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Comparative study of three Maximum Power Point Tracking algorithms for photovoltaic modules

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Abstract - *This paper presents simulation of a photovoltaic panel connected to a load through a boost converter. Due to the nonlinear characteristics of the PV panel and in order to increase its performance, reduce cost of the application and improve the efficiency of the photovoltaic system, maximum power point tracking algorithm is necessary. We present also an implementation of three maximum power point tracking algorithms: Perturb and Observe (P&O), Incremental Conductance (INC-COND) and Fractional Open Circuit Voltage (FOCV) which are widely studied and used in many researches papers. Experimental and simulation results are obtained using Matlab/Simulink software. The results show the efficiency of these MPPT algorithms in tracking the maximum power and its faster response to adapt to the change in irradiation condition.*

Résumé - *Cet article présente la simulation d'un panneau photovoltaïque relié à une charge à travers un convertisseur boost. En raison de la non linéarité des caractéristiques du panneau PV et dans le but d'augmenter ses performances, de réduire les coûts de l'application et d'améliorer le rendement du système photovoltaïque, un algorithme de suivi du point de puissance maximum (MPPT) est nécessaire. Nous présentons également une implémentation de trois algorithmes MPPT: Perturb and Observe (P&O), Incremental Conductance (INC-COND), et Fractional Open Circuit Voltage (FOCV) qui sont largement étudiés et utilisés dans de nombreux travaux de recherche. Les résultats expérimentaux et de simulation sont obtenus en utilisant le logiciel Matlab-Simulink. Les résultats montrent l'efficacité de ces algorithmes MPPT dans le suivi du point de puissance maximum et la capacité à s'adapter plus rapidement aux changements des conditions d'irradiation.*

Key words: PV panel - Boost converter - MPPT - P&O - INC-COND - FOCV - Simulation.

1. INTRODUCTION

Unlike fossil fuels which are non-renewable energies and pollute the environment, the sun power is free and very important. The renewable energy is more and more explored due to its availability around the earth. Thanks to various stimulating factors: lower production costs and support policies, investment on photovoltaic installations grow over large scale this few 1ast years.

Like other industrial processes, a photovoltaic system can be subjected to various defects and anomalies during its operation, which causes a reduction in the performance

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of the system caused by the reduction of the energy furnished that may damage the installation.

The solar energy may be converted to electrical energy through solar module which is mainly composed of several series/parallel connected solar cells. These cells are constructed on the basis of P-N junctions made by semiconductor materials generally silicon. When the photovoltaic (PV) cell is exposed to light, the electrons move creating a potential difference through the P-N junction and generate a direct current.

The PV module has a non-linear current / voltage (I-V) characteristic which contain a peak point known as maximum power point(MPP) where the system works with maximum efficiency. With the aim to maximize the energy supplied to load and ensure the performance of PV panel, many MPPT algorithms have been developed in order to force the PV panel to work at this peak point.

There are MPPT algorithms studied, developed and implemented in the literature, such as Perturb and Observe [1], Incremental Conductance [2], Fractional Open Circuit Voltage [3], Fractional Short Circuit Current [4], fuzzy logic control based MPPT [5] and Neural network [6]. Among these methods Perturb and Observe, Incremental Conductance and Fractional Open Circuit Voltage algorithms are frequently used due to their simplicity and fast tracking.

Our paper is divided into 05 sections: the first one presents the modelling of the PV panel and its characteristics. The second presents the DC-DC boost converter topology. The third concerns the simulation of the 3 chosen algorithms using Matlab/Simulink model. The fourth presents the simulation results with comparison between the three MPPT methods. We sum with a conclusion.

2. MODELING AND CONTROL OF THE SYSTEM

2.1 The photovoltaic generator

In this work, single-diode model of photovoltaic cell is chosen. The equivalent circuit is shown in figure 1.

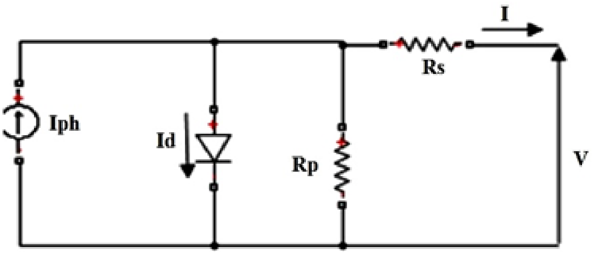

Fig.1: Equivalent circuit single diode model of photovoltaic cell.

Applying Kirchoff's current law, we get the following equations:

$$I_{ph} = I_d + I_{RP} + I \tag{1}$$

so,

$$I = I_{ph} - I_D - I \tag{2}$$

So,

$$I = I_{ph} - I_0\left(\exp\left(\frac{V + IR_s}{V_T} \right) - 1 \right) - \left(\frac{V + IR_s}{R_p} \right) \tag{3}$$

Where, the short circuit current is the value of current, when the output voltage of the cell is zero.

$$I_{sc} = I_{ph} - I_0 \left(\exp\left(\frac{I_{sc} \cdot R_s}{V_T} \right) - 1 \right) - \left(\frac{I_{sc} \cdot R_s}{R_p} \right) \tag{4}$$

Where, the open circuit voltage is obtained when the output current of the cell is zero.

$$V_{oc} = V_T \ln\left(\frac{I_{ph}}{I_0} - \frac{V_{oc}}{I_0 \cdot R_s} + 1 \right) \tag{5}$$

Where, $V_T = n k T / q$, Thermodynamic potential; n, Ideality factor of the solar cell; I_d, Direct diode current; k, Boltzmann's constant (1.3805 10^{-23} J/K); q, Electron charge (1.6 10^{-19} C); T, Cell temperature (in Kelvin); I, V, Cell output current and voltage; I_{ph}, Light-generated current proportional to the solar irradiation; I_0, Cell reverse saturation current; R_s, Series resistance; R_p, Shunt resistance; I_{sc}, Short circuit current; V_{oc}, Open circuit voltage.

The output $I-V$ characteristic of the module depends on the variation of the irradiance, temperature and the state of load. The figure 2 shows a PV panel which is in series/parallel connection of solar cells attached directly to variable resistor (load) in order to get its different characteristics. This PV model is simulated using Matlab/Simulink blocs. Data sheet of PV panel used in the simulation are summarized in this **Table**.

Table 1: The different parameters of the PV panel used in the simulation

Parameter	Value	Parameter	Value
P_{max}	200 W	K_i	3.8733 10^{-4}
V_{mpp}	26.3 V	K_v	-0.0037
I_{mpp}	7.61 V	N	1.3
I_{sc}	8.21 A	R_s	0.2479 Ω
V_{oc}	32.9 V	R_p	1.7387 10^{-5} Ω
N_s	54	N_p	1

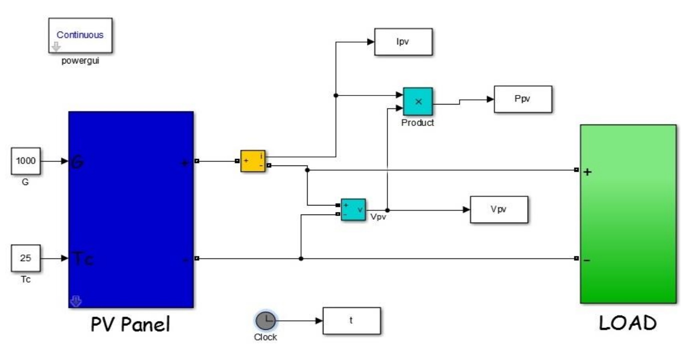

Fig. 2: PV panel connected directly to load

The variation of the output $I-V$ characteristics of the PV module as function of the irradiation and temperature is shown in figures 3 and 4, respectively. It is seen that the temperature changes affect mainly the PV output voltage, while the irradiation changes affect mainly the output current.

The intersection of the load-line with the PV module $I-V$ characteristic, for a given temperature and irradiation, determines the operating point. The maximum power production is based on the load-line adjustment under varying atmospheric conditions.

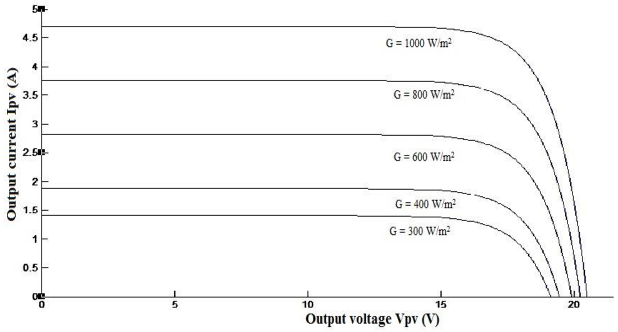

Fig. 3**a**: Characteristic $I-V$ of the module with constant temperature (T = 25 °C) and varying irradiation

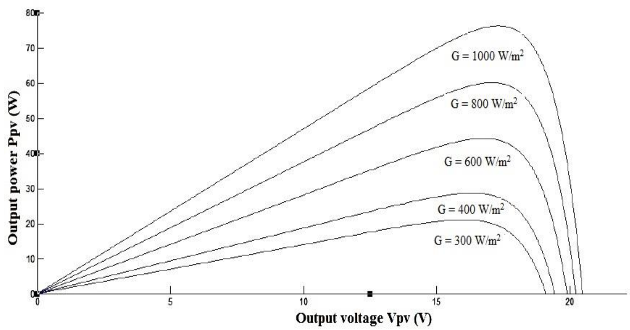

Fig. 3**b**: Characteristic $P-V$ of the module with constant temperature (T = 25 °C) and varying irradiation.

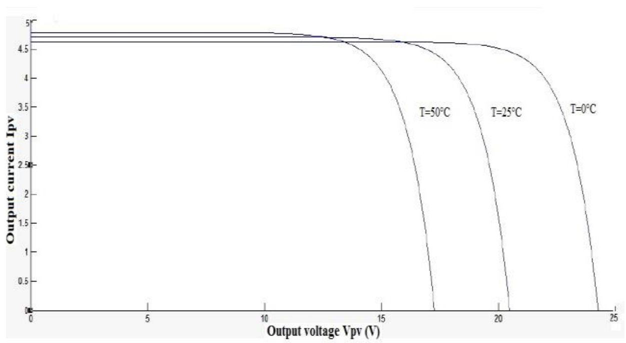

Fig. 4**a**: Characteristic $I-V$ of the module with constant irradiation (G = 1000 W/m^2) and varying temperature

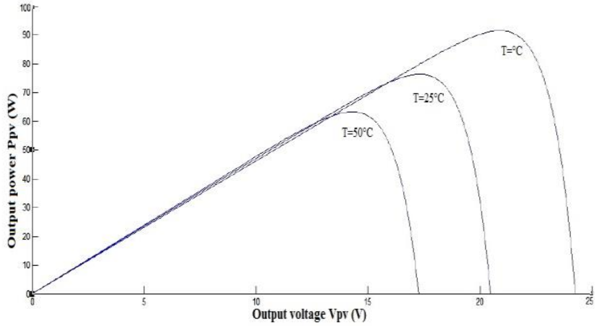

Fig. 4**b**: Characteristic $P-V$ of the module with constant irradiation (G = 1000 W/m^2) and varying temperature

2.2 The boost converter DC-DC

Figure 5**a** shows a typical boost converter which contains two electrical storage elements (inductor L and capacitor C). A boost converter is also called a step-up converter because the output voltage is higher than the input voltage. As a result, the output current is lower than the input current because of the power balance. Hence, the converter have two states modes, **ON** state mode and **OFF** state mode.

The equivalent circuits in these two modes are shown in figures 5**b** and 5**c**, respectively.

During **ON** mode, the inductor stores energy from the power source while the capacitor discharges through the load. In this case, the diode is blocked; the current of the inductor i_L increases linearly according to this equation.

$$L\frac{di_L}{dt} = V_s - 0 \tag{6}$$

During **OFF** mode, the diode becomes short circuited; the inductor discharges its stored energy through the load and the capacitor. The inductor current decreases linearly according to this equation.

$$L\frac{di_L}{dt} = V_s - V_0 \tag{7}$$

The net energy changed in the inductor should be zero during one period in the steady state, which means, the current increased in **Mode 1** should be equal to the current decreased in **Mode 2**. That is,

$$\frac{DT}{L}V_s = \frac{(1-D)D}{L}(V_0 - V_s) \tag{8}$$

$$V_0 = \frac{1}{1-D}V_s \tag{9}$$

Indeed, this is a boost converter because.

$$\frac{V_0}{V_s} = \frac{1}{1-D} > 1 \qquad \text{for } D \in [0\,1] \tag{10}$$

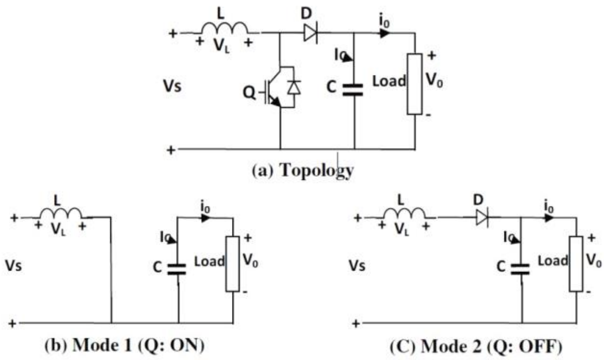

Fig. 5: Boost converter

2.3 Control of the boost converter

The control of DC-DC converter is ensured using maximum power point tracking algorithm known as MPPT. Various MPPT algorithms are studied and implemented with the aim to extract the maximum power from the PV generator. The most widely algorithms used are Perturb & Observe (P&O), Incremental Conductance (Inc-Cond) and Fractional Open Circuit Voltage (FOCV) due to their simplicity and ease to implement.

3. MPPT ALGORITHM

3.1 Perturb and Observe algorithm

The principle of the P&O algorithm is to oscillate the output voltage around the MPP that may cause wastage of energy and observe the effect on the power output of the PV generator. These oscillations can be minimized by reducing the fixed perturbation step size, but then it takes more time to reach MPP.

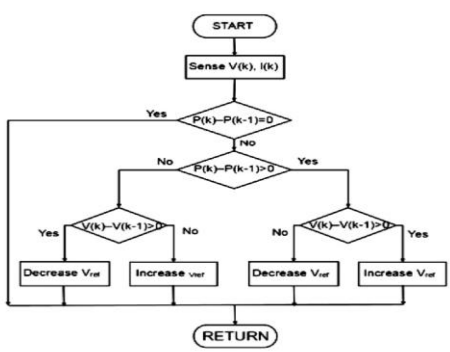

Fig. 6: Flow-chart of the P&O algorithm

The principal of this algorithm is to compare the actual power with the previous one, if the difference is positive the voltage is increased by given perturbation step size, else the voltage is decreased by the same given perturbation step size, the MPP is reached when this difference is zero. The flow-chart of P&O algorithm is show is figure 6.

3.2 Incremental conductance algorithm

This algorithm is based on the fact that the slop of the power curve is zero at the MPP, positive to the left and negative to the right. The Inc-Cond method works by comparing the instantaneous conductance $\frac{1}{V}$ to the incremental conductance $\frac{\Delta I}{\Delta V}$, the MPP is obtained when $\frac{dP}{dV} = 0$.

$$\text{As} P = VI$$

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I + V\frac{\Delta I}{\Delta V} \tag{11}$$

Hence:

$\frac{\Delta I}{\Delta V} = -\frac{I}{V}$ at the MPP.

$\frac{\Delta I}{\Delta V} > -\frac{I}{V}$ on the leftside of the MPP.

$\frac{\Delta I}{\Delta V} < -\frac{I}{V}$ on the rightside of the MPP.

The algorithm function is detailed in the following flowchart (figure 7).

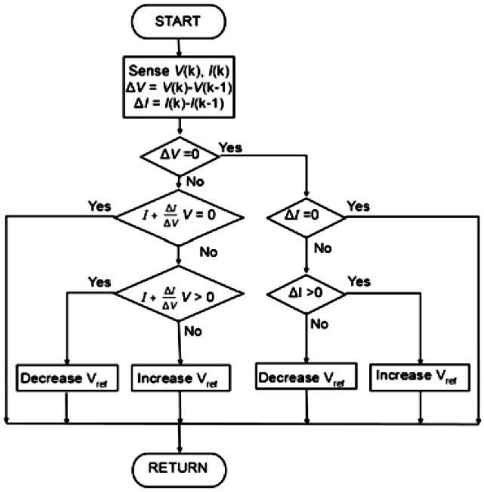

Fig. 7: Flow-chart of the Incremental Conductance algorithm

3.3 Fractional open circuit voltage (FOCV) algorithm

This method is based on the mathematical relationship between the output PV panel voltage V and the open circuit voltage V_{oc}. The MPP is reached at a voltage value given by this relationship:

$$V_{mpp} = K_V \times V_{oc}$$

Where K_V vary between 0.76 and 0.82. If the difference between this value and the output voltage of the PV panel is positive the reference voltage is increased by a voltage step size, else the reference voltage is decreased by the same voltage step size.

The algorithm is shown in the flowchart of the figure 8.

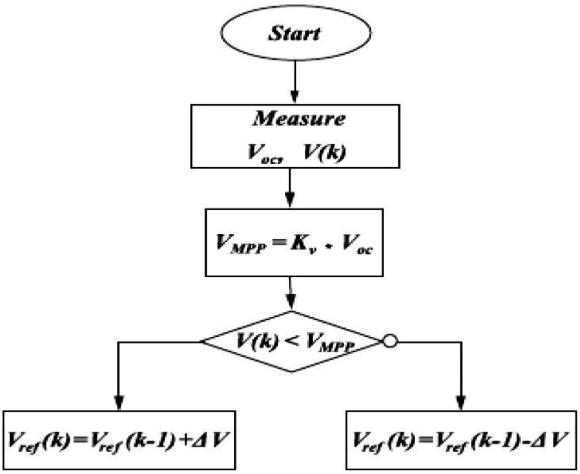

Fig. 8: Flow-chart of the FOCV algorithm

The simulation model of the PV panel connected to the load through DC – DC boost converter using the three MPPT algorithms with the same PI controller to regulate the duty cycle of the converter is shown in the figure 9.

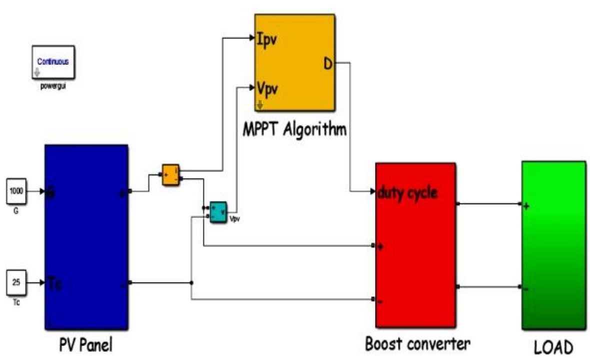

Fig. 9: Photovoltaic power system circuit

3. SIMULATIONS RESULTS

The INC-Cond and P&O are direct methods which don't need prior knowledge of the PV model in contrast to V_{oc} MPPT which need to isolate the PV panel to record open circuit voltage.

The following figure 10 shows the simulation results of these MPPT methods using Simulink Matlab under fixe irradiance G = 1000 W/m^2 and temperature T = 25°C. The results show that the INC-Cond has fast response to track the MPPT however the P&O oscillate around the MPP thus the V_{oc} PP take time to reach the MPP.

At different level of irradiance simulated using irradiance signal illustrated in the figure 11. The power harvested by the three different MPPT algorithms is illustrated in figure 12.

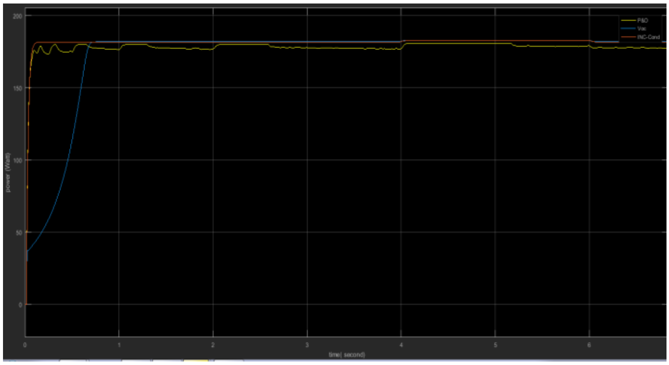

Fig. 10: The power harvested by the three different MPPT algorithms using Matlab-Simulink under fixe irradiance G = 1000 W/m^2 and temperature T = 25 °C.

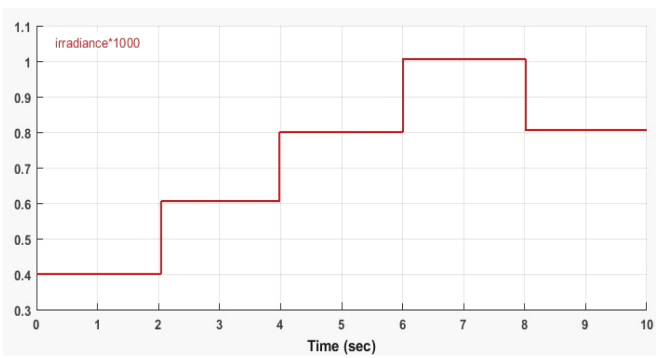

Fig. 11: The different level of irradiance using in the second simulation

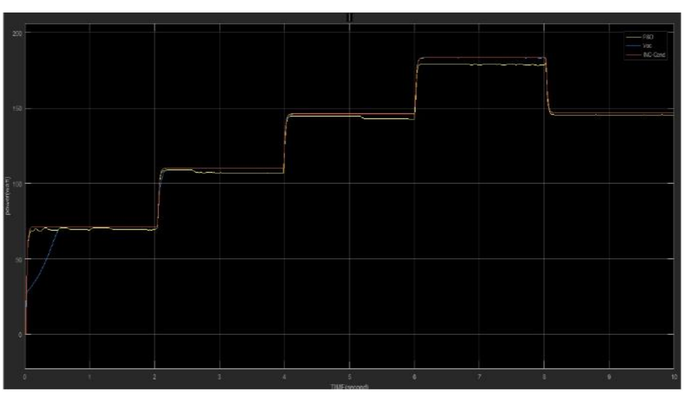

Fig. 12: The power harvested by the three different MPPT algorithms using Matlab - Simulink under varying irradiance and temperature T = 25 °C

The results show the efficiency of these MPPT algorithms in tracking the maximum power and its faster response to adapt to the change in irradiance condition.

4. CONCLUSION

This paper presents simulation and analysis of the PV model with the aim of testing the performance of three MPPT algorithms: Perturb and Observe (P&O), Incremental Conductance (INC-COND) and Fractional Open Circuit Voltage (FOCV) which enable to control the maximum power point (MPP) of the photovoltaic system under different levels of irradiance. The simulation of MPPT were performed using Matlab/Simulink software.

This work focused on the evaluation of behavior of these MPPT algorithms by using the same PI controller. The performance and response of each algorithm were given.

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