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Comparative study of MPPT control algorithms of a PV system: Modeling and simulation

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Abstract - The proper operation of a photovoltaic installation depends on meteorological conditions such as lighting and temperature, in fact, for example in a mobile station supplied by a photovoltaic source, the power delivered by the PV generator undergoes fluctuations during the change of direction or during passage in poorly sunny places. In other words, a good photovoltaic installation is one where the power delivered by the photovoltaic generator is maximum whatever the conditions of use. In this document, we first presented generalities on the PV system, then we proceeded to model the PV panel and we used several techniques of MPPT control namely P&O and we found that it presents that this method still presents drawbacks require improvement for this we have introduced neural networks in order to limit the drawbacks of the P&O method, Finally, we made a comparison between the two techniques presented and analyzed.

Keywords: Perturbation and observation (P&O) algorithm, Incrementation of Conductance (INC), Maximum power point tracking (MPPT), Photovoltaic (PV) system, Boost converter.

INTRODUCTION

Energy consumption during the last century has increased dramatically due to massive industrialization. Forecasts of energy needs for the coming years only confirm or even amplify this trend, especially given demographic changes and the development of certain geographic areas. The deposits of traditional energy resources, mainly of fossil origin, can only be exploited for a few decades, which portend an imminent situation of energy shortage at the global level. Today, much of the world's energy production is derived from fossil sources. The consumption of these sources gives rise to greenhouse gas emissions and therefore an increase in pollution. The additional danger is that excessive consumption of the stock of natural resources reduces the reserves of this type of energy in ways that are dangerous for future generations. In addition, the waste from nuclear power plants poses other problems in terms of pollution of radioactive waste, the upcoming dismantling of power plants and industrial risk. Today, renewable energies are gradually becoming energies in their own right, competing with fossil fuels in terms of cost and production performance. However, their power conversion systems are still too expensive systems, and have some significant deficiencies in efficiency and reliability, but for this, although there is a great deal of research proving the reliability of these sources like energy photovoltaic (PV), and wind power. Photovoltaic solar energy comes from the direct transformation of part of solar radiation into electrical energy. This energy conversion takes place through a so-called photovoltaic (PV) cell based on a physical phenomenon called the photovoltaic effect which consists of producing an electromotive force when the surface of this cell is exposed to light. The voltage generated may vary depending on the material used to manufacture the cell. The association of several cells (PV) in series/parallel gives rise to a photovoltaic generator (GPV) (Srinivas et al., 2018; Berrezzek et al., 2020; Dib et al., 2015; Lerma, 2021; Ul Haq et al., 2020).

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Although photovoltaic energy has been known for many years as a source that can produce electrical energy ranging from a few milliwatts to megawatt, it still remains at a little-known stage and is not yet developing in large proportions, in particular because the excessively high cost of the sensors. In addition, several technical problems must be solved to bring these systems to a sufficient degree of maturity to make them fully fledged industrial products. The problems concern both the photovoltaic conversion material, which remains expensive to synthesize, and the electrical conversion chain, which presents a lot of losses when used poorly. Several specific control laws have been developed, making it possible to optimize the production of photovoltaic energy in order to ensure better conversion efficiency. In this general context, our study is interested in photovoltaic energy which is potentially an inexhaustible source of energy and relatively more acceptable for our environment. In addition, the evolution of long-term costs, upwards for non-renewable energies and downwards for photovoltaics, will make it a competitive partner to supply the networks in a few years. It is in this context that there is currently a market for a new form of grid-connected photovoltaic generators, which are the forerunner of the photovoltaic power plants of tomorrow, and whose installed power varies between a few kW and a few hundred kW. Currently, the efficiency of converting solar energy into electrical energy is still low (often less than 12 %) under nominal solar irradiance of photovoltaic panels are needed to provide 1kW peak. This low efficiency, as well as the high cost of the panels, has encouraged users to exploit the maximum electrical power available at the level of the photovoltaic generator. This maximum is generally obtained by ensuring good adaptation between the generator and the associated receiver. This adaptation is carried out using static converters controlled for different operating modes.

Our work is based on the study and comparison between two techniques for maximizing the power delivered by the photovoltaic generator: Perturbation and Obsarvation (P&O) (Jiang et al., 2018; Jiang et al., 2019; Gao et al., 2020), Incrementation of Conductance (INC) (Hossain et al., 2016; Qin and Che, 2019; Chaurasia and Gidwani, 2017).

DC-DC boost converter

The example of figure (1) corresponding to a DC-DC converter (boost) (Boujelben et al., 2017; Azer and Emadi, 2020; Sinha et al., 2018; Malik, et al., 2021). This type of converter can be used as a source-to-load adapter when the load needs a higher voltage than the PV generator.

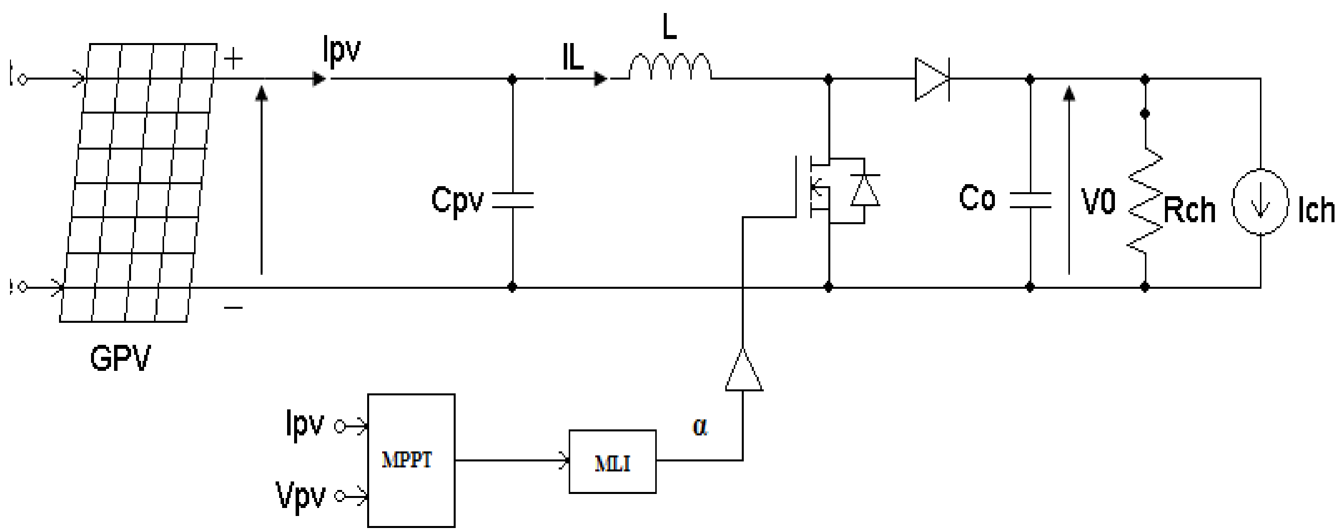


Figure 1: Example of a DC-DC converter that can be used as a PV adapter and a load

The adaptation between the source and the load is carried out by the variation of the duty cycle α, indeed, if we suppose that the boost works in continuous conduction and we consider that the efficiency of the latter is 100%. Then the electrical relationships between the input quantities of the converter (corresponding to *Ipv* and *Vpv* of the generator) and output of the converter (respectively *Is* and *Vs*) depend only on the duty cycle α and can thus be expressed (Fig. 2).

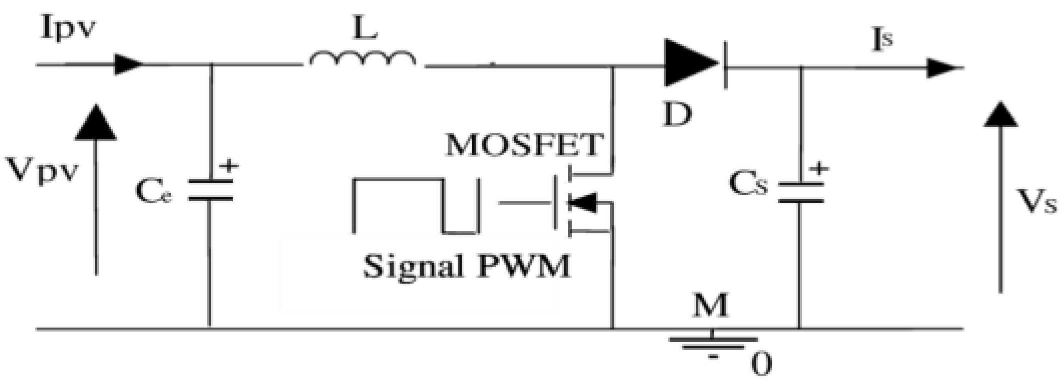


Figure 2: Structure of the BOOST converter

The converter can then work in two operating modes depending on its energy storage capacity and the switching period. These two operating modes:

- Continuous mode: in this case the energy stored in the inductance is transferred partially and therefore the current in it does not cancel out.
- Discontinuous mode: in this case, on the contrary, the energy stored in the inductor is transferred completely and therefore the current in it is canceled.

Solar PV system with MPPT using boost converter

Figure (3) shows the block diagram of a PV system supplying a resistive load.

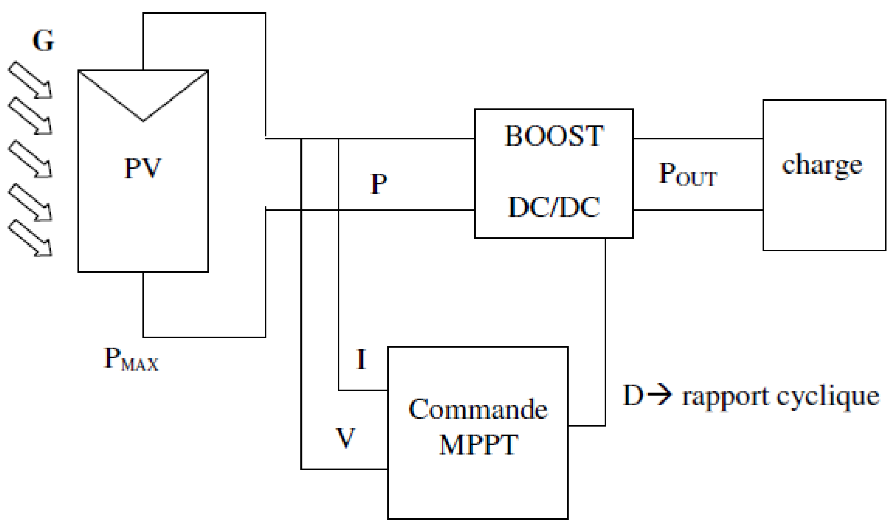


Figure 3: Block diagram of a PV system with a converter (DC/DC) controlled by MPPT on load (DC)

In our study, we need:

- A GPV which can deliver under standard test conditions, a power of 175W and a current of 4.95A under an optimal voltage of 352V.
- An adaptation quadruple is a booster type energy converter.
- An MPPT (Maximum Power Point Tracking) command that allows us to find the optimal operating point of our PV generator, knowing that this GPV depends on weather conditions is stable load variation.

The regulation principle is based on the automatic variation of the duty cycle (to the appropriate value so as to continuously maximize the power at the output of the PV panel.

We cannot start the simulation without going through the modeling of the most important part in the photovoltaic system, which is the PV generator. To simplify the tasks, we will present an electrical diagram of a PV cell (figure 4) (Gastli et al., 2015), (Paraskeva et al., 2017), (Perera and He, 2018).

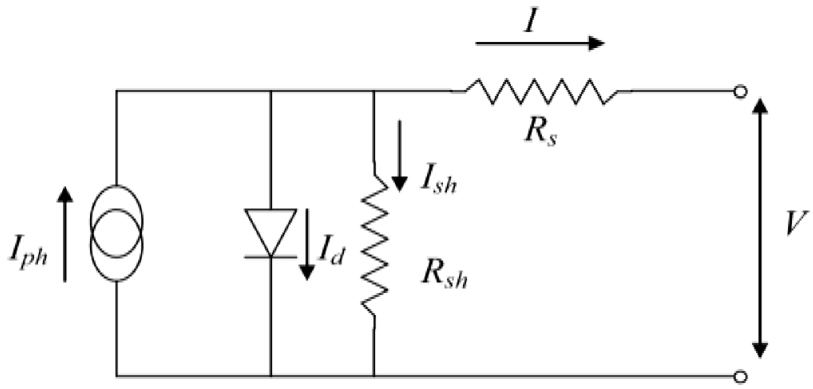


Figure 4: Equivalent electrical circuit of a photovoltaic cell

A partir de la figure (4) on peut tirer plusieurs fonctions mathématiques pour calculer le courant *Ipv* fourni par la cellule ainsi que la tension *Vpv*. In that case. We chose a simple model requiring only the parameters given by the manufacturer.

$$I_{pv} = I_{ph} - I_{sat}\left[e^{\frac{\left(q(v_{pv} + R_S)\right)}{nKT}} - 1\right] - \frac{v_{pv} + (I_{pv} + R_S)}{R_{sh}} \quad (1)$$

Where V_{pv} is the voltage (V) of the panel, I_{pv} and the current (A) of the panel, I_{ph} is the photocurrent in amperes of the cell depending on the illumination and the temperature or short-circuit current, I_{sat} current in the diode (A), R_s is the series resistance in ohm, R_{sh} the shunt resistance in ohm, characterizing the leakage currents of the junction, *q* is the charge of the electron which is equal to $1.602*10^{-19}$ coulomb, *K* is Boltzmann's constant k = 1.381*10-23 J/K, *n* is the quality factor of the diode, it is between 1 and 2.

If we assume that the parallel resistance (shunt) is infinite ($R_{sh} = \infty$), equation (1) becomes:

$$I_{pv} = I_{ph} - I_{sat}\left[e^{(\frac{\left(q(V_{pv} + R_S)\right)}{nVT})} - 1\right] \quad (2)$$

Where I_{pv} is the current supplied by the PV cell and V_{pv} is the voltage at the terminal of the PV cell. We can calculate the series resistance in the point V_{co}. It can be calculated by the following formula:

$$Rs = -\frac{dV_{pv}}{dI_{pv}} - \frac{nVT}{I_{sat}\left[e^{(\frac{V_{pv} + (R_S * I_{pv})}{nVt})}\right]} \quad (3)$$

The nonlinear equation (1) is solved by simple iteration methods generally the newton-raphson method is described as follows:

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \quad (4)$$

Where $f'(x_n)$ is the derivative of the function $f(x_n)$, X_n represents the iteration and X_{n+1} is the following iteration:

$$f(Ipv) = Icc - Ipv - I_{sat}\left[e^{(\frac{V_{pv} + (Rs*Ipv)}{nVt}) - 1}\right] = 0 \quad (5)$$

Replacing (5) in (4), and we calculate the current I by the iterations:

$$I_{n+1} = I_n - \frac{I_{cc}\ (-I_{sat}\left[e^{(\frac{V_{pv} + (R_S * I_n)}{nVt}) - 1}\right] - I_n}{-1 - I_{sat}\left[\frac{R_S}{nVt} e^{(\frac{V_{pv} + (R_S * I_n)}{nVt}) - 1}\right]} \quad (6)$$

The previous equations are only valid for the optimum operating mode. To generalize our calculation for different illuminances and temperatures, we use the model which moves the reference curve to new locations.

$$I_{cc}\ (T) = I_{cc}\ (T_{ref}\ ) * [1+a(T\text{-}T_{ref}\ )] \quad (7)$$

$$I_{ph}\ = I_{cc}\ (\frac{G}{1000}) \quad (8)$$

$$I_{sat}\ (\mathrm{T}) = I_{sat}\ \left(T_{ref}\ \right) * (\frac{T_{ref}}{T})^{3/n}\ [exp(\frac{q*Eg}{nk})*(\frac{1}{T} - \frac{1}{T_{ref}})\ ] \quad (9)$$

Where a is the coefficient of variation of current as a function of temperature, T_{ref} is the reference temperature, 298K (25°C) and G is solar irradiation.

Various publications on controls ensuring MPPT control type operation have appeared regularly in the literature since 1968, when the first control law of this type was published, adapted to a renewable energy source of the photovoltaic type of publications in this field, we made a classification of the various existing MPPTs by grouping them according to their basic principle. The classification, in addition to the principle, was carried out according to criteria such as the precision of the search or its speed to make a comparative evaluation. Only algorithms that seem to us to describe a specific research method are reported in this manuscript and briefly analyzed.

In the literature, we can find different types of algorithms performing the search for PPM. In our work we are interested in two methods Perturb & Observ (P&O) (Jiang et al., 2018), (Jiang et al., 2019), (Gao et al., 2020), Incrementation of Conductance (INC) (Hossain et al., 2016), (Qin and Che, 2019), (Chaurasia and Gidwani, 2017). Flowcharts of the P&O and INC algorithms are shown in Fig. 5 and Fig. 6 respectively.

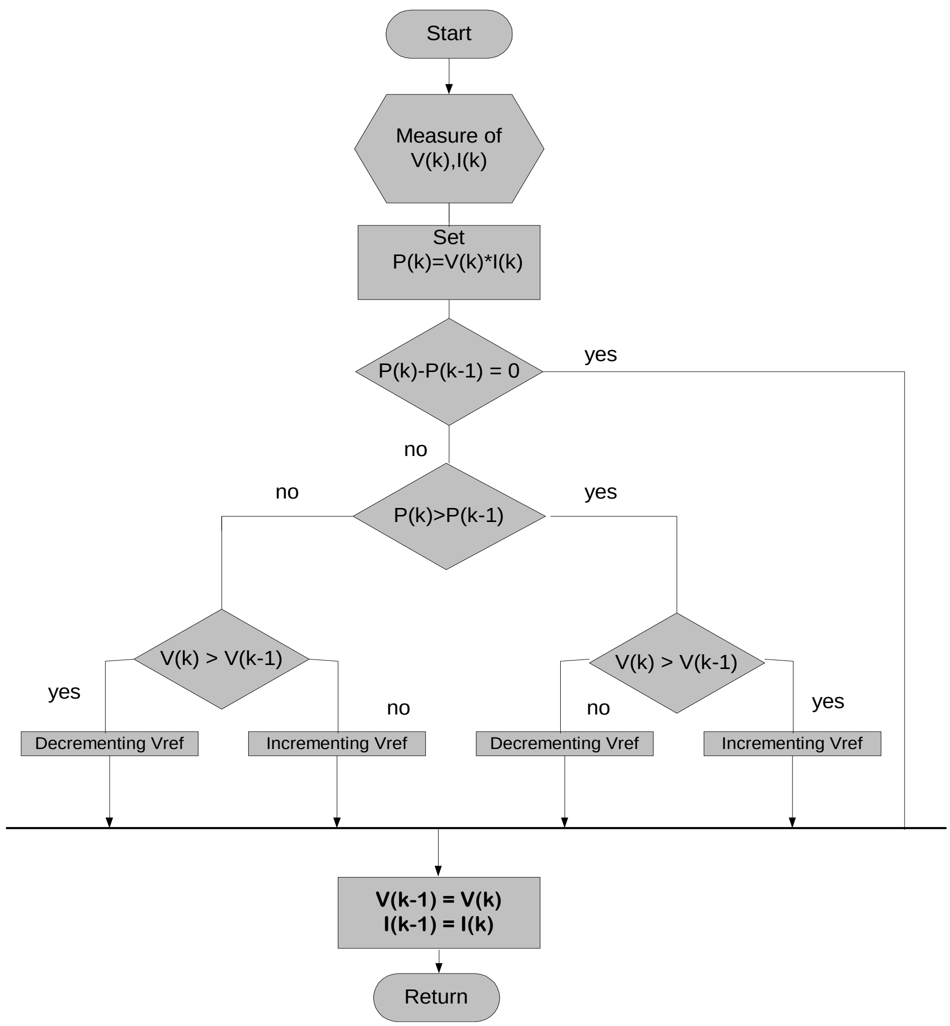


Figure 5: Flowchart of the P&O method

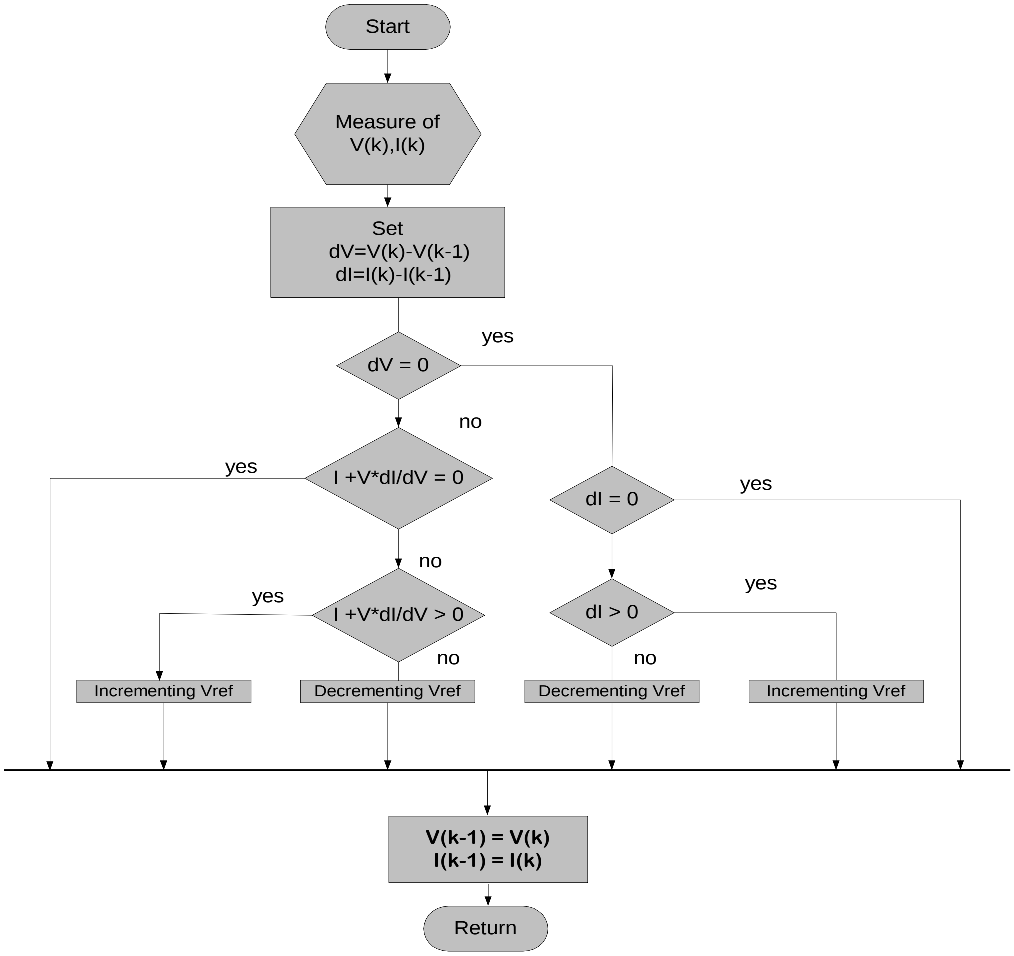
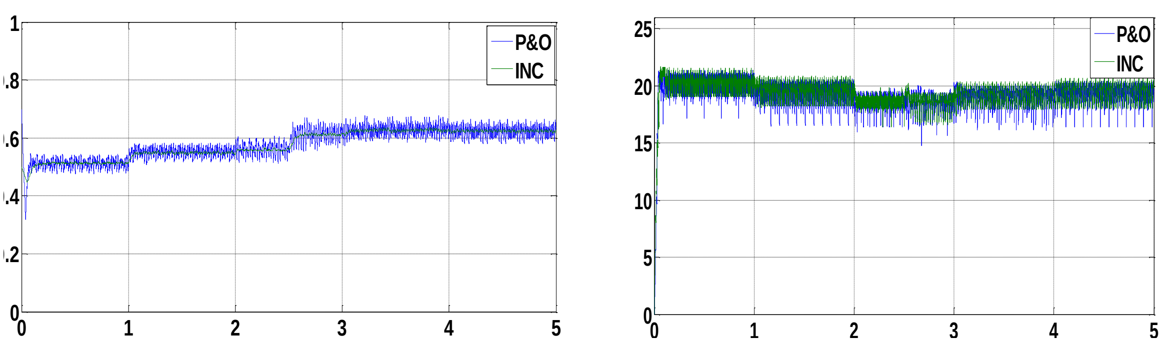


Figure 6: Flowchart of the INC method

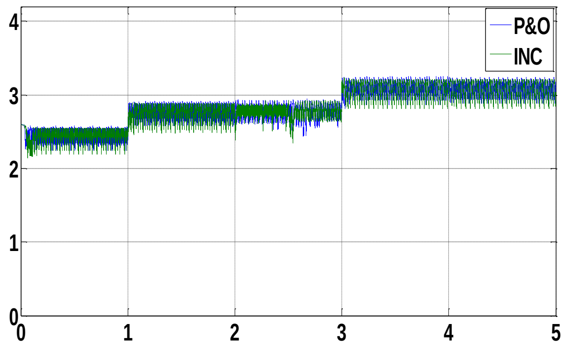
Simulation results

We used a solar module containing 36 cells in series, and a resistor as a load. In order to validate the operation of the MPPT algorithms on the GPV, one proceeds by introducing the variations on the different quantities involved in the operation of MPPT with an equal voltage step $dV = 0.00$V. For this, we have introduced steps for some quantities at time $t = 2.5$s.

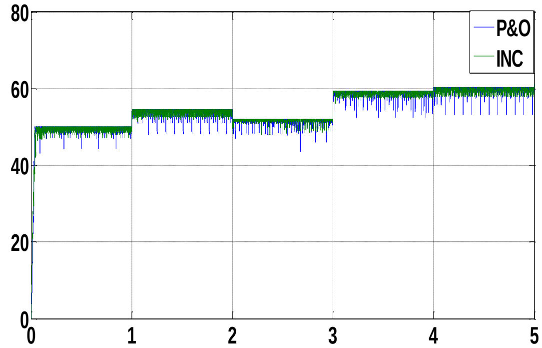
And finally, we subject the two MPPT algorithms to a change of different parameters: temperature, solar irradiance and load at the same time. Figure (7) shows the performance of two algorithms in the case of variation of all climatic conditions and of the load The results obtained by this test show the good continuation of the two algorithms but with a higher speed and a higher stability and less disturbance in response quality for the MPPT INC controller compared to the MPPT P&O controller.



(a) (b)



(c)



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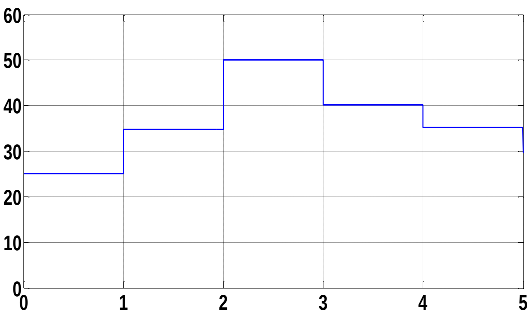
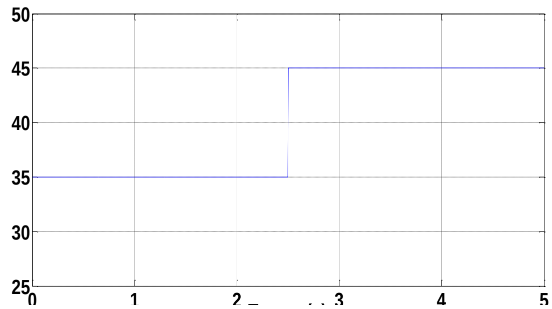
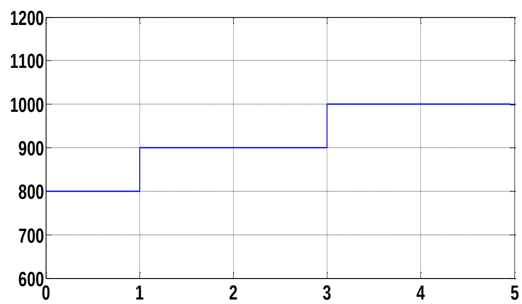


(e)



(f)



(g)

Figure 7: Responses of the MPPT P&O and MPPT INC algorithms for a variation in sunlight, temperature and load: a) duty cycle, b) voltage (V), c) current (A), d) power (W), e) temperature (C°), f) load (ohm), g) illumination (W/m^2)

Conclusion

In this paper we have studied the MPPT control. This choice was justified by the simplicity of the design of this control. To further improve the performance of this control, we have proposed two control techniques: the first technique represents the P&O algorithm. The second concerns the MPPT-INC algorithm. Thus, we presented a comparative study of the static and dynamic performances and the sensitivity to variations of the electrical and climatic parameters of the two types of algorithms: MPPT control by P&O and by INC. The results obtained show the good continuation of the two algorithms but with a higher speed and a greater stability and less disturbance in quality of the responses of the INC controller compared to the P&O controller.

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