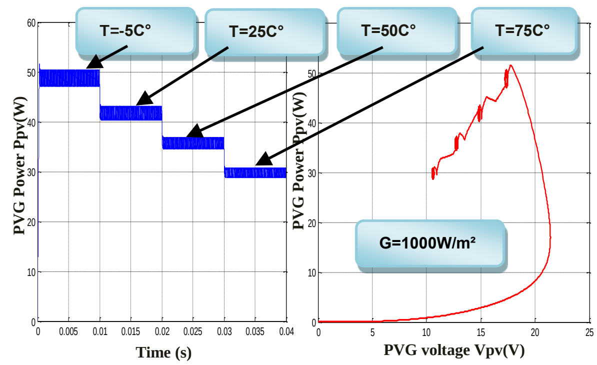


Fig. 13. Variation of the PVG power for a constant illumination and variable temperature.

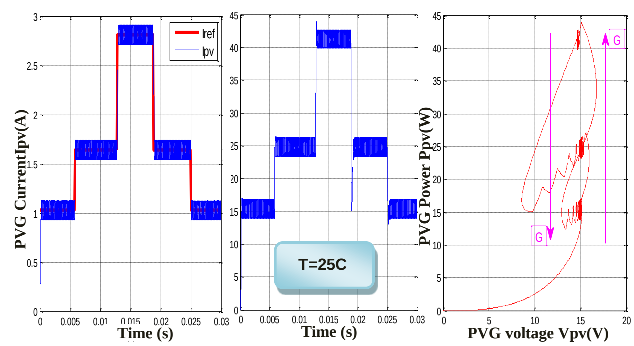


Fig. 14. Variation of the PVG power and current for anincrease and decrease illumination.

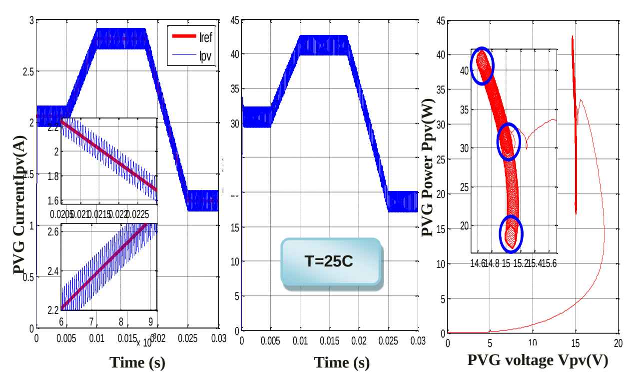


Fig. 15. Variation of the PVG power and current for a random illumination.

For a photovoltaic solar station made up of 9 panels in series in parallel with 4 others, and a storage system of 20 batteries in series (12V, 150Ah); the current and the power of the PVG and chemical storage system are given as follows:

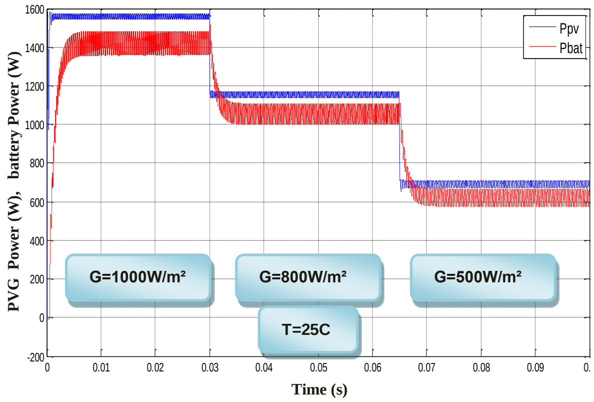


Fig. 16. Variation of the PVG and battery current for a constant temperature and variable illumination.

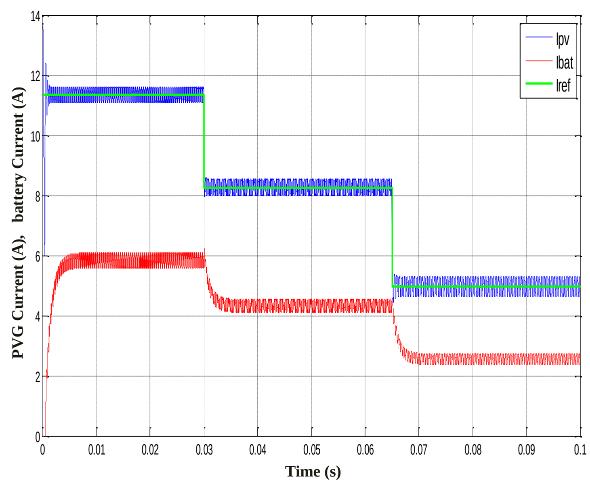


Fig. 17. Variation of the PVG and battery current for a constant temperature and variable illumination.

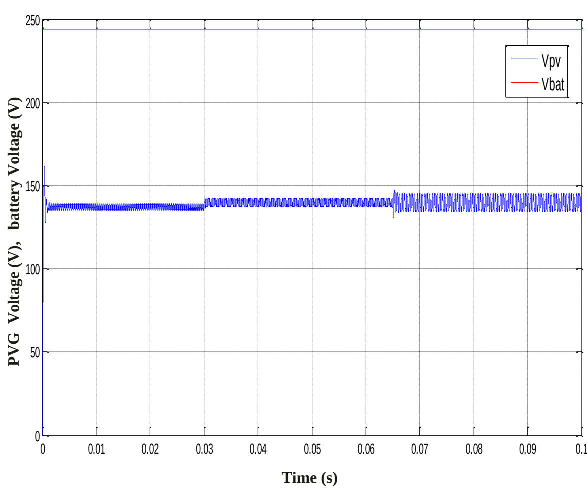


Fig. 18. Variation of the PVG and battery current for a constant temperature and variable illumination.

If illuminations change, the systems arrive at the new operation point very quickly, with the same imposed oscillations.

If the temperature increased, the panel power decreased, therefore the use of the photovoltaic panels in heat places limited the total power installation used.

The use of the hysteresis regulator makes it possible to simplify the control and to limit the panel current in ΔI band; on the other hand the commutation frequency is variable.

VI. EXPERIMENTAL TESTS

The experimental platform that we are realized on the power electronics laboratory is shown in (Fig.19).

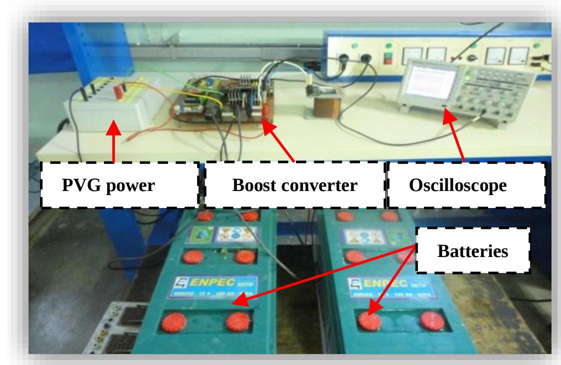


Fig. 19. Tests platform

Our loop of current is realized by analogical circuit such show in (Fig.20).

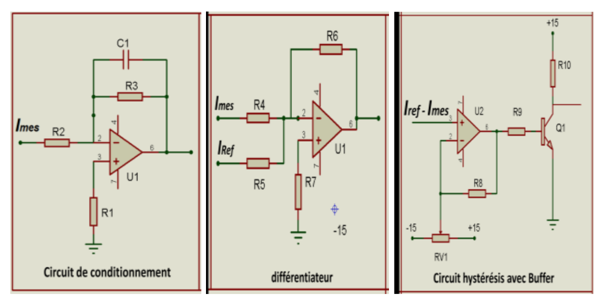
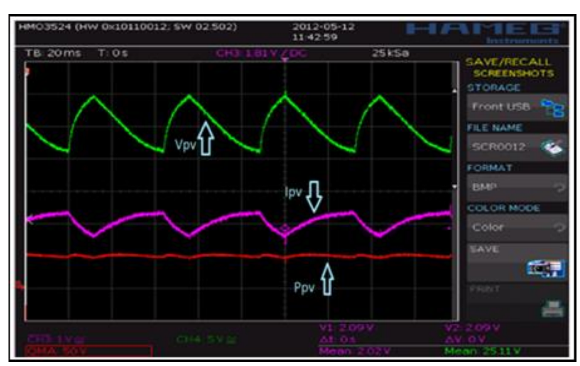
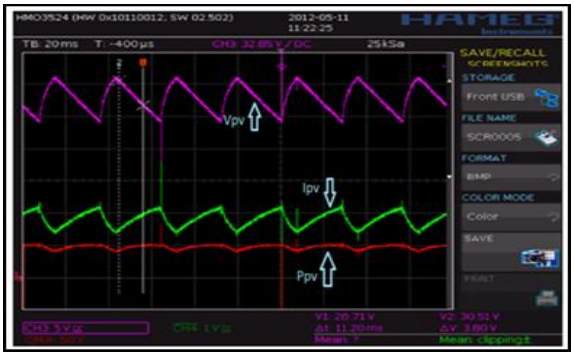


Fig. 20. Detailed diagram of the analogical loop of current.

In experimental tests we used two panels UDTS50 and three batteries (12V, 150Ah). The results obtained are given in (Fig.21).



a. PVG current, voltage and power, with 3 batteries (12V, 150Ah).



b. PVG current, voltage and power, with resistor load (R=30Ω).

Fig.21. Experimental results.

The form of the current, voltage and power obtained are the same one as that of theory end simulation what proves the reliability of the carried out control.

VII. CONCLUSION

The indirect approach used in this work (MPPT with loop of current) to Track the (PPM) is based on the investigation in real time the PVG optimal current, which always corresponds to the maximum power under all conditions which can really exist (illumination, temperature).

By using the PVG characterizations tests, the curve of the optimal current according to the short-circuit current is a linear, therefore to obtain the reference current (an illumination and temperature given) it is enough to know the value of the two relation constant.

In simulation and experimental test, we shorted-circuit the panel to have the reference current (while respecting the series and/or parallel connection adopted for the panels constituting the photovoltaic station), since we does not have the pilot cell which is normally used in this method.

The simulation and experimentation results obtained of this approach show and confirm the reliability and the simplicity of this control type.

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BIOGRAPHIES

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