A new approach of variable step-size maximum power point tracking algorithm used in photovoltaic systems

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ABSTRACT

To exploit the maximum power generated by the photovoltaic (PV) panel, it is necessary to use the maximum power point tracking (MPPT) controller. The main concern of MPPT algorithms is how to reach the maximum power point (MPP) quickly with less oscillation. To achieve this objective, this paper studies and compares the performance of different MPPT algorithms with a new proposed criterion of variable step size in terms of convergence speed towards the MPP and reduced oscillations around it. The proposed method utilizes a simple way to build multi-operating zones. In each field, the step size depends on the closeness to the MPP. The simulation results are obtained under Proteus and Arduino software; we use physical security information management (PSIM) software for the modeling of the PV panel and MATLAB software to display the comparative results between the different algorithms.

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1. INTRODUCTION

Photovoltaic energy is growing rapidly due to its significant potential as a suitable solution for free energy. Renewable energy is used in several fields, such as domestic use and street lighting, as well as in commercial and research fields, which allows it to occupy the first rank of the attention of researchers, because of its advantages such as the absence of noise and pollution, ease of installation and low costs. Alternative energy sources have become necessary as an accurate solution to overcome energy problems using renewable energy sources [1], Especially in harsh areas and for environmental reasons. However, the low efficiency of these systems in extracting the maximum electrical energy from the solar panels and storing it poses the greatest challenge to relying on them as the main source of energy. Therefore, the most recent studies focus on the optimal use of the energy provided by solar panels and the means of storing it [2].

An accurate extraction and optimization of solar generators (cells, modules, and array) parameters are very important in improving the device quality during fabrication and in device modeling [3]. The electrical properties of photovoltaic panels represent non-linear curves, mainly affected by temperature, solar radiation and load resistance, these mentioned factors are the main factors affecting the performance of photovoltaic (PV) systems. To track optimal operation, maximum power point tracking (MPPT) control is required because of the non-linear performance characteristics of a PV system [3]. Several researchers researched PV modules using MPPT methods. Indirect MPPT methods, including fractional short circuit power and open circuit stress, provides a simple way to get the highest energy based on traditional methods that cannot track the maximum point efficiently under changing weather conditions [4]-[6]. But the normal disconnection or short circuit of the PV panel needs to be used to calculate short-circuit or open-circuit tension for comparison which leads to greater power loss.

The two famous direct MPPT approaches are perturb and observe (P&O) and incremental conductance (INC) [3], [7]. The good advantage of these two methods is that they can work with any PV module [8], they do not require any prior information about the characteristics of the PV module, and their implementation is very easy. In the same context, we may find more complex and expensive algorithms such as the method of hill-climbing in the presence of a shadow [9], [10].

To achieve the optimum MPPT, a scaling factor is usually necessary. The most popular strategies for applying adaptive step-sizing are voltage derivatives (dPPV/dVPV), service cycle (dPPV/dD) and current derivatives (dPPV/dIPV) [11]. All these adaptive step-size methods take a comparatively long time to hit the MPP due to the necessary step-size measurements. Therefore, the efficiency of these adaptive approaches is degraded under continuous solar radiation, but under rapid irradiance shifts. Problems overcoming, reverse due to sluggish convergence periods, continuous scaling factor and costly implementation are usually problems relevant to traditional MPPT derivative method [12].

To solve these problems, this paper proposes a robust technique of variable step size. The present technique determines the MPP in several fields according to the energy change between each two successive steps. The successful monitoring efficiency and enhanced stability of the proposed system are confirmed with the aid of comprehensive simulation and test results. This paper is devoted to the study and comparison of different MPPT control techniques from the photovoltaic generator (GPV), for good operation, whatever the weather conditions (temperature and lighting). The study has been carried out on a system consisting of a photovoltaic panel, a resistive load, and a DC-DC converter. The essential points dealt with in this study consist of the modeling of a photovoltaic system integrating the MPPT by using of Arduino board in real-time simulation. By considering a comparison of obtained results of the proposed method with other some maximum power point tracking techniques namely P&O, INC [13], fractional short-circuit current (FSCC) [14], fraction algorithm open circuit voltage (FCO) [15], hill-climbing [16], input characteristic impedance (ICI) [17].

The paper is organized as follows: In section 2, we will size and model a DC-DC converter of type BOOST to adapt the power generated by the PV panel to the load. Then in section 3, we talked about two algorithms that use variable step-size instead of fixed step-size, and then we propose another criterion of variable step-size to overcome the drawback of existing methods. Section 4 presented the simulation in real-time of the electrical circuit of our project then we present the simulation results of the proposed method studied in section 3, and compare its performance with the conventional one that used the fixed step size. Section 5 concludes the paper.

2. SIZING AND MODELING OF THE BOOST DC-DC CONVERTER

Boost, also known as a parallel chopper, is a direct DC-DC converter consisting of capacitors, inductors, and switches. In the ideal case, all these devices do not consume any active power his is the reason why we have good yields in the choppers as shown in Figure 1 [18].

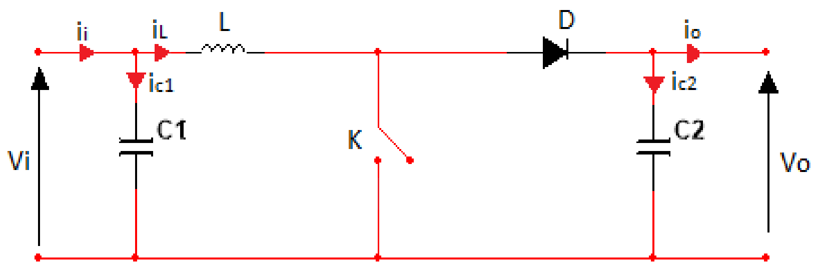


Figure 1. Boost DC-DC converter

Inductance and capacitances (L, C1, C2) are calculated to essentially filter the current and minimize the voltage ripple at the input and output of converters [19]. These values are calculated by the following expressions [20], [21].

$$L \geq \frac{V_O}{4\,\Delta i_{maxf}} \tag{1}$$

$$C_1 \geq \frac{I_i}{\Delta V_{imax} f} \quad (2)$$

$$C_2 \geq \frac{\Delta i_{Lmax}}{8\,\Delta V_{cmax} f} \quad (3)$$

With,
Δi_{max}: is the maximum current ripple.
ΔV_{cmax}: is the maximum voltage ripple.
f: switching frequency.
For a resistive load of 20 Ω and with a switching frequency of 20 kHz, Δi_{max}= 0.5 A and $\Delta V_{cmax} = 0.5v$, and according to (1)-(3) we have chosen the components of boost type converter as shown in Table 1.

Table 1. Boost converter components

Component	Information
Transistor	IRF540
Diode	15ETH06
Frequency	20k
L	284µH
C1	4700µF
C2	4700µF

Figure 2 presents the simulation diagram of a boost type converter supplied by a GPV under ISIS PROTEUS. To test this converter we applied a square wave frequency of 20 KHz and a duty cycle of 50% on the transistor trigger. The resulting curves are represented by Figure 3. We can see that with a duty cycle equal to α=0.5, the output voltage Vaut is twice as high as the input voltage Vin. Therefore, the boost converter under Proteus worked well.

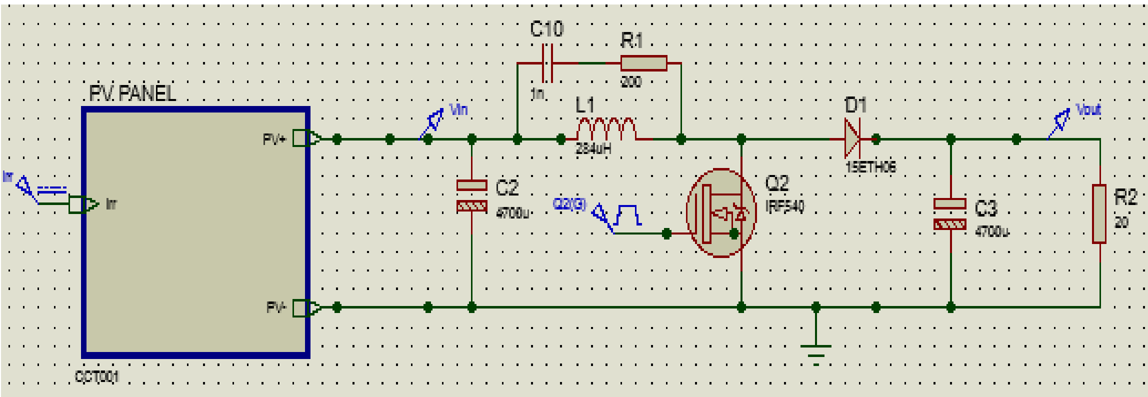


Figure 2. Simulation of a boost converter powered by PV panel under Proteus

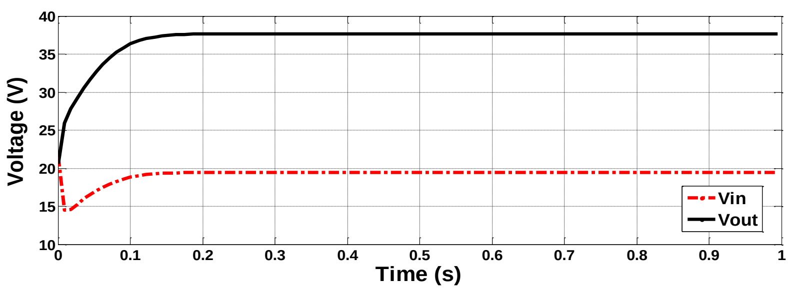


Figure 3. Boost converter test with duty cycle 0.5

3. THE PROPOSED METHOD OF MPPT VARIABLE STEP-SIZE ALGORITHM

The choice of the search step-size algorithm influences the oscillation around the MPP and the algorithm convergence time towards that point. For this, we find some MPPT algorithms use a variable size to make an adequate combination between precision and speed [22], [23]. One of these algorithms is that given in [23] when the fixed step size is replaced by a variable step size equal to 0,01 multiplied by the power difference. Another P&O algorithm with variable step size is developed in [24]. In this algorithm, the step will change its value in each iteration according to the variation in power and voltage according to the [24].

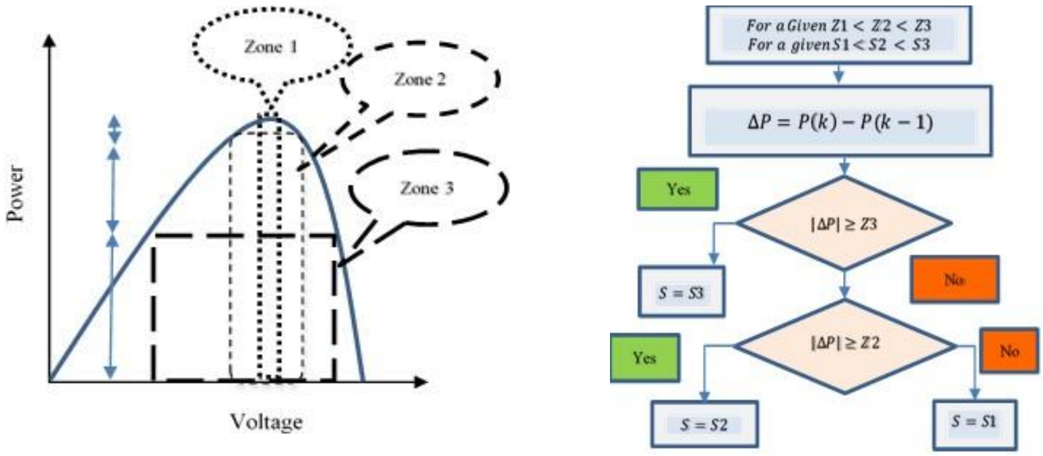
$$D(k) = D(k-1) \pm \Delta D * \left|\frac{dp}{dv}\right| \tag{4}$$

Where: dp and dv are the changes in power and voltage.

The difference between the two preceding algorithms is the number of values, which can take it the duty cycle. In the first algorithm, the step can take two values only but in the second algorithm, the step can take several values (an indeterminate number of steps). In the present paper, the step is varied between two values or more, according to the comparison between the absolute power variation value and a given value as showen in Figure 4.

The distribution of power is depicted in Figure 4(a), it can be seen that more the area of pawer is far from MPP more the value of voltage and power is wide; it is therefore useful to take a big step in this area to quickly get out of it towards the area closest to MPP. This strategy of searching was explained by the flowchart shown in Figure 4(b).

The value of step-size chosen by the algorithm is corresponding to the area of power, more the output power extracted from the PV panel near to the maximum more the value of step-size is small as shown in Table 2, it should also be noted that the determination of these areas and the values of the steps are mainly related to the electrical properties of the solar panels.



(a) (b)

Figure 4. The proposed technique for choosing the step size (a) power distribution zones and (b) the corresponding flowchart, case of 3 value

Table 2. Step-size values when the number of power variation intervals equal to 3

Variation in power	Step-size value
$\lvert\Delta P\rvert \geq Z3$	$S = S3$
$\lvert\Delta P\rvert \geq Z2$	$S = S2$
$\lvert\Delta P\rvert < Z2$	$S = S1$

We can summarize the procedure of the proposed algorithm given in Figure 4.

a) First, we calculate the difference between the previous and the next value of power.

b) If the power change ΔP is greater than or equal to $Z3$ (zone 3), then the step size value is equal to $S = S3$ and it remains constant until the power change is less than $Z3$.

c) Then, we go to zone $Z2$ and the search becomes at step size $S = S2$, knowing that $S2$ is less than $S3$. Then it stays constant until it moves to the next zone.

d) So, we repeat the same process as before until we reach the narrow zone in which the MPP resides. In this Zone, we are researching a more precise step than all the previous steps.

The proposed method of variable step-size technique can be applied in all MPPT algorithms by choosing the duty cycle periodically at the beginning of each iteration as shown in Figure 5 example of P&O algorithm. With this research technique, the maximum value is reached quickly with less ripple around the maximum value. Note that the values of the power intervals are chosen according to the energy curve of the PV panel.

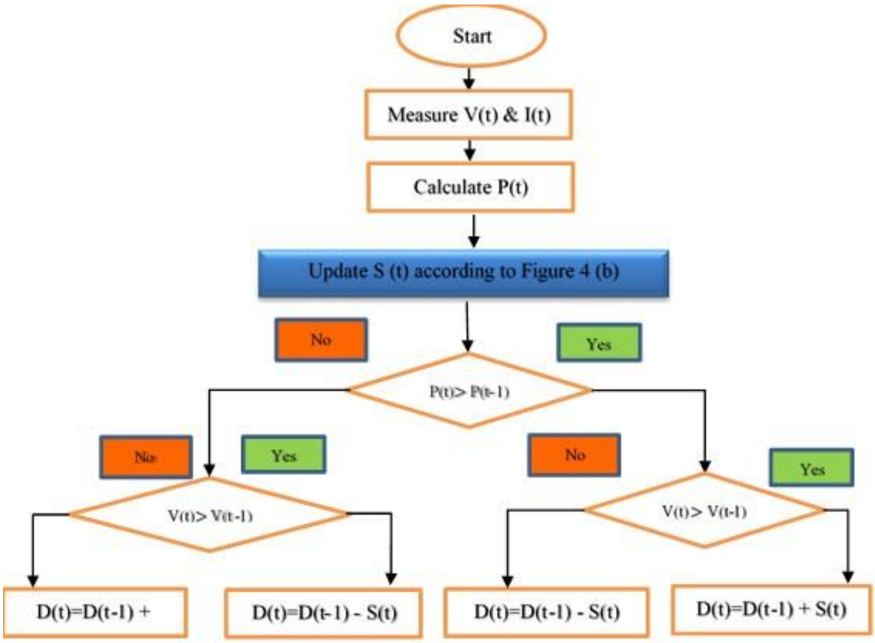


Figure 5. Modified P&O algorithm flowchart using variable step-size

4. RESULTS AND DISCUSSION

In this section, the Proteus software is used to simulate the system shown previously. The PV panel considered in this study is the single-diode model [25]. Figure 6 shows the considering photovoltaic system that is composed of a PV generator followed by a DC-DC converter connected to a 20 Ω resistor and controlled by the Arduino Mega 2,560 board. The PV panel is a module of 36 monocrystalline silicon cells, with a maximum power of 80 W. We use the DC-DC converter that is developed in section 2, the Arduino card used is of type Mega 2560, all the other component such as, the current and voltage sensors was detailed in [26].

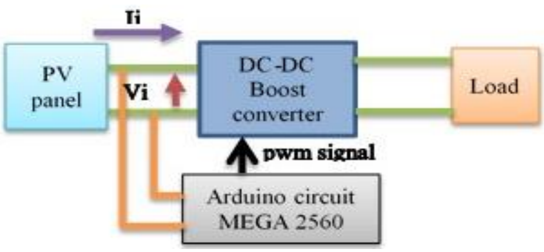


Figure 6. PV system controlled by Arduino circuit (mega 2,560)

4.1. Comparative study of the performance of different MPPT algorithms

In this part, the objective is to make a comparative study between the performances of a different method of MPPT (P&O, INC, FSCC, FSCO, Hill Climbing, ICI) under standard climatic conditions. The atmospheric conditions chosen in this part are the standard operating conditions (radiation of 1,000 W/m2 and a temperature of 25 °C). Therefore, the maximum power desired at the output of the GPV is 80 W. The results obtained are given in Figure 7.

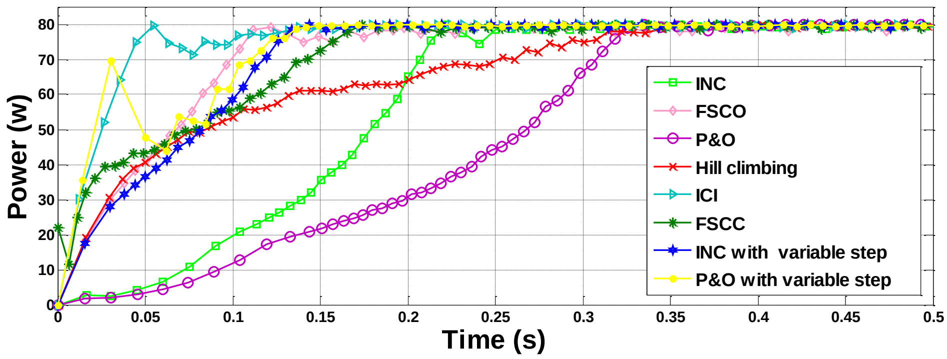


Figure 7. Power at the output of GPV as a function of time

4.2. Step-size choice influence

For this part, the objective is to make a comparison between the results of the fixed-step-size P&O algorithm with that of variable step size. Figures 8 and 9, illustrate the results obtained by the simulation of a PV system controlled by the P&O and INC algorithms, with a fixed and variable steps, respectively. The number of steps is chosen between three values and then five according to our algorithm developed in section 3.

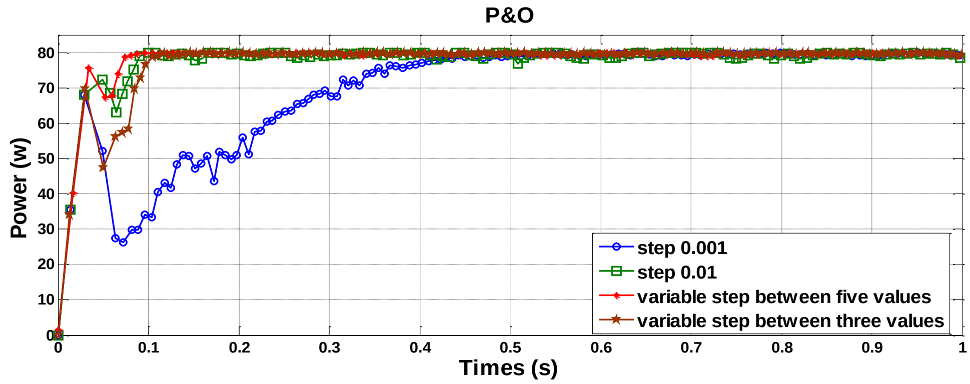


Figure 8. Power versus time for P&O algorithm with different steps

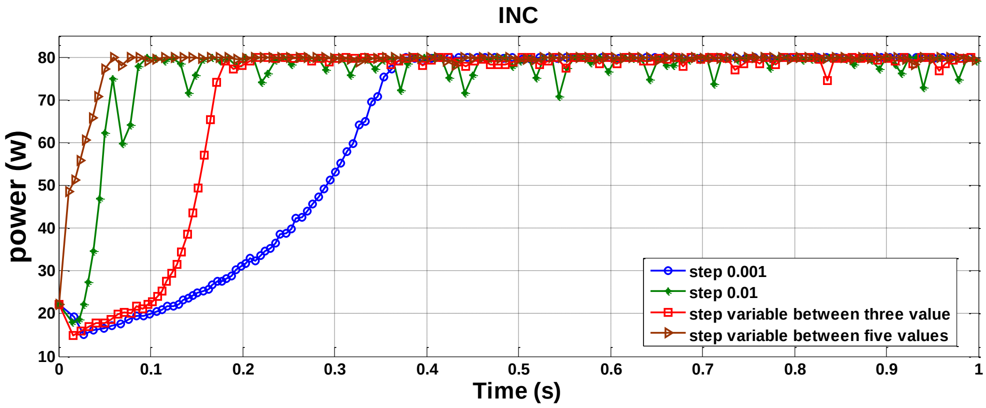


Figure 9. Power versus time for INC algorithm with different steps

According to the results presented in the two Figures 8 and 9, we can observe that:

- A large step gives an algorithm quickly converges to the optimum value of power generated by the GPV, however, it causes a wide range of oscillations around this value.
- With a small step, the algorithm converges slowly, but it has a small range of oscillations around the optimum power value.
- Variable step-size algorithms provide an acceptable balance between good convergence time and low oscillation range, with improved performance as the number of steps increases.

4.3. Operation with sudden changes in radiation level

Figure 10 depicts the simulation results of different MPPT controls with abrupt changes in solar irradiance ranging from 1,000 W/m2 to 700 W/m2. From Figure 10, we can see that the INC algorithm seems to be better than the P&O algorithm. Indeed, it behaves better during a rapid change of metrological conditions. However, it is a more complicated algorithm than the previous one. Algorithms based on FCO, FSCC, or Hill Climbing are very simple and easy to implement. The major drawback is the loss of energy and the stopping of power transfer when measuring the quantities Voc and Isc. The P&O and INC algorithms with variable step-size are robust, very fast, and efficient. Indeed, these algorithms operate at the optimum point almost without oscillations.

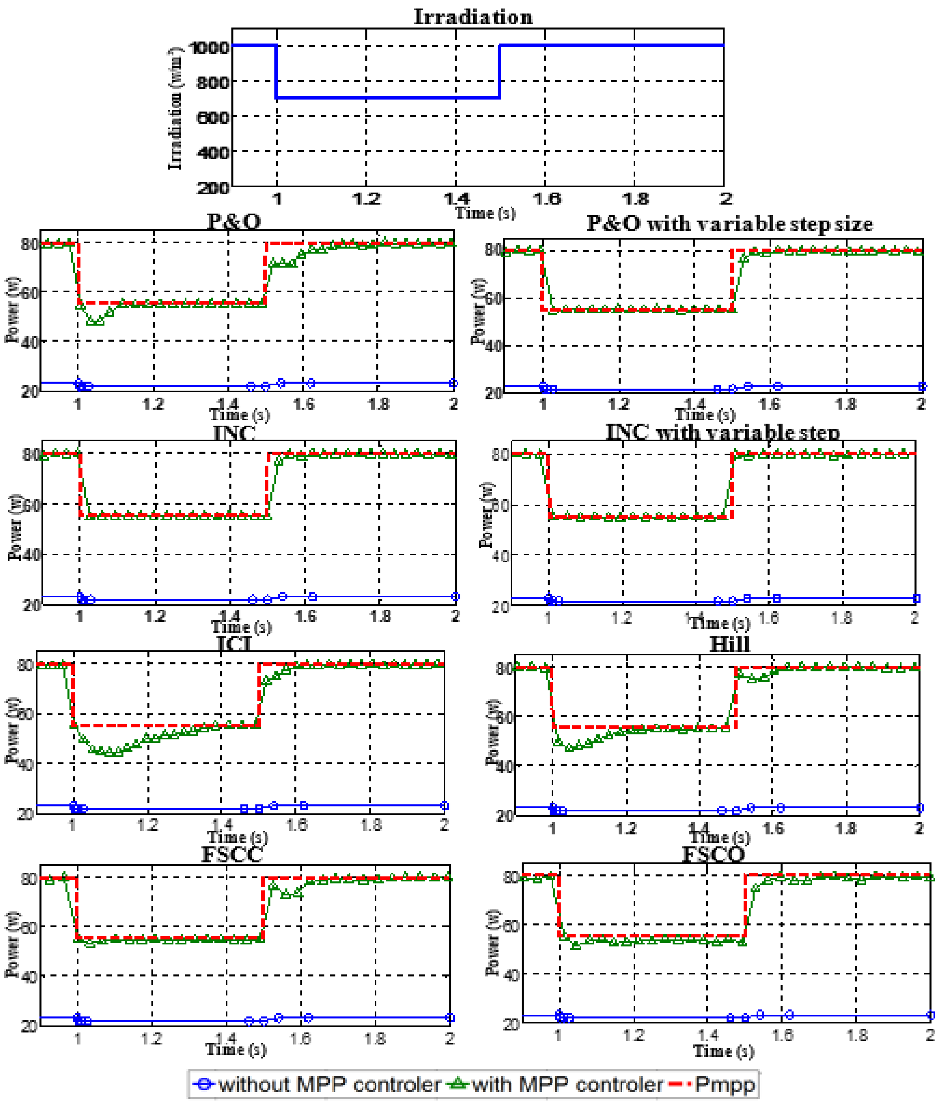


Figure 10. Power output from GPV with different MPPT controls under sudden changes in radiation level

5. CONCLUSION

This paper is devoted to the simulation under PROTEUS of a PV system piloted by different types of MPPT algorithms. The system includes a photovoltaic generator, a DC-DC converter of BOOST type, an ARDUINO Mega 2,560 board that is used to control the converter, a resistive load, current, and voltage sensors. From the simulation results obtained in this paper, we can conclude that the MPPT control (whatever) makes better use of power supplied by the PV than the direct use of GPV-Charge. We have shown by simulation that MPP tracking is strongly related to the choice of the step size of the duty cycle and that the performance of the proposed variable step-size algorithm is better than the conventional algorithms that existed in the literature in terms of MPP tracking speed and steady-state around MPP.

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