# An Optimal Control Approach For Off-grid PV System Using Current Strategy Technique

Kamal Hirech*‡, Mustapha Melhaoui**, Ilias Atmane**, Khalil Kassmi**

*Renewable Energy and Energy Efficiency (REEE) team, Faculty of science, Department of Physics, Moulay Ismail University, Meknes, Morocco

** Laboratory of Electromagnetics, Signal Processing & Renewable Energies (LESPRE), Mohammed Premier University, Faculty of science, Department of Physics, Oujda, Morocco

(Hirech@gmail.com, Melhaoui.M@gmail.com, Iatmane@gmail.com, khkassmi@yahoo.fr)

‡ Corresponding Author; Kamal Hirech, Faculty of science, Department of Physics, BP. 11201, Meknes, Morocco,

Tel: +212 682 803 292, Hirech@gmail.com.

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**Abstract-** In this work, a method of control and optimization is developed for off-grid PV installations. The purpose of this method is to maximize the output current absorbed by batteries in order to optimize the Photovoltaic system operation. In this paper, a special interest has been attributed to performances comparison (production, efficiencies and systems speed convergence) of the studied method and a classical one of literature (Perturb and Observe). The comparison is realized under the same meteorological conditions. The results obtained during these studies show an average improvement in performances of the proposed system compared to the classical one.

**Keywords** Photovoltaic panels, perturb and observe, Boost converter, MPPT, solar battery, MPP.

## 1. Introduction

In front of environmental problems [1], global warming [2] and the need to reduce greenhouse gas emissions [3], the renewable energies are developing considerably against traditional sources [4]. In addition, they contribute to the diversification of the energy sources [5].

The photovoltaic energy is an alternative to produce the electricity directly from the light [6]. However, PV systems suffer from different problems and limitations regarding the energy conversion, efficiencies and the operation optimization [7]. Many works presented in the literature deal with this kind of issues, especially the optimization side. On the other hand, these solutions also have performance limits, such as the operation optimization in the case of climatic conditions variation, the search and convergence time to the maximal power point (MPP), the inaccuracy, and the limitations of system efficiencies. These problems introduce energy losses and reduce the efficiency of the systems [8, 9].

To contribute to the operation improvement of the off-grid PV systems associated with batteries, a technical method of control and optimization is developed to maximize the extraction and transfer of power by maximizing the current absorbed by batteries. Besides, this method takes into consideration the characteristics of the equipment used such as the PV panels and the loads (batteries) [10].

In this paper, the design, the implementation and the operation of control system are proposed. A particular attention is given to the experimental results to compare the performances of the system designed, with a system of the literature equiped by a perturb and observe (P & O) MPPT control [11].

## 2. The PV system design and operation

### *2.1. The synoptic diagram*

The block diagram of the studied installation is shown in Fig.1, its role is to improve the PV system operation using a new control approach. The PV installation is composed by:

- A Photovoltaic generator (G PV) for the conversion of irradiance to electrical energy.
- Batteries for energy storage.
- A Boost DC / DC converter [12] to adapt the source (PV panels) to the load (batteries).
- The proposed system control (hardware + software) to optimize and secure the operation of the PV installation.
- An acquisition interface (software) developed in the laboratory to automate the operation.

On the other hand, the control system (Fig. 1) allows to optimize the installation operation by generating a PWM signal. This latter controls the switch of the Boost converter. The acquisition interface is created to communicate with the control system in order to manage the operation in real time, store the recovered data according to the installation and manage the display of the various electrical quantities.

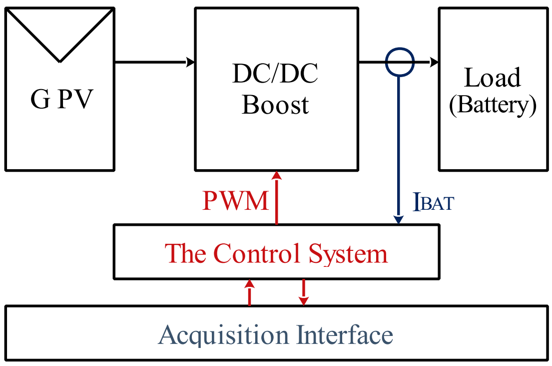



**Fig. 1**. The synoptic diagram of the PV installation

### *2.2. Discription and operation*

In the installation studied, a battery of 12V has been used as load. The optimization process requires the maximization of power delivered by the photovoltaic generator; this is verified by equation 1. In this case, the power transferred to the output of the converter for charging the battery will also be maximal (equation 2). Since the voltage of the battery is slightly variable (some mV during a long period of operation), this condition makes it possible to check the equation 3. And consequently, the optimization of the power in the installation passes through the maximization of the current at the output of the converter.

$$\frac{d\,P_{PV}}{d\,t}\bigg|_{P_{MAX}} = 0 \tag{1}$$

$$\frac{d\,P_{BAT}}{d\,t} = V_{BAT} \times \frac{d\,I_{BAT}}{d\,t} + I_{BAT} \times \frac{dV_{BAT}}{d\,t} = 0 \tag{2}$$

$$\frac{d\,I_{BAT}}{d\,t}\bigg|_{P_{MAX}} = 0 \tag{3}$$

The Figure 2 shows the flowchart of the algorithm proposed in this work. This algorithm takes into consideration the technical characteristics of the PV panels in order to reduce the operation to a range of optimum voltages [$V_{MIN}$, $V_{MAX}$] [13]. The range is determined in advance for the PV panels used. In principle, this algorithm carries out the acquisition of the $I_{BAT}$ current at the output of the converter, and generates a PWM signal of a variable duty cycle (α). The duty cycle (α) is incremented or decremented based on the flowchart (Fig. 2) to guarantee the optimization of the operation (maximization of $I_{BAT}$ current therefore the $P_{PV}$ power) by the following tasks:

- If the condition $V_{MIN} < V_{PV} < V_{MAX}$ is not satisfied, the control system brings back the VPV voltage in the range [$V_{MIN}$, $V_{MAX}$] by incrementing the duty cycle if $V_{PV} < V_{MIN}$ or decrementing it if $V_{PV} < V_{MIN}$.
- In the case where the condition $V_{MIN} < V_{PV} < V_{MAX}$ is verified, the control system tests the sign of $dI_{BAT}$ / dt by going through the following steps:
  - If $I_{BAT} \neq 0$ and $dI_{BAT} / dt = 0$, then the current of the battery charging is maximum ($I_{MAX} = I_{BAT}$) and the same for the power absorbed by the battery $P_{BAT}$ which the power generated by the panel is also maximum ($P_{PV} = P_{MAX}$). Therefore, the system keeps the same duty cycle.
  - If ($dI_{BAT}$ / dt)> 0, the $I_{BAT}$ current approaches the maximum value and consequently the maximum power point MPP, Therefore the control system keeps the same direction of the duty cycle evolution.
  - However, in the case where $dI_{BAT}$ / dt <0, then the system moves away from the maximum current, consequently the power decreases at the output of the converter. As a result, the control system reverses the direction of the duty cycle evolution.

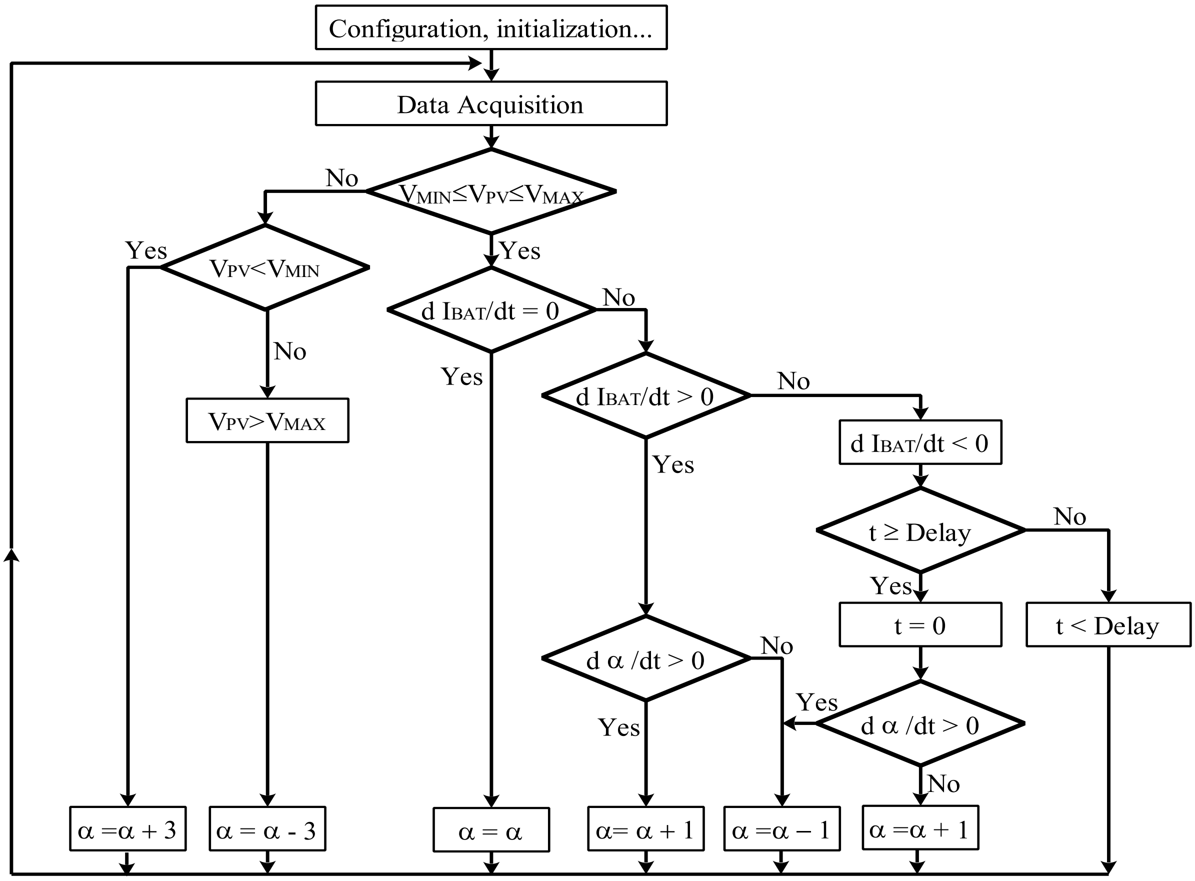



**Fig. 2.** The flowchart of the optimization algorithm of the PV installation.

## 3. The installation modelling and simulation

The synoptic diagram of the PV installation designed in the Fig. 1 is modelled on Matlab Simulink [14], and to simulate the operation correctly, sudden changes of irradiance are imposed on the system. However, the different equipments used in the simulation are characterized by the data in Table. 1.

The simulation results are presented in the Fig.3, they affect the variations of Photovoltaic power PVP, the output converter power $P_{BAT}$ (battery charging), the converter efficiency and the global installation efficiency. The obtained results show that:

- Despite the sudden changes in irradiance (between 600 W / m² and 900 W / m²) the system always converges to the optimal conditions, consequently, the maximum of the power is transferred to the battery (Fig. 3.A).

- The efficiencies presented in Fig. 3.B that illustrate the DC/DC efficiency (Rconverter around 92%) and the overall efficiency of the installation (Rglobal around 11%), show very good results, that witness the good operation of the installation.

**Table. 1.** Technical characteristics of the equipment used in the PV installation

| | |
|---|---|
| The PV generator | • Panels (SP75) with optimal voltage 13.7V and optimal current 4A under STC conditions.<br>• The optimum voltage range [Vmin, Vmax] = [12.5V, 14.5V] |
| The Boost converter | • Can boost the voltage up to 100V<br>• Dimensioned to work for a max current around 12A and a chopping frequency of 10KHz |
| The solar battery | • With a capacity equal to 110Ah and a nominal voltage equal to 12V<br>• Depth of discharge: 40% |

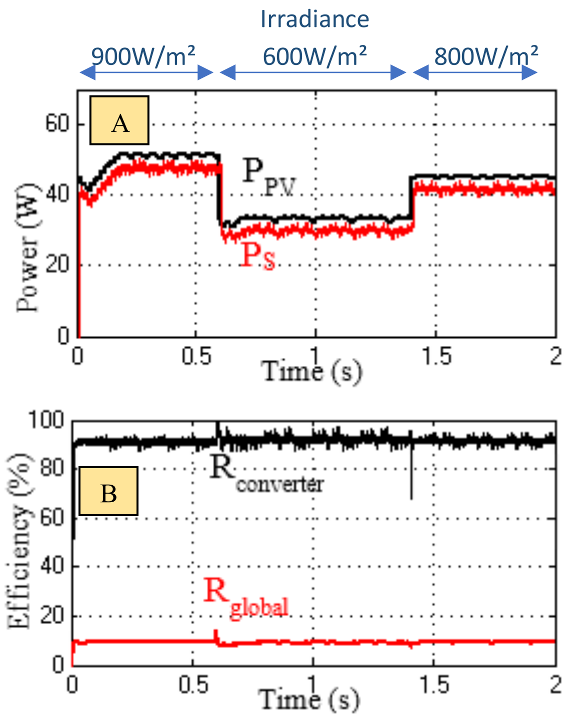



**Fig. 3.** The variation of the electrical quantities as a function of time of: A; the $P_{PV}$ power generated by the PV panels and the $P_{BAT}$ power transfer to the load (battery), B; Rconverter conversion efficiency and Rglobal overall efficiency.

## 4. Experimentation of the prototype

### *4.1. The measurement bench*

The experimentation and the validation of the results is confirmed **by carrying out** an automated measurement bench. The bench to consider is equipped essentially by:

- The fabricated prototype (Fig. 4) comprises a photovoltaic panel (SP75), two batteries in series, a boost converter and the control system. The technical characteristics of these equipment are presented on table 1.
- A mini weather station (Fig. 5) for measuring the temperature and the irradiance for studying their influence on the installation operation.
- An automated acquisition interface (Fig.6) for the recovery the various quantities and the electrical data from the installation in real time.

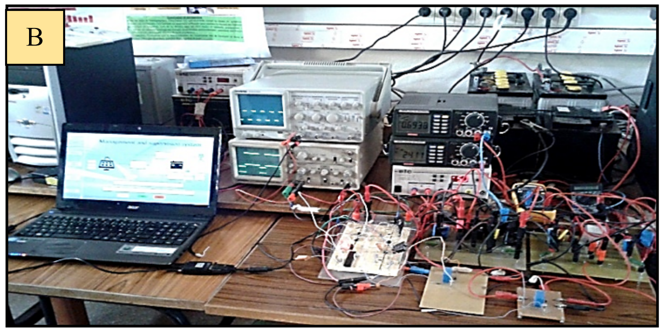




**Fig. 4.** the PV system prototype, A: the SP75 panels, B: the electrical circuit built.

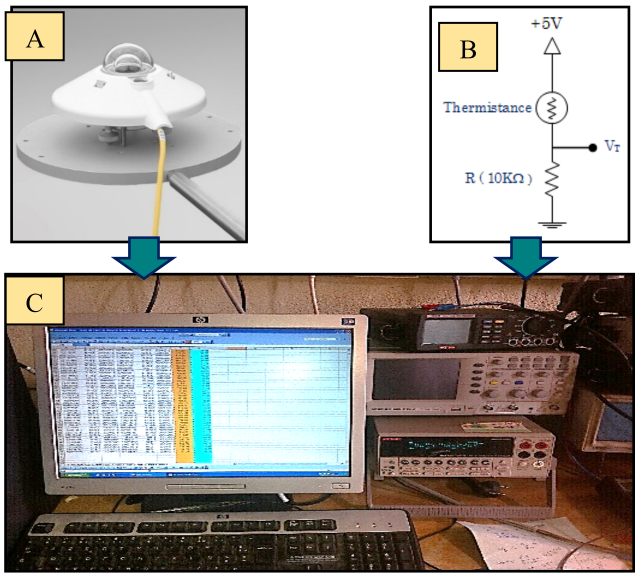
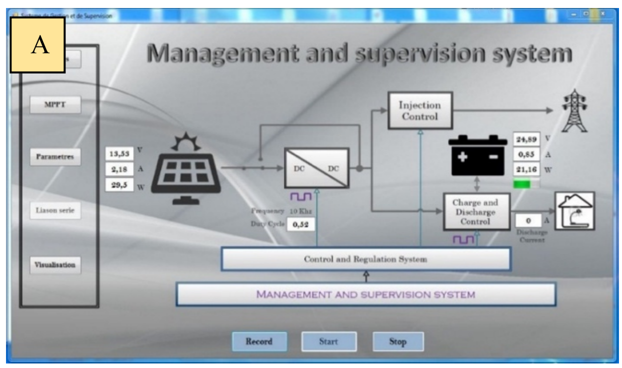



**Fig.5.** The mini weather station, A: the pyranometer for measuring the irradiance, B: the thermistor for measuring the temperature, C: the PC for acquisition and display of the data



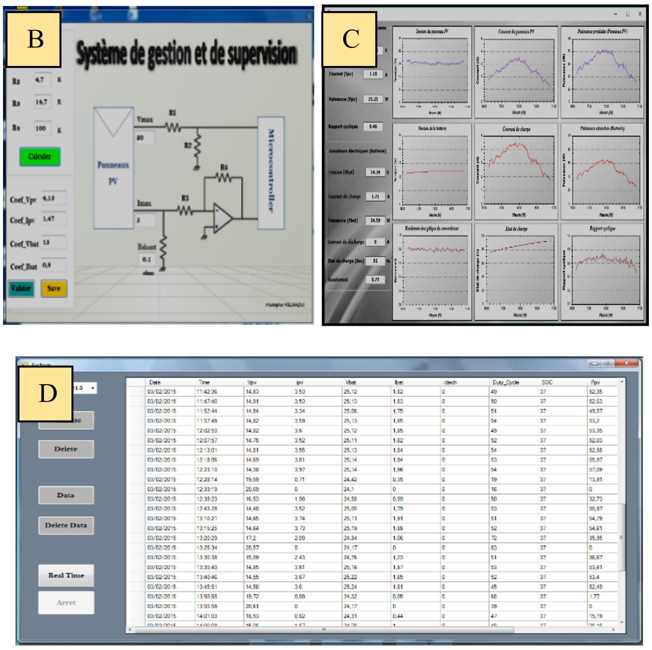



**Fig. 6**. The interface for acquisition of the electrical quantities, A: main menu, B parameterization of acquisition circuits, C: digital display and graph of electrical quantities, D: data storage.

*4.2. The system operation and the results comparison*

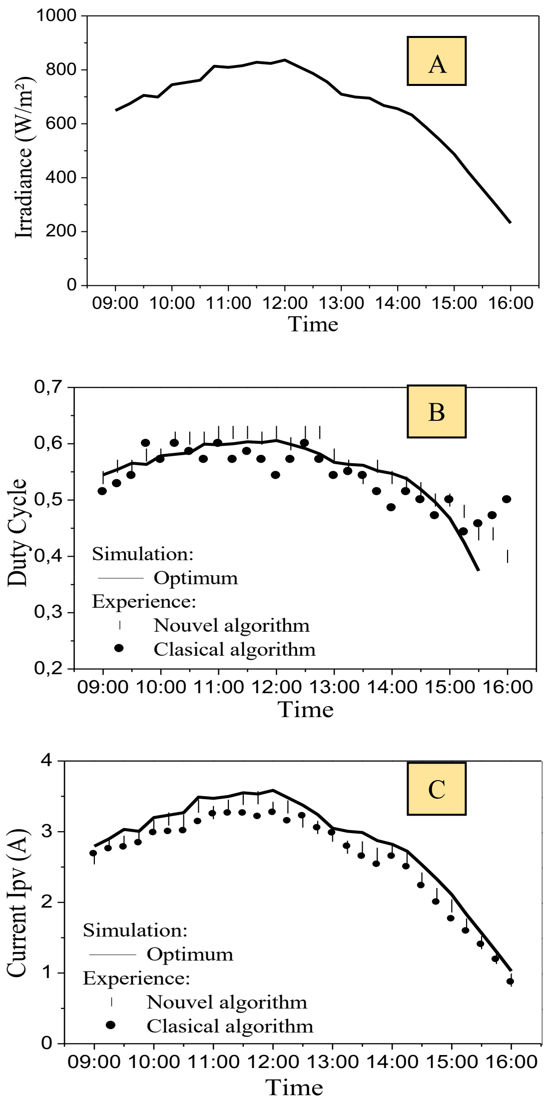
*4.2.1. The optimal operation*

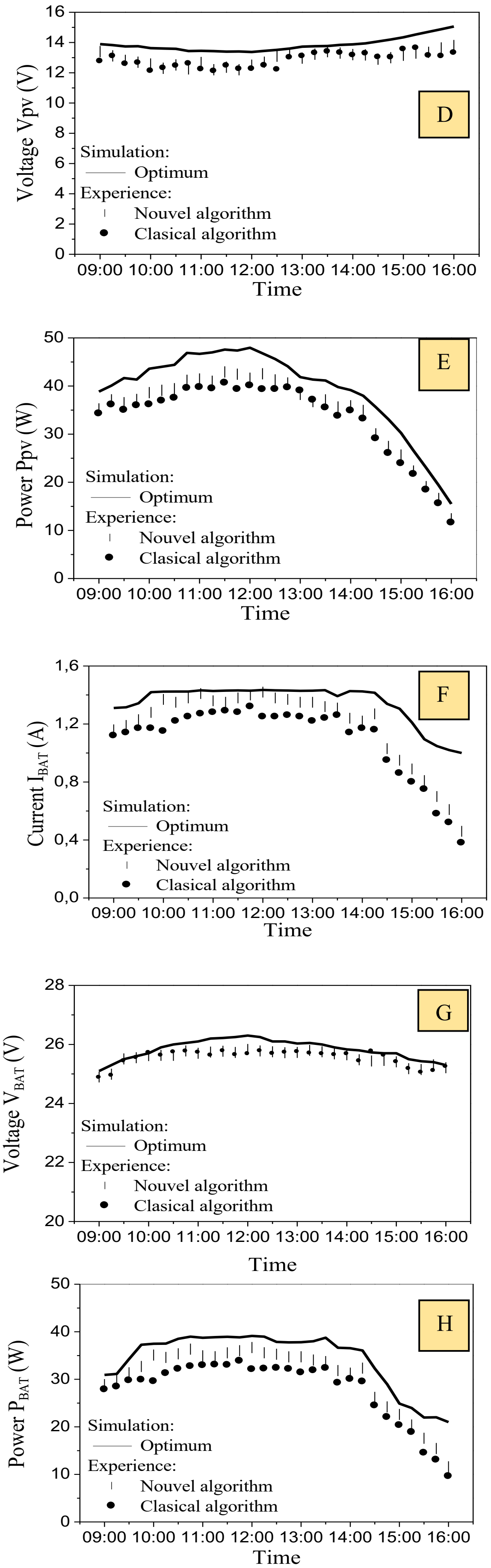
For the enhancement of the system and the proposed system control, two PV installations have been built in order to study their operations and to compare their performance. The 1st installation is equipped by the proposed system control which optimizes the operation through the maximization of the current and the 2nd installation equipped by a classical MPPT control (P & O [15] ).

In this paragraph we expose the results obtained from the optimization of the two installations compared to the optimal results obtained with Pspice software [16,17] under the same conditions and during one day of experimentation.

The Figure 7 shows the variation as a function of time of irradiance (Fig. 7.A), the duty cycle (Fig. 7.B), the $I_{PV}$ current (Fig. 7.C), the $V_{PV}$ voltage (Fig. 7.D), the $P_{PV}$ power. (Fig. 7.E), the $I_{BAT}$ current (Fig. 7.F), the $V_{BAT}$ voltage (Fig. 7.G), the $P_{BAT}$ power (Fig. 7.H), the conversion efficiency (Fig. 7.I), and the overall efficiency (Fig. 7.J). The results obtained show that:

- The irradiance varied during the experimental day from 250 W / m² to 850 W / m². The maximum values are recorded around noon.
- The values of the electrical quantities (duty cycle, current, voltage, power) of the proposed control and the P & O control follow the evolution of the optimal ones obtained by simulation on Pspice. However, the values of the electrical quantities related to the proposed control are closer to the optimum quantities than those of the P & O control.
- By comparing the two PV powers produced using the two methods control, with the optimal electrical quantities, the results show that for the proposed one; The losses are estimated at 12%, while for the Classical one (P & O) these losses are of the order of 15.5%
- The energy produced by the PV panel during this day is in the order of 244Wh by using the proposed Method control and is of the order of 234Wh by using the classical one. These values show that the energy gain provided by the new method is in the range of 3.66%.
- The operation of the system carried out during this day presents an average conversion efficiency of about 88% and an overall system efficiency of about 9.3%. For the P&O MPPT control; the conversion efficiency is in the order of 85.2% and the total is in the order of 8.7%. The efficiencies of the proposed control are satisfactory and show a clear improvement in value that could reach 3.5% for the converter performance and 5.5% for the overall performance.





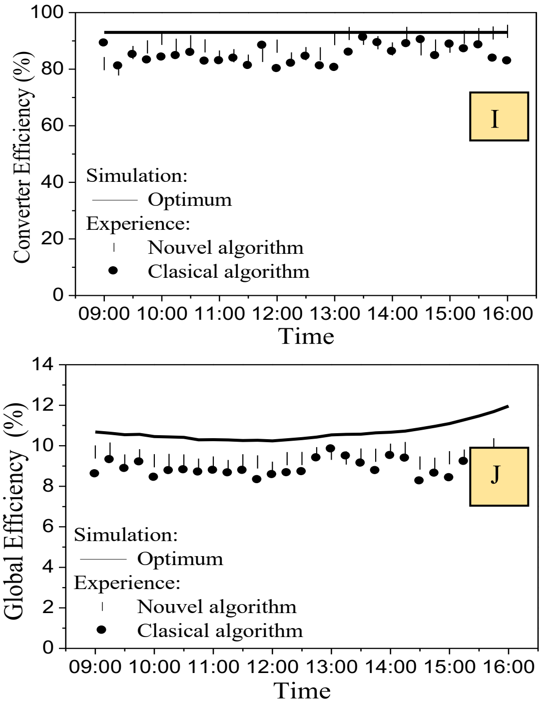




**Fig.7.** The evolution of the experimental electrical quantities (proposed control and P & O control) and simulated on Pspice. A: The irradiance, B: the duty cycle. C: the $I_{PV}$ current, D: the $V_{PV}$ voltage, E: the PPV power, F: the $I_{BAT}$ current, G: the $V_{BAT}$ voltage, H: the $P_{BAT}$ power, I: conversion efficiency J: global efficiency

*4.2.2. The convergence time to the MPP point*

In this paragraph, we present a comparative study of the convergence time to the MPP point by the proposed control method and the classical one (P&O) [18]. The experiment was carried at the same time and under the following conditions : we imposed the starting operation point by fixing the value of the duty cycle [19] at different positions of the panel power-voltage characteristic, then we identified the electrical characteristics (voltage, current, power) points in the beginning and the end of operation as well as the convergence time to MPP point [20]. The experimental results (Fig. 8) show that:

➢ The convergence time to the MPP depends strongly on the displacement direction along the characteristic of the panel. Indeed, in Fig. 8.A we show the above mentioned time time and concluded that under the conditions of open circuit the search time of the MPP is significantly higher than that in the conditions of the closed circuit.

➢ The ratio of research time ($T_{CLA}$ / $T_{NEW}$) in the presence of classical MPPT method P&O ($T_{CLA}$) and algorithm of the proposed control ($T_{NEW}$) depends strongly of operating conditions. Indeed, in Fig. 8.B we present the evolution $T_{CLA}$ / $T_{NEW}$ relative to the PV panel operating point to different irradiances. This allows us to see that; in the range of the optimal operation of panel (12V-15V) and for fairly high irradiance, the report $T_{CLA}$/$T_{NEW}$ tends to 1 which means the convergence time of the two controls methods are almost the same. For relatively low irradiance and/or outside of the optimal range (12V, 15V) the algorithm of the proposed control is faster than the classical one, indeed, and as illustrated in Fig. 8.B the ratio of search time ($T_{CLA}/T_{NEW}$) reached 2 in the range of values in the short-circuit conditions, and 1.3 under the conditions of open circuit.

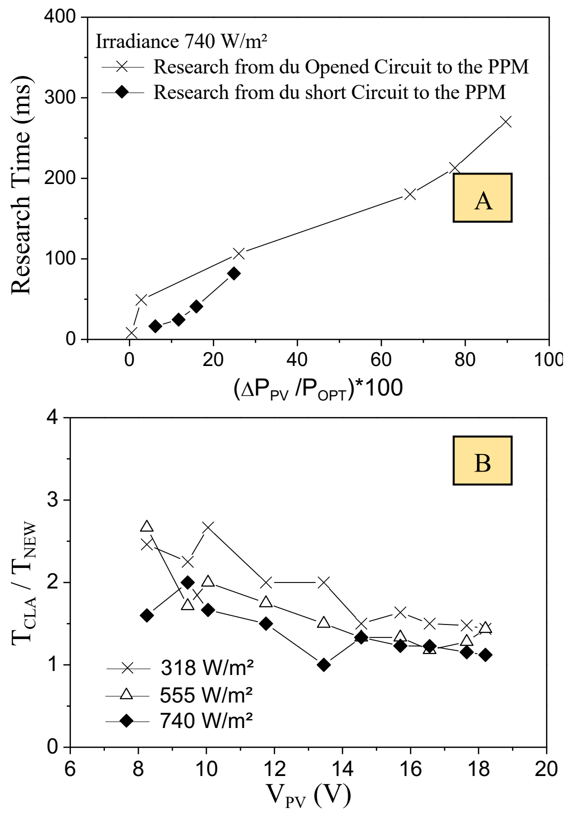



**Fig. 8.** The experimental results of evolution: A: Search time of the MPP point as function as the

## 5. Conclusion

In this work, a technique is developed to extract the maximum of power from the photovoltaic panels by maximizing the current at the output of the DC/DC converter. This technique is easily applied in off-grid PV installations. The experimentation and the comparison of its performances with the P&O method show a clear improvement during the operation of the installation. Besides, the PV system using this new method ensures the stability of the system, which make it reliable and faster compared to the P&O one.

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