A Combined MPPT Algorithm for Photovoltaic Systems Based Arduino Microcontroller

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A Combined MPPT Algorithm for Photovoltaic Systems Based Arduino Microcontroller

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Abstract – *Photovoltaic energy is a renewable source of clean and attractive energy compared to conventional energy sources. Photovoltaic panels (PV) have a non-linear I-V characteristic that depends on climatic conditions. In order to operate the photovoltaic modules at their maximum power point (PMM), MPPT algorithms are developing in order to extract the maximum energy. The Perturb and Observe (P & O) technique is widely used in photovoltaic systems because of its simplicity but remains vulnerable to sudden changes in weather conditions. In this paper, a new multi-objective MPPT algorithm combining three techniques: MPPT type (P & O), fractional short-circuits current (FSCC) and fractional open circuit voltage technique (FOCV) is proposed. This multi-objective algorithm improves the performance of conventional MPPT (P & O). A variable pitch perturbation and detection of sudden changes in illumination and / or temperature levels allows better stabilization of the duty cycle once the PPM is reaching. The proposed algorithm is testing by Matlab/Simulink and the results obtained are compared with experimental results using Arduino Uno microcontroller and appropriate sensors.*

***Keywords**: Photovoltaic Panel, P&O MPPT, FSCC MPPT, FOCVMPPT, Arduino Microcontroller*

I. Introduction

To reduce the damage caused by fossil energy to earth ecological environment, their limited resources and the danger posed by nuclear energy, it is very necessary to develop renewable energy technology, with unlimited sources of energy like solar, wind, biomass, etc. The development of renewable energy technology is becoming increasingly necessary due to the damage caused by fossil energy sources to the terrestrial ecological environment and their limited resources as well as the danger posed by nuclear energy. The photovoltaic energy is also increasingly important thanks to the abundance of the sun and the know-how acquired by many scientists in recent years. It is a non-polluting, silent energy and does not require much maintenance, hence its involvement in the economic field and its impact on the ecological environment [1], [2].

Solar panels have a non-linear I-V characteristic with a maximum power point that depends on climatic conditions and solar cell fabrication technology [3], [4]. Due to the non-linear relationship between current and voltage of the photovoltaic cell, there is a single maximum power point (MPP) in a particular environment, and this power point continues to change with the solar irradiance and ambient temperature [3]. Therefore, Peak Power Point Monitoring (MPPT) is a critical part of the PV system to ensure that power converters operate at the maximum power point (MPP) of the PV module.

Directly connecting the photovoltaic modules to the load causes enormous energy losses because the PV may not work at its maximum power point. To solve this problem and optimize the PV output power, different MPPT (Maximum Power Point Tracking) control techniques are used by adding an adaptation interface between PV module and load. These techniques differ in terms of the number of sensors used, the complexity and the cost of the algorithm implementing [5], [6], [7].

The MPPT (P and O) is one of the most used techniques because of its simplicity and the ease of its implementation; it consists of disrupting the voltage of the system and observing the power delivered by PV module. If the disturbance increases the power, the next increment will be in the same direction, otherwise the disturbance will be reversed [8]-[10].

The major disadvantage of this method is that it does not follow the maximum power point of the solar panel during sudden changes in temperature or irradiance. Because during the process and if there is an increase or decrease in PV output power due to weather conditions, the system will take it for a result of the previous disturbance, which is false. The oscillation around the PPM once reached, causes losses in power. Increasing the step of the increment makes it possible to respond rapidly to these changes but increases the losses by oscillation. If the pitch is narrower, oscillation losses will be minimal but the control will not follow the sudden changes [11], [12].

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Other techniques like the fractional short circuit current (FSCC) are used. It consists on periodic measurement of the short circuit current of the PV module, which is in approximately linear relation to the current of the PPM, the fractional open circuit voltage (FOCV) that consists of permanent measurement of the open circuit voltage of the PV module to calculate the PPM voltage. These are simple techniques and relatively easy to implement, but the permanent measurement of the short circuit current or the open circuit voltage requires that the photovoltaic module be periodically short-circuited or open-circuited. This cause loss of power at each measurement performed [13].

In the present paper, a new algorithm combining three MPPT (P & O, FSCC and the FOCV) control techniques is proposing to optimize the performance of conventional P&O MPPT, with a variable increment step in order to accelerate the process to reach PPM and reduce the losses caused by the oscillation around of the PPM. This new algorithm treats the malfunction during sudden changes in illumination and temperature levels and has an increment that stabilizes if the output power of the solar panel exceeds a pre-calculated threshold. Matlab Simulink tests the proposed organization chart under various climatic conditions. An implementation of the proposed method is elaborating using Arduino microcontroller with current, voltage and temperature sensors. The experimental obtained results are comparing with the results of the simulation.

II. Photovoltaic Panel Modeling

The scientific community offers several models for modeling photovoltaic generators [14], [15], [24]-[26]. The equivalent electrical model used in this paper is the single-diode model with a series resistor as shown in Fig. 1 [16]. We take the technical specifications of photovoltaic panel from the datasheet, delivered by the manufacturer in order to model it by Simulink-Matlab. The equivalent electrical circuit is shown in the following figure.

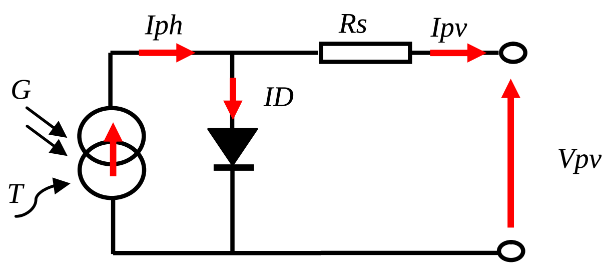

Fig. 1. Electric circuit equivalent of one diode PV model [16]

The photovoltaic panel I-V characteristic is giving by Eq.(1):

$$I_{pv} = I_{ph} - I_D \tag{1}$$

where I_{ph} and I_D are the current photon and diode current:

$$I_{ph} = \frac{G}{G_{ref}}\left[I_{scr} + \mu\left(T - T_r\right)\right] \tag{2}$$

$$I_D = I_S\left[\exp\left(\frac{q\left(V_{pv} + R_S I_{pv}\right)}{AKT}\right) - 1\right] \tag{3}$$

$$\mu = \frac{I_{sc}\left(T_2\right) - I_{sc}\left(T_1\right)}{I_{sc}\left(T_1\right)} \times \frac{1}{T_2 - T_1} \tag{4}$$

$$I_S = I_{sr}\left(\frac{T}{T_r}\right)^{\left(\frac{3}{A}\right)} \exp\left[\frac{qE_G}{AK}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right] \tag{5}$$

$$I_{sr} = I_{scr}\exp\left(\frac{-qV_{ocr}}{AKT_r}\right) \tag{6}$$

V_{pv} and I_{pv}: PV output voltage [V] and current [A] respectively.
G and G_{ref} : Irradiance and reference irradiance [W/m²].
I_{scr} [A] and V_{ocr} [V]: Reference short-circuit current and open circuit voltage respectively.
μ : Temperature short circuit current coefficient.
T and T_r : Temperature and reference temperature [K].
I_S : Diode saturation current.
q: Elementary charge [1.6×10^{-19} C].
A: Diode ideality factor [included between 1 and 2 for Silicium].
E_G : Silicium band gap [1.19eV].
K: Boltzmann constant [1.381×10^{-23} J K^{-1}].

We can find various ways for calculation series resistance in the literature, for simplification of simulation; we use the formula given by [17]:

$$R_S < 0.1\frac{V_{oc}}{I_{cc}} \tag{7}$$

The Canadian Solar Inc type CS4-55 PV specifications are shown in Table I.

TABLE I
PARAMETER SPECIFICATION OF CS4-55 PV PANEL

Irradiance	G_{ref}	1000	W/m²
Temperature	T_r	25	°C
Open circuit Voltage	V_{ocr}	21.6	V
Short circuit current	I_{scr}	3.48	A
Voltage peak power	V_m	17.2	V
Current peak power	I_m	3.2	A
Typical peak power	P	55	W
Temperature coefficient of I_{sc}	μ	-0.047	A

The curves I (V) and P (V) of the photovoltaic panel modeled by the Simulink for 1000 W/m² of irradiance and a temperature equal to 25°C are represented on Fig. 2.

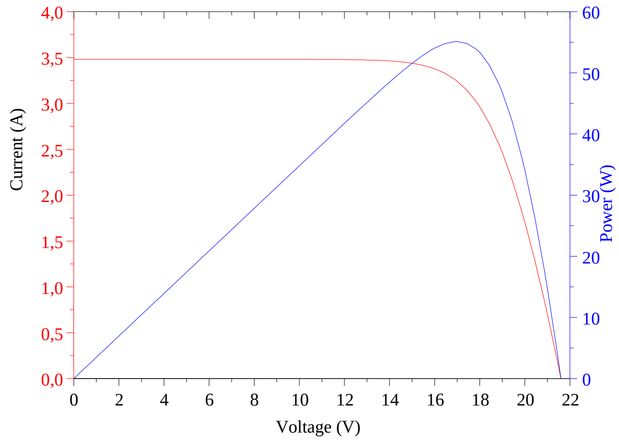

Fig. 2. I(V) and P(V) characteristic

III. DC/DC Boost Converter

In order to optimize the PV output power, we use an adaptation stage between the source and the load. In this paper we use a DC / DC boost converter to adapt the PV impedance to the load impedance by modifying chopper duty cycle to track the PV maximum power point.

Fig. 3 shows that the converter comprises an inductive filter *L*, a capacitive filter *C*, a diode D and a switch K. When K is closed, the current increases linearly in the inductance *L*, the diode is blocked. When K is open, the energy stored in *L* is released at the input of the RC circuit [18].

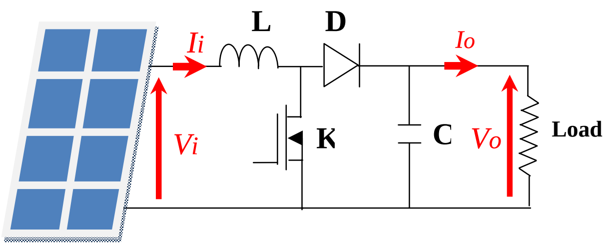

Fig. 3. The boost converter synoptic circuit

The output voltage V_o of the chopper function of input voltage V_i and duty cycle D is given by equation (8) [18]:

$$V_o = \frac{V_i}{1-D} \tag{8}$$

The minimum value of the inductance and capacitance of the capacitor for the DC/DC boost converter to operate in CCM mode is given as follows [18]:

$$L_{min} = \frac{(1-D)DR}{2f} \tag{9}$$

$$C_{min} = \frac{DV_S}{V_r Rf} \tag{10}$$

In this paper, we use an N-channel Mosfet transistor (IRFZ44N) which does not consume much energy with a high switching frequency. We modify the output PWM frequency of Arduino uno microcontroller to obtain 7.8kHz, the input and output capacitor is 470µF, the inductance is equal to 0.11mH.

IV. MPPT Techniques

In this section, we begin by presenting the principle of the three MPPT techniques used, conventional MPPT (P&O), fractional short circuit current method (FSCC) and fractional open circuit voltage method (FOCV). After, we explain how to combine these three techniques to obtain the proposed algorithm.

IV.1. Perturb & Observe MPPT

Tracking the maximum power point of PV by conventional Perturb & Observe algorithm is the most used in photovoltaic field for its simplicity to implement [9],[10]. This technique consists of disturbing the voltage of PV and observing the evolution of its output power, if it increases the output power the disturbance continuous in the same direction. Otherwise, the disturbance is reversing. The disadvantage of this method is that it does not follow good sudden changes in illumination and / or temperature. Also, the oscillation around the MPP causes energy losses, decreasing the step size of disturbance, reduce these losses, but the method will be slow and sudden changes in climate will greatly affect the process of the maximum power point tracking. Increase the step size of disturbance makes this technique rapid but this will cause more loss by oscillation. The flow chart of the conventional MPPT P & O is shown in Fig. 4.

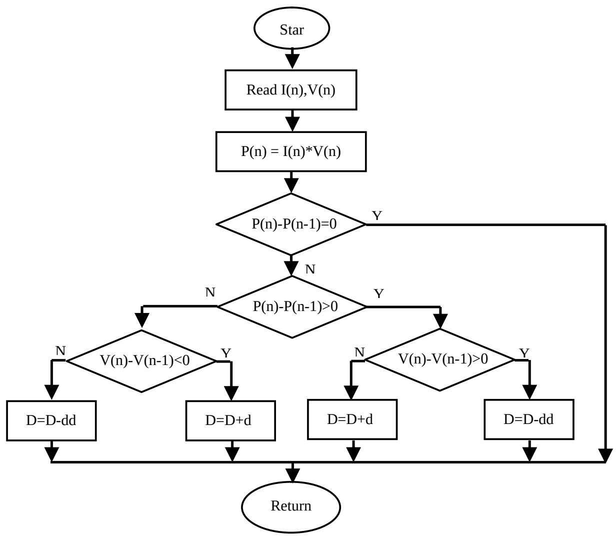

Fig. 4. P&O MPPT technique Flowchart

IV.2. The Fractional Short-Circuit Current (FSCC) MPPT

This technique is based on approximately linear relation between the short-circuit current I_{SC} and the maximum current that corresponds to the current of the PV maximum power point I_{MPP} under various atmospheric conditions [19],[20]:

$$I_{MPP} = K_1 I_{SC} \tag{11}$$

The constant K_1 is proportional to the used PV characteristics and generally included between 0.78 and 0.92, this constant varies little with illumination and temperature [21] and can be calculated from the datasheet by calculating the ratio from equation (11) [22]. This method is simple and inexpensive, but its disadvantage is that PV must be short-circuited periodically to measure the short-circuit current, which causes losses at each measurement. The flowchart of this technique is shown in Fig. 5 [13].

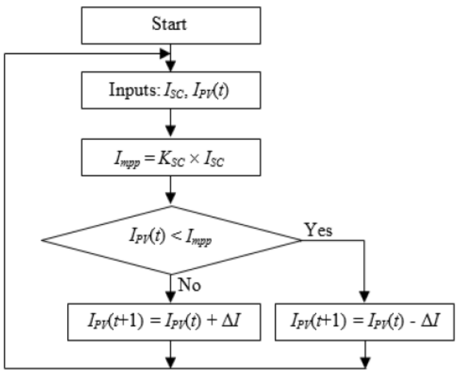

Fig. 5. Flowchart of FSCC MPPT technique

IV.3. The fractional Open-Circuit Voltage (FOCV)MPPT

The algorithm of this technique is based on the approximately linear relation between the open-circuit voltage V_{OC} and the PV maximum power point voltage V_{MPP} under various levels of irradiance or temperature [20]. This equation is giving by the following equation:

$$V_{MPP} = K_2 V_{OC} \tag{12}$$

The constant K_2 is proportional to use PV characteristics and generally included between 0.71 and 0.78, this constant varies little with illumination and temperature [21] and can be calculated from the datasheet by calculating the ratio from equation (12), [22]. The disadvantage of this technique is that the open circuit voltage is measuring by periodically isolating boost DC/DC converter, which causes energy losses. The flowchart of this technique is shown in Fig. 6 [13].

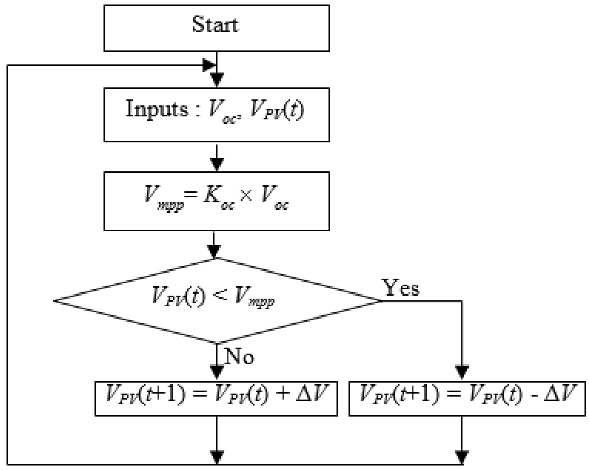

Fig. 6. Flowchart of FOCV MPPT technique

IV.4. The Proposed MPPT Algorithm

In this paper, we present an algorithm of an improved MPPT P & O with a variable step size to accelerate the process and decrease the losses caused by oscillation around the MPP. Perturb & observe technique is vulnerable to sudden climatic changes. To remedy this problem, the proposed algorithm detects changes in insulation levels and / or temperature and in this case, we have two possibilities:

- If the MPP is already reached, the incrementing is done immediately, and the algorithm continues its search.
- If the MPP has not yet been reached; the increment will be annulated before the algorithm continues its search.

The oscillations around the MPP are a major disadvantage of this technique and cause considerable losses. By combining two other techniques (FOCV and FSCC) to assist the conventional P & O technique, we can deduce the power of PPM by calculating I_{MPP} and V_{MPP}. If the output power of the PV is greater than or equal to 99% of P_{MPP}, the duty cycle is maintaining at its value then reduces the oscillation around MPP.

The flowchart of the P & O technique with a variable step size assisted by the FOCV and FSCC techniques is showing in Fig. 7.

V. Results and Discussions

We present the Simulink simulated results under various levels of illumination and temperature and then we expose the experimental results using an Arduino uno microcontroller with appropriate current, voltage and temperature sensors.

V.1. Simulation Results

In this section, we present the results of simulation of the proposed MPPT method and compare them with the conventional MPPT P & O for different levels of irradiance and temperature. The PV and boost converter were made using the different Matlab Simulink blocks, and the MPPT command using the embedded Matlab function.

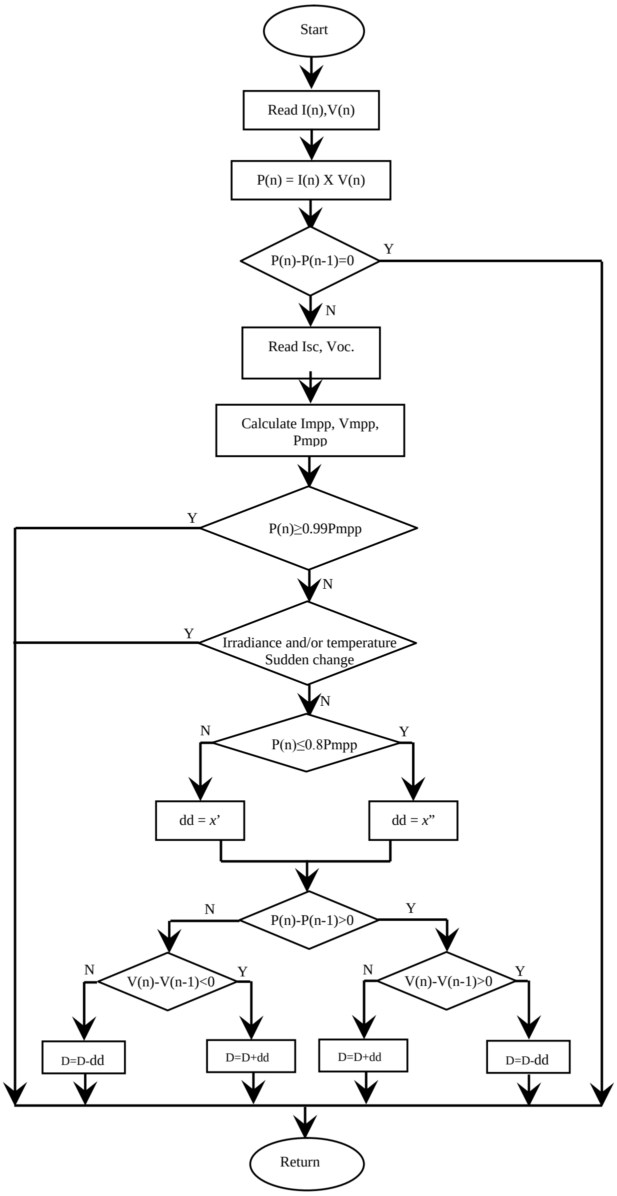

Fig. 7. The flowchart of the proposed MPPT

In our simulation, we use three identical PV, the first one to apply the MPPT command, the second and the last one to measure the short-circuit current and the open-circuit voltage respectively.

We can use two pilot cells with the same characteristics of those constituting the PV used for the proposed MPPT to measure the short-circuit current and open circuit voltage [23], in our case we do not have pilot cells available and its why we use two identical PV for our measurements.

The block diagram of the realized circuit to track the maximum power point is shown by Fig. 8.

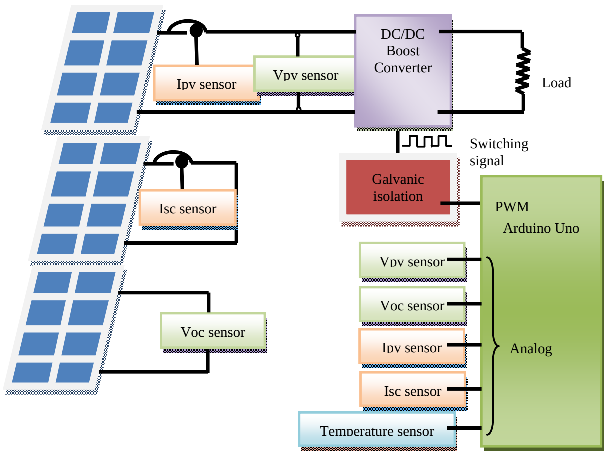

Fig. 8. Circuit diagram of the proposed system

There is an approximately linear relation between the short-circuit current I_{SC} and the irradiance G [13],the constant K is specific to each PV, in order to know its value in our case, we made the following calculation:

$$I_{SC} = K\,G \tag{13}$$

with G = 1000 W/m² ; I_{SC} = 3.48 A.

Then $K = 3.48\times10^{-3}$ Vm².

In the first part of simulation, we fix the temperature at 25 °C and we vary the irradiance by sudden jumps from 1000W/m² to 500W/m² then to 800W/m², and we compare the results of proposed algorithm to conventional P&O MPPT.

Figures 9 show the variation of the irradiance as a function of time, and we remark in Figures 12 that the boost converter output power oscillations around the maximum power point is decreased under varying climatic conditions. The step size of the disturbance varies to reach the MPP faster than the conventional method, and this is shown in Figures 9(b), 10 and 11. Once the PPM is reached, the duty cycle will stabilize and will only change if there is a change in temperature or illumination.

In order to study the influence of the gradual change of irradiance, we apply a fixed temperature equal to 25°C and a gradual change of illumination on the PV as shown in Figure 12(a).

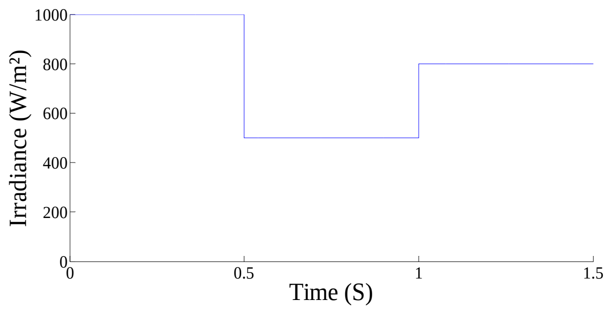

Fig. 9(a). Solar irradiance

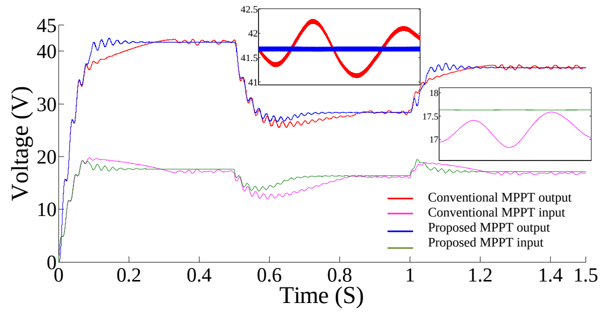

Fig. 9(b). DC/DC boost converter input output voltage

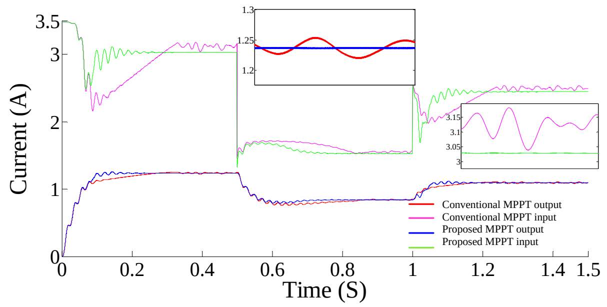

Fig. 10(a). DC/DC boost converter input output current

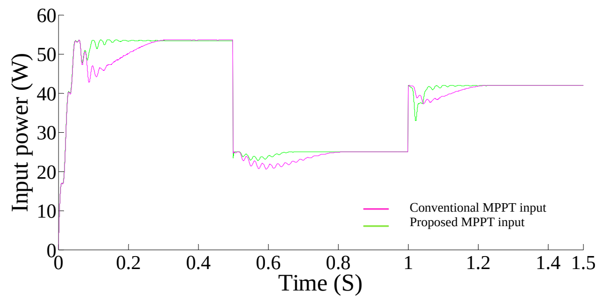

Fig. 10(b). Input power

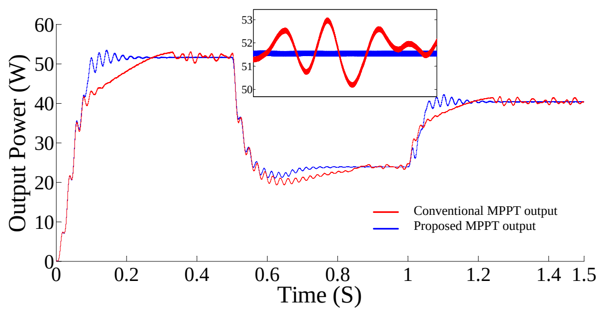

Fig. 11. DC/DC boost converter output power

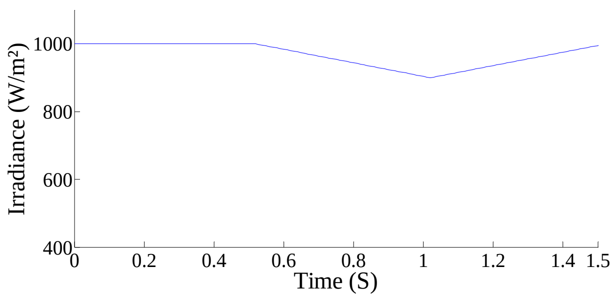

Fig. 12(a). Solar irradiance

Figures 12(b) and 13 show the output voltages, currents and powers of the DC/DC boost converter. We note that the oscillation around the maximum power point is greater in the conventional method than that proposed algorithm, which reduces the power losses by oscillation.

The second part of simulation consists on fixing the illumination applied to the PV at 1000W/m², and varying the temperature by sudden jumps of 25°C to 35°C then 15°C as shown in Figure 14(a). The results obtained are compared with those of the conventional algorithm.

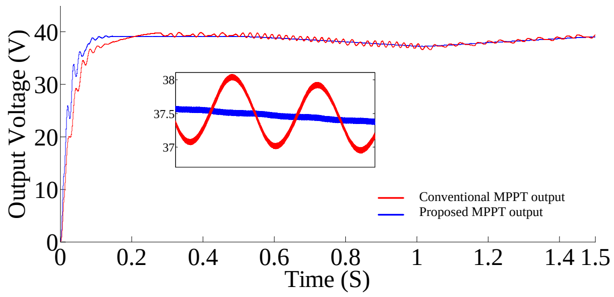

Fig. 12(b). DC/DC boost converter output voltage

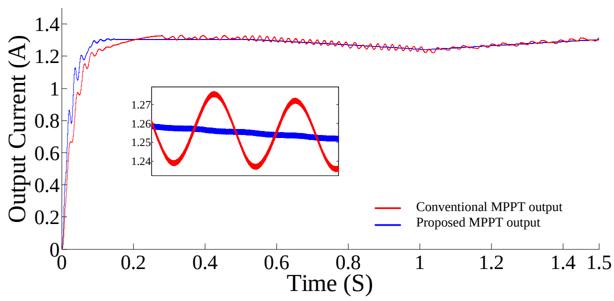

Fig. 13(a). DC/DC boost converter output current

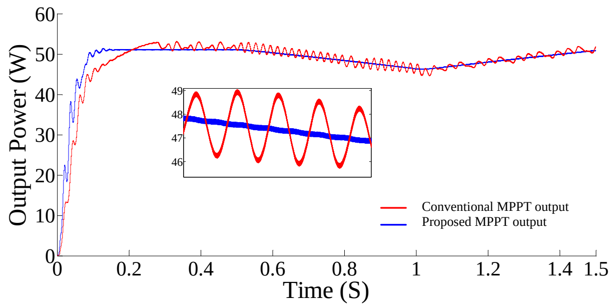

Fig. 13(b). Output power

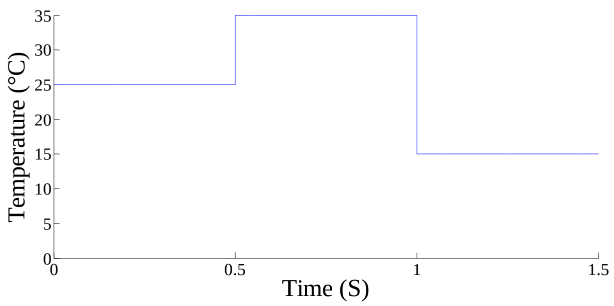

Fig. 14(a). Temperature

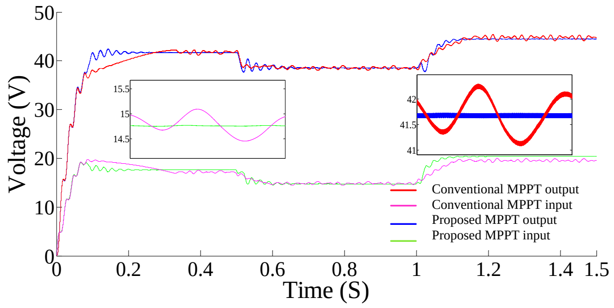

Fig. 14(b). DC/DC boost converter input output voltage

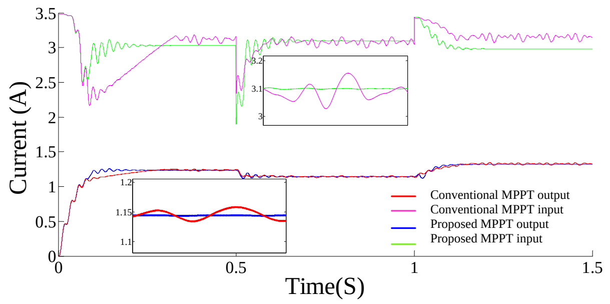

Fig. 15(a). DC/DC boost converter input output current

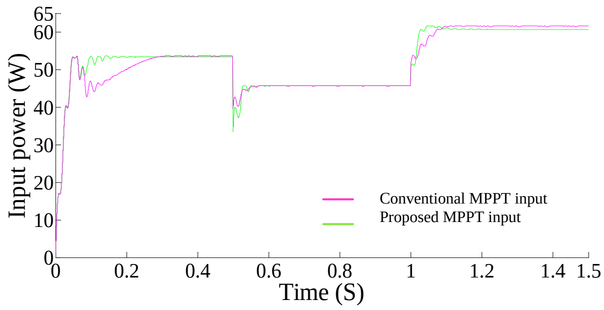

Fig. 15(b). Input power

Figure16 show that the proposed method follows the sudden changes in temperature and the oscillation around the maximum power point was reduced.

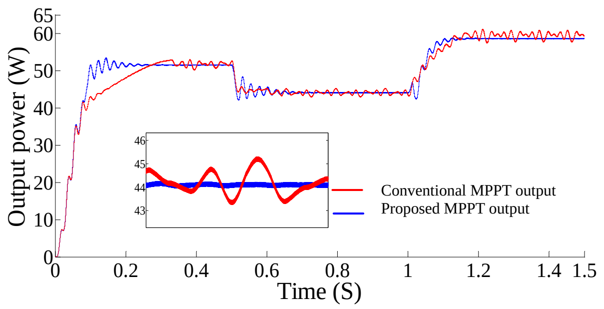

Fig. 16. DC/DC boost converter output power

V.2. Experimental Results

We use an Arduino uno microcontroller to drive all the process to track the PV maximum power point. Two ACS712 current sensors are used: the first one to measure the output current of the PV for MPPT algorithm, the second one to measure the short-circuit current and detects the sudden change of illumination at the same time.

Two voltage sensors are also used: the first for PV voltage measurement, and a second to measure the open circuit voltage. A voltage divider bridge circuits with high resistance are used to measure the voltage by the analog pins of the Arduino uno microcontroller.

The temperature was measured using LM35 temperature sensor with inexpensive simple mounting, reliable and a wide temperature range to perceive.

To control the grid V_{GS} and to isolate the Arduino uno microcontroller from the power circuit, we use the following galvanic isolation circuit [13].

To write the code of the proposed algorithm on C++ language and charged it on Arduino uno microcontroller, we use the open source Arduino software IDE.

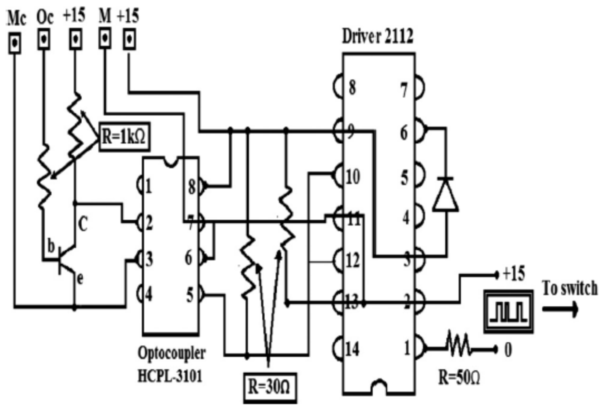

Fig. 17. Galvanic isolation circuit

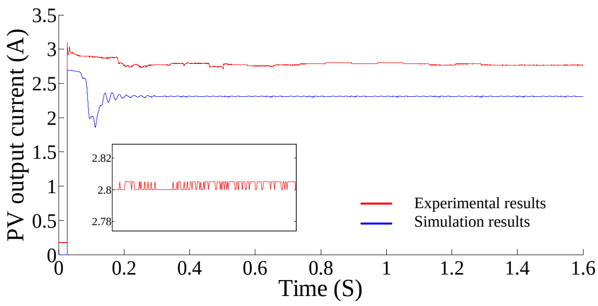

Fig. 18(a). PV output current

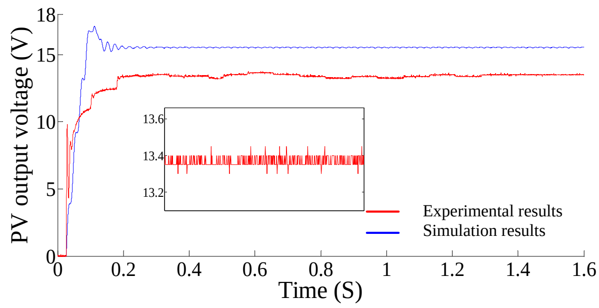

Fig. 18(b). PV output voltage

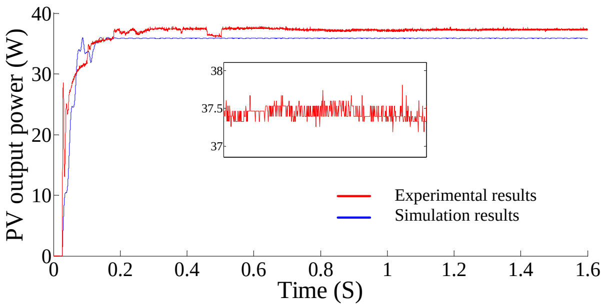

Fig. 19. PV output power

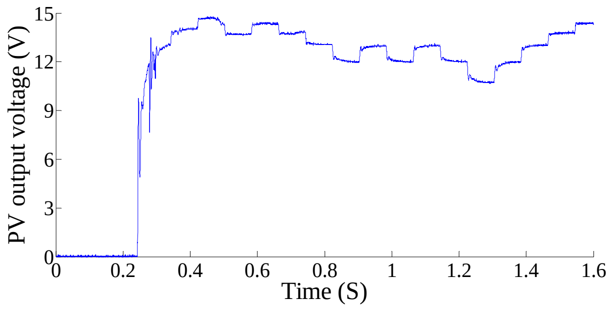

Fig. 20(b). PV output voltage

We measure the short-circuit current to calculate the maximum current and the irradiance using ACS 712 current sensor, and LM35 temperature sensor. We inject the average value of irradiance and temperature measured during the experience on Simulink Matlab to compare simulation and experimental results like shown on Figures 18 and 19. To observe the conventional P&O MPPT behavior, we charged to Arduino microcontroller another code who corresponding to conventional method, we obtain results shown on Figures 20 and 21. On Figure 21, we remark that the PV output power is disturbed by oscillation around the maximum power point while the Figure 19 show that the proposed algorithm reduce those oscillations.

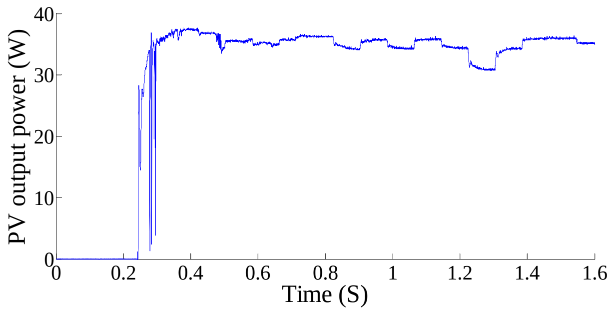

Fig. 21. PV output power

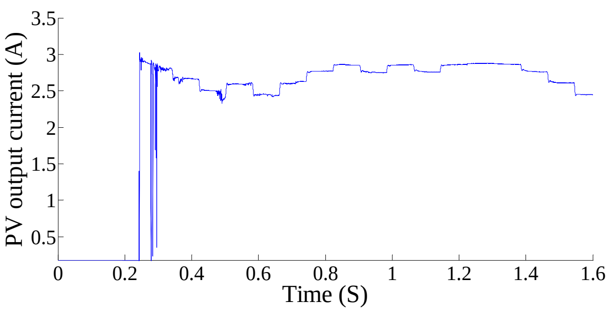

Fig. 20(a). PV output current

VI. Conclusion

Photovoltaic energy is a good solution to energy and environmental problems for many countries. The major stake is to increase the cost-efficiency ratio in order to be able to replace the fossil energies by the photovoltaic energy. The MPPT control systems have a very important role to extract the maximum power utilizable from PV array. This paper presents a novel MPPT algorithm to resolve the conventional P&O MPPT method inconvenient like oscillation around maximum power point and its performance during sudden changes on weather conditions.

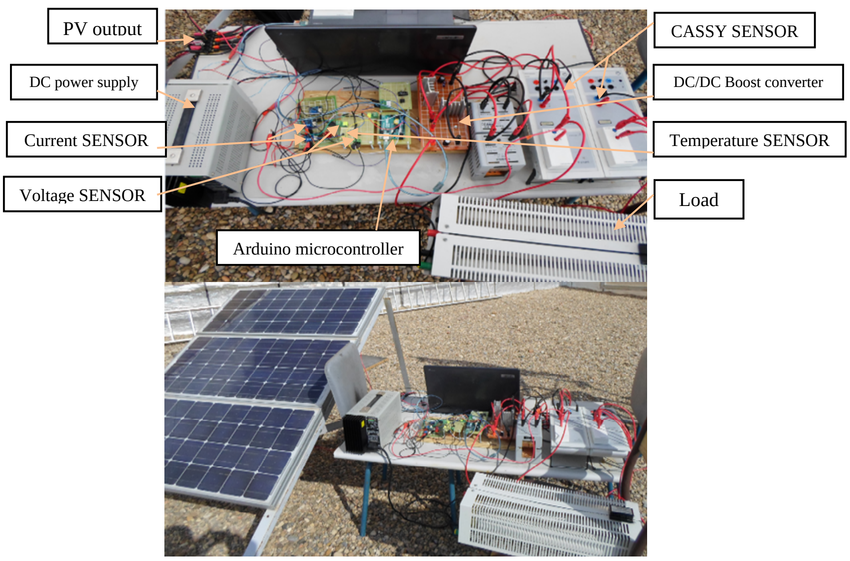

Fig. 22. Experimental set-up

We combine three MPPT techniques (P&O, FSCC and FOCV) with using variable step size voltage perturbation to reach the maximum power point speedily.

We calculate the maximum power of PV using maximum current obtained by FSCC technique and maximum voltage obtained and FOCV technique (we can use two pilot cell for this procedure) to stabilize the duty cycle for minimizing oscillation around MPP.

The proposed algorithm satisfies the two essential elements in determining MPP, which are fast and accurate response in case of rapid change of climatically conditions of temperature and solar radiation, compared to conventional algorithms.

We analyze the proposed algorithm by Matlab Simulink and compare it to conventional P&O algorithm, simulation results are validated by experimental results, using Arduino microcontroller and acquired by Cassy Lab Sensor.

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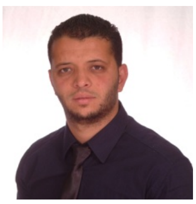

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