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Comparative Study of Three Algorithms (MPPT) Applied to Photovoltaic Systems

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ABSTRACT: This paper attempts to study the behavior of different maximum power tracking (MPPT) applied to PV systems. The study includes discussion of three MPPT algorithms (the perturb and observation, incremental conductance, and first-order differential method), and performs comparative tests between them using actual irradiance. First, the PV system with storage battery is highlighted; the modeling and the simulation of the three techniques are carried out using Psim package.

KEYWORDS: MPPT; PV system; Perturb and observation; Incremental conductance; First-order differential.

1 INTRODUCTION

Renewable energies such as wind, solar, biomass and hydropower are promising solutions to compete with mass energies (fossil and nuclear energy). Unlike fossil fuels, renewable energies are energies with unlimited resources. Solar energy is an interesting energy: it is an abundant energy, clean and inexhaustible to use for different applications [1]. Solar energy can be directly converted into direct current (DC) electricity using a photovoltaic (PV) panel [2]. The characteristics of the PV panel (I-V and P-V curves) have a non-linear relationship with temperature and irradiance. However, on this characteristic curve Figure1, there is a single point where the entire system is able to operate with maximum efficiency. This point is called the maximum power point, and it requires calculations, monitoring, and control techniques to ensure that the PV system is operating at this unique point, in order to achieve the greatest harvesting power [3]. PV MPPT control methods have been widely studied by many specialists and have obtained such fruits as perturbation and observation algorithms (P & O), an incremental conductance algorithm and a first-order differential method ... etc. The MPPT technique not only reduces the power delivered by PV panels but also improves the life of the PV system. These techniques vary from one another in many aspects, including simplicity, the speed of convergence, the system stability, and popularity [4], [5].

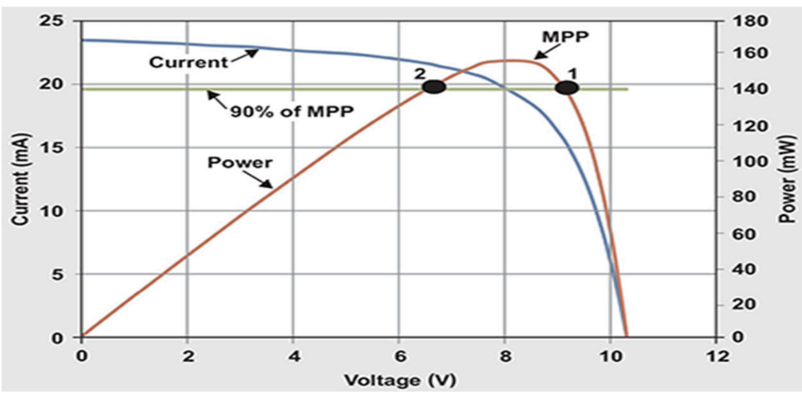

Fig. 1. PV panel Characteristics (I-V and P-V curves)

2 MODELING OF THE PV SYSTEM

The PV System is considered as a photovoltaic generator coupled to a DC-DC step-down converter controlled by an MPPT device, making it possible to supply a storage battery with a direct current in a condition of reducing the influence of the radiation and temperature on the maximum peak Power (MPP). The system being modeled is represented in Figure 2, implemented in a Psim package, it consists of a PV generator supplying a storage battery with a step-down converter controlled by an MPPT algorithm, the control of charge allows supervising the state of charge (SOC) to avoiding the overcharge and over-discharge condition when the battery voltage reaches some critical values [6].

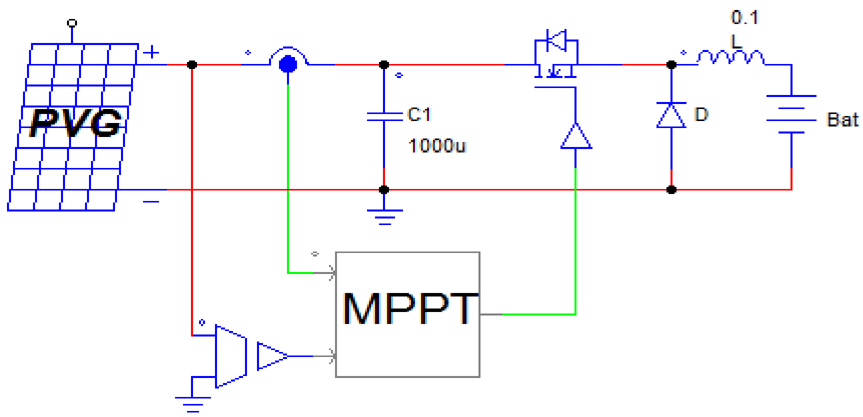

Fig. 2. Photovoltaic System with MPPT Controller

2.1 MODELING OF THE PV MODULE

A photovoltaic module is a device which converts the light into electricity directly using semiconducting materials that present the PV effect. The shape of the solar cell is defined as the device whose electrical distinctiveness, such as voltage, current and resistance vary when exposed to light [7][16]. Figure3 depicts the equivalent circuit of the solar cell. The working of solar cell based on semiconductor type requires minimum energy to excite electrons from valence band to conduction band which generates controllable current in the circuit. This model consists of series-parallel resistances, light generating source, and a diode. The mathematical expressions of the SPV cell are given by Eq. (1), (2) and (3).

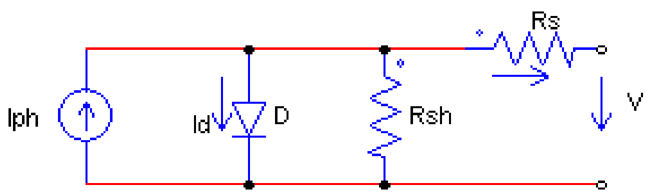

Fig. 3. Equivalent Circuit of a Solar Cell

where V is the output voltage, I is the current, T is the cell temperature (K), q is the electron charge, ki is the coefficient of short-circuiting temperature, S is the solar irradiance (W/m2), A is the ideality factor, kb and k are the Boltzmann's constant, Id is the PV saturation current, Iph is the load current, Iscr is the short-circuit current at reference condition, Tr is the reference temperature, Irr is the saturation current at Tr, Eg is the band-gap energy of the material, Q is the total electron charge [8].

$$I = I_{ph} - I_d \left[exp\left(\frac{qV}{K_b TA}\right) - 1\right] \quad (1)$$

$$I_{ph} = S[I_{scr} + K_i(T - T_r)] \quad (2)$$

$$I_d = I_{rr}\left[\frac{T}{T_r}\right]^3 exp\left(\frac{qE_g}{KQA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \quad (3)$$

2.2 DC-DC BUCK CONVERTER

A buck converter is a DC-DC electronic device which steps down voltage from its input to its output. It is a class of switched-mode power supply typically containing at least two active elements a diode, and a MOSFET transistor which is a semiconductor device in mode (locked-saturated), and at least one energy storage element, a capacitor, inductor, or the two in combination [9]. For continuous conduction mode the output voltage of the converter varies linearly with the duty cycle for a given input voltage Eq4:

$$V_{out} \;= D * \; V_{in} \qquad (4)$$

3 MPPT CONTROL TECHNIQUES

Many MPPT techniques have been developed to track the maximum power point, as like as perturb and observe, incremental conductance, and first-order differential. For comparison, we implemented some of the existing algorithms and analyzed the performance.

3.1 PERTURB AND OBSERVE METHOD

The operating principle of the P & O algorithm is presented in FIG. 4, the latter disrupts the duty cycle in order to modify the operating voltage, and then the modification of the operating power is observed. The next disturbance is made according to the observed value. This process drives the photovoltaic system to operate near MPP. However, steady state oscillations occur after the MPP is reached due to the continuous disturbance created by this technique to maintain the MPP. [10].Psim software package has been used to simulate this technique as demonstrated in figure 5[11].

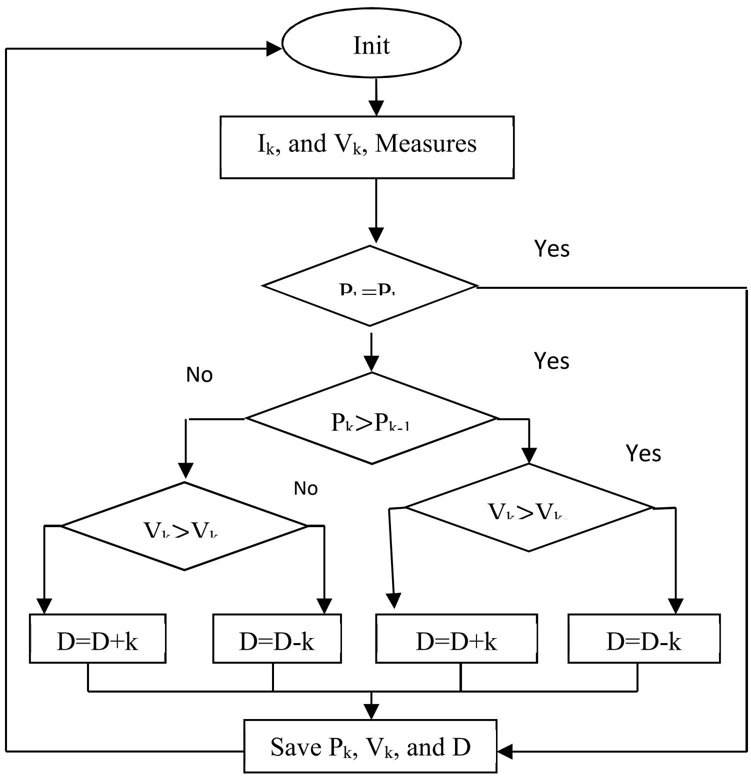

Fig. 4. Flowchart of Conventional P&O Technique

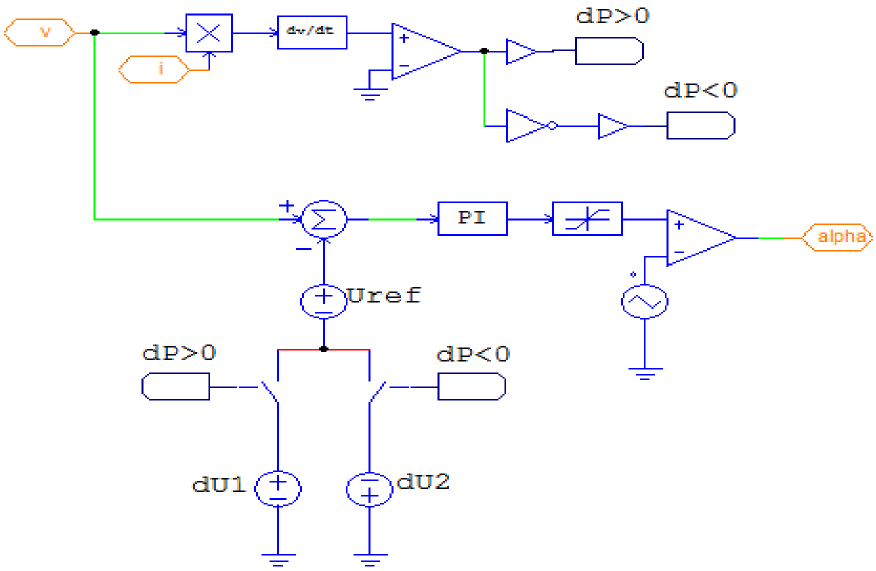

Fig. 5. Implementation of P&O Technique

3.2 Incremental Conductance Method

Incremental conductance algorithm is largely used because of the high steady-state tracking accuracy and good adaptability to rapidly changing atmospheric conditions [11]. Incremental conductance was designed based on observation of the characteristic P-V curve. This algorithm was developed in 1993 and was intended to overcome some of the disadvantages of the P & O algorithm. IC attempts to enhance tracking time and produce more energy over a wide irradiation environment [12]. The MPP can be calculated using the relationship between dI/dV and –I/V. If dP / dV is negative then MPPT is located on the right side of the recent position and if the MPP is positive, the MPPT is on the left side [13]. The equation of IC algorithm is:

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I + \frac{dI}{dV} \qquad (5)$$

MPP is reached when ($\frac{dP}{dV} = 0$) and

$$\frac{dI}{dV} = -\frac{I}{V} \qquad (6)$$

$$\frac{dP}{dV} > 0 \; then \;\; V_P < V_{MPP} \qquad (7)$$

$$\frac{dP}{dV} = 0 \text{ then } \; V_P = V_{MPP} \qquad (8)$$

$$\frac{dP}{dV} < 0 \; then \;\; V_P > V_{MPP} \qquad (9)$$

If MPP is on the right side, dI / dV <-I / V, the PV voltage must be decreased to reach the MPP [14]. IC technique can be used for reaching the MPP, enhance the PV efficiency, decrease power loss and system cost [13]. Compared to P & O technique, the IC implementation on a microcontroller produces more stable performance [15]. The oscillation around MPP area also can be suppressed in trade-off with its implementation complexity. Figure 6 shows the Flowchart of the Incremental Conductance Algorithm. Figure7 depicts the implementation of IC MPPT technique under psim environment.

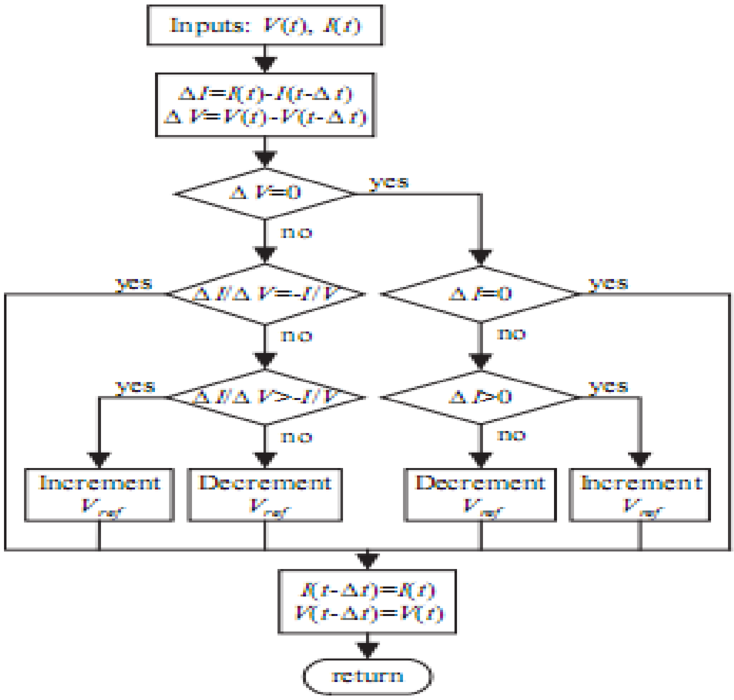

Fig. 6. Flowchart of the Incremental Conductance Technique

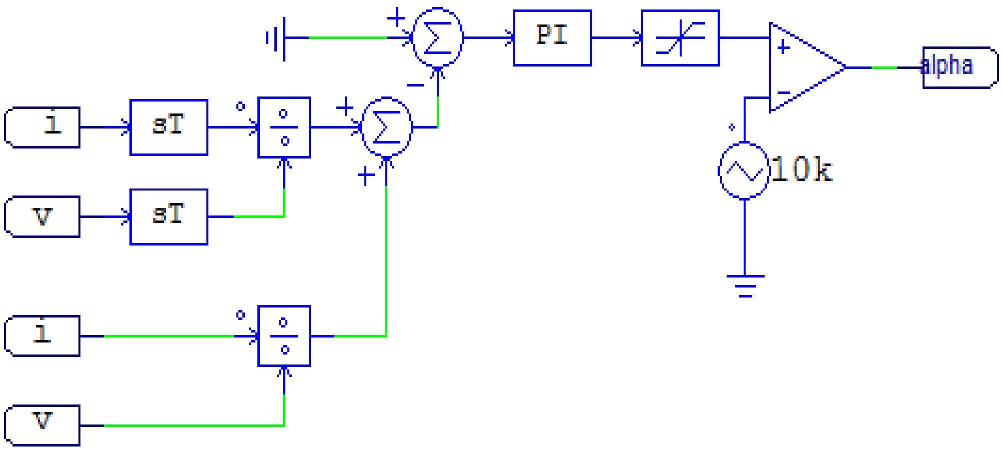

Fig. 7. Implementation of IC MPPT Technique

3.3 First-Order Differential Method

The first-order differential MPPT is very simple and depends on measuring the current and voltage at each time sample and calculating $(dP/\,dV)$ .When $(dP\,/dV)$ = 0, it is the point of maximum power. The equations of FOD method are:

$$\frac{dP}{dV} = 0 \qquad (10)$$

$$\frac{d(V * I)}{dV} = 0 \qquad (11)$$

$$V * \frac{dI}{dV} + I = 0 \qquad (12)$$

We get

$$V * dI = -I * dV \qquad (13)$$

Psim software package has been used to simulate this technique as sketched in figure 8.

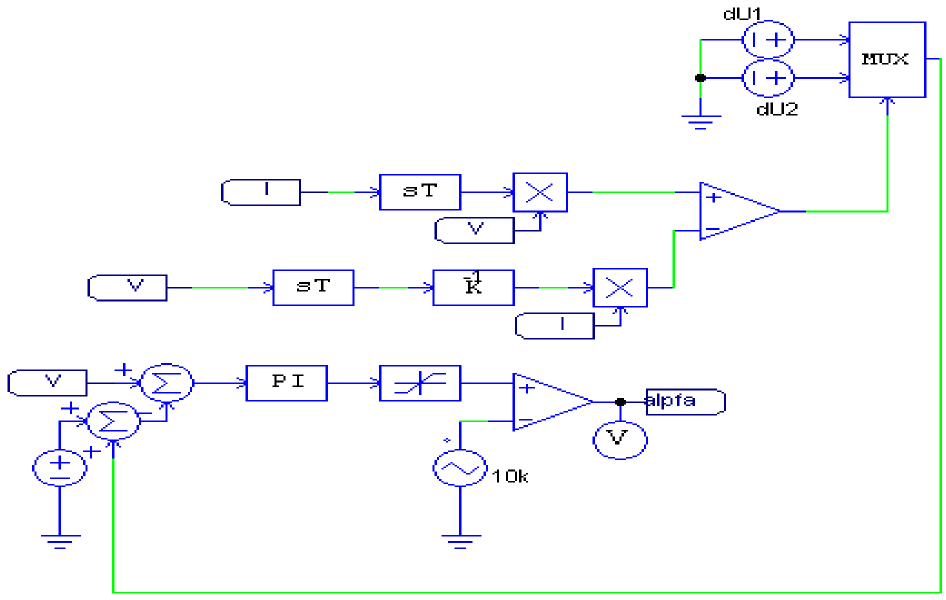

Fig. 8. Implementation of First-order Differential MPPT Technique

4 RESULTS AND SIMULATION

The three foregoing methods are implemented under PSim environment. After running various programs the results are as follows:

4.1 RESULTS OF THE P&O METHOD

The waveforms of irradiation, currents, voltages, extracted power, maximum theoretical power, and an average efficiency of the system using P&O technique are shown in figures 9, 10, 11, 12, and13 respectively.

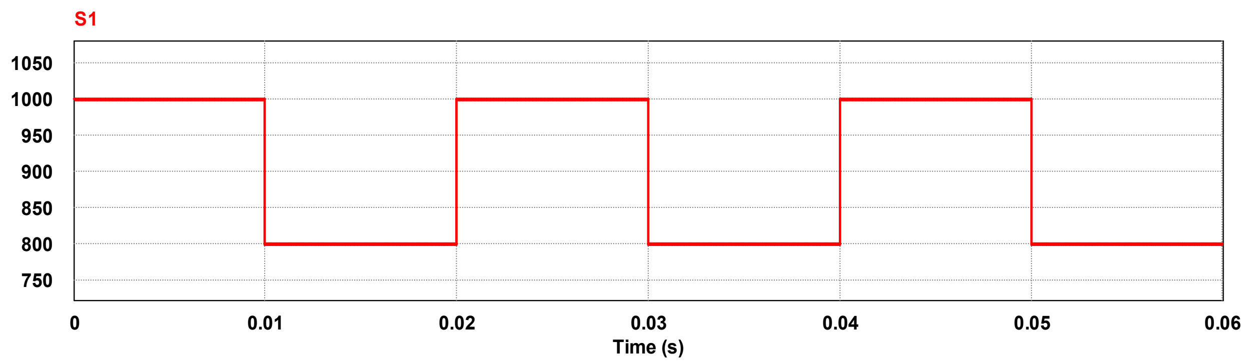

Fig. 9. Irradiance Profile (S1)

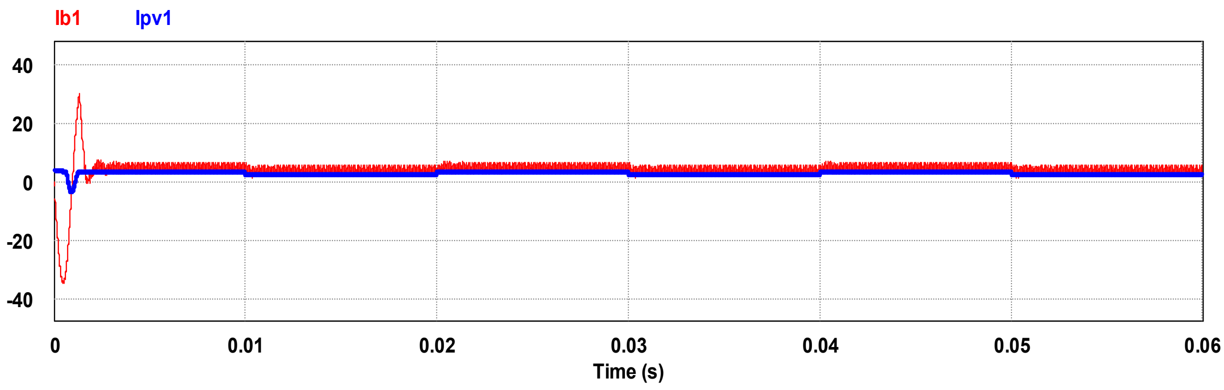

Fig. 10. Current Consumed by the Battery (Ib1), and Current Generated by PV Module (IPV1)

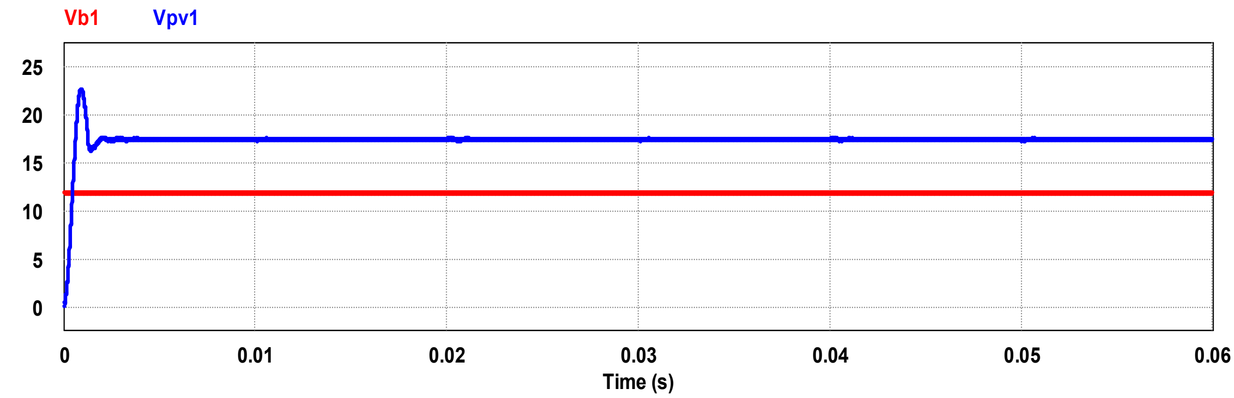

Fig. 11. Voltage of The Battery (Vb1) and Voltage of the PV Module (VPV1)

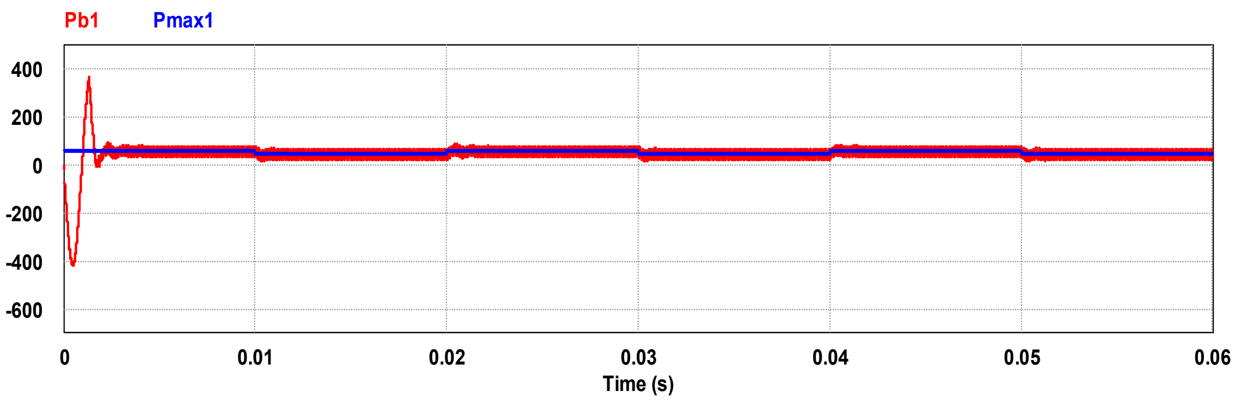

Fig. 12. Extracted Power (Pb1), and Theoretical Maximum Extracted Power (Pmax1)

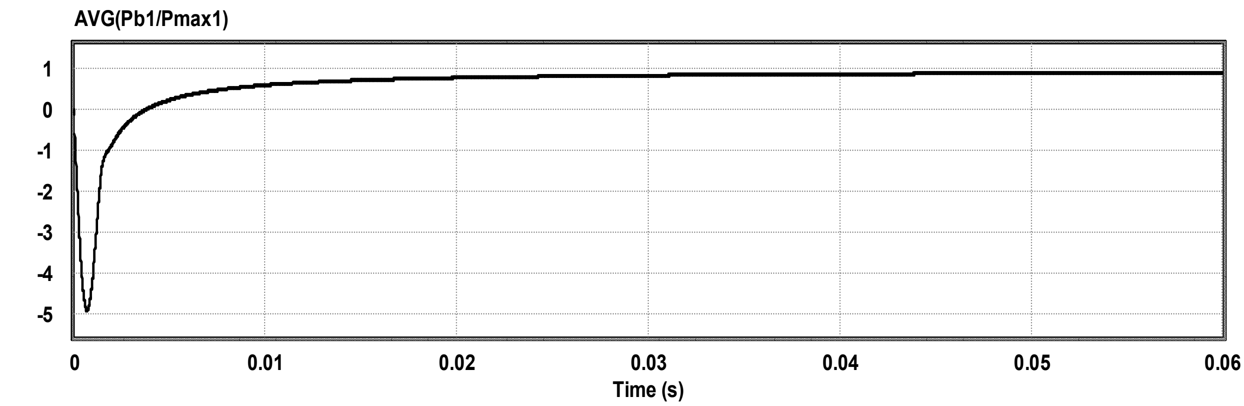

Fig. 13. Average Efficiency Obtained with P&O Technique

4.2 RESULTS OF THE IC METHOD

Figures14, 15, 16, 17, and18 present the waveforms of irradiation, currents, voltages, extracted power, maximum theoretical power, and the average efficiency system obtained with IC technique.

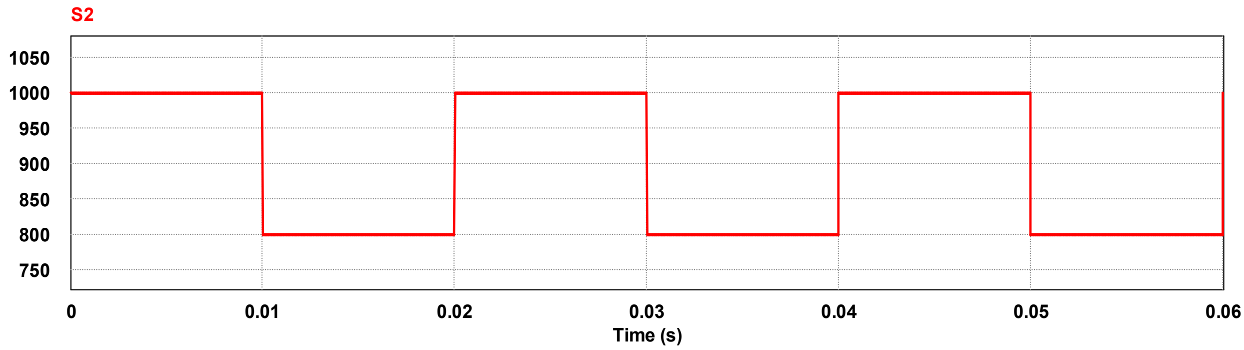

Fig. 14. Irradiance Profile (S2)

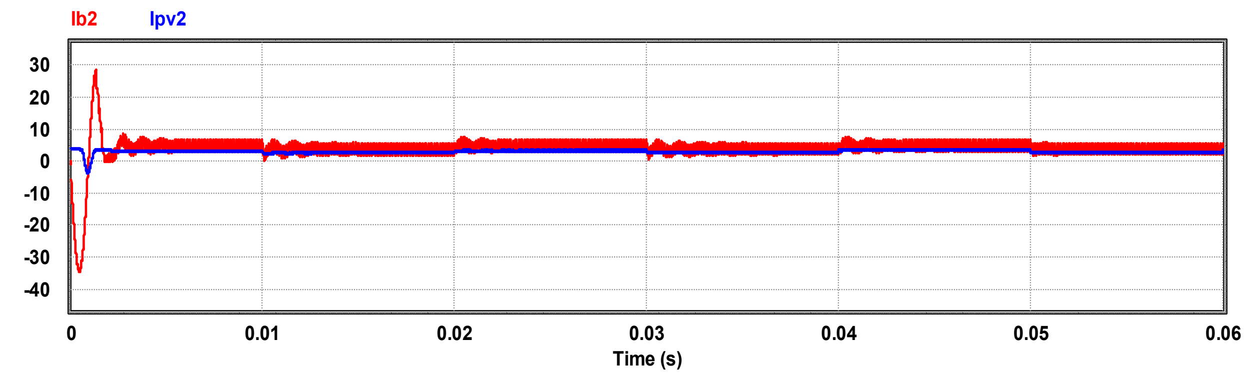

Fig. 15. Current Consumed by the battery (Ib2), and Current Generated by PV Module (IPV2)

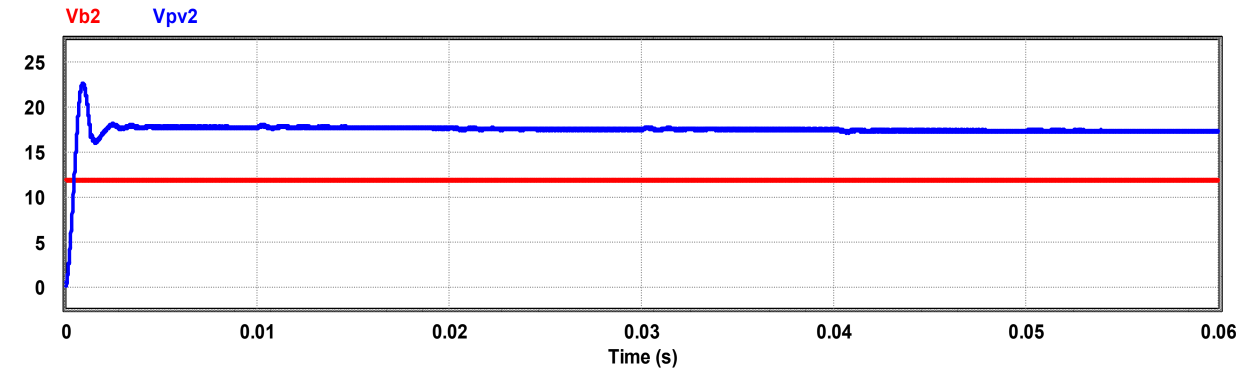

Fig. 16. Voltage of The Battery (Vb2) , and Voltage of the PV Module (VPV2)

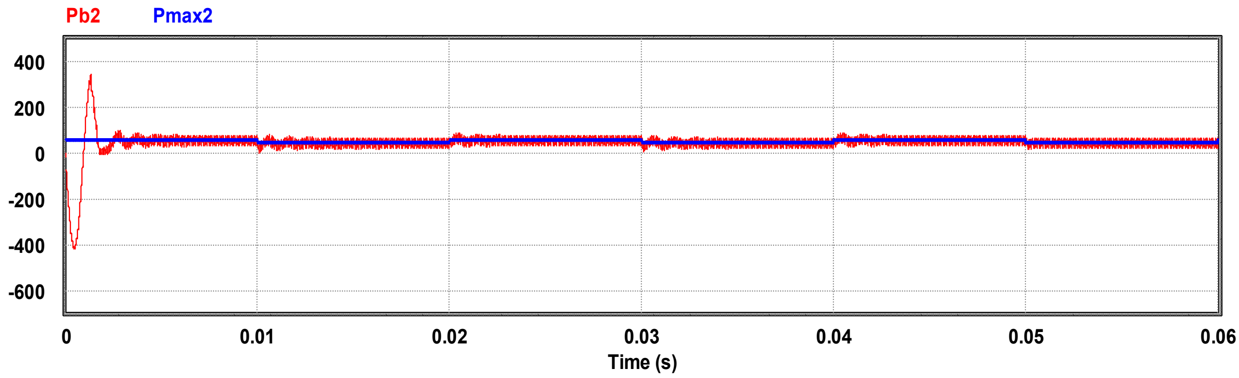

Fig. 17. Extracted Power (Pb2), and Theoretical Maximum Extracted Power (Pmax2)

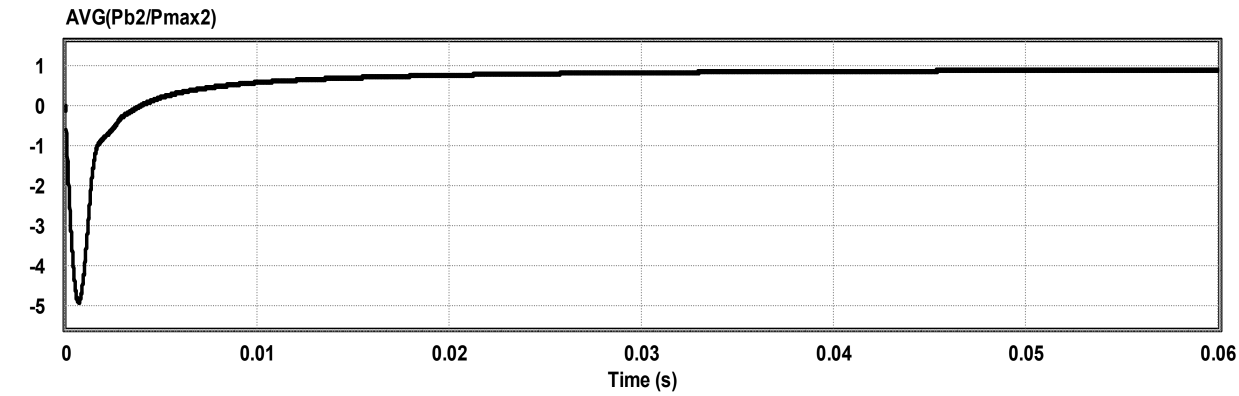

Fig. 18. Average Efficiency Obtained with IC Technique

4.3 Results of the FOD Method

Figures19, 20, 21, 22, and23depict the waveforms of irradiation, currents, voltages, extracted power, maximum theoretical power, and the average efficiency system obtained with FOD technique.

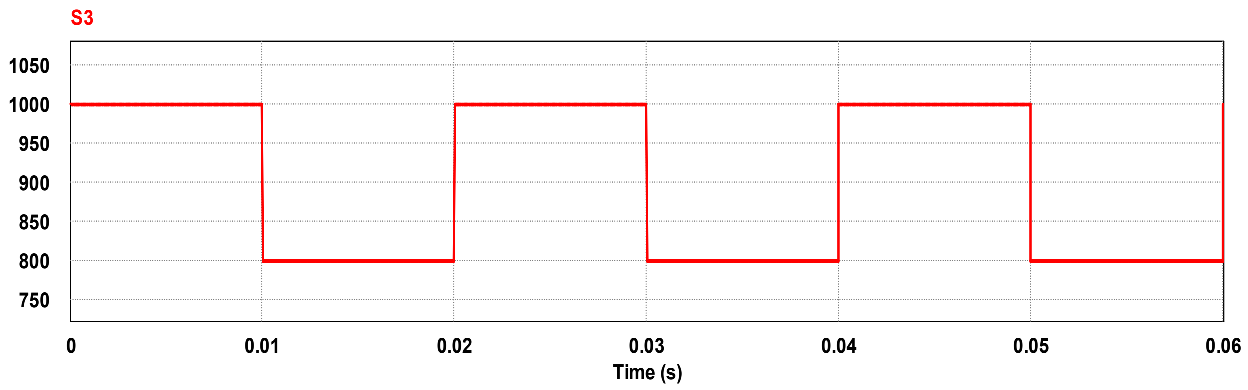

Fig. 19. Irradiance Profile (S3)

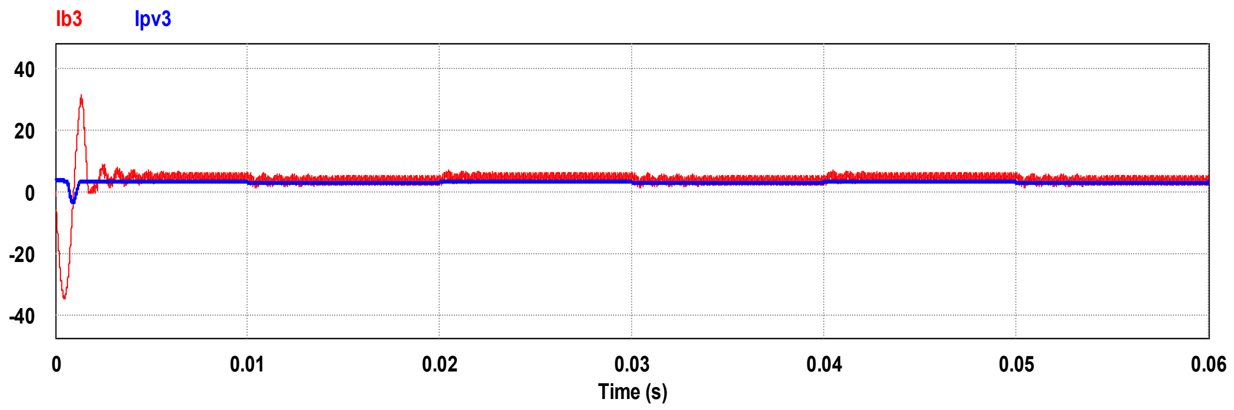

Fig. 20. Current Consumed by the Battery (Ib3), and Current Generated by PV Module (IPV3)

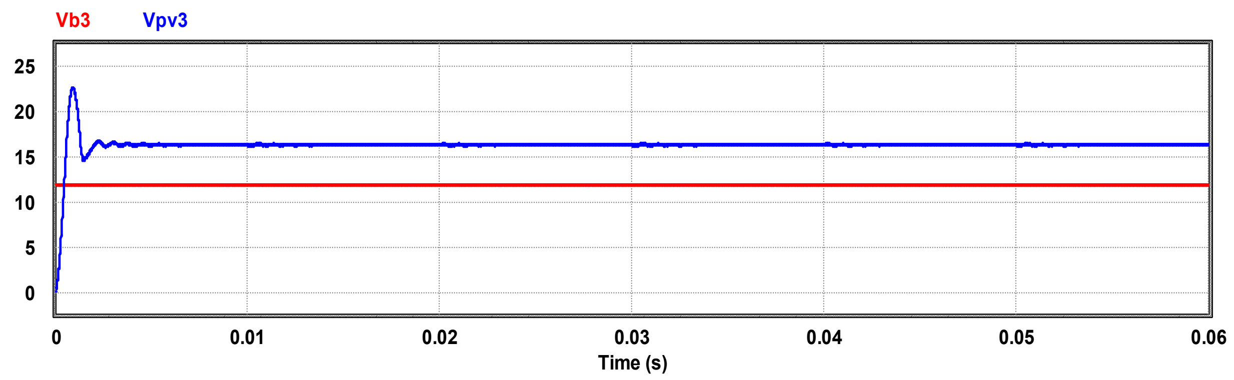

Fig. 21. Voltage of The Battery (Vb3), and Voltage Generated by of The PV Module (VPV3)

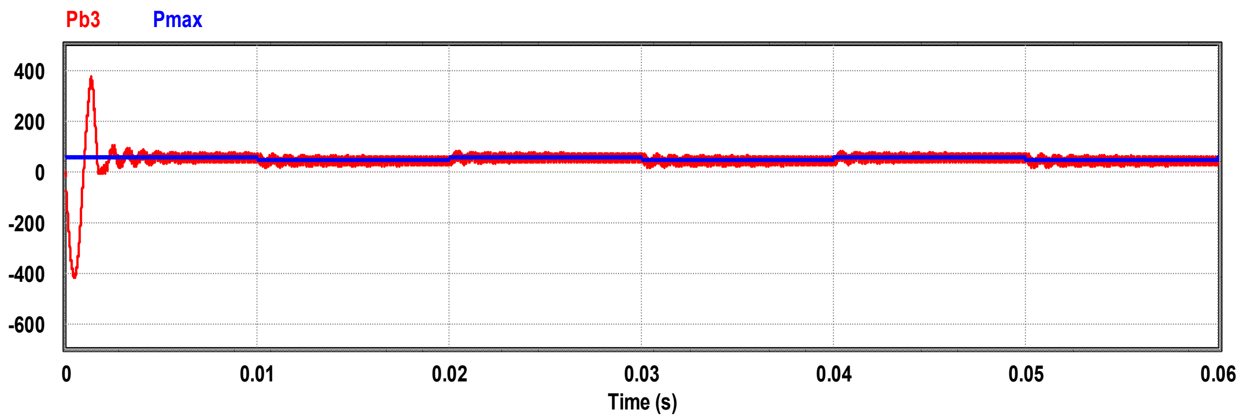

Fig. 22. Extracted Power (Pb3), and Theoretical Maximum Extracted Power (Pmax3)

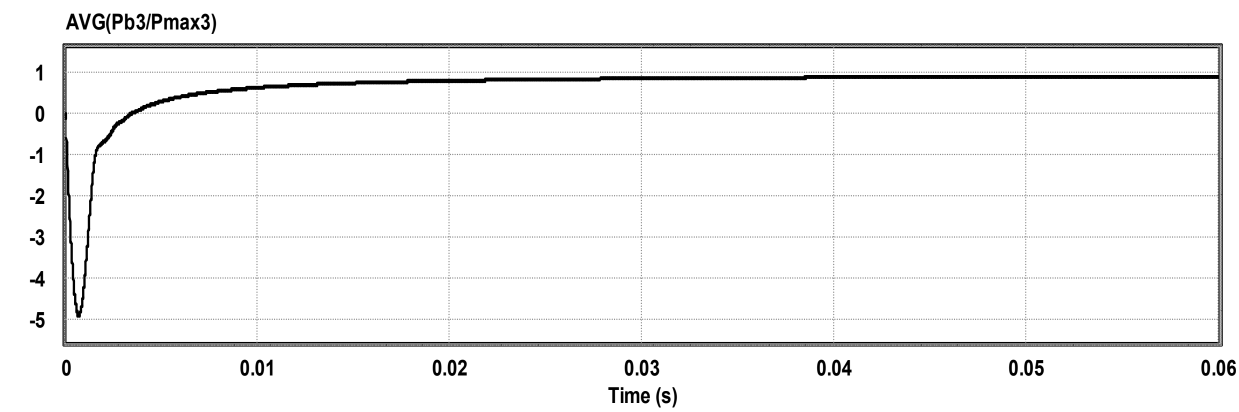

Fig. 23. Average Efficiency Obtained with FOD Technique

Table 1 summarizes the comparison of the performances between of P&O, Incremental Conductance, and First-Order Differential Method, at metrological conditions

Table 1. Comparison results under 800w/m², T=25C°

MPPT	Time responcse(s)	Ib	Ipv	Vpv	Vb	Pmax	Pb	Aver(Pb/Pmax)
P&O	0.06	3.46	2.72	17.55	12	48.30	41.62	91.89%
IC	0.06	3.49	2.82	17.09	12	48.30	41.94	92.45%
FOD	0.06	3.55	2.92	16.40	12	48.30	42.65	89.80%

5 CONCLUSION

In this article, techniques such as P & O, IC and the first-order differential method are evaluated. A model of PV module and DC / DC buck converter with different MPPT techniques was simulated using PSIM software. The different responses of the MPPT techniques are studied under specific meteorological conditions. The results show that the IC algorithm is the most efficient among the MPPTs followed by P & O and the first-order differential algorithm in most normal operating ranges.

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