

Comparative Study of SEPIC Converter Commands Fitted with Classic MPPT Algorithms Combined with Two Cascaded PI Correctors

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Abstract: - Instantaneous extraction of the maximum power available at a photovoltaic generator (GPV) terminal and its transfer to the load requires some techniques. The most practical is the use of an adaptation stage between GPV and load.

This paper presents a use case of a single ended primary inductor converter (SEPIC) as an adaptation stage in a PV system. The converter performance is evaluated by applying two different most used Maximum power point tracker (MPPT) Methods, including the Perturb and Observe (P&O) technique and the conductance increment.

Several works investigate in this field regarding these commands. However, this work shows the efficiency of algorithms P&O as well as conductance increments cascaded with two proportional-integral (PI) controllers. These allow regulating and stabilize voltage output and the current in the system while keeping the reference from the MPPT. The goal is to extract, the maximum power whatever the sunshine variation, the temperature and the load.

Keywords: MPPT control, SEPIC, PI controllers, PV system, GPV, P&O

I. INTRODUCTION

Using photovoltaic solar power is the most elegant way to produce electricity, without moving parts, gas emissions or noise. It consists of converting abundant and non-exhaustible sunlight into useful electrical energy. Photovoltaic (PV) systems generate power-dependent on climate conditions; such as solar radiation, panel temperature and the change of the charge. Hence, an extraction technique of the maximum power point (MPP) which control the direct current to direct current (DC/DC) converter duty cycle is required to ensure suitable operation of the PV chain in different operating conditions [7]. Prior works investigate the problem of finding operating point which allows extracting the maximum energy from PV modules using SEPIC converters controlled by MPPT regulators.

Some paper [1] [2] [4] proposes algorithms which use a very popular method based on the value of the reference voltage instead of MPPT algorithm output. Other uses MPPT but combine it directly with Pulse Width Modulation (PWM) technique [12].

The objective of this work is to improve the energy efficiency of the standalone PV system using a SEPIC converter. It is controlled by a conventional P&O MPPT as well as a conductance increment, where output is used as a reference for the PI voltage regulator.

This paper organized as follows: In section II, we will see the whole system to study. Section III presents the modeling of a PV Module. Section IV is devoted to the operating principle of SEPIC. Section V discusses the PI controllers. In Section VI, we talk about the classic MPPT command. In section VII and VIII, the simulation and interpretations of the results and finally the conclusion.

II. SYSTEM PRESENTATION

The system contains three blocks including a PV generator, an adaptive stage and a set of batteries. The adaptive stage is controlled by MPPT to ensure the continuation of the optimum operating point. The batteries store energy produced by the PV module during the day (phase sunshine) and stored energy is used during the night (dark phase) or when the solar radiation is insufficient.

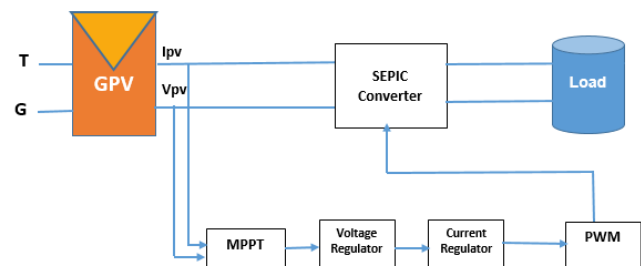


Fig 1. Synoptic diagram of a Standalone PV system

III. MODEL OF A PV MODULE

Modelling PV cell behaviour uses the solar radiation properties and those of semiconductors. Multiple mathematical models of a photovoltaic cell exist in the literature [1][5]. The goal is to generate the current-voltage characteristic (I-V) in order to analyze and evaluate the photovoltaic modules performance. The single diode model is the most classic and the most

commonly used model, due to its simplicity and precision [11]. From a behavioural point of view, Figure 2 shows an equivalent model of the ideal cell including a diode in parallel with a current generator.

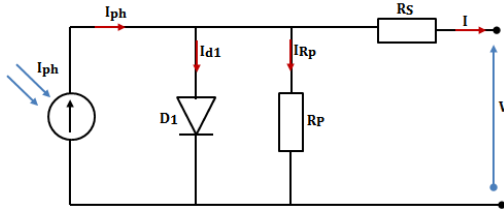


Fig 2. Equivalent circuit of a PV cell

Thus, equation (1) shows the mathematical model of a one-diode photovoltaic cell defined in [7].

$$I = I_{ph} - I_{sat} \left[e^{q \left(\frac{V + I R_s}{V_t} \right)} - 1 \right] - \frac{V + I R_s}{R_p} \quad (1)$$

With $V_t = \frac{nKT}{q}$

Where:

m is the material index (between 1 and 2 depending on the technology); **k**, the Boltzmann constant; **T**, the temperature in Kelvin; **q**, the charge of the electron.

For a given temperature and irradiation, the photo-current I_{ph} and saturation current I_{sat} are defined in equation (2) and (3).

$$I_{sat} = I_{sat-ref} \left(\frac{T}{T_{ref}} \right)^3 \exp \left[\frac{-qE_g}{nK} \left(\frac{1}{T} - \frac{1}{T_{ref}} \right) \right] \quad (2)$$

$$I_{ph}(G, T) = (I_{ph-ref} + \beta \Delta T) \times \left(\frac{G}{G_{ref}} \right) \quad (3)$$

Where:

I_{ph-ref} : current at reference Temperature; **β** , temperature coefficient given in the datasheet; **G_{ref}** , reference irradiation (1000W/m²); **E_g** , width of the prohibited band; **$I_{sat-ref}$** , saturation current at **T_{ref}**

Figures 3 and 4 show the characteristics I-V and P-V obtained under the influence of the change in temperature (for a given G) and sunshine (for constant T).

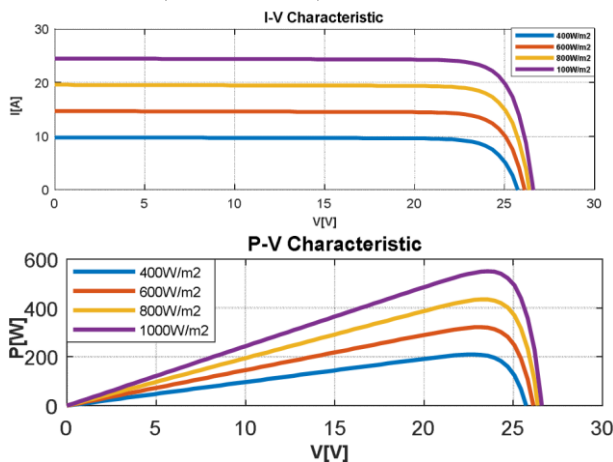


Fig 3. Characteristics Current-Voltage and Power-Voltage with irradiation variation

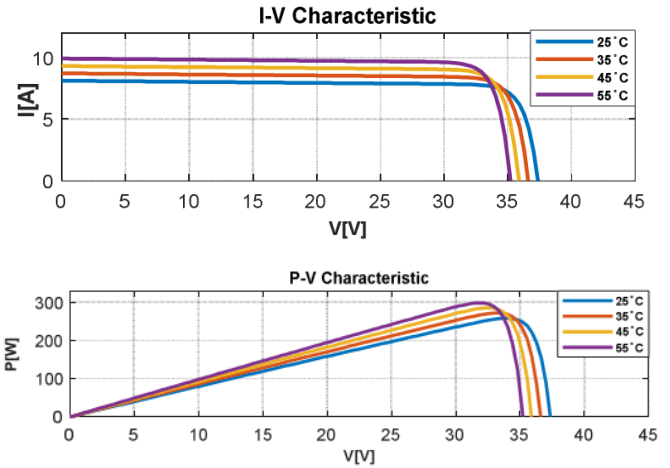


Fig 4. Characteristic Current-Voltage and Power-Voltage with Temperature variation

IV. MODELLING A SEPIC CONVERTER

The main role of the SEPIC converter is to form an impedance adaptation. In that case, the GPV delivers the maximum power irrespective of the value of the load. Synchronous converters (SEPIC or CUK) are now becoming more advantageous than other converters due to the reduced current ripple and better efficiency. It is used for interfacing the PV generator output to the load as well as keeping the maximum power point [11].

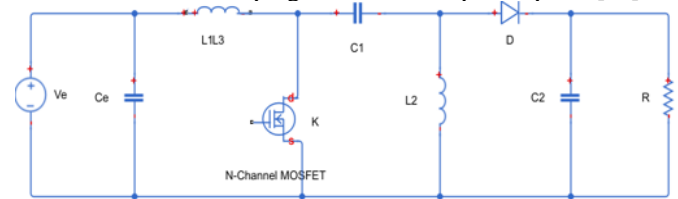


Fig 5. SEPIC converter

Analyzing its operation will be done in two phases according to the conduction state of the switch K.

A. Energy accumulation phase:

When switch K is closed, the converter behaviour is described by the equation (4).

$$\begin{cases} v_e(t) = v_{L1}(t) = L_1 \frac{di_{L1}}{dt} \\ v_{L2}(t) = v_{C1}(t) = L_2 \frac{di_{L2}}{dt} \\ i_e(t) = i_{C1}(t) = i_{L1}(t) = C_1 \frac{dv_{C1}}{dt} \\ -i_s(t) = i_{C2}(t) \Leftrightarrow -\frac{v_s(t)}{R} = C_2 \frac{dv_{C2}}{dt} \end{cases} \quad (4)$$

B. Recovery phase:

When switch K is open, the equation (5) describe the converter behaviour.

$$\begin{cases} v_{L1}(t) = v_e(t) - v_{c1}(t) - v_s(t) = L_1 \frac{di_{L1}}{dt} \\ v_{L2}(t) = -v_s(t) = L_2 \frac{di_{L2}}{dt} \\ i_e(t) = i_{c1}(t) = i_{L1}(t) = C_1 \frac{dv_{c1}}{dt} \\ i_{L1}(t) - i_{L2}(t) - \frac{v_s(t)}{R} = C_2 \frac{dv_s}{dt} \end{cases} \quad (5)$$

The state model of the converter is deduced from equations (4) and (5) during a T_c switching period. This model is presented in the equation (6).

$$\begin{cases} \frac{di_{L1}}{dt} = \frac{1}{L_1} \left[(d-1)(v_{c1} + v_{c2}) + v_e \right] \\ \frac{di_{L2}}{dt} = \frac{1}{L_2} \left[(d-1)v_{c2} - dv_{c1} \right] \\ \frac{dv_{c1}}{dt} = \frac{1}{C_1} \left[(d-1)i_{L1} - di_{L2} \right] \\ \frac{dv_{c2}}{dt} = \frac{1}{C_2} \left[(d-1)(i_{L1} + i_{L2}) - \frac{v_{c2}}{R C_2} \right] \end{cases} \quad (6)$$

The corresponding Simulink simulation model is shown in the figure 6.

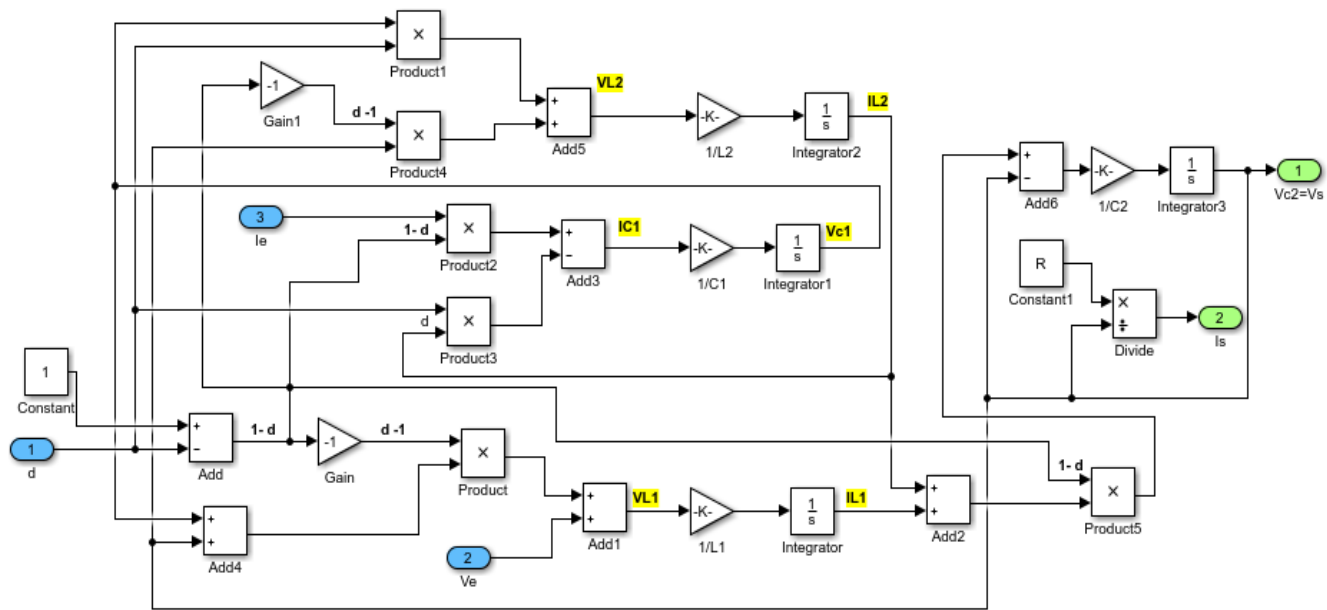


Fig 6. SEPIC simulation model

V. PI REGULATOR

The task of the regulators is, firstly, to compare, a reference value with the corresponding measured value. Secondly, it acts on the control quantity to make the measured value as close as possible to the reference value.

A. Voltage regulator

The voltage control loop regulates the generator voltage PV around the constant reference value delivered by the MPPT algorithm. It also controls the process of loading and unloading of capacitors C1 and C2, according to the load variations [9].

Equation (7) describes the transfer function of PI-Tension regulators.

$$C(s) = k_{pT} + \frac{k_{iT}}{s} \quad (7)$$

k_{pT}, k_{iT} : the gains of the corrector

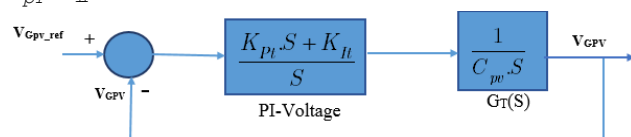


Fig 7. PI Controller of Vpv voltage

Equation (8) shows the closed loop transfer function.

$$H(s) = \frac{1}{C_{PV}} \frac{(s k_{pT} + k_{iT})}{s^2 + \frac{k_{pT}}{C_{PV}} s + \frac{k_{iT}}{C_{PV}}} \quad (8)$$

And equation (9) is formed through the identification of the second-order system of PI controllers:

$$\begin{cases} k_{pT} = 2C_{PV} \xi \omega_n \\ k_{iT} = C_{PV} \omega_n^2 \end{cases} \quad (9)$$

Where ξ is the own pulsation and ω_n is the damping factor.

B. Current regulator:

Another PI regulator is useful to adjust the current of the inductor L1. It corrects the error between measured current I_{L1} through the inductor and the reference provided by the control loop of the PV generator voltage.

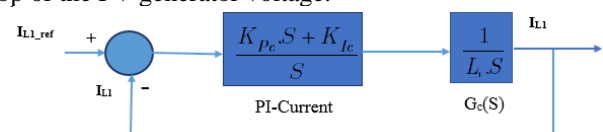


Fig 8. Current regulator I_{L1}

PI-current controller transfer function is presented in equation (1).

$$C(s) = k_{pc} + \frac{k_{ic}}{s} \quad (10)$$

Equation (11) shows the closed loop transfer function

$$H(s) = \frac{\frac{1}{L_1} (sk_{pc} + k_{ic})}{s^2 + \frac{k_{pc}}{L_1} s + \frac{k_{ic}}{L_1}} \quad (11)$$

Identification with the second order system results the equation (12).

$$\begin{cases} k_{pc} = 2L_1 \xi \omega_n \\ k_{ic} = L_1 \omega_n^2 \end{cases} \quad (12)$$

VI. MPPT COMMAND

The MPPT control is essential for an optimal operation of a photovoltaic system. The principle of this control is based on the automatic change of the duty cycle to an optimal value in order to maximize the power output of the PV panel [1].

A. The P&O algorithm

The P&O algorithm is widely used because of its simple structure particularly with the fewest measurement parameters. To use it, we consider that the PV generator works at a point which is not necessarily the PPM. The principle of the P&O command consists of triggering a disturbance the GPV voltage and observing the power variation [5].

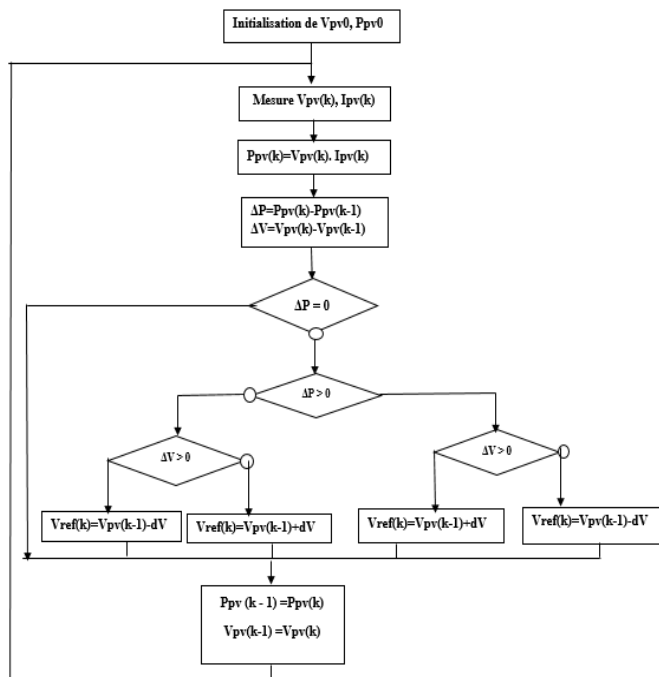


Fig 9. P&O algorithm

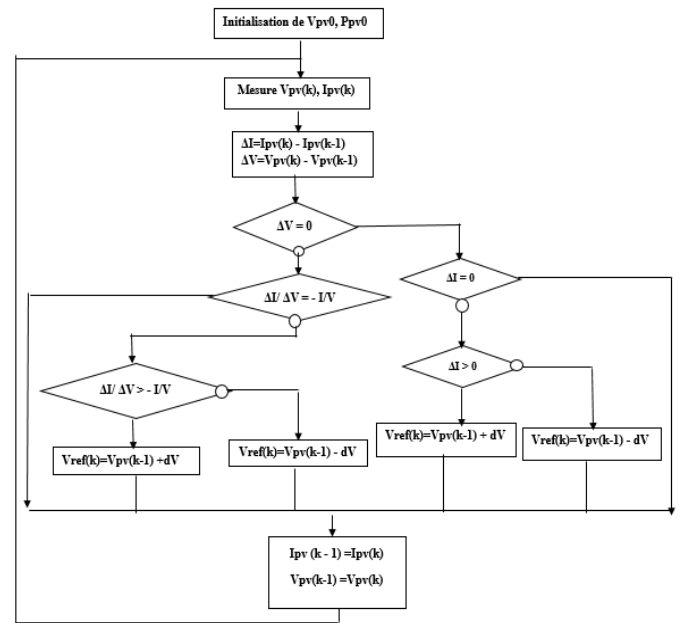


Fig 10. Conductance increment

B. Conductance increment

This method focuses directly to the power variations according to the voltage.

The conductance is the quotient of the intensity of the voltage. The incremental conductance is the quotient of the variation between two-time values of intensity by those of the voltage.

$$G = \frac{I_{Gpv}}{V_{Gpv}}$$

Comparing the conductance with the Incremental conductance, we

obtain $\Delta G = \frac{\Delta I_{Gpv}}{\Delta V_{Gpv}}$, the maximum of the curve by seeking the power derivative cancellation point [5].

VII. SIMULATION SETUP

The entire system is formed by a PV generator including twelve panels connected in series, a SEPIC converter and a resistive load. The control part has four Simulink blocks. The first function block contains the classic MPPT method which uses P&O or Increment of conductance. Two blocks of PI correctors control and stabilize the output voltage and current according to their reference. The last block contains the control law of the SEPIC converter.

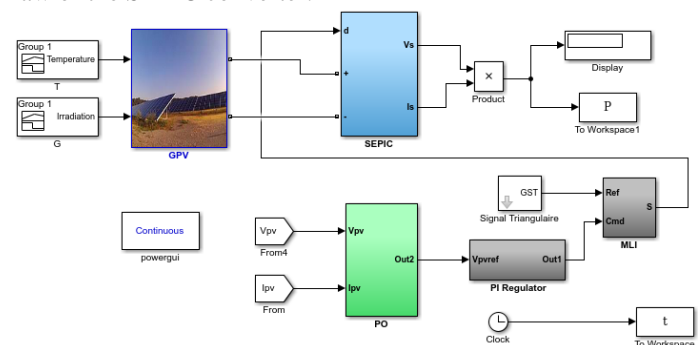


Fig 11. The entire system

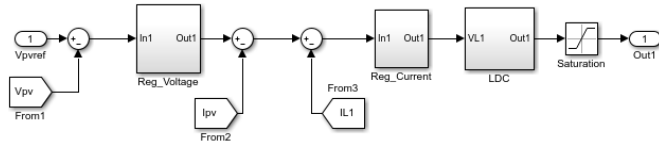


Fig 12. Blocks of the Cascade Voltage and Current Regulators

VIII. RESULTS ANALYSIS

Figure 13 (b) shows that with the two MPPT controls, the curves of the optimal voltage and the corresponding maximum power, merge.

We can notice the immediate recover after a sudden change of irradiation (response time $t = 0.06s$). However, the zooms in figure 13(c) shows that with P&O, there are a voltage ripple and a lower power value.

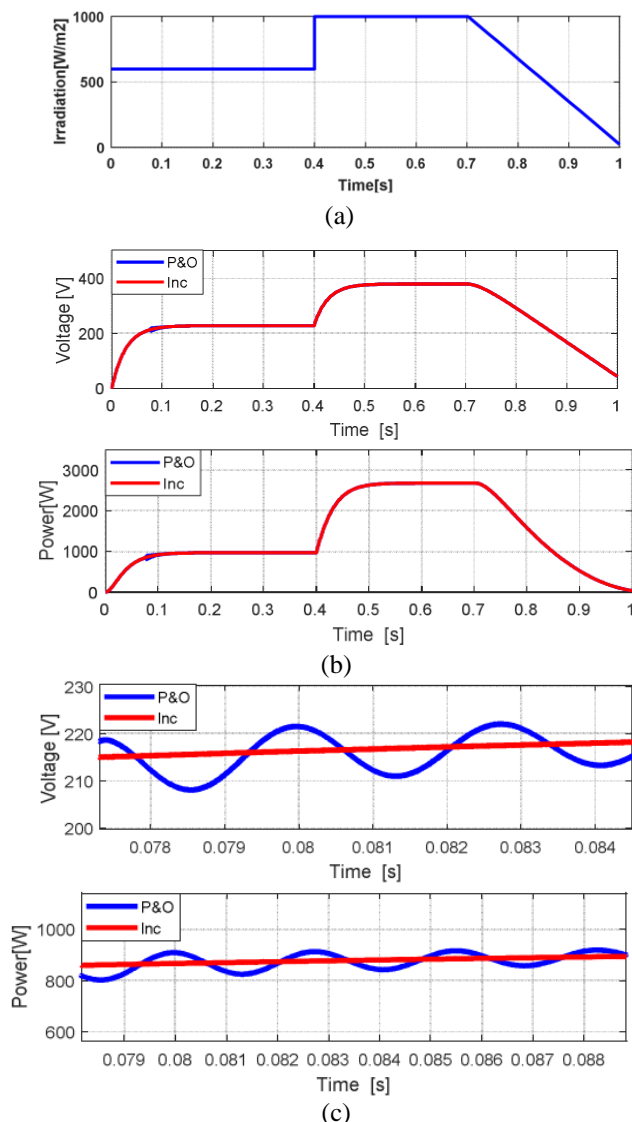


Fig 13. (a) Sunshine, (b) SEPIC output voltage and power, (c) zooms on curves in (b)

The Figure 14 shows the system behaviour with the variation in temperature of the panels. We will observe that with these two commands, the system is stable only after $t = 0.04$ [s] of sudden change in temperature. Its power gets back and always

follows the maximum power value whatever the change (figure 15).

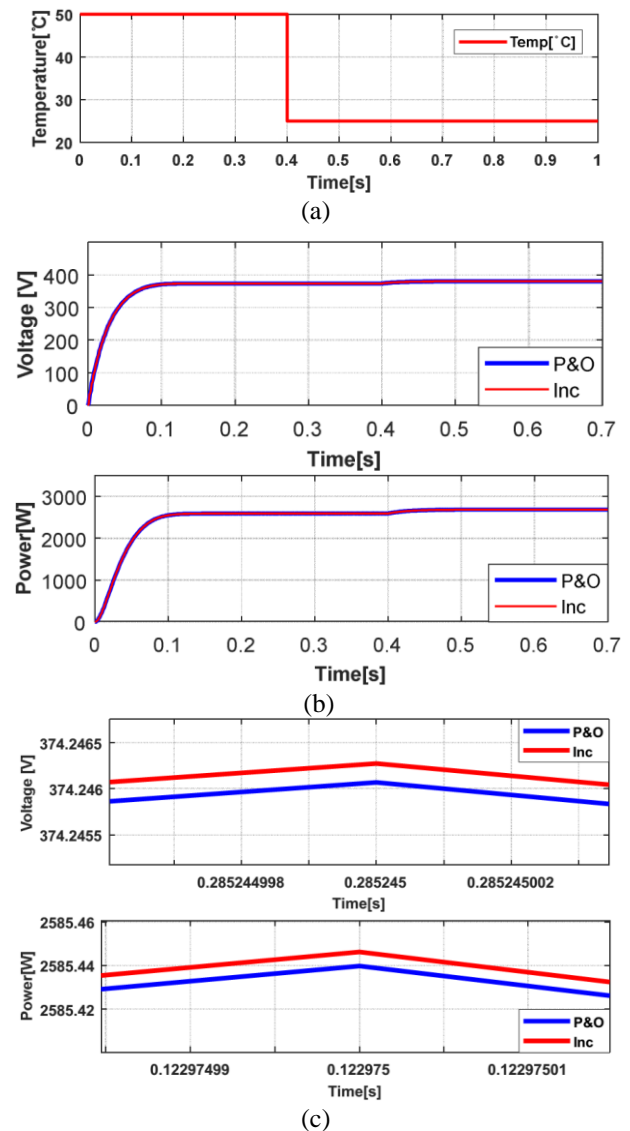


Fig 14. (a) Temperature, (b) SEPIC output voltage and power, (c) zoom on curves in (b)

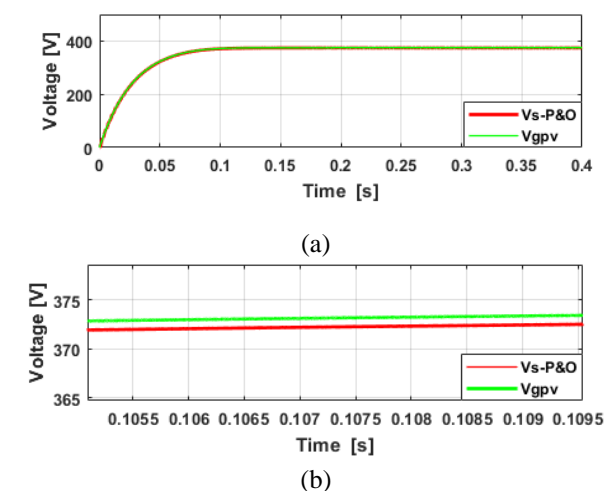


Fig 15. (a) Comparison of the GVP voltage and the SEPIC output voltage, (b) their zooms

IX. CONCLUSION

In this paper, the models of a PV generator, and a SEPIC converter have been presented. We have seen two different techniques for optimizing the power supplied by the GPV. Note that the value of Pmax, with these two methods, oscillate around the value of the MPP. It means that these methods can be used to determine the MPP. The results confirm the performance improvement of the conductance increment. Indeed, with the latter, the response time is faster and error steady state is low, contrariwise, with P&O, we note the existence of a small voltage ripple. Obtained results also shows that the system adapts well to external disturbances change (Temperature and Sunlight). Its efficiency consists not only for tracking maximum power point but also the response time and stability.

APPENDIX

TABLE I. SEPIC CONVERTER PARAMETERS

Nominations	Symbols	Values
Resistance	R	54[Ω]
Inductances	L1,L2	10.39[μH]
Capacitor	Ce	4.7 [μF]
Capacitor	C1	5 [mF]
Capacitor	C2	1.156 [μF]

TABLE II. GPV PARAMETERS

Nominations	Symbols	Values
Maximum Power	P _{max}	246[W]
Voltage at P _{max}	V _{mp}	32.2[V]
Current at Pmax	I _{mp}	7.62[A]
Open-circuit voltage	V _{co}	37.40[V]
Short-circuit current	I _{sc}	8.12[A]
Number of Cells in series	Ns	36
Number of modules in series	Ms	12
Number of modules in parallel	Mp	1

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