Comparative Studies Between Some Maximum Power Point Detection Methods

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Abstract:
Electricity generated by photovoltaic (PV) panels is considered a reliable alternative to fossil fuels. However, the conversion efficiency is often low and the initial cost remains significantly high. In order to relatively improve the conversion efficiency of a PV system, we often resort to Maximum Power Point Tracking (MPPT) techniques. In this work, we compare "MPPT-P&O", "MPPT-IncC", "MPPT-PI", "MPPT-PI-P&O" and "MPPT-FOPI-P&O". This allows to see the added value of the FOPI split controller compared to the traditional PI controller. Based on this comparison, for different values of solar irradiance, the PI and FOPI based controllers seem to perform quite similarly; both are fast and show small oscillations around the optimal value; nevertheless, the FOPI controller performs slightly better than the PI controller. This is due to the fact that it is faster and has less oscillations. The simulation is implemented numerically using the well-known development tool MATLAB/Simulink software.

Keywords: Solar panel; energy; photovoltaic; MPPT technic; P&O-PI; FOPI.

1 INTRODUCTION

In the coming years, the world is expected to face several problems related to the depletion of certain energy sources, especially fossil fuels. It is also well known that various causes of rising oil prices due to economic and political problems have contributed to the economic crises of the past decades. Therefore, the search for renewable energy sources is becoming more and more urgent as a viable option to solve the global energy dilemma. Solar PV is a credible and attractive source to enhance power generation among the perfect and green energy sources. Solar PV has become increasingly attractive in recent years due to the significant reduction in PV module costs, mainly in tiny single-phase home systems related to stand-alone and utility grid applications [1].

The photovoltaic effect is a direct conversion of light into electricity, used to produce electrical energy. Despite all the above advantages, the conversion efficiency is low, and the initial cost remains high as MPPT techniques are required to maximize the harvested energy. It is essential to note that each curve has only one MPP (Maximum Power Point) for each temperature and irradiance level.

MPPT techniques or approaches aim to harvest, under various climatic, solar irradiation and temperature conditions, the maximum electrical power generated by a PV panel system. In terms of the time and speed of convergence to MPP, the cost of implementation, these approaches differ in several respects [2]. However, they have several shortcomings, including slow MPP tracking speed, when the environment changes suddenly and steady-state inaccuracy of the PV power output around the MPP, which leads to higher power losses of the PV system.

This paper is organized as follows: after the introduction, section 2 is reserved for the mathematical description of a PV panel using the one-diode model. In Section 3, the methods of MPPT control are discussed by dealing with the five most popular algorithms; namely, "MPPT-P&O", "MPPT-IncC", "MPPT-PI", "MPPT-PI-P&O" and "MPPT-FOPI-P&O" controls. In section 4, the simulation results are presented and discussed in order to evaluate the presented algorithms and deduce the best performing technique. Finally, we conclude with a conclusion.

2 SOLAR CELL MATHEMATICAL MODEL

The basic unit of a PV module is the PV cell. To generate the required current and voltage, several PV cells are connected in parallel and/or in series. A current source produces a direct current. The intensity of the light landing on the PV cell determines the current. PV systems are directly affected by solar radiation and temperature. The performance and cost of these solar systems are influenced by outdoor working conditions and other variable conditions affecting the operation of the components of these systems.
The relationship between the voltage and current output of a PV cell, is modeled as shown in Figure 1, by the single diode model scheme. In the latter, there is a current source (I_{ph}), a diode saturation current (I_0), a parallel diode, a resistor (R_{sh}) and a series resistor (R_s) connected in series with the load.

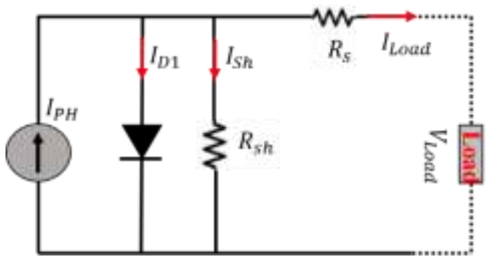

Figure 1: Mathematical model of the
PV cell - Single diode case

For a PV module composed of Ns and Np PV cells, respectively connected in series and in parallel, the output current in the case of this single diode model is given by the expression [3]:

$$I = N_p \times (I_{ph} - I_{01} \left[\exp\left(\frac{N_p V + N_s R_s I_{pv}}{n V_{th} N_p N_s}\right) - 1\right] - \frac{N_p V_{pv} + N_s R_s I}{N_s R_{sh}}) \qquad (1)$$

Where:
N_s: Number of PV cells connected in series.
N_p: Number of PV cells connected in parallel.
I_{ph}: Photo-generated current (A).
Ipv: Solar cell terminal current (A).
I_{01}: Reverse saturation current of diode i in conventional model (A).

n: Ideality factors.
R_s: Series resistance (Ω).
R_{sh}: Shunt resistance (Ω).
V_{pv}: Solar cell output voltage (V).
$V_{th} = kT/q$: Thermal voltage (V).
In this equation we find the modelling of a PV cell called simple diode with 5 parameters (I_{ph}, I_{01}, R_s, R_{sh}, I_{ph} and n).

3. MPPT TECHNIQUE

3.1 Literature Review

Although the focus of this study is limited to a comparison of the MPPT methods cited above, there are numerous other research articles in the literature on MPPT, some of which are briefly detailed below, to highlight the importance of the topic. This paper presents a simplified control strategy for low power MPPT converters based on the positive feedback effect of the output current [4]. This paper also reviews the characteristics and behaviour of the PV module and an efficiency analysis of the system.

Huang's research [5] presents PV panels and a Buck-type DC-DC converter tracking MPP to power the solar system. The output voltage is measured and compared to the open circuit voltage in a lookup table to produce a relationship between these quantities to determine the specific voltage across the PV module. The dynamic model PV system consisting of the relationship of a dc-dc converter, induction motor, and inverter was used in this study to achieve an appropriate output voltage result using the same comparison technique used in a solar system [6]. Similarly, this research proposes an approach based on open circuit monitoring voltage. The PV module voltage across is about 76% of the open circuit voltage. Therefore, it reflects the operating point near the maximum power point.

The method presented in this study is to experiment with different ways to evaluate the effectiveness of various MPPT algorithms. Note that P&O is the most widely used algorithm in commercial converters. Even though IncC has a better performance level than P&O, except that the implementation cost is higher than P&O which will not be acceptable by a performance advantage [7]. This research by Macaulay [8] focuses on several MPPT approaches based on a review of over

90 papers. The Hill Climbing (HC) and P&O methods are straightforward to implement in either analog or digital format. On the other hand, the IncC method is a bit more complicated and requires the use of appropriate digital circuits [9].

In our work we opt for the PI controller which is a standard solution for most industrial applications. The main reason is that its structure is quite simple and easy to implement practically. In this case, the PI controller is used in a voltage loop, to control the duty cycle of the signal acting on the switch of the DC-DC converter in order to extract the maximum power from the GPV (PV Generator). The structure of our proposed control strategy is shown in Figure 2.

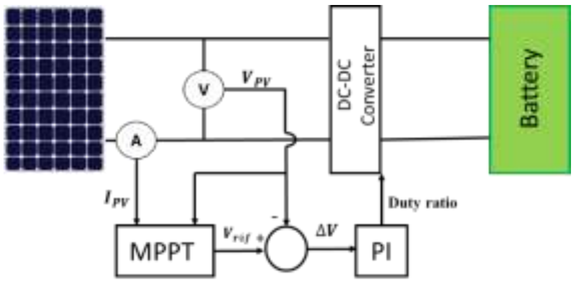

Figure 2: Block diagram of the studied PV system

For simulation purposes, the PV system used is composed of a PV module type XXR-SFSP-H50-62 W [10], whose specifications are summarized in Table 1, and a DC-DC converter and a battery whose parameters are reported in Tables 2 and 3 respectively.

Table 1: PV module specifications

Settings	Label	Value
Maximum power (W)	Pmp	62
Open circuit voltage (V)	Voc	19
Short-circuit current (A)	Isc	5.8
Voltage at MPP (V)	Vmp	13.3
Current at MPP (A)	Imp	4.68
Cells number per module	Ncell	32

Table 2: Booster converter specifications

Settings	Label	Value
Switching frequency (kHz)	F	30
Booster inductance (H)	L	330.10 -6
The input capacitor (F)	C	10^{-4}

Table 3: Battery specifications

Settings	Symbol	Value
Nominal voltage (V)	Vn	48
Nominal capacity (Ah)	Cn	10
The initial state of charge (%)	SOC	10

During our simulations, the irradiation profile used for the interval of 0.3 s and for a fixed temperature of 25 ºC is shown in Figure 4. The profit of the maximum power delivered by the PV panel under test and corresponding to the considered irradiation profile is presented in figure 3.

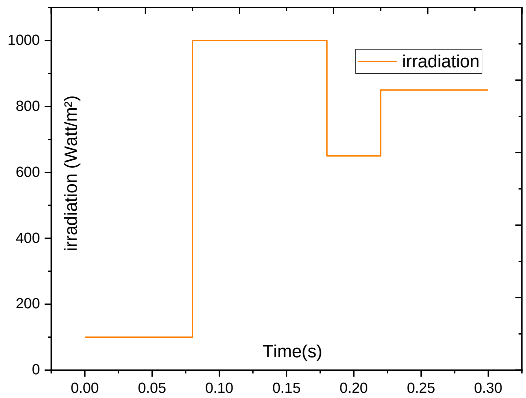

Figure 3: Used irradiation during the simulations

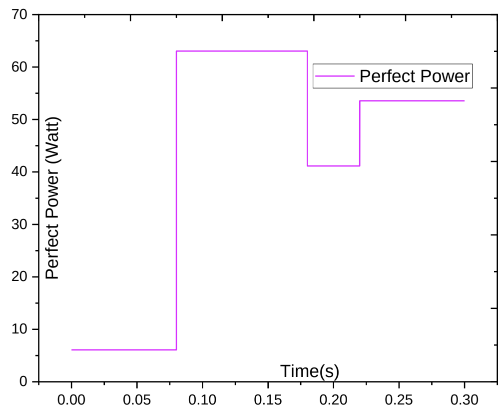

Figure 4: Ideal power of used system under Matlab

In the design of PV system controllers, MPPT algorithms are commonly used. To ensure that the PV system provides maximum power at all times, the algorithms take into account variations in temperature and irradiation. In fact, among the most used algorithms, we have the so-called "P&O" (Perturbation and Observation Classic) and "IncC" (Incremental Conductance) techniques.

In what follows, we will expose, concerning the MPPT, the basic algorithms "P&O" and "IncC" as well as the Simulink schemes used in the simulations under Matlab, namely the techniques; "MPPT-PI", "MPPT-PI-P&O" and MPPT-FOPI-P&O". This will allow us, after comparison of the results, to evaluate their performances and to extract the best performing technique.

3.2 "P&O" technique

In the case of PV systems the "P&O" method is the most used due to the simplicity of development and implementation of its algorithm. In it, the PV module voltage is measured and then continuously disturbed and it is compared with the previous measurement, in order to decide the magnitude and direction of the next disturbance “Figure 5”. This method induces slight fluctuations. Because of these, the power generated by the PV module will also fluctuate. If the power increases, the disturbance will continue to develop in that direction. After reaching the peak, the power variation at the MPP is zero and then decreases, causing the disturbance to reverse in that direction [11].

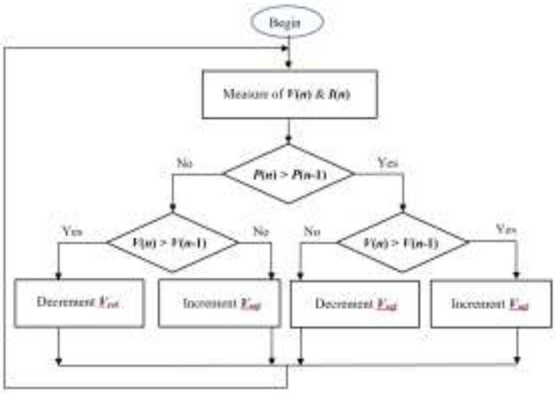

Figure 5: Algorithm of the "Disturb and Observe" method

3.3 "IncC" method

Concerning this INC_C technique, the flowchart presented in figure 6 explains the different steps of its implementation. The quantity V_{ref} visible in this flowchart is the reference voltage for which the PV panel is forced to operate. Once the MPP is reached, the corresponding operating point is maintained, unless a change in I is noted, indicating a change in atmospheric conditions and therefore in the MPP. The algorithm then increases or decreases V_{ref} to search for the new MPP [12].

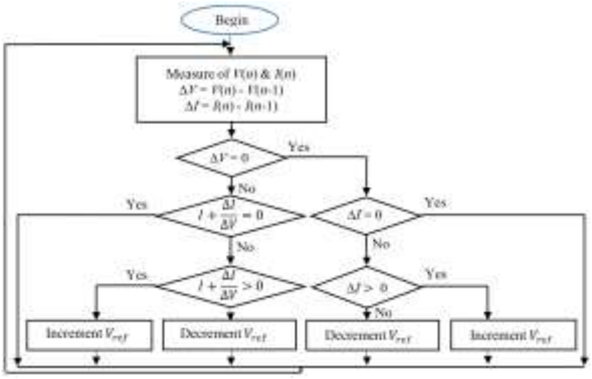

Figure 6: IncC method algorithm

3.4 MPPT control by a PI corrector (MPPT-PI)

The Simulink diagram used during the simulations of the "MPPT-PI" corrector (Figure 7), contains a 62 W PV panel whose characteristics are summarized in Table 1. This PV module feeds a load via a boost converter controlled by a PI controller.

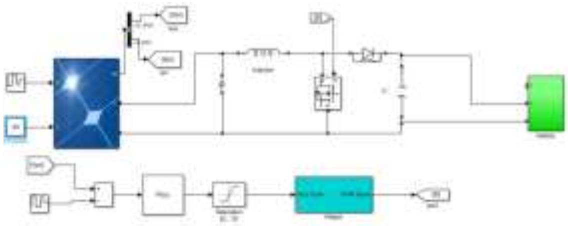

Figure 7: MPPT-PI control schematics

The simulation results of the MPPT algorithm by a PI on MATLAB/SIMULINK under the conditions cited at the beginning of this paper are presented in Figure 7. In this figure we have grouped three graphs representing respectively the voltage, current and power at the output of the PV panel, in a time interval of 0.3 s. These results show that the PI corrector corrects the error between the referential voltage and the PV panel voltage.

The results we obtained concerning the optimal values of the voltage at the output of the PV panel, its current and the power delivered by the latter using the PI-MPPT technique. Except that the major drawback of this method is that the reference voltage V_{ref} is obtained from the ideal characteristics of the PV panel, which makes V_{ref} constant. However, in reality this value depends on the illumination and the temperature. For this reason, the method that will be presented in the rest of our study is the MPPT technique using a PI corrector of the quantities controlled by the P&O algorithm, thus making V_{ref} variable and dependent on the temperature and irradiance conditions [13-14]. In this case, we will talk about autonomous techniques.

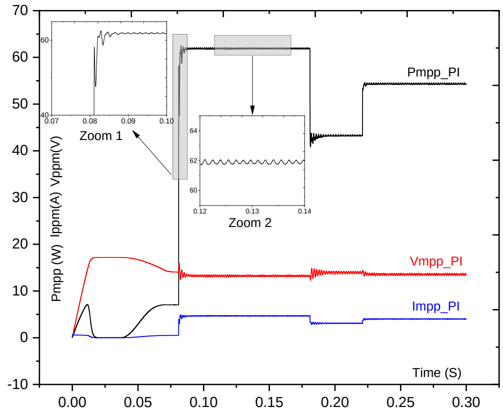

Figure 8: PV module power response with "MPPT-PI" algorithm

3.5 Control with a PI and P&O controller (MPPT-PI-P&O)

Unlike the MPPT control with PI corrector, in the MPPT control with the "MPPT-PI-P&O" corrector, the reference voltage V_{ref} is obtained from the P&O algorithm. This makes the system autonomous by this method [14-15]. The diagram of this "MPPT-PI-P&O" technique is presented in Figure 9.

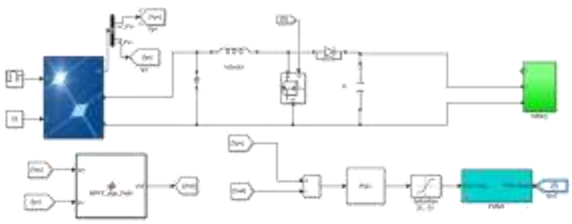

Figure 9: Simulink diagram used for the "MPPT-PI-P&O" method

The simulation results of this "MPPT-PI-P&O" technique on Matlab / Simulink under the conditions mentioned at the beginning of this paper, are presented on figure 10. The latter is composed of three graphs over a period of 0.3 s. The first one represents the PV panel output voltage. The second one represents the PV panel current. And the third one represents the PV panel power.

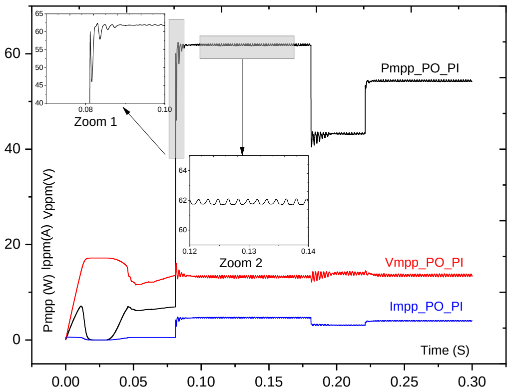

Figure 10: PV system response using in the "MPPT-PI-P&O" algorithm

These simulation results in Figure 10 show that the "MPPT-PI-P&O" method has the same advantages as the MPPT-PI method over conventional algorithms. However, with this "MPPT-PI-P&O" method the system automatically follows the variations of V_{ref}.

3.6 MPPT control by a fractional order PI and P&O (MPPT-FOPI-P&O)

In the case of the fractional order PI corrector, the transfer equation is given by [16-17]:

$$C(s) = \frac{U(s)}{E(s)} = K_p + K_i \frac{1}{s^m} \text{ With } m \geq 0$$

Where, C(s) is the transfer function of the controller, U(s) is the control signal, E(s) is the error signal, K_p is the proportional constant gain, K_i is the integration constant gain, and m is the integration order.

The synthesis of the fractional corrector we will use is based on the optimization of the parameters K_p, K_i and m by an evolutionary algorithm (PSO) [18, 19].

The proposed scheme for this MPPT control using fractional order PI with P&O (MPPT-FOPI-P&O) on Matlab / Simulink is shown in Figure 11. The simulation results of this algorithm, under the conditions mentioned at the beginning of this work, are presented in Figure 12

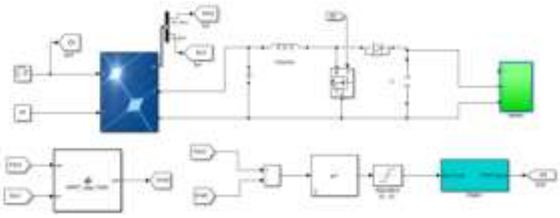

Figure 11: Simulink diagram adopted for this "MPPT-FOPI-P&O" technique

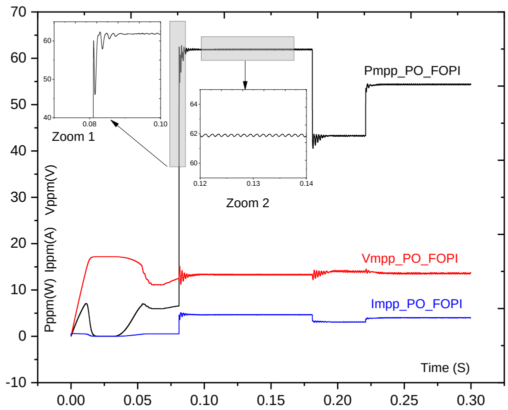

Figure 12: PV system response with the "MPPT-PO-FOPI" algorithm

This figure 12 shows us that the PV system converges to the optimal values with less oscillations around them compared to the previous methods.

4. Comparison of the different techniques

The comparison between the various controls techniques discussed above is presented in Figure 13. It allows to observe the added value of the fractional controller FOPI compared to the classical controller PI. On the basis of this comparison, we have reached the following conclusions: The various techniques using PI or FOPI controllers seem to have the same performance for the various irradiation values evolving according to the template used in Figure 3. They are fast and show small oscillations around the optimal value (zoom 2) in Figure 13. Thus, as shown by the zooms 1, 2 and 3 in Figure 13, for different irradiation values the FOPI controller is slightly better than the PI controller. In fact, the FOPI controller leads to a fast convergence with less oscillations.

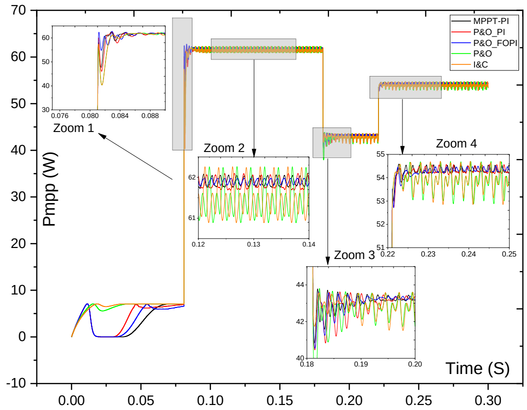

Figure 13: Comparative results between MPPT algorithms

The results reported in Table 4 show that the best of the five techniques processed is the "MPPT-P&O-FOPI". It presents almost zero oscillations and a static deviation less than 0.22 at steady state.

Table 4: Calculated performance parameters

MPPT method	Convergence time (in ms)	Oscillation deviation (in W)
1 : P&O	0.0871	1.15
2 : IncC	0.0863	1.15
3 : MPPT-PI	0.0839	0.02
4 : MPPT-P&O-PI	0.0846	0.32
5 : MPPT-P&O-FOPI	0.0842	0.22

5. CONCLUSION

This study investigated five MPPT techniques for obtaining the maximum power generated by PV modules. The performance of the common maximum power point techniques is investigated in this work, namely; "MPPT-P&O", "MPPT-IncC", "MPPT-PI", "MPPT-PI-P&O" and "MPPT-FOPI-P&O" controls. Simulation results were also produced from a PV array and the maximum power was obtained. Based on the comparison of the simulation results of the various techniques, we came to the following conclusions: For 1000 W/m² irradiance, the controls using PI or FOPI controllers, seem to perform similarly; they are both fast and show slight oscillations around the optimal value. However, it should be noted that the MPPT control using the FOPI controller performs better than the PI controller for different irradiations, given its speed of convergence while presenting less oscillations.

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