



RESEARCH ARTICLE

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COMPARISON OF MAXIMUM POWER POINT TRACKING TECHNIQUES
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ABSTRACT

Among the various renewable energy sources, photovoltaic (PV) systems are experiencing a great expansion, due to their low polluting levels, the abundance of solar energy and the cost decreasing of PV technologies, attracting research and investments in the field. The maximum power generated in a PV panel varies according to irradiation and temperature. Since the conversion efficiency of photovoltaic modules is low, it is necessary to implement sophisticated control techniques for monitoring the maximum power point (MPPT). Maximum power point tracking techniques are automatic control algorithms that adjust power interfaces to achieve the maximum power generation, during variations in irradiation, temperature, and characteristics of the photovoltaic module. The purpose of the MPPT is to adjust the solar panel operating voltage near the maximum power point (MPP) according to environmental conditions. This technique has become an essential component in photovoltaic power system designs. This article presents comparison of the performance of various MPPT tracking methods in photovoltaic systems using the MATLAB / Simulink software and a comparative approach.

Keywords: photovoltaic systems, maximum power point (MPPT).



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I. INTRODUCTION

The use of photovoltaic (PV) systems has been growing in the last decade. However, this type of generation has two critical disadvantages: the high cost of installed capacity and efficiency ranges between 9%–15% [1], which is considered low. Considering the above, it requires the use of maximum power point tracking techniques (MPPT) to generate maximum power according to the variable environmental conditions [2]. In this way, methods such as Perturb & Observe and incremental conductance have been widely used because they are easy to implement and converge quickly the MPP [3]–[6]. However, in some situations, the photovoltaic system may be subject to variations in irradiation and temperature, and a point different from the point of maximum power may follow its output characteristic curve [6]–[8]. That is why this article does not just seek to present several of the most

used methods in the literature, but to compare them computationally, using reliable and internationally consolidated software. Six MPPT methods applied to a buck-type system connected to a photovoltaic generator will be presented and simulated in MATLAB / Simulink. Finally, a comparison will be made between the simulated methods.

II. THEORETICAL REFERENCE

The MPPT methods consists of a DC / DC converter comprising a stage that liaison algorithm that receives information from the photovoltaic system, and a second power stage responsible for requesting the voltage and current that correspond to the desired values according to the environmental conditions of temperature and irradiation.

The objective is to analyze its response to variations in temperature and irradiance. Of the selected methods two are of constant relationship: constant cyclic ratio (Rcte) and constant voltage (Vcte), the rest of the chosen methods: Perturbe & Observe classic (P&OC), Perturb & Observe modified (P&OM), Conductance Incremental (CI) and Modified Incremental Capacitance (CIM). Each of these methods is described below.

II.1 CONSTANT CYCLICAL RATIO METHOD (Rcte)

This is the simplest of the methods analyzed because there is no feedback or control. The cyclical ratio is adjusted only once and remains constant.

II.II CONSTANT VOLTAGE METHOD (Vcte)

This technique is based on the premise that the maximum power voltage has an approximate linear relationship independent of the external factors. The voltage factor depends on the characteristics of the PV array used and is empirically calculated. The value falls between 0.7 and 0.8.

The method uses only one sensor. Fig. 1 shows the algorithm presented in [9].

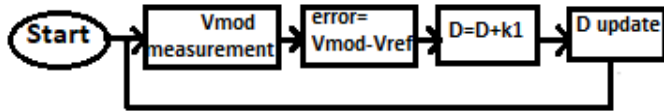


Figure. 1. Algorithm for the constant-voltage method.

II.III PERTURB & OBSERVE CLASSIC(P&OC)

This technique is the most widely used due to its simple implementation. As the name suggests, the method involves disturbing the voltage of the photovoltaic array in one direction and observing the output power. If the power increase, the disturbance continues in the same direction, otherwise the disturbance changes the direction as shown in figure 2.

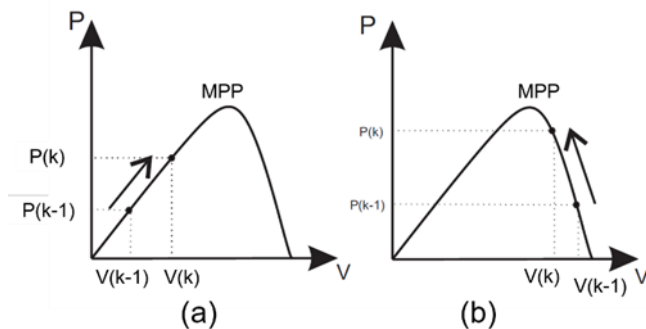


Figure 2. P&OC algorithm. (a) power increase, (b) Decrease power disturbance changes direction.

As the process is continuously repeated, the maximum power point is never reached because the disturbance is always carried out, leaving the system oscillating next to it in a permanent regime. Fig. 3 shows the flowchart of the method.

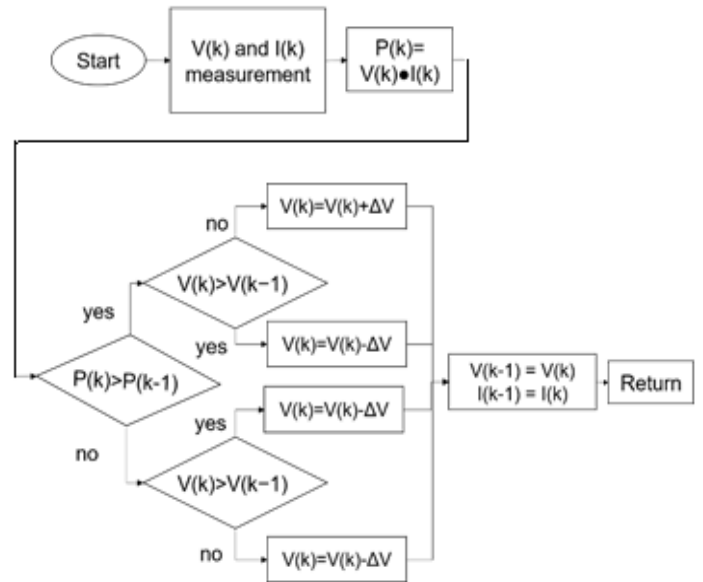


Figure 3. P&OC method flowchart

II.IV PERTURB & OBSERVE WITH STOP CRITERION (P&OM)CLASSIC(P&OC)

This method is similar to the previous one with a small modification, consisting in the implementation of a stopping criterion in the algorithm; this is done to reduce the oscillations in a permanent regime. The flow chart of this method is shown in figure 4.

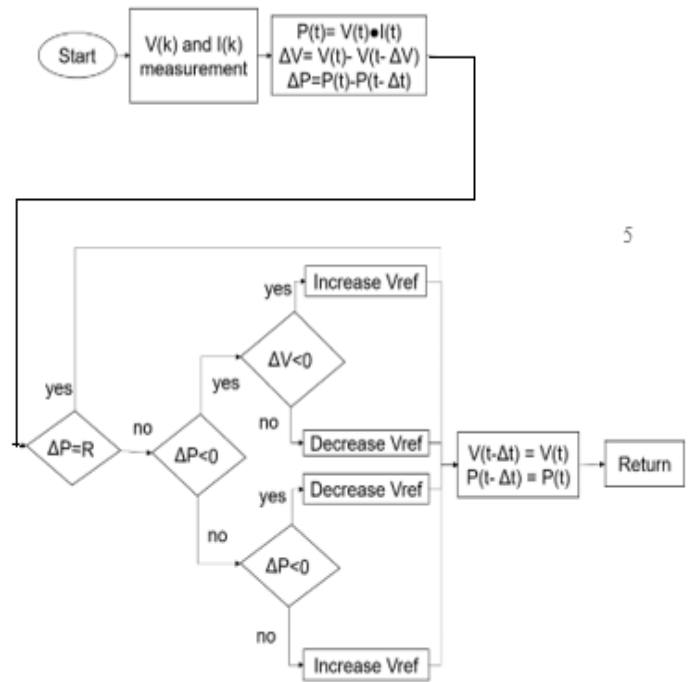


Figure 4. P&OM method flowchart.

II.V INCREMENTAL CONDUCTANCE (IC)

The method is based on the instantaneous and incremental conductance values of the photovoltaic array. Current and voltage measurements are necessary, and through these, the power

obtained by the voltage can be derived. Equation 1 can describe the method.

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I \frac{dV}{dV} + V \frac{dI}{dV} = I + V \frac{dI}{dV} \cong I + V \frac{\Delta I}{\Delta V} \quad (1)$$

Basically, there are three situations for incremental conductance on PV module: $I + V \frac{\Delta I}{\Delta V} > 0$, Figure 5 (a), the action is to increase the output voltage. $I + V \frac{\Delta I}{\Delta V} = 0$, Figure 5 (b), the action is to maintain the output voltage. $I + V \frac{\Delta I}{\Delta V} < 0$, Figure 5 (c), the action is to decrease the output voltage.

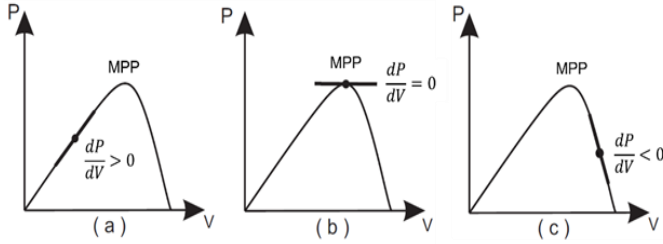


Figure 5. CI algorithm

If ΔV is equal to zero, which can occur when there is variation in irradiation and not in temperature, ΔI must be analyzed to determine the type of action to be taken. Figure 6 presents the flow chart of the Incremental Conductance method.

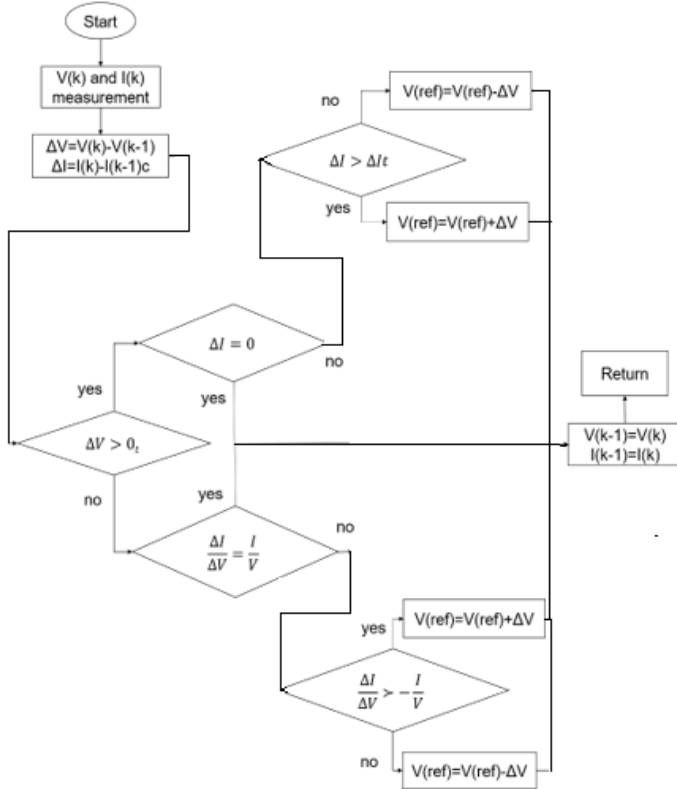


Figure 6. CI method flowchart

II.VI MODIFIED INCREMENTAL CONDUCTANCE (CIM)

This method takes into account the term that indicates that the system is in MPPT, that describes Equation 2:

$$\frac{I}{V} + \frac{dI}{dV} = 0 \quad (2)$$

In practice, this criterion will hardly be satisfied due to measurement errors, quantization errors, and discretization of the reference voltage. It is, therefore, necessary to define a tolerance range ($\Delta\omega$) in which the situation can be considered correct. The flow chart in Figure7 presents the operation of this method [10]

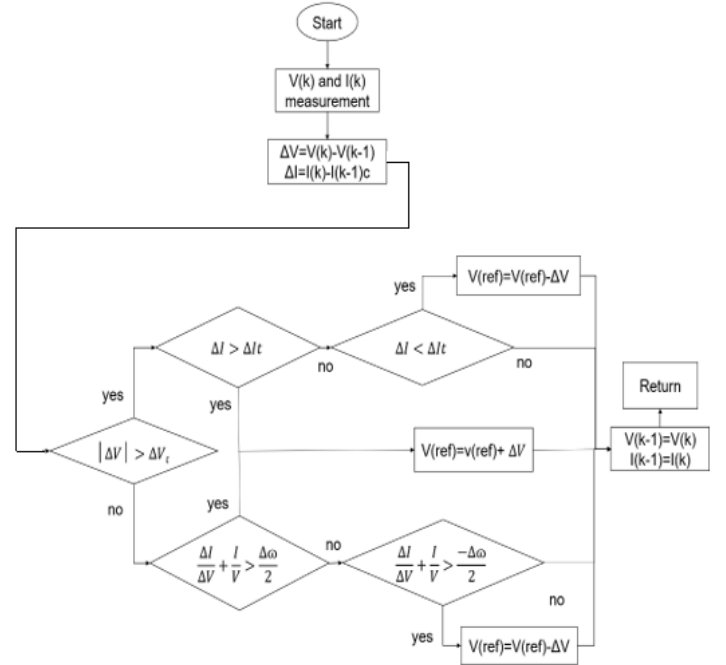


Figure 7. CIM method flowchart

III. MATERIALS AND METHODS

The simulation model used is a two-state inverter, as shown in the following Figure 8 (a). Where the objectives of the DC/AC inverter are: Synthesize the current to be injected into the electrical network and adjust the voltage of the DC bus (C_{DC} capacitor), while the DC/DC converter (Boost) has the objective of controlling the voltage in the PV terminals (Capacitor C_{PV}). Considering the network as an infinite bus and the DC/AC inverter controlling capacitor voltage correctly, we can then represent the system as shown in Figure 8 (b).

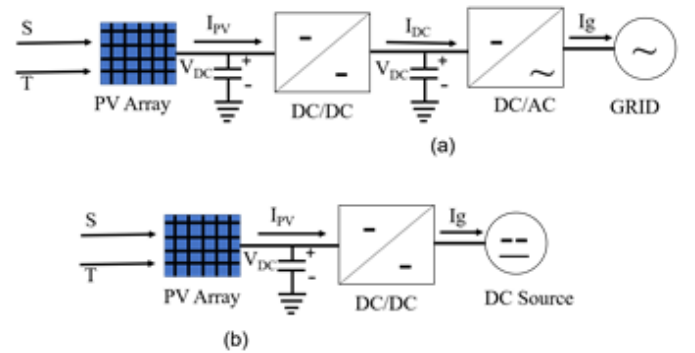


Figure 8. Diagram used for the simulation (a) y Simulated reduced diagram (b). Source: Authors, (2020).

Considering the network as an infinite bus and the DC/AC inverter controlling capacitor voltage correctly, we can then represent the system as shown in Fig. 9.

A. Photovoltaic module

To research with photovoltaic modules, it is necessary to know first the operation and characteristics of the modules. Various techniques for estimating parameters for photovoltaic modules were found in the literature. This article will use the technique presented by Xiao in [11]. This technique is based on the fact that the derivative of the power about the voltage in a photovoltaic module is zero at the maximum power point. Also, the influence of R_p (parallel resistance of the photovoltaic module circuit) is neglected. The flowchart used to determine the new parameters of the photovoltaic module in the condition of variations in temperature and irradiance is shown in Figure 9.

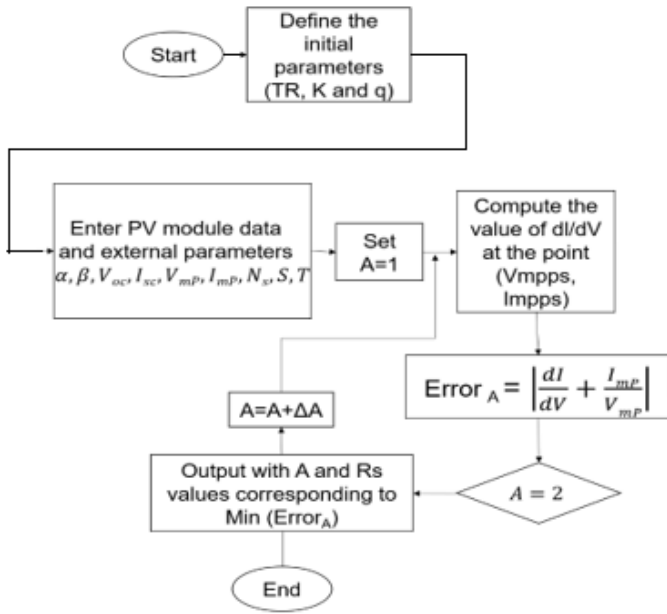


Figure. 9. Flowchart of the technique used by Xiao for parameter estimation

The variables are:

α : Coefficient that relates the variation in the short circuit to that in the temperature, β : Temperature coefficient of V_{OC} , V_{OC} : Open circuit tension, V_{SC} : Short-circuit current, V_{mpp} : Voltage at the maximum power point, N_s : Number of cell-associated in series in the PV module, S : Irradiance in W/m^2 , T : Temperature (K), Voltage converter.

The Boost converter used in the simulation shows the values that inductance and capacitors can take. Equations 3 to 6, are used to calculate the inductor and capacitor values of the Boost converter input [12].

$$L_{boost} = \frac{V_{in} D}{f_s \Delta I} \quad (3)$$

$$C_{in} = \frac{\frac{P_{in} D}{V_{in}}}{f_s V_{in} R_{ip} V} \quad (4)$$

$$D = \left(1 - \frac{V_{in}}{V_{out}}\right) \quad (5)$$

$$\Delta I = R_{ip} I_{admitted} \frac{P_{in}}{P_{out}} \quad (6)$$

Where Voltage volts [V], current amps [I], power Watts [P], R_{ip} : admitted ripple (voltage or current), D : cyclical ratio, capacitance Farad [C], L_{boost} : inductance Henry [H], f_s : switching frequency Hertz [Hz]. The subscripts *in* and *out* indicate the input and output values, respectively.

The calculated Parameters to consider for the designs of the inductor and capacitor of the boost converter are L (500×10^{-6} H), C_{in} (400×10^{-6} F) and f_s (10 kHz). It should be noted that the converter's control is applied to regulate the input voltage to it and not the output voltage as it usually happens. In this case and as explained above, the Boost converter's output capacitor is replaced by a DC voltage source since the voltage is regulated by a second DC/AC converter.

IV. RESULTS AND DISCUSSIONS

Figure 8 shows the PV system simulated in this article. The system consists of a PV array of the type (mSi460A8); it consists of the association of six modules in series. The output of the PV array is connected to a DC/DC Boost converter, which is associated with a three-phase inverter that keeps the output capacitor voltage constant. The data of the photovoltaic module used in the simulation have been taken from the NREL (National Renewable Energy Laboratory) database of standard test condition (STC) parameters are $V_{OC_{STC}}$ (21.61 volts), $I_{SC_{STC}}$ (5.012 amps), α (0.06644), β (-0.32983) and N_s (36). The simulation is performed, starting with the photovoltaic module under STC conditions of $S = 1000 W/m^2$ and $T = 250^\circ C$. To verify the MPPT algorithm's response and the control of the input voltage to the Boost converter, a variation in the irradiation of $1000 W/m^2$ is applied to $500 W/m^2$ at 0.3s and then after 0.6 s it is restored to the initial value. At the instant of time 0.9 s, an increase in temperature is applied, varying from 25 to $40^\circ C$.

The figures 10–15 show the responses to these variations in irradiation and temperature of each of the MPPTs analyzed. It is possible to verify that the irradiation and temperature variations result in changes in the modules' voltage to guarantee that the panel's power is maximum. Increasing irradiation increases voltage while increasing temperature results in a reduction in voltage. Also, note that when the variations are applied, the algorithm finds the new point of maximum power transfer.

For the calculation of the cyclical ratio, equation (7) is used, considering six solar modules in series with a voltage of 180 V in the direct bus and an MPPT voltage of 17.31 V, the cyclical ratio can be calculated.

$$D = 1 - \frac{V_i}{V_o} = 1 - \frac{6 \cdot 17.31}{180} = 0.423 \quad (7)$$

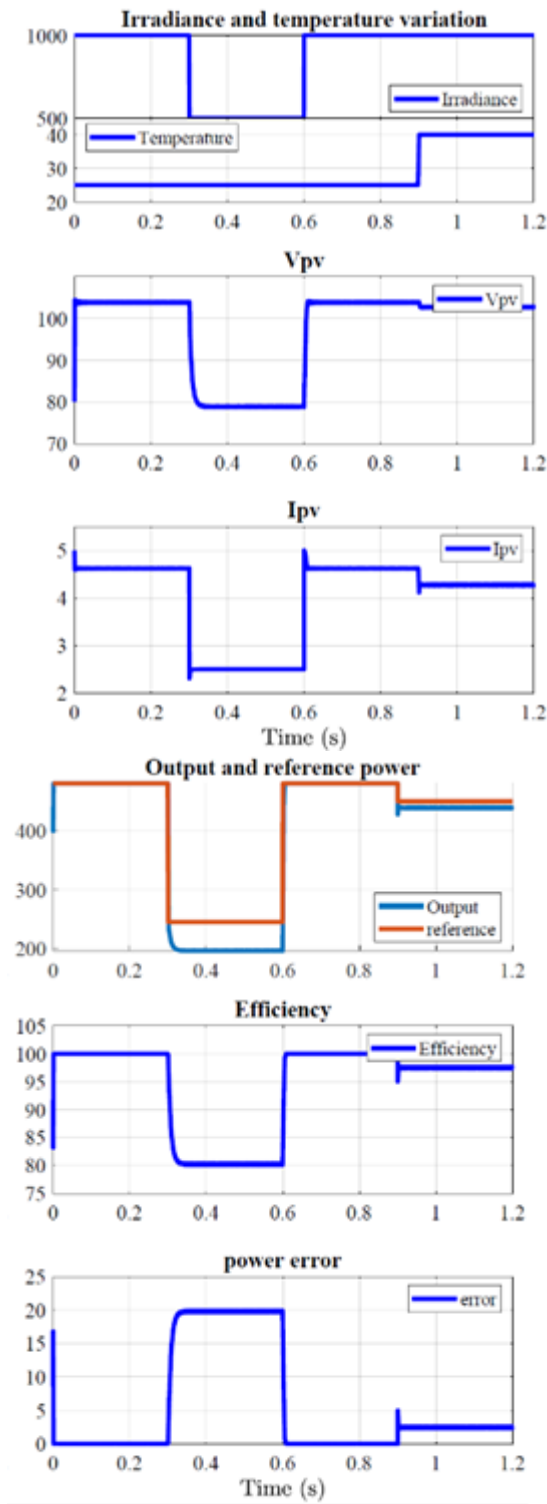


Figure 10. Simulation results of the constant cyclical ratio method

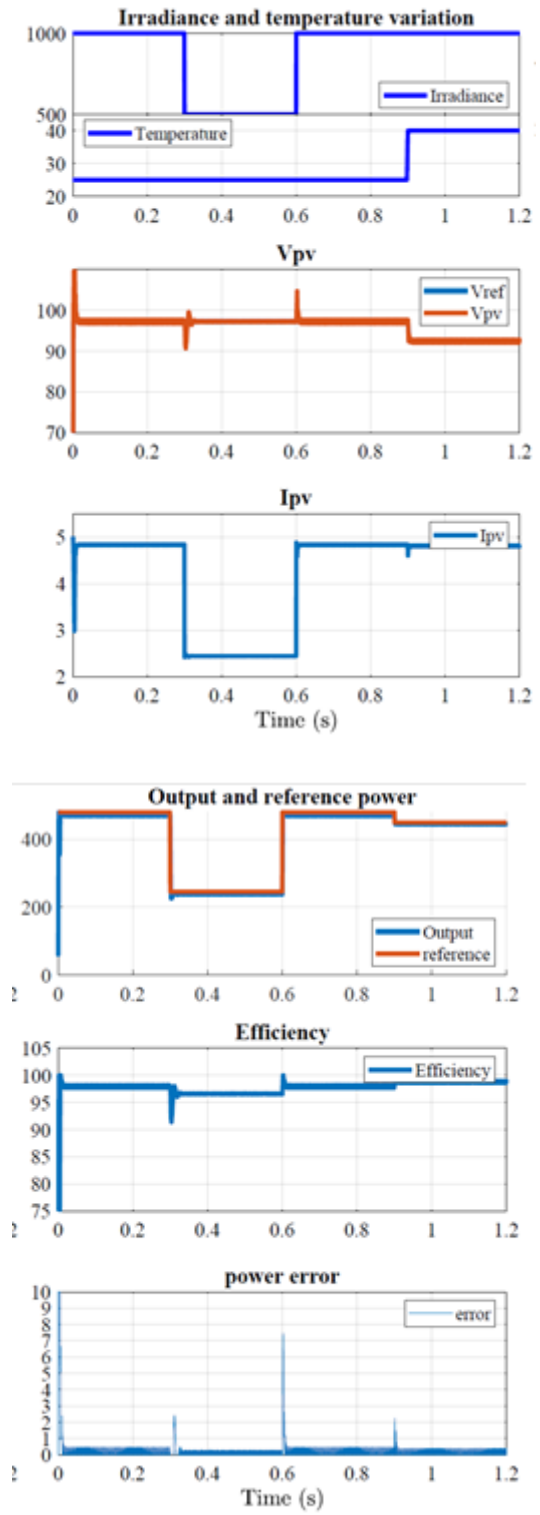


Figure 11. Simulation results of the constant-voltage technique

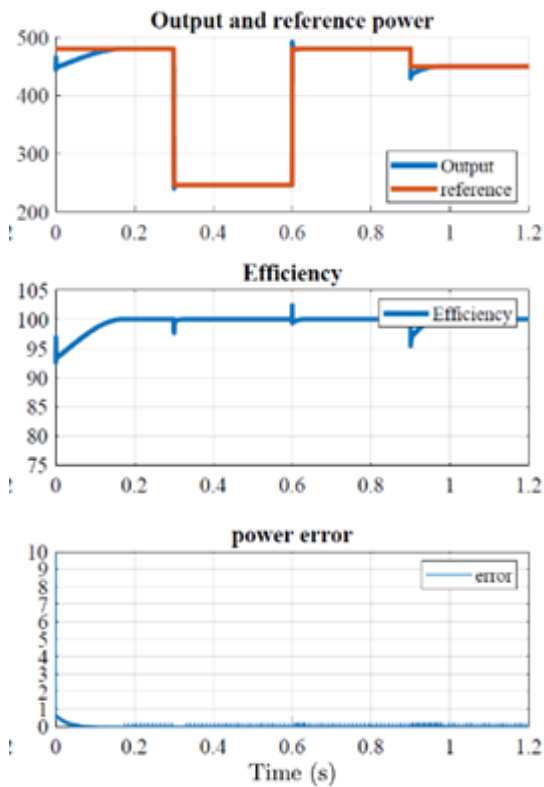
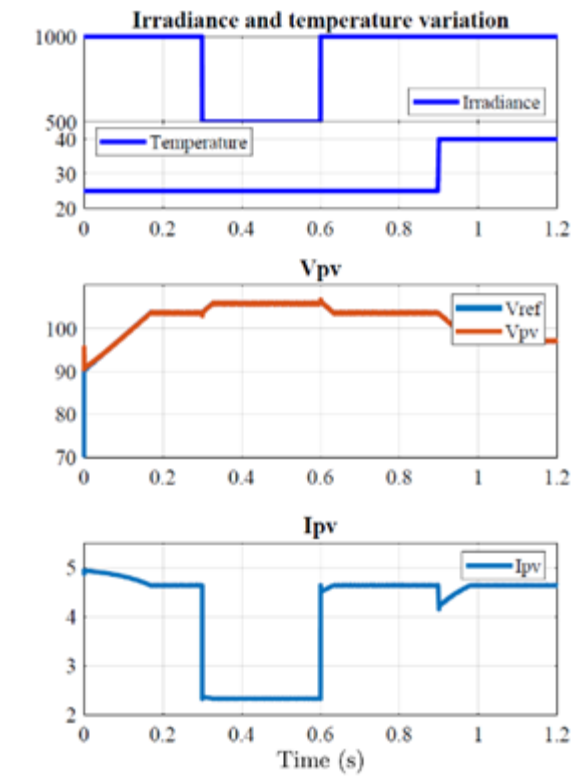


Figure 12 Simulation results of the CI technique

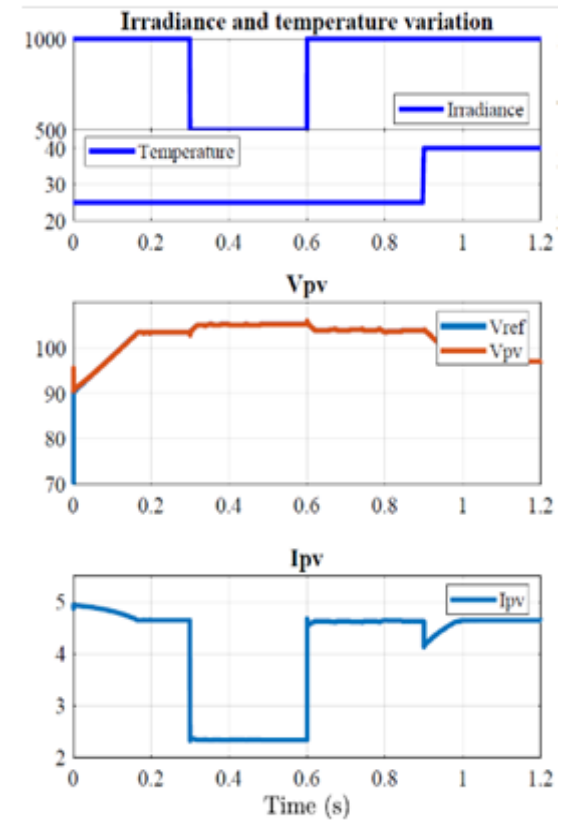
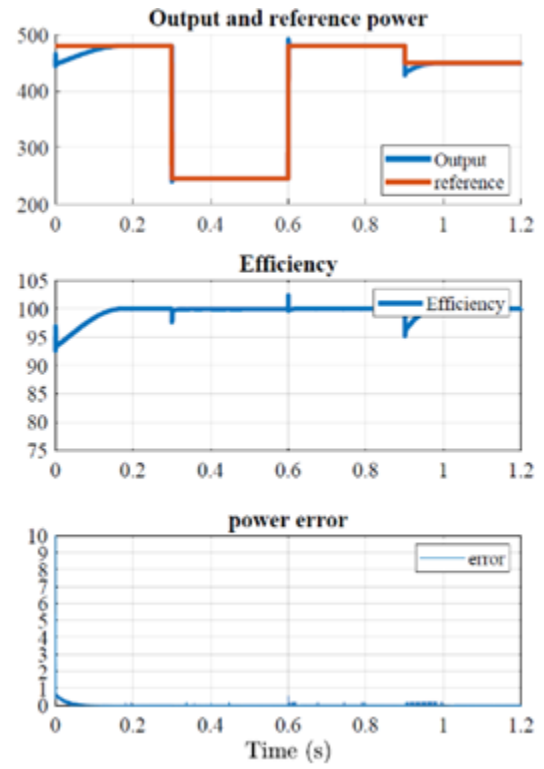


Figure 13 Simulation results of the CIM technique

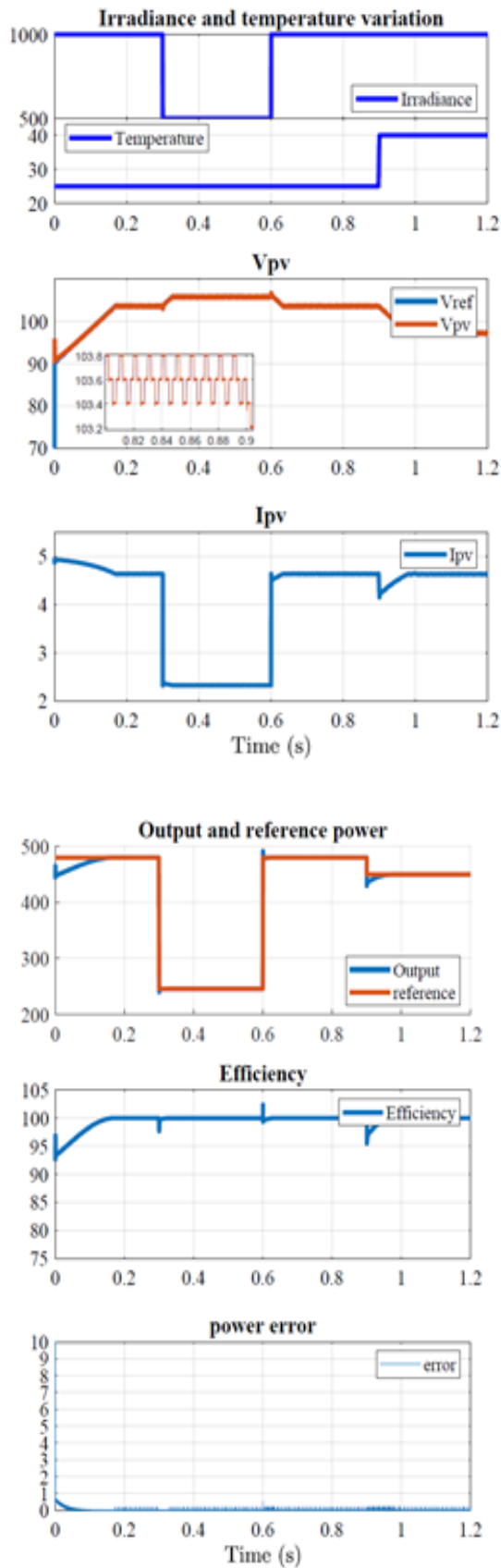


Figure 14 P&OC technique simulation results

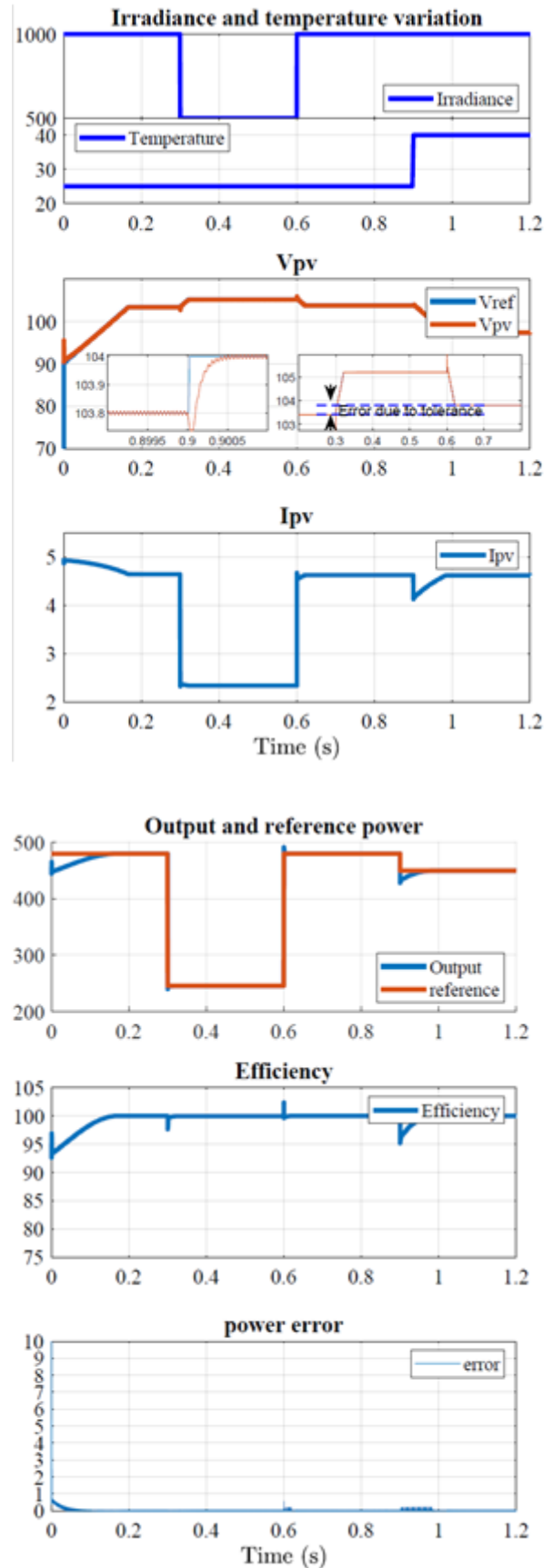


Figure 15. Simulation results of the P&OM technique.

The zoomed-in view in Figure 15 shows the variation in the reference voltage around the MPPT voltage, which is one of the characteristics of this method. This variation is attributed to the lack of algorithm-stopping criterion when the MPP is reached.

Finally, Table 1 presents the advantages and disadvantages of each method.

Table 1. Advantages and disadvantages of each MPPT method used

MPPT Method	Advantages	Disadvantages
Constant Cycle Ratio	Low implementation complexity.	Have a high error in steady-state for conditions other than tuning. Cycle reason tuning is done offline.
Constant Voltage	Low implementation complexity. If a pilot cell is used, V_{mp} tuning is done online.	If a pilot cell is not used, the reference voltage is tuned offline. If a pilot cell is used, it must be ensured that its operation is in the same condition as the other PV modules. Error in the steady state because $V_{mp} = 0.75$ is always considered.
Incremental Conductance	Online tuning. Low implementation complexity.	Has a slow response to rapid changes in the temperature and radiation. Oscillations in the steady state.
Modified Incremental Conductance	Online tuning. Low implementation complexity. Reduced oscillations.	Has a slow response to rapid changes in the temperature and irradiation. Error in steady-state.
Classic P&O	Online tuning. Low implementation complexity.	Slow response to rapid changes in the temperature and irradiation. Oscillations in steady-state.

MPPT Method	Advantages	Disadvantages
P&OM	Online tuning. Low implementation complexity. Stopping criterion ends with steady-state oscillations, but this implies a small permanent error.	Has a slow response to rapid changes in the temperature and irradiation

V. CONCLUSIONS

The output power delivered by a photovoltaic field can be maximize using MPPT controls on the system. The use of six MPPT methods applied in MATLAB / Simulink already opens a range of viable options for the control of a photovoltaic system. As seen in the figures, the MPPTs have the desired functionality, keeping the voltage at the level where the power transfer is maximum. The information obtained in the qualitative comparison of behaviors and the accurate information explained were collected, concluding the advantages and disadvantages of each method, with the exception that each technique has its different application.

Note that all the techniques had similar behavior about environmental influences. Even with such a drastic variation in their temperature and irradiation values, the control was able to withstand climate disturbances, where it was concluded that the techniques have excellent reliability before abrupt environmental variations.

VI. AUTHOR'S CONTRIBUTION

The contribution in the work by the authors was made as follows: the context and state of the art investigation were carried out by Aybar-Mejía, León-Viltre and Gallego-Landera executed the experiments, C. Neto prepare the analysis about advantages and disadvantages of each method. The, data analysis and writing of this paper was carried out by the three authors.

VII. ACKNOWLEDGMENTS

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