A comparison of various P&O algorithm in order to truck the MPPT of solar panel

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ABSTRACT

A maximum power point track (MPPT) circuit should be used to improve and maximize photovoltaic (PV) power production. Different algorithms are proposed in the literature, and it is imperative to compare them in order to identify which MPPT approach is best for a specific application or to provide recommendations for future MPPT research. This article presents a benchmarking of the most widely used MPPT algorithms, such as the perturbation and observe classic (POC), the perturbation and improved adaptive observer (POAM), the perturbation and observe modified (POM) as well as the combination of the POM and POAM algorithms called PAMM. The comparative study presented in this work will confirm that the PAMM is the best MPPT technic to improve the performance of a PV system.

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1. INTRODUCTION

The increasing request of electrical energy and the pollution caused by the use of fossil fuel have prompted the scientific committee to encourage the use of renewable energy [1]. In these situations, solar PV is classified as one of the most important renewable energy sources. Moreover, this energy seems to be the most promising, clean and inexhaustible [2], [3]. However, the generation of this energy is random since it varies with daylight and temperature. Therefore, the maximum power point (MPP) of a PV panel does not always necessarily correspond to its maximum power point given at standard test conditions (STC) of 1000 W/m², AM 1.5 and a module temperature 25 °C. The research for an MPPT method allowing the monitoring of A PV panel's MPP is important [4].

Several research on the methodologies for finding the PPM of PV systems have been conducted in this regard. These technics are based on algorithms to extract the maximum energy converted by the PV panel thus inducing an optimal operation of the solar energy system [5]. Algorithms based on several methods are found in the literature, such as perturb and observe (PO) and increment conductance (INC) [6], [7]. Other commands have been developed, such as the measurement of a short circuit current fraction (CCF) or the measurement of an open circuit voltage fraction (COF) [8]. The PO technique is the most MPPT method used because of its simplicity. As the name suggests, it works by introducing a disturbance (Offset) of the voltage or current of an operating point n. The enormity of the problem, this disturbance will depend on the variation in the operating power observed with the samples of voltage V(n) and current I(n) [9]. This will make it possible to make a decision on the value and the sign of the disturbance to be imposed. This article is structured as follows: after the introduction, section 2 is reserved for the description of a PV system.

Section 3 focuses on the methods of the MPPT command. Indeed, we will deal with the four most popular algorithms of the basic technique perturb and observe, mentioned above; namely POC, POAM, POM and POMM. In paragraph 4, the simulation is shown below results with discussion to evaluate the algorithms presented. Finally, we end with a conclusion.

2. SOLAR CELL MATHEMATICAL MODEL

Explaining research there are several models to electrically identify a PV panel; models single diode and two diodes have been widely used to represent the I(V) output characteristic of a PV cell or module [9]. However, the model with a single diode is the simplest configuration in which a constant-current source is connected to a diode in parallel [10]. Taking into account a series resistor R_s output of the PV cell. Due to the simplicity of this model, the prediction of PV cell performance is incorrect under adverse conditions, when subjected to temperature differences [11]. An additional shunt resistor or parallel resistor R_{sh} can be used to improve the model [12]. Although a significant development has been achieved, this approach requires a considerable computational effort. In addition, its accuracy decreases at low irradiance, especially in the vicinity of the open circuit voltage V_{OC}.

According to the one-diode model in Figure 1, the electric current of the PV panel (I_{pv}) is given by (1) [13], [14]:

$$I_{pv} = I_{ph} - I_{d1} - I_{sh} \tag{1}$$

Where the photocurrent I_{ph} depends essentially on solar radiation G and temperature T, according to the (2) [16], [17]:

$$I_{ph} = (I_{ph,ref} + \alpha_0\,\Delta T)\,\frac{G}{G_{ref}} \tag{2}$$

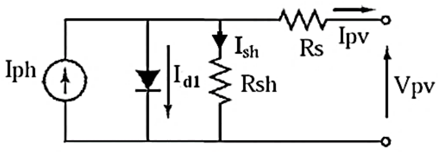

Figure 1. PV cell's equivalent circuit with one diode1 [15]

In the standard test conditions (STC): G_{ref} = 1000 W/m², T_{ref} = 298 K and AM = 1.5), the expression of $I_{ph,ref}$ is given by :

$$I_{ph,ref} = \left(1 + \frac{R_s}{R_{sh}}\right) I_{sc,ref} \tag{3}$$

Therefore:

$$I_{ph} = \left(\left(1 + \frac{R_s}{R_{sh}}\right) I_{sc,ref} + \alpha_0 \Delta T\right) \frac{G}{G_{ref}} \tag{4}$$

According the Meshe law, the Ish is expressed by:

$$I_{sh} = \frac{V_{pv} + R_s I_{pv}}{R_{sh}} \tag{5}$$

I_{d1} is given by:

$$I_{d1} = I_{01}\left[\exp\left(\frac{V_{pv} + R_s I_{pv}}{n_1 V_{th}}\right) - 1\right] \tag{6}$$

With:

$$I_{01} = \frac{I_{sc,ref} + a_0 \Delta T}{exp\left(\frac{V_{oc,ref} + \beta_0 \Delta T}{V_{th}}\right) - 1} \tag{7}$$

So, the relation $I_{pv} = f(V_{pv})$ is given by the following relation [18]:

$$I_{pv} = I_{ph} - I_{01}\left[exp\left(\frac{V_{pv} + R_S I_{pv}}{n_1 V_{th}}\right) - 1\right] - \frac{V_{pv} + R_S I_{pv}}{R_{sh}} \tag{8}$$

3. MPPT TECHNICS

Each MPPT technique mentioned in the introduction will be discussed in the following. For comparison purposes, we try to test these methods MPPT represented by their algorithms under the same conditions, on PV production systems by simulation, under the MATLAB/Simulink environment. Each of the simulation cases will lead to the results that we will discuss. These results will finally allow us to designate the best MPPT algorithm(s) to be implemented in a PV installation.

As illustrated in Figure 2, the system offered under MATLAB/Simulink is composed of a PV panel, a DC-DC booster with its MPPT control block and a battery. The MPPT control block ensures, under certain conditions, the command of the blocking and conduction of the MOSFET by changing the duty cycle of the PWM signal driving this MOSFET [19].

Table 1 shows the specifications of the PV modules used (XXR-SFSP-H50-62W) [20]. As for Table 2, it shows the characteristics of this boost converter. In addition, Table 3 shows the specifications of the battery used as the output charge of the converter.

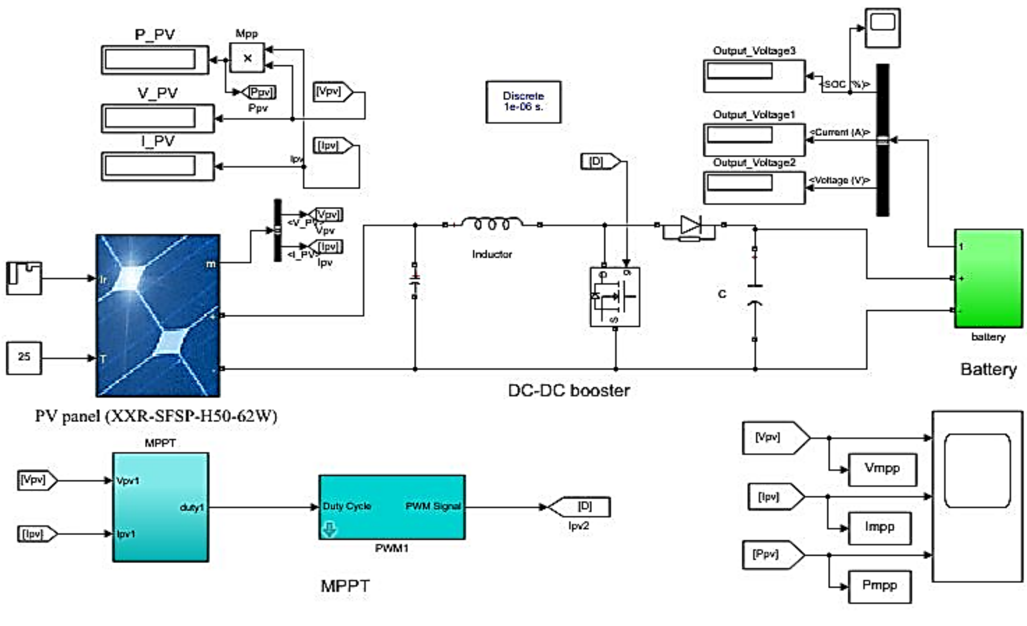

Figure 2. MPPT diagram in MATLAB

Table 1. PV panel electrical characteristics used in MATLAB/Simulink

Parameter	Symbol	Value
Maximum power (W)	P_{mp}	62
Open circuit voltage (V)	V_{OC}	21
Short circuit current (A)	I_{SC}	3.8
Voltage at maximum power point (V)	V_{mp}	18
Current at the maximum power point (A)	I_{mp}	3.5
Number of PV cells per module	N_{cell}	18

Table 2. Boost converter specifications

Parameters	Symbol	Value
Switching Frequency (kHz)	F	30
Booster Inductance (μH)	L	330
Input Capacitor (μF)	C	100

Table 3. Battery Specifications

Parameters	Symbol	Value
Nominal voltage (V)	V_n	48
Nominal capacity (Ah)	C_n	10
Initial state of charge (%)	*SOC*	10

Figure 3 shows the disturbance of the irradiation used at fixed temperature (25 °C) during 0.15 s. As for Figure 4, it represents the maximum power corresponding to the radiation profile considered. This power corresponds to the power that the panel can provide under the environmental conditions imposed by the chosen irradiation and temperature profile. Four variants of the perturb and observe PO technique: POC, POAM, POM and PAMM are described below while presenting some associated algorithms as well as the results of the commented simulations of each case. Towards the end of this paper, we expose the comparison of the numerical results; concerning the convergence time and the oscillation deviation. This will allow evaluating the performance of each of the four study methods.

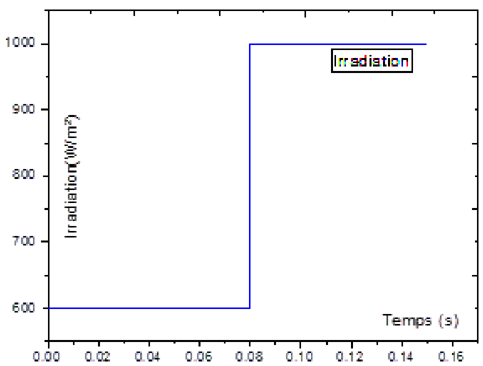

Figure 3. The irradiation used in the simulations system used in MATLAB/Simulink

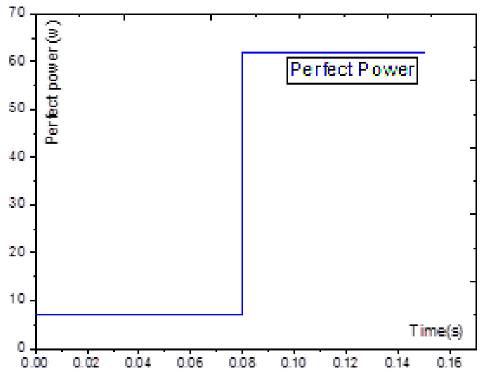

Figure 4. Ideal power of the system used in MATLAB/Simulink

3.1. Disturbance and classical observation method (POC)

The POC algorithm is the most used for solar PV cells due to the simplicity of its development. In this algorithm, the voltage of the module is measured and then it will be continuously disturbed and compared to the previous measurement. This method induces slight fluctuations. Due to these, the power generated by PV module will also fluctuate. If the power increases, the disturbance will continue to develop in this direction. After reaching the peak, the power variation at the MPP is zero and then decreases, thus causing the disturbance to reverse in this direction [21]. The flowchart explaining the principle of operation of this algorithm “POC” is shown in Figure 5 [22], [23]. Under the conditions mentioned at the beginning of this work, the simulation results (PPV) of the POC algorithm on MATLAB/Simulink are presented in Figure 6. These results show that the PV system converges on the best value P_{mpp} and has oscillations around it, as shown in zoom 2 of Figure 6. The main drawback of this algorithm is its bad behavior after a sudden change in illumination, as shown in zoom 1 of Figure 6.

3.2. Enhanced adaptive PO method (POAM)

Given the contradiction between the tracking accuracy and the POC convergence speed, we propose here an improved algorithm, namely the variable-step “adaptive PO” (POAM) method. The basic idea is as follows that when the point of operation is far from the MPP, a sufficiently high step must be selected to accelerate the speed of convergence. When close to MPP, it is necessary to choose a size of not small enough to make the accuracy more important.

The curve P(V) is divided into three parts, as shown in Figure 7. Let k = dP/dV, the slope at an n point of this curve; in zone A, k is basically positive and in zone C it is negative. In addition, the absolute value of k in zones A and C is greater than its absolute value in zone B. The point of operation can be determined according to the sign of k. When k>0, mainly in zone A, the disturbance can be adjusted larger (d1). When k<0 (zone C), we can choose a small disturbance step (d2). When $|k| < \varepsilon$ while tending towards 0, the system works in region (B), corresponding to an operation around the MPP i.e. $\varepsilon \cdot |dV| - |dP| > 0$. In this case, we just have to fix a small step of disturbance (d3). Subsequently, based on the value of the variation step dx, determined by the algorithm, we can estimate the appropriate value of the duty cycle α. The calculation of this duty cycle is carried out according to the following logic: if $\Delta P . \Delta V > 0$ then this duty cycle α will be decreased according to the step dx determined before, otherwise α will be increased according to the step dx. This principle of operation is illustrated by the flowchart of the algorithm POAM given in Figure 8. By analyzing the simulation results, we observe that after reaching the maximum value P_{mpp}, the traditional POC method fluctuates near the MPP, which can lead to a loss of power. While the results in Figure 9, obtained by the adaptive method POAM can be stabilized with negligible fluctuation and thus having good dynamic characteristics in steady state.

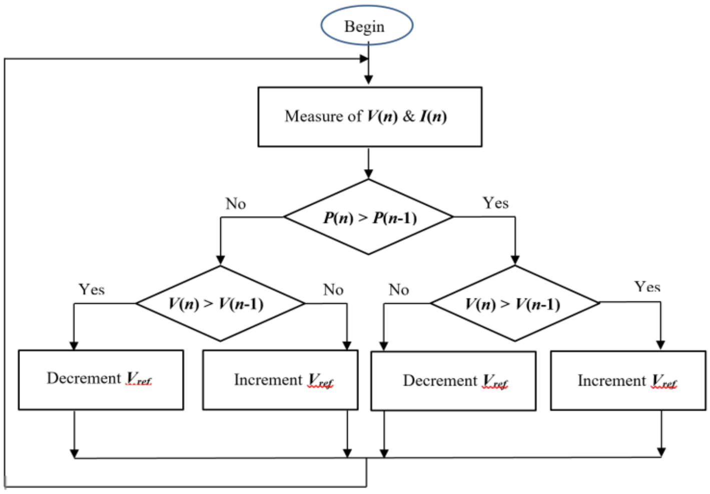

Figure 5. Algorithm of the method perturbed and observer classic (POC)

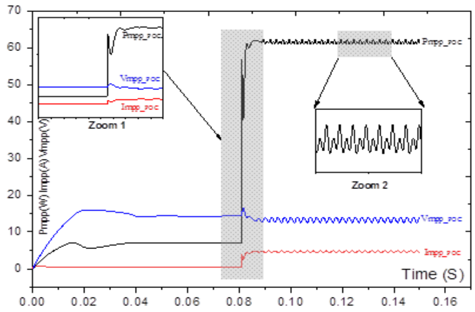

Figure 6. Response in terms of PV panel power with the POC algorithm

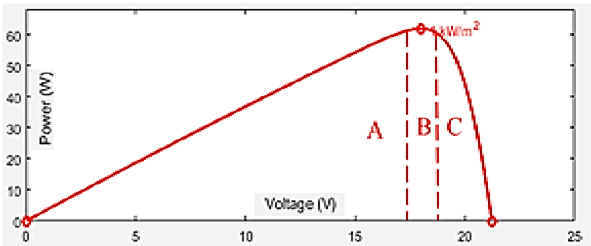

Figure 7. PV module characteristics P(V)

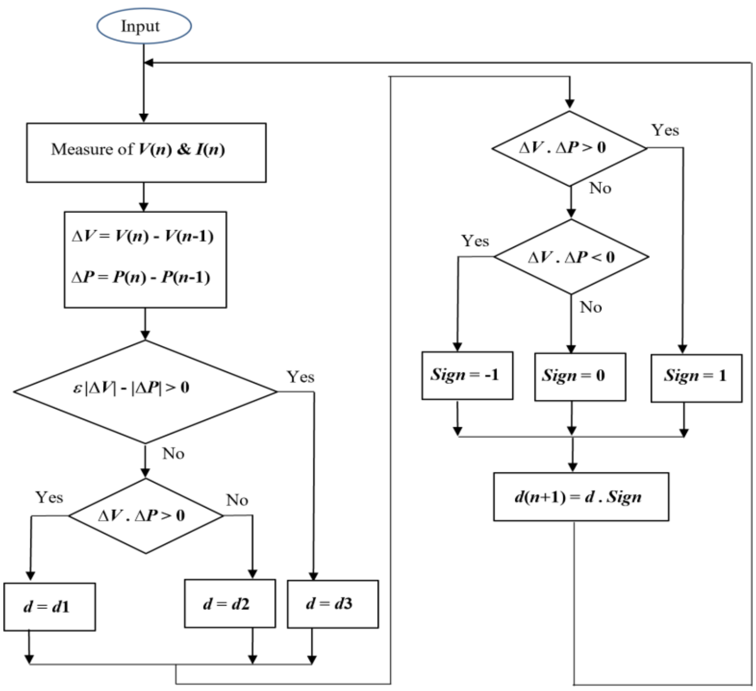

Figure 8. POAM algorithm flowchart

3.3. Modified PO method (POM)

This method corresponds to a three-level operation called POM technology to achieve an optimal state as illustrated in Figure 10. Indeed, assuming that the point of operation has been moved from point 1 to point 2 and that a decision must be taken at point 2 according to the algorithm associated with this technique, then in this case, considering the dP and dV values; such that $dP=P_2-P_1> 0$ and $dV =V_2-V_1> 0$, Because the algorithm reduces the duty cycle, the operating point shifts to point 3, and the operating point returns to point 2. At point 3, as $dP=P_2-P_1<0$ and $dV=V_2-V_1>0$, As a result of the algorithm increasing the duty cycle, the operating point returns to point 2. At point 2, as $dP=P_2-P_1>0$ and $dV=V_2-V_1< 0$, the algorithm increases the duty cycle again so that the operating point will be placed again at point 1. At point 1, when $dP=P_2-P_1<0$ and $dV=V_2-V_1< 0$, a gain's the algorithm decreases the duty cycle so that the operating point returns again to point 2.

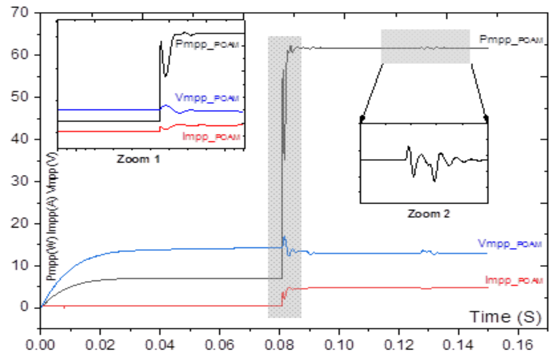

Figure 9. Power response with the POAM algorithm

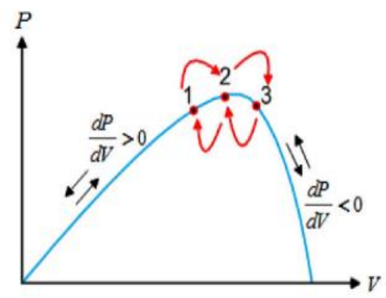

Figure 10. Slope variation curve k=dP/dV steady state

In this diagram, the algorithm oscillates the operating point at three points around the MPP. With the increase in illumination, the problem of drift will appear which will be all the more serious during a rapid variation of solar radiation; results usually take place in cloudy weather. A drift can occur from one of the three points in the steady state, as shown in Figure 11(a).

This problem of drift is because it is not known whether the increase in power ($dP>0$) is due to the disturbance or a sudden increase in irradiation. Assuming that the irradiation increases during the operation at point 1, as shown in Figure 11(a), so the operating point is moved from point 1 to the new point 4, when $dP=P_2-P_1>0$ and $dV=V_2-V_1>0$ and consequently the algorithm decreases the duty cycle, thus moving away from the MPP to point 5 of the new curves which is called drift. As shown in Figure 11(b), with the rapid increase in radiation, the problem of drift will become more accentuated and more complex for control [24].

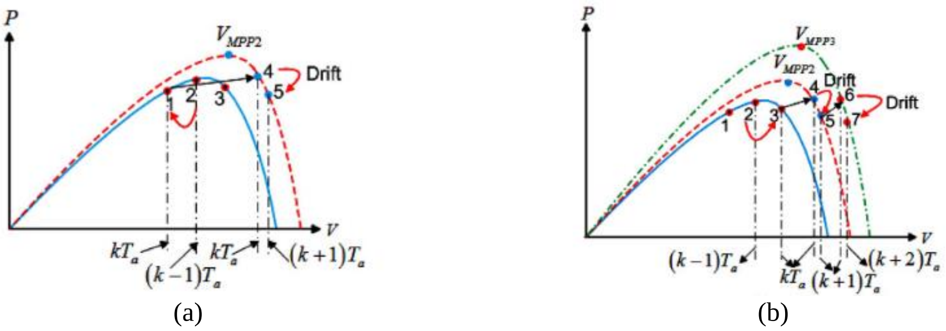

Figure 11. Drift analysis: (a) drift in case of normal increase and (b) drift in case of sudden increase in sunshine

The modified PO is developed by considering the characteristics P(V) of the PV modules on the basis of taking into account the variations dP and dV. As mentioned earlier, the PO technique has a drift demerit in case of a significant increase in sunshine thus causing confusion. This confusion can be eliminated or at least minimized by evaluating and introducing another parameter due to the variation of the PV current (d1).

Figure 12(a) shows the characteristics I(V) of the PV modules and the change in the point of operation due to the increase in sunshine. The positive value of dP for the reason that the solar irradiance has undergone an increase; this effect can be detected by using an additional parameter dI As shown in Figure 12(a), assuming that there is an increase in solar irradiance while the module is operating at point 3, the operating point stabilizes at a new point 4 in the new solar irradiance curve. Now, the decision must be made by the point 3 algorithm as shown in Figure 12(a).

At the same time, on the characteristics P-V, at point 4 point 4, both dP>0 and dV=>0 as shown in Figure 12(b). Thus, all three parameters dP, dV and dI are positive at point 4, as shown in Figure 12(a) and Figure 12(b). The positive value of dP is due to a disturbance or increase in sunlight, which can be detected using the additional parameter dI. From the I-V characteristics, it can be observed that the two parameters dV and dI can never have the same sign for a single insolation. Both parameters dV and dI will only be positive for an increase in insolation as shown in Figure 12(a). Thus, an increase in insolation can be detected using the additional parameter dI. And thus, by increasing the duty cycle (by decreasing the operating voltage). When both dV and dI are positive, can eliminate the drift problem by moving the operating point.

Drift problem by moving the operating point closer to the MPP as shown in Figure 12(b). Similarly, for an increase in sunlight at point 1 and point 2, the drift problem can be solved by incorporating dI into the algorithm. By incorporating dI into the algorithm, and moving the operating point with the proposed drift method. The flowchart associated with this technique POM without drift is presented in Figure 13 [25].

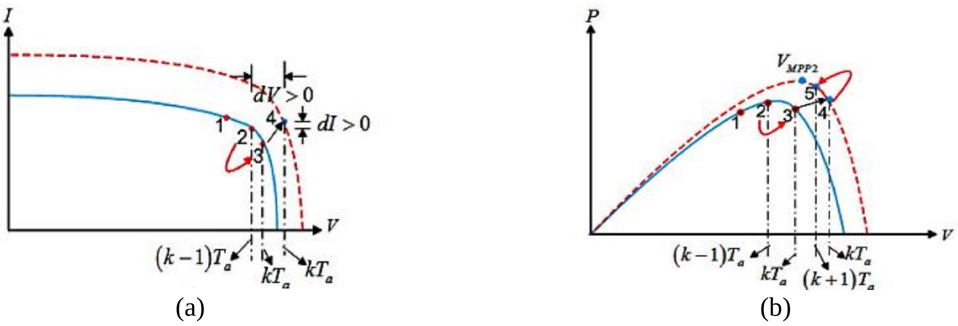

Figure 12. Analysis without drift with the MPPT POM, (a) variation of the current with the output voltage of the PV module and (b) point increase in sunshine [25]

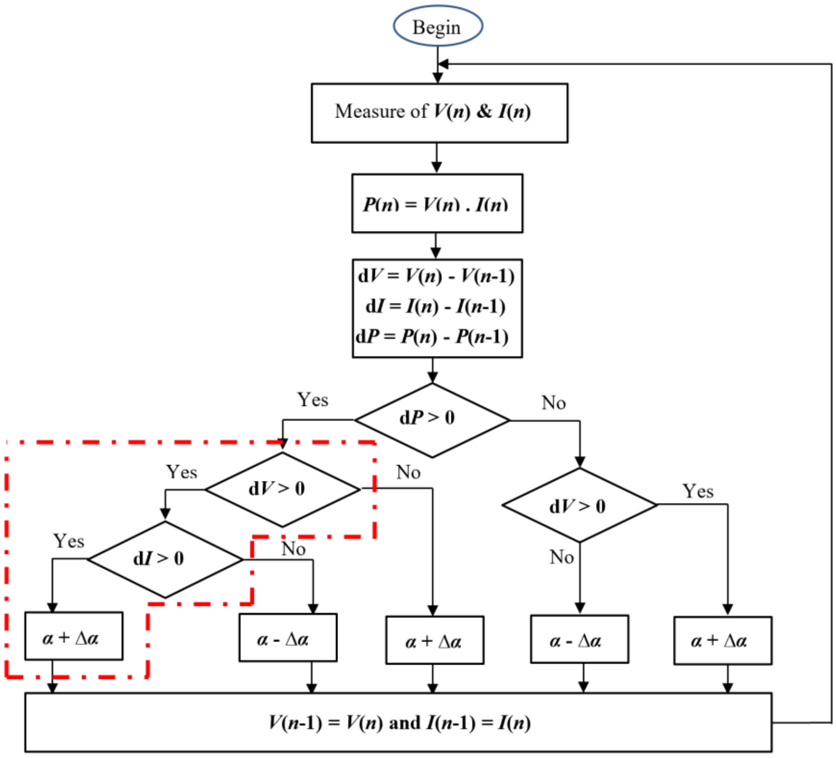

Figure 13. Flowchart of the POM algorithm without derivative

3.4. Modified enhanced adaptive PO (PAMM) method

The simulation results of Figure 14 (POM) compared to those of Figure 6 (POC) show that the POM technique makes it possible to reduce relatively the oscillations during rapid changes in solar irradiation, and weeklies during the sudden switching from 100 W/m² to 1000 W/m² (zoom 1). Nevertheless, the POM algorithm still present slight oscillations around the optimal values (Zoom 2). The so-called PAMM method obtained by combining technic 2 and 3 makes it possible to solve the contradiction or rather the confusion between the tracking accuracy and the convergence speed, in addition to the elimination of the effect of the drift during a sudden variation of the solar illuminance. Figure 15 shows the optimal simulated results of the PAMM method.

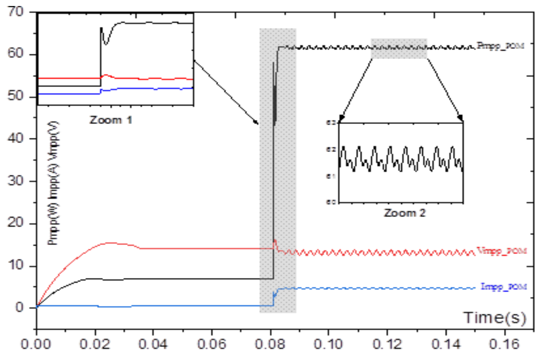

Figure 14. Response in terms of power s of the PV module with the algorithm POM

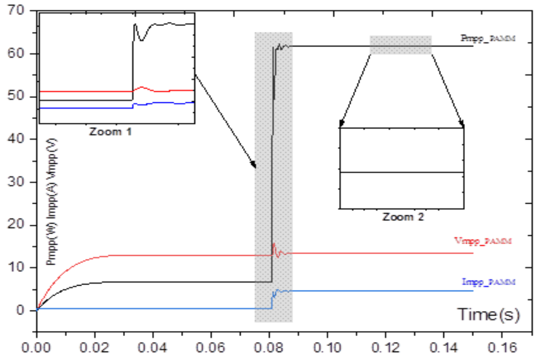

Figure 15. Response in terms of power of the PV module with the algorithm

4. COMPARISON OF MPPT ALGORITHM PERFORMANCE

To ensure an adequate comparative study between the MPPT algorithms processed, we evaluated some performance parameters; namely the oscillation difference ε_0, extracted from the curves of Figures 6, 9, 14 and 15, and the convergence time τ_c for a tilting irradiation from 600 to 1000 W/m² for each of the four algorithms. Table 4 summarizes the results of the calculations. The results of this table show that the best of the four algorithms is the PAMM. It presents almost zero oscillations and a static deviation of less than 0.1 W at steady state.

Table 4. Calculated performance parameters

MPPT method	Convergence Time τ_c (ms)	Oscillation gap ε_0 (W)
LITTLE	87.0	1.31
POAM	83.5	0.50
POM	83. 1	0.76
PAMM	82. 5	0.10

5. CONCLUSION

In this work, devoted to the study of MPPT methods, we started with the most widely used method which is disrupt and observe classic (POC), and its improved versions. The POAM (disrupt and adaptive observer), the POM (disrupt and observe modified), and finally the POMM (disrupt and adaptive observer modified). These technics have simple algorithms to implement to control a boost converter. In general, conventional algorithms (POC) give good results, but have major drawbacks. To remedy their improved versions have been processed. In order to make a ranking in terms of performance, we carried out Benchmarking between these methods. This enabled us to evaluate and comprehend the benefits and drawbacks of each method. As a result of our comparative analysis, we were able to conclude that the PAMM method is the best with a convergence time (82.5 ms) the lowest compared to the other methods. Similarly, the deviation of the oscillations obtained for this method PAMM is minimized to a value of 0.1 s against 1.31 s for the method POC. This presents almost 93% reduction of oscillations by this method PAMM.

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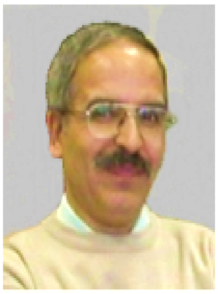

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