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# Implementation in Arduino of MPPT Using Variable Step Size P&O Algorithm in PV Installations

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**ABSTRACT**

In order to maximize the electric energy production of a photovoltaic generator (PVG), the maximum power point tracking (MPPT) methods are usually used in photovoltaic systems. The principle of these techniques is to operate the PVG to the maximum power point (MPP), which depends on the environmental factors, such as solar irradiance and ambient temperature, ensuring the optimal power transfer between PVG and load. In this paper, we present the implementation of two digital MPPT commands using the Arduino Mega type. The two proposed MPPT controls are based on the algorithm of perturb and observe (P&O), the first one with fixed perturbation step and the second one with two perturbations step varying with some conditions. The experimental results show that the P&O algorithm with variable step perturbation gives good results compared to the P&O algorithm with fixed perturbation step in terms of the time response and the oscillations around the MPP.

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## 1. INTRODUCTION

The use of renewable energy sources has become increasingly popular around the world, due to their functioning friendly to the environment [1]. Solar energy is the most promising one. It is a clean and important source for producing electricity [2],[3]. It has a huge energy potential compared to other sources [4]. Indeed, with an average irradiation of 5630 Wh/m$^2$/day, Morocco may cover their energy needs and export a part of it [5].

However, the output characteristics of PV module depend strongly on the solar radiation attaining the active surface of PV module and cell temperature of PV module. Furthermore, these parameters have a variable character depending on the latitude, the orientation of the solar field, the season and the hour of day. In other terms, the characteristics of the PV panels depend on the parameters continually changing during the day [6].

These characteristics, specifically those of PVG power P(V), admit a point corresponding to the maximum power, that is the optimum operating point, named MPP (maximum power point). A converter that ensures the conversion of electricity exploitable by the user must find and track the MPP continuously on the curve P (V). In this context, a large number of technical research of the maximum power point tracking (MPPT: Maximum Power Point Tracker) are well established in the literature.

Indeed, several methods exist, such as: "Perturb and Observe" (P&O) [7]-[10], the "Incremental conductance" (InC) [11]-[13] which are variants of the "Hill Climbing" [14], Fractional open circuit voltage

(FCO) or Fractional short circuit current algorithm (FCC) [15],[16], the techniques of artificial intelligence, such as the control by fuzzy logic [17]-[19], by genetic algorithm [20] or by neural networks [21]-[23] etc. Among these techniques, the "P&O" Classic is the most popular and easiest way to implement [24].

In this paper, we focus on the implementation of the command "P&O" classic with fixed perturbation step as well as variable step. This command is implemented on the Arduino board. Our paper is organized as follows: After this introduction, we will describe in the second part the test bench and measurement, then in the third part we will present the modeling of the Boost converter as well as their MPPT techniques. The last part will be devoted to the exhibition and analysis of experimental results followed by a conclusion.

## 2. TEST BENCH AND MEASUREMENT

### 2.1. Test bench

The present conversion chain constituting our test bench comprises a photovoltaic generator (PVG), supplying a DC load through a boost converter. This latter is controlled by an MPPT control type "P&O" in order to have the power supplied by the PVG corresponds to the maximum power generated. The block diagram of this system is illustrated in Figure 1.

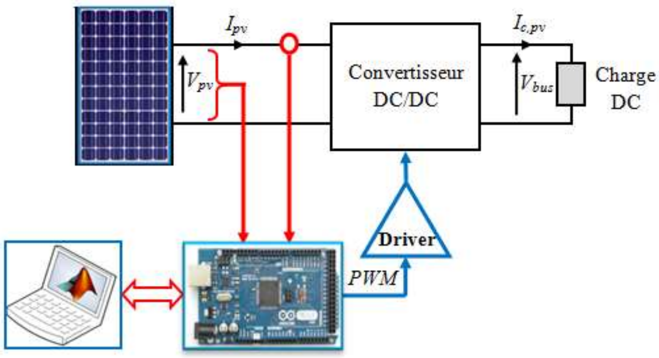


Figure 1. Synoptic scheme of the realized PV conversion chain

The principle measuring adopted in this test bench, is to take the current $I_{pv}$ supplied by the PVG as well as the voltage $V_{pv}$ between its terminals. These variables *Ipv* and $V_{pv}$ are delivered by the current and voltage sensors connected to the inputs of the analog digital converter integrated in the Arduino board type Mega 2560. This latter is programmed to be used as an acquisition card transmitting in real time, the numerical values acquired ($I_{pv}$, $V_{pv}$) to a computer through an RS232 / USB serial converter. Figure 2 below shows the realized prototype to validate the developed MPPT algorithms.

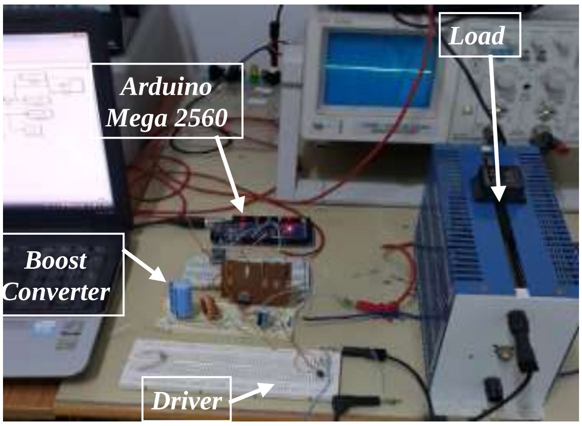


Figure 2. Realized test Bench

In terms of treatment unit, we have developed under the Matlab-Simulink environment a program that ensures the capture of the data ($I_{pv}$, $V_{pv}$) that will serve as inputs for the MPPT algorithms that we have developed. These algorithms determine the appropriate duty cycle $\alpha_{pv}$ for the Arduino board in order to produce a PWM signal (Pulse Width Modulation) this latter attack a driver amplifying the current control of the MOSFET transistor of Boost converter.

Concerning the capture, archiving and treatment of $I_{pv}$ and $V_{pv}$ sizes, the Figure 3 shows the block diagram for the program that we have developed under Matlab-Simulink. This allows us to visualize in real time the characteristics $I_{pv} = f(t)$, $V_{pv} = f(t)$, $I_{pv} = f(V_{pv})$ and the evolution of the power $P_{pv} = f(V_{pv})$ of PV module.

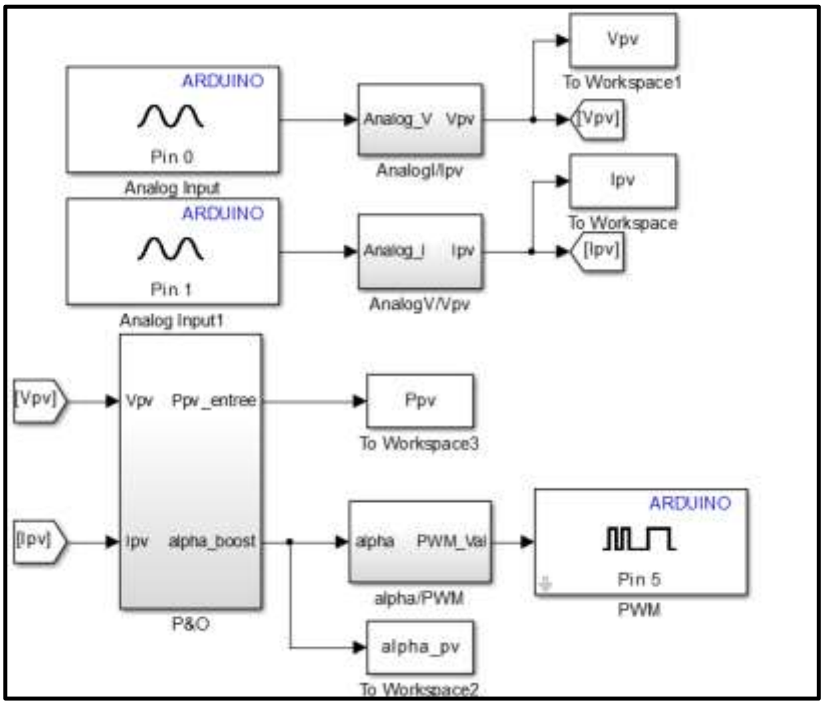


Figure 3. Acquisition program through the Arduino board and data processing under Matlab-Simulink

### 2.2. PV Module

The PVG used in our investigations is BP Solar MSX-64. Their electrical specifications provided by the manufacturer are given in Table 1 [25], under the standard test conditions STC (Standard Test Conditions: $G = 1000$ W/m$^2$, AM 1.5, $T = 25$°C). The results of characterization of this PVG using many models have been the subject of the publication [26].

Table 1. Electrical characteristics of the PV panel MSX-64 in STC[25]

| Parameters | Value |
|---|---|
| Maximum power Pmax | 64 W |
| Voltage at maximum power Vmpp | 17.5 V |
| Current at maximum power Impp | 3.66 A |
| Short-circuit current Isc | 4 A |
| Open-circuit voltage Voc | 21.3 V |

### 2.3. Bench measurement of meteorological conditions

In order to have the meteorological conditions of solar irradiance $G$ and temperature $T$, under which the quantities ($I_{pv}$, $V_{pv}$) are recorded, the Fig.4 illustrates the test bench installed in our laboratory of *EST* Agadir. Indeed, the solar irradiance $G$ and the temperature $T$ are measured by means of various sensors managed by *Cambell* acquisition unit of CR10X kind. The data $G$ and $T$ are collected every 10 seconds, depending on the configuration of the data acquisition unit [27].

Figure 4. Meteorological station with its *Cambell* central acquisition CR10X

## 3. MODELING

Before starting our study concerning the modeling of MPPT controls, we will propose to model the boost converter between the GPV and the DC load.

### 3.1. Boost converter modeling

The converter used in our work is the Boost type. It allows to increase the output voltage $V_s$ relative to the input voltage $V_{pv}$. The Figure 5 shows the circuit diagram modeling the converter, while Table 2 summarizes the values of the elements used to make this converter.

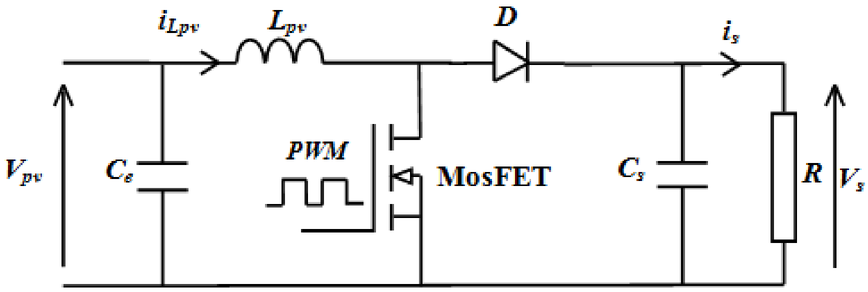


Figure 5. The Boost converter scheme

Table 2. Values of Boost converter elements

| Element | Symbol | Value |
|---|---|---|
| Coupling Capacitor | Ce | 2200 µF |
| Bobbin | $L_{pv}$ | 1 mH |
| Condensateur de sortie | $C_s$ | 220 µF |
| Load | R | 28 Ω |
| switching frequency of the MosFET | f | 1 KHz |

From the scheme of Figure 5 and the analysis of the various sequences of the boost converter functioning, our converter is represented by the following equations:

$$V_{pv} = L_{pv}\frac{di_{Lpv}}{dt} + (1-\alpha_{pv})V_s \quad (1)$$

$$C_s\frac{dV_s}{dt} + \frac{V_s}{R} = (1-\alpha_{pv})i_{Lpv} \quad (2)$$

With $\alpha_{pv}$ is the duty ratio of the PWM signal generated by the Arduino. Its value is between 0 and 1.

### 3.2. MPPT modeling

MPPT is one of the most used solutions to optimize the energy efficiency of PVG. In our case, we describe below the principles and the algorithms of two commands "P&O" with fixed perturbation ($PO_F$) and with variable step ($PO_V$). Then we test their validity experimentally.

#### 3.2.1. The principle of the technique $PO_F$

Generally, $PO_F$ method consists in perturbing the voltage $V_{pv}$ with fixed low amplitude, or with a fixed increment $C$ of duty cycle $\alpha_{pv}$, around its initial value and analyze the behavior of the variation of resulting power $P_{pv}$.

As illustrated in Figure 6, if the fixed perturbation of voltage $V_{pv}$ leads in one direction to the increased power $P_{pv}$, then the perturbation allows to move the operating point to the MPP, therefore the $PO_F$ algorithm will continue to trouble the voltage with the same increment and in the same direction. On the other hand, if the voltage perturbation causes the decrease of the power, then the direction of the perturbation must be reversed to achieve the convergence to the MPP. The corresponding flowchart of this algorithm is shown in Figure 7.

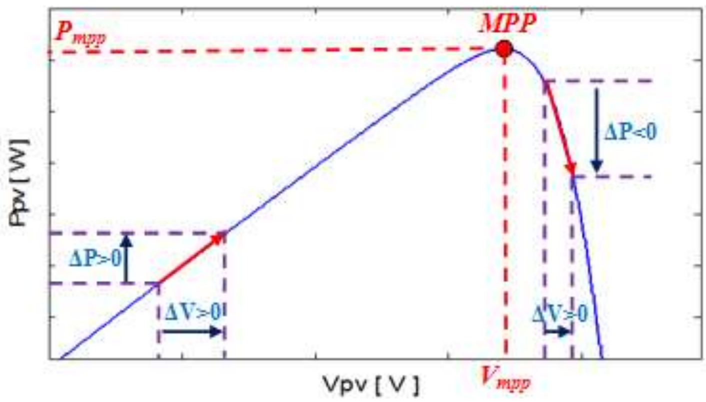


Figure 6. Principle research of MPPT by "P&O"

#### 3.2.2. The principle of the technical $PO_V$

The $PO_F$ algorithm with fixed perturbation has two major disadvantages related to the time convergence and oscillations around the MPP generated in permanent regime. These two problems are related to the increment step of the perturbation. However, a high value of the increment step minimizes the convergence time, but increases the oscillations around the MPP, while a low value of this step increment causes the minimizing of the oscillations but slows the research of MPP. We must find a compromise between precision and speed. To overcome to this problem, we proposed to use two steps $C_1$ and $C_2$ perturbation. If the variation of the power $P_{pv}$ is less than a certain threshold $Val$, then we use the $C_1$ step perturbation. In our case $C_1 = 0.01$ and $Val = \pm 5$ W. On the other hand, $C_2$ will be used with $C_2 = 0.001$. These two values were selected to have a rapidity initially and low oscillations around the PPM in permanent regime. The partial flowchart associated to this $PO_V$ method is illustrated in Figure 8. This latter is complementary to the flowchart of the Figure 7.

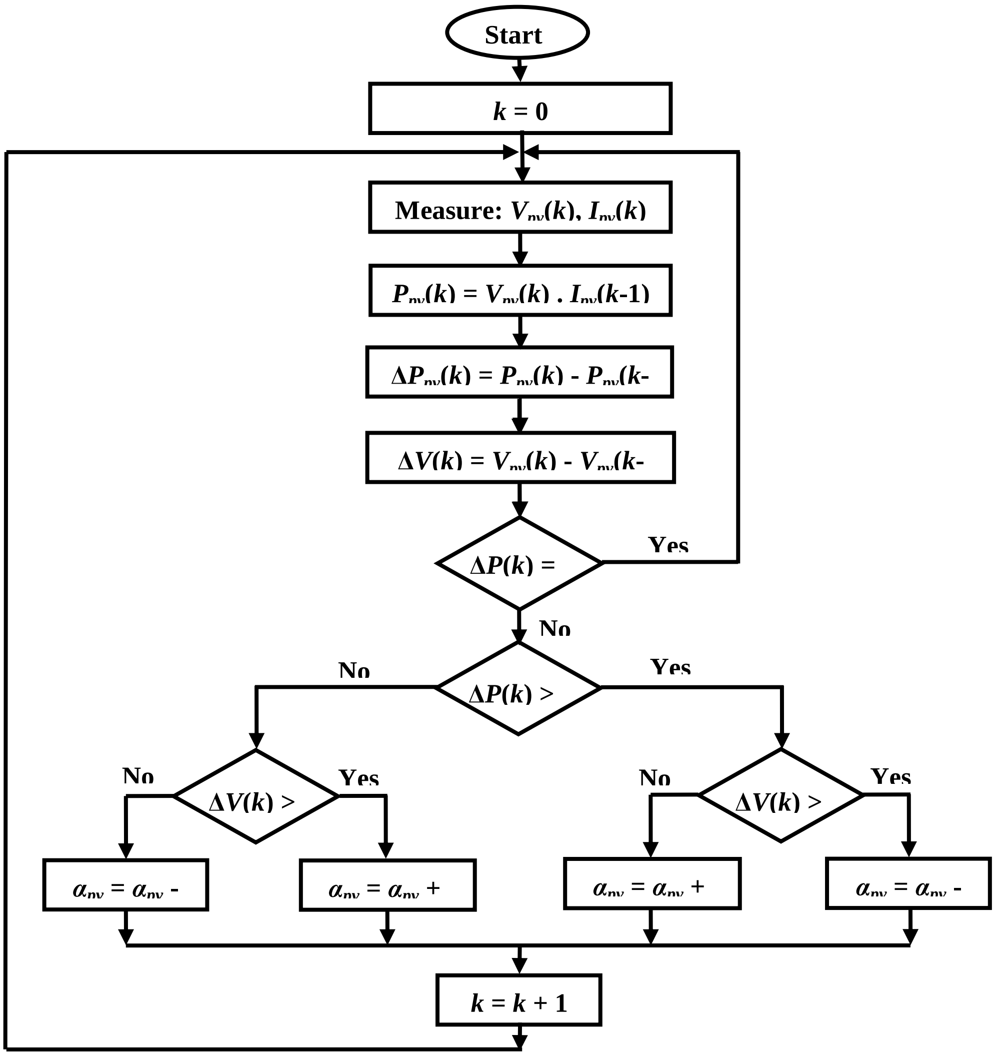


Figure 7. Algorithm of $PO_F$ method

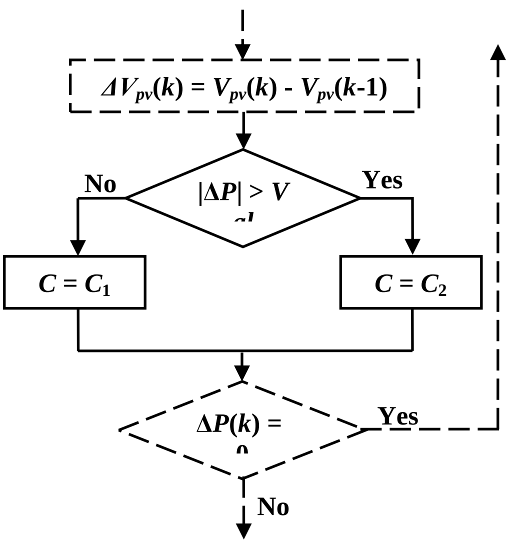


Figure 8. Partial algorithm of the method $PO_V$

## 4. EXPERIMENTAL RESULTS

In order to test the performance of the MPPT algorithms cited in Part 3.2, we are going to plot the output $I_{pv} = f(V_{pv})$ and $P_{pv} = f(V_{pv})$ of our PVG for different values of solar irradiance $G$ and temperature $T$. For this, we vary the duty cycle $\square_{pv}$ of 5% to 95% with a fixed increment. The obtained measurements allow us to determine the maximum power $P_{max}$ generated by our PVG. And then $P_{max}$ will be compared to the maximum power $P_{mpp}$ extracted by either algorithms $PO_F$ and $PO_V$. We note that $G$ and $T$ values measured by the weather station in Figure 4, are considered constant throughout the characterization duration.

The obtained measurements allow us to represent in Figure 9 the characteristics $I_{pv} = f(V_{pv})$ and $P_{pv} = f(V_{pv})$ for $G = 982$ W/m$^2$ corresponding to an irradiance received on the active surface of the PV module.

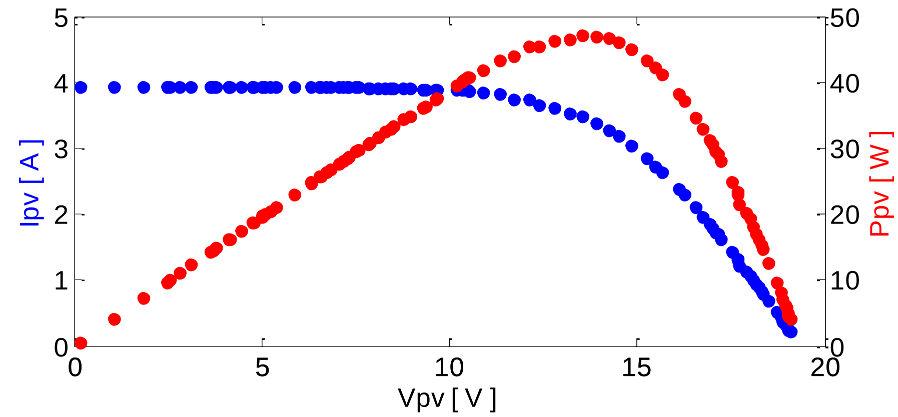


Figure 9. Experimental characteristics$I_{pv} = f(V_{pv})$ et $P_{pv} = f(V_{pv})$ of PVGMSX64type for$G = 982$ W/m$^2$ et $T = 25.1$°C

Figure 10 to 12 summarizes the experimental responses of power $P_{pv}$, of voltage $V_{pv}$ and of current $I_{pv}$ under $PO_F$ and $PO_V$ methods. For the first method $PO_F$, we have presented two responses, one with a fixed perturbation step $C = 0.01$ during the measurement, and another with $C = 0.001$ which does not vary during the test. While for the second method $PO_V$, we have presented in the same figures the experimental responses $P_{pv}$, $V_{pv}$ and $I_{pv}$ with a step depending on the proposed algorithm and can be $C_1 = 0.01$ or $C_2 = 0.001$, during the time of characterization.

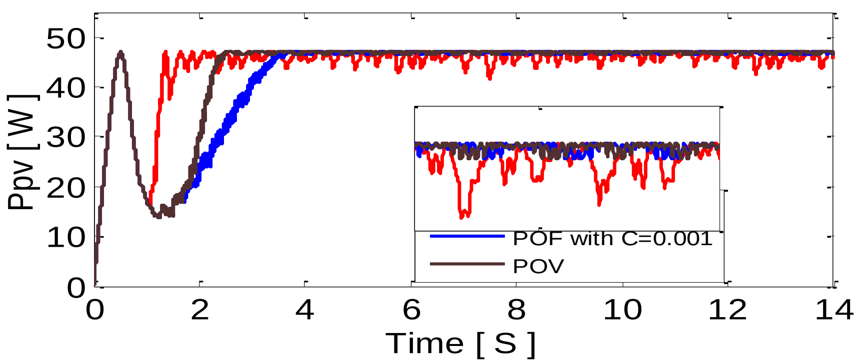


Figure 10. Experimental response of the power $P_{pv}$

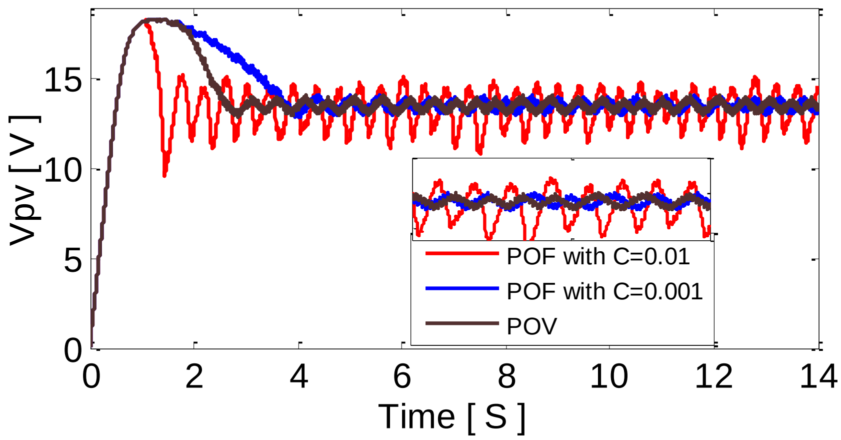


Figure 11. Experimental response of voltage $V_{pv}$

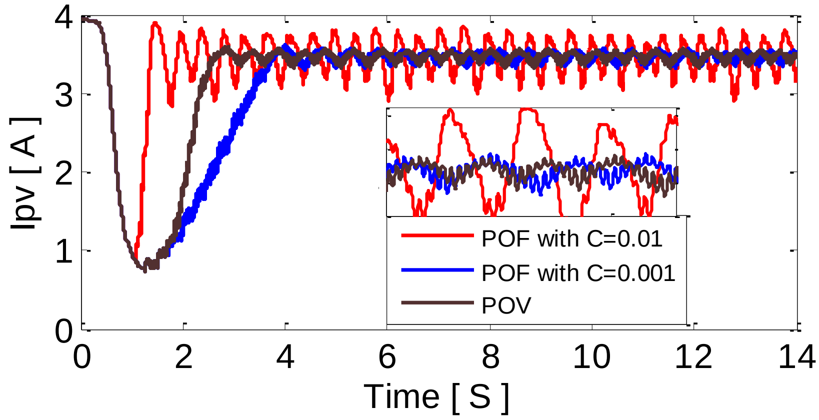


Figure 12. Experimental response of current $I_{pv}$

After analyzing these figures, we notice that for the algorithm $PO_F$ with a fixed step $C = 0.01$ along the measurement, the operating point reaches the MPP in 1.65 s against 3.72 s for a perturbation step $C = 0.001$ also invariable during the test. As a result, the response is logically faster for the big step $C = 0.01$. However, the oscillations around the MPP are less important for the small step $C = 0.001$. This allows us to confirm that with a big step, the algorithm is faster but less accurate. Whereas, with a small step, the algorithm is slower but fairly accurate. Regarding the algorithm of the $PO_V$ technique with $C_1 = 0.01$ and $C_2 = 0.001$, the operating point reached the MPP in 2.47 s with small oscillations around the MPP which is identical to the method $PO_F$ with low step. Therefore, this algorithm shows a good compromise between speed and accuracy.

## 5. CONCLUSION

In this paper, we have presented the implementation of the command "P&O" with a fixed perturbation step ($PO_F$) and the command "P&O" with a double perturbation step ($PO_V$) using the arduino Mega board. The experimental result shows that the command $PO_V$ gives good results compared to the control $PO_F$ in terms of time response and oscillations around the MPP.

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