

Survey of Six Maximum Power Point Tracking Algorithms under Standard Test conditions

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ABSTRACT

In this work, a survey is carried out on six MPPT algorithms which include conventional and artificial intelligence based approaches. Maximum Power Point Tracking (MPPT) algorithms are used in PV systems to extract the maximum power in varying climatic conditions. The following most popular MPPT techniques are being reviewed and studied: Hill Climbing (HC), Perturb and Observe (P&O), Incremental Conductance (INC), Open-Circuit Voltage (OCV), Short Circuit Current (SCC), and Fuzzy Logic Control (FLC). The algorithms are evaluated, analyzed, and interpreted using a Matlab-Simulink environment to show the performance and limitations of each algorithm.

I. Introduction

Photovoltaic solar energy is one of the renewable energy sources which consists of transforming solar radiation into electricity using the photoelectric effect [1]. In photovoltaic systems, the transfer of the energy from the PV generator via converters needs an MPPT controller for ensuring the optimal power transfer. In current literature, several MPPT algorithms are being classified into two main categories that are conventional and intelligent [2]–[7]. In order to differentiate the characteristics of available algorithms and properly use the appropriate algorithm for a given situation, MPPT techniques have to be evaluated in the same system configuration and environmental conditions. In this context, this work aims to evaluate the considered algorithms on a PV system subject to fixed STC climatic conditions. Hill Climbing (HC), Perturb and Observe (P&O), Incremental Conductance (INC), Open-Circuit Voltage (OCV), Short Circuit Current (SCC), and Fuzzy Logic Control (FLC) MPPT algorithms are implemented in Matlab-Simulink environment in order to give an insight on the performance and limitations of each algorithm.

II. PV energy generation system

The components shown in Fig. 1 are connected to form the PV system [8] which are composed as follows:

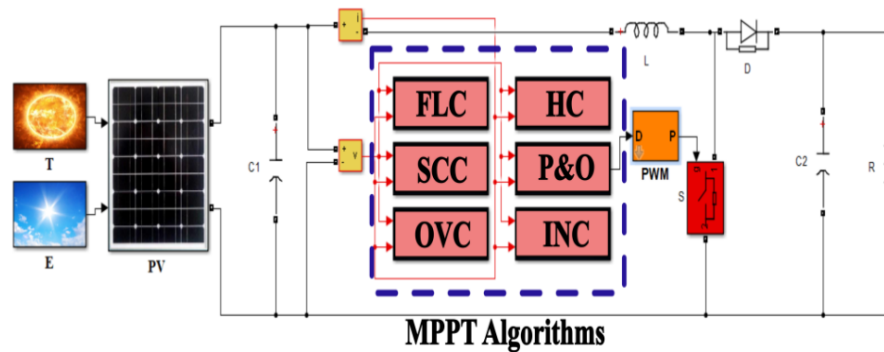


Figure 1. PV System with MPPT Algorithms.

II.1. Photovoltaic array model

The PV cell has been the subject of modeling studies resulting in the three known and most used models depending on the application. The one-diode model is usually used for simulation purposes as shown in **Fig. 2**.

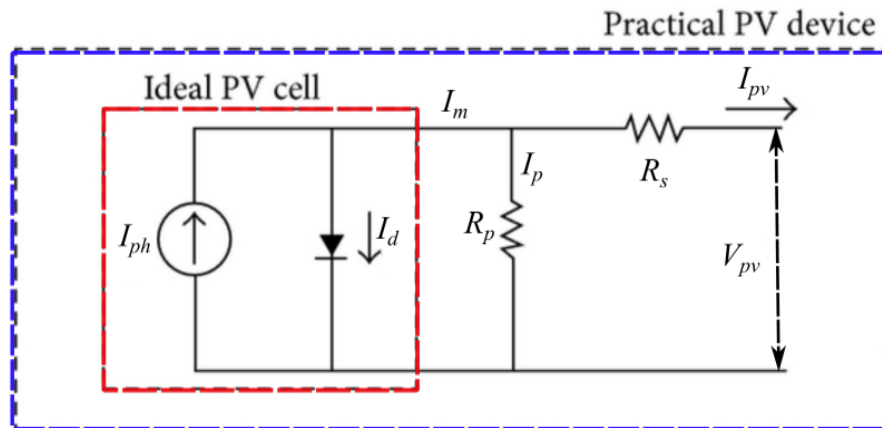


Figure 2. PV panel one-diode equivalent electric circuit.

The relationship between the output current-voltage is expressed by the following equation:

$$I_{pv} = I_{ph} - I_d - \frac{V_{pv} + I_{pv}R_s}{R_p} \quad (01)$$

II.2. Boost converter

The boost DC-DC converter consists of one energy storage element, two switching devices and a capacitor, and a filter [8]. The boost converter is shown in **Fig. 3**.

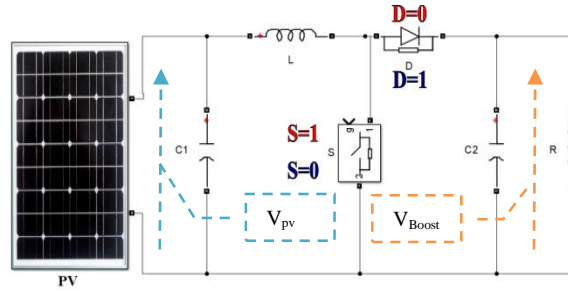


Figure 3. Boost DC-DC converter operation.

The voltage at the output (V_{Boost}) of the boost DC-DC converter at MPP is determined as;

$$V_{Boost} = \frac{V_{pv}}{1 - d} \tag{02}$$

where d is the duty cycle, and V_{pv} the PV panel output voltage.

III. MPPT Algorithms

Maximum Power Point Tracking techniques are considered as an essential control for the optimal operation of the photovoltaic energy generation system. The operation principle of this algorithm is based on the gradual variation of the duty cycle by converging it to the optimum value to maximize the power delivered by the PV panel. The most used and popular control algorithms are studied and presented in the consequent sections.

III.1. Hill Climbing

The Hill climbing (HC) technique (Fig. 4) is widely implemented in commercial MPPT controllers. Hill climbing strategy is based on the introduction of a change in the duty cycle of the power converter [9].

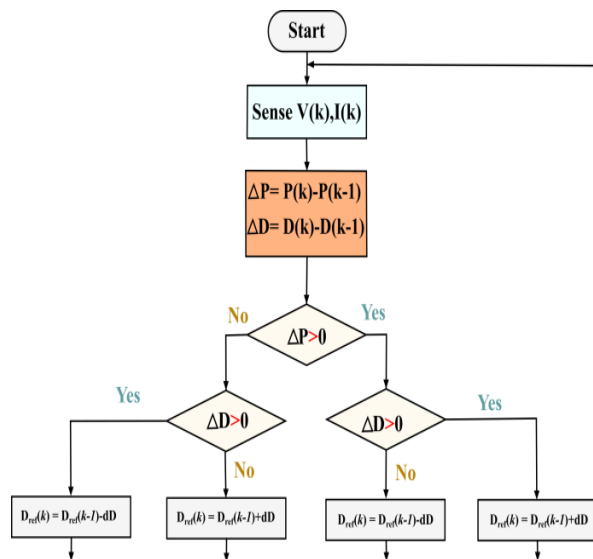


Figure 4. Flowchart of the Hill Climbing (HC) MPPT Algorithm.

Eq. (03) is used to obtain the MPPT in this technique:

$$S = \frac{\Delta P}{\Delta d} * \frac{d}{P} \tag{03}$$

III.2. Perturb & Observe

The P&O algorithm is the most popular MPPT technique (Fig. 5) because of its simplicity. The main principle of this controller is to induce perturbation on the PV system by acting on the PWM duty cycle variable and next observe how it affects the output PV power [10], [11].

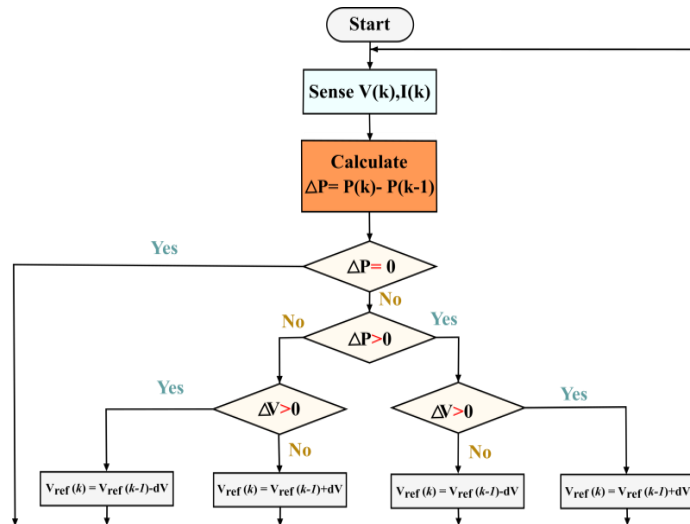


Figure 5. Flowchart of the Perturb and Observe (P&O) MPPT Algorithm.

Eq. (04) is used to obtain the MPPT in this technique:

$$\frac{\Delta P_{pv}}{\Delta V_{pv}} = 0 \tag{04}$$

III.3. Incremental Conductance

The incremental Conductance (INC) technique (Fig. 6) uses the information of the PV array voltage and current to track the desired operating point [12], [13].

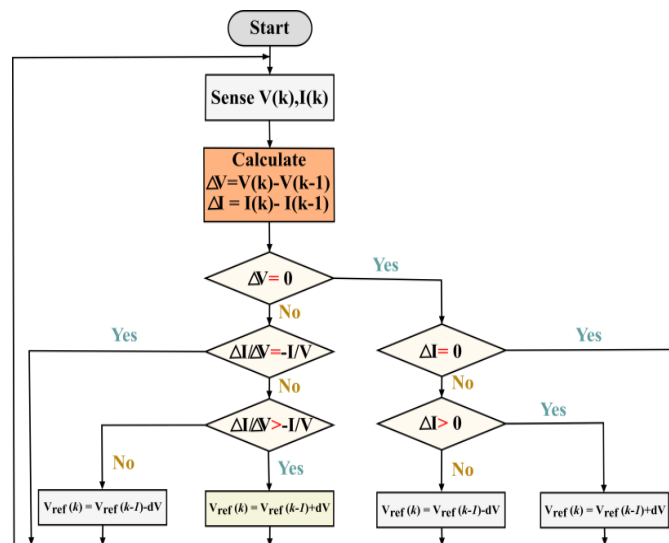


Figure 6. Flowchart of the Incremental conductance (INC) MPPT Algorithm.

Eq. (05) is used to obtain the MPPT in this technique

$$\frac{dI}{dV} + \frac{I}{V} = 0 \tag{05}$$

III.4. Fuzzy Logic Controller

The fuzzy logic controller has 2 inputs (E and ΔE) and 1 output (ΔD). A change in duty cycle ΔD is induced by the FLC in the form of step value which is summed to the previous step in order to obtain the next duty cycle (D). The principle of operation of the FLC technique [9], [14] is shown in Fig. 7

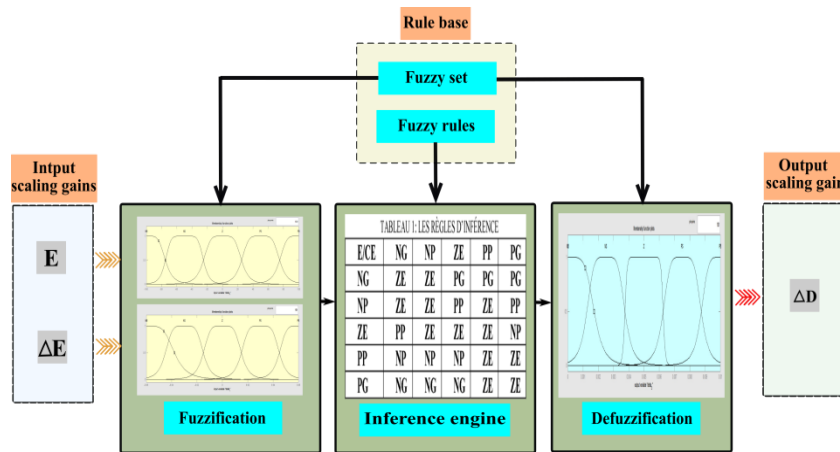


Figure 7. Operation principle of Fuzzy inference for MPPT.

Eq. (06),(07) are used to obtain the MPPT in this technique

$$E(k) = \frac{P(k) - P(k - 1)}{V(k) - V(k - 1)} \tag{06}$$

$$\Delta E(k) = E(k) - E(k - 1) \tag{07}$$

III.5. Short Circuit Current

The SCC method consists of comparing the current delivered by the PV panel with the maximum current (Fig. 8) [15].

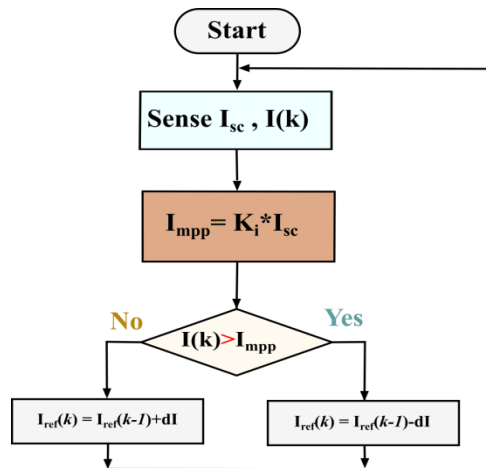


Figure 8. Flowchart of Short Circuit Current based MPPT Algorithm.

Eq. (08) is used to obtain the MPPT in this technique

$$I_{mpp} = K_i * I_{sc} \tag{08}$$

III.6. Open Circuit Voltage

The OCV method consists of comparing the voltage delivered by the PV panel with the maximum voltage (Fig. 9) [16].

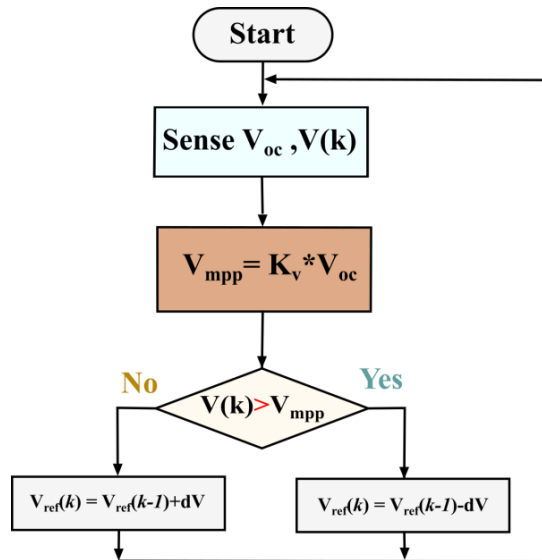


Figure 9. Flowchart of the Open Circuit Voltage (OCV) MPPT algorithm.

Eq. (09) is used to obtain the MPPT in this technique

$$V_{mpp} = K_v * V_{oc} \tag{09}$$

III. Simulation results and discussions

The six MPPT Algorithms are designed and tested under MATLAB/Simulink using the *Kyocera KC200GT* PV panel. Obtained results show very similar performance for conventional methods, i.e. HC, P&O, INC methods which extract slightly more power than HC algorithm. In Fig 10 and Fig.11 simulation results are given which represent the output power of the PV system under standard test conditions (STC). It has been clearly shown how the FL-based MPPT controller reduces the photovoltaic system response time. It is also obviously observed that the six MPPT algorithms have a loss of energy in terms of conversion efficiency. In Fig.10 (a) it is clearly noted the oscillations in the operating point in the case of the P&O technique resulting from the continuous perturbation of the operating voltage of the PV array in order to reach the MPP. Such effect is less present in FLC based MPPT technique, where power signals remain almost constant. This improvement has a direct effect on power loss reduction. The noted differences are shown in the obtained results (Fig. 10-11) as *Zoom 01* and *Zoom 02* which represent a zoomed portion of the transient and steady state responses respectively. A comparison between the characteristics of the studied algorithms is given in Table 1, which also summarizes the main known limitation for each technique.

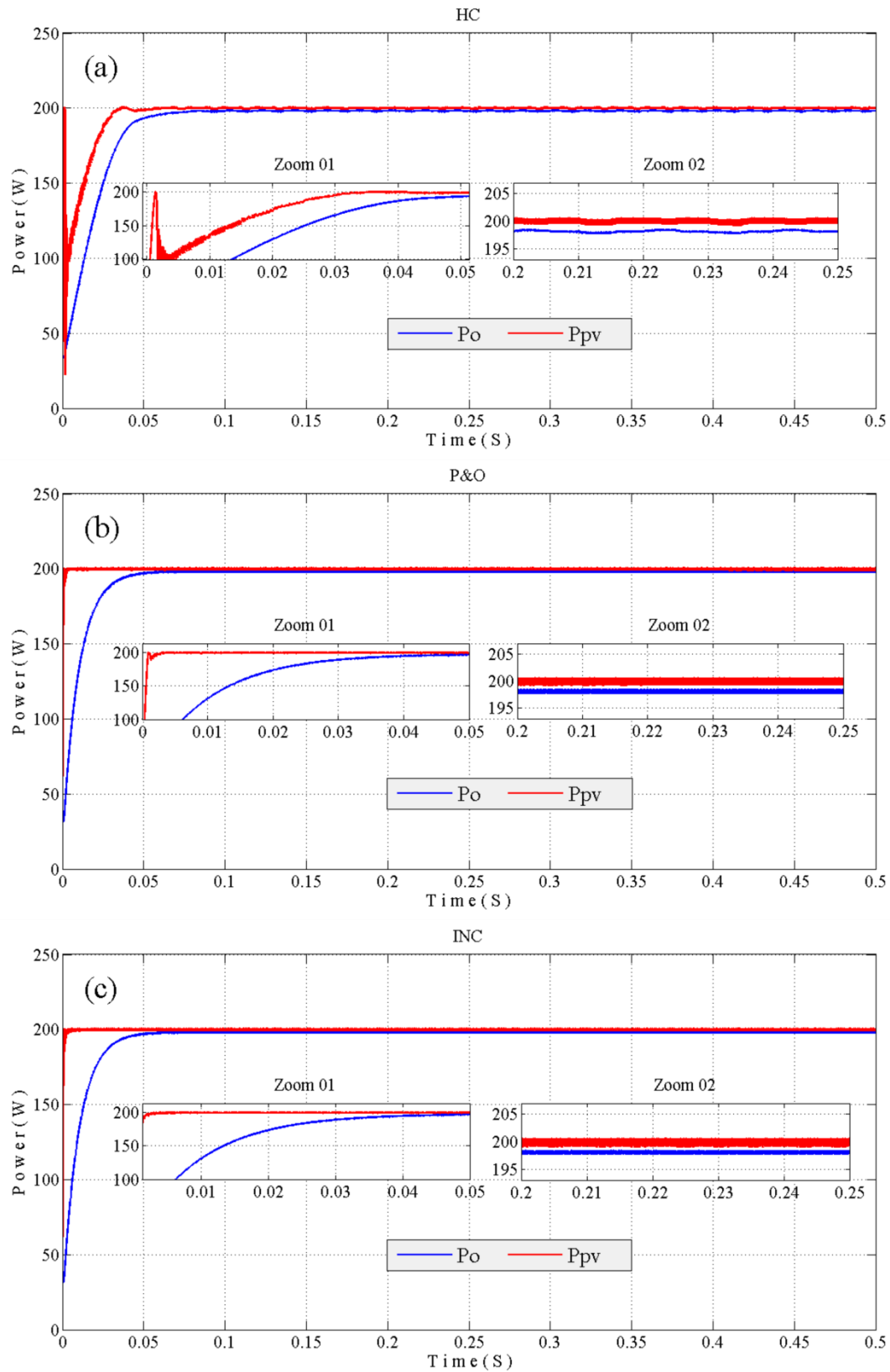


Figure 10. Response of the PV array at STC: (a) HC, (b) P&O, (c) INC.

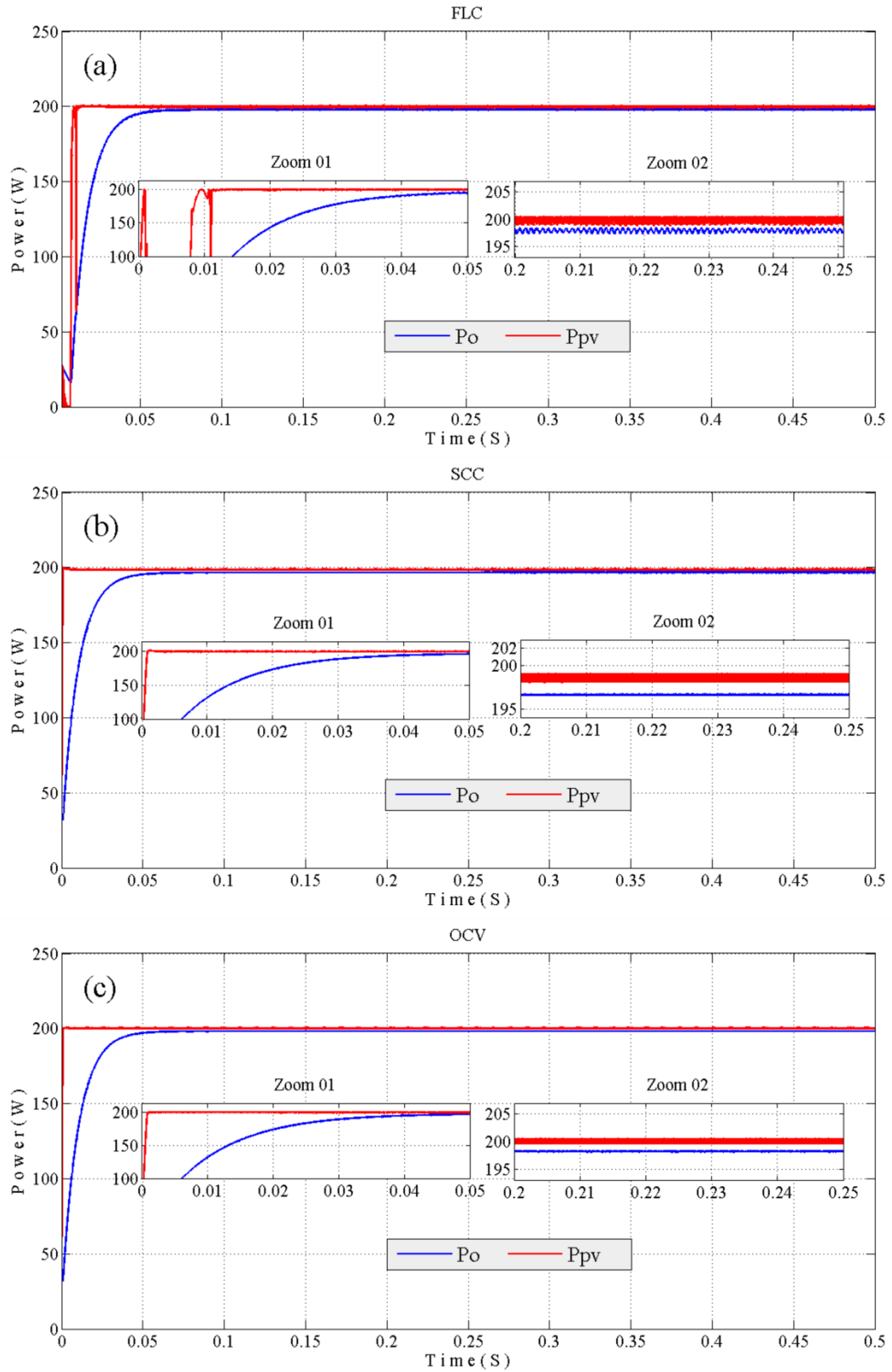


Figure 11. Response of the PV array at STC: (a) FLC, (b) SCC, (c) OCV.

Table 1. Comparative analysis of MPPT techniques and Limitations.

MPPT Technique	Converge to MPP?	Efficiency	Tracking speed	Main limitation
HC	Yes	Low	Slow	Sensitive to fast irradiation change
P&O	Yes	High	Fast	Sensitive to fast irradiation change
INC	Yes	High	Fast	Sensitive to measurement noise
FLC	Yes	High	Fast	Implementation complexity/cost
SCC	Yes	Low	Fast	Sensitive to PV panel degradation
OCV	Yes	Low	Fast	Sensitive to PV panel degradation

IV. Conclusion

In this paper, the studied MPPT strategies have been selected to show the performance of the PV system under STC conditions. The results of the simulations show that the Incremental Conductance (INC) algorithm gives better results than the P&O technique. On the other hand, the Short-Circuit Current method has shown better performance when compared with the Open-Circuit Voltage method. Among all these algorithms, the P&O and INC are largely used but the control technique based on Fuzzy Logic shows good transient behavior and better performance when compared to other methods. The main implementation limitation for the studied techniques has been provided in order to better choose the appropriate technique depending on available operating conditions.

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