ROBUST MAXIMUM POWER POINT TRACKING TECHNIQUE AND PI CURRENT CONTROLLER DESIGN FOR GRID CONNECTED PV SYSTEM USING MATLAB/SIMULINK

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Abstract—*this study presents a PI controller design and Incremental inductance optimization technique is applied to track maximum power of photovoltaic cells for grid connected photovoltaic systems. In this control system, it is necessary to measure the PV array output power and to change the duty cycle of the DC/DC converter control signal. This method is simple and robust to irradiance and temperature inputs. This system contains the problem of degradation of photovoltaic power with climatic factors and the problem of synchronization of currents to be injected to the grid. We use a phase locked loop to solve the problem of synchronization of grid voltage and current.The model of the grid connected photovoltaic system had been implemented in the MATLAB/SIMULINK software and simulation studies have been presented. The Results had proved the effectiveness of the proposed system, the utility of the maximum power point tracker and the robustness of the phase locked loop.*

Keywords— *Modeling; Grid connected photovoltaic system; Maximum power point tracking; Incremental conductance, inverter.*

I. INTRODUCTION

Photovoltaic solar energy is one of the most dynamic markets in the renewable energy sector. It represents an alternative to traditional methods of producing electrical energy, which emit combustion wastes and pollutants harmful to the ecosystem. Solar energy can be converted into electricity using solar panels based on photovoltaic (PV) cells [1]. However, the conversion efficiency is low and the cost of panels is relatively high. For this reason, the photovoltaic energy conversion must be optimized to the maximum. The output characteristic of a panel or PV generator (PVG) is nonlinear [1][2] . It is characterized by a particular point for which the power supplied by the PVG. This is usually denoted MPP (Maximum Power Point). The MPPT (Maximum Power Point Tracker) is an electronic device that maintains the operating point of the system as close to the MPP. There are several MPPT control algorithms in the literature, the most used is the Perturb and Observe algorithm (P&O). Remember that solar sources are DC power, so an inverter is needed to ensure a DC / AC conversion and allow AC power or a possible injection of this photovoltaic power system. This article is intended for modeling various component of a system of photovoltaic energy conversion parts, and we quote: cell and photovoltaic panel, static converter (boost) suite is the optimization phase of the power operated and finally, we proceed with the injection of such power to a low grid voltage [3][4][15].

II. MODELLING OF PV ARRAY

A solar PV array is developed in Simulink. This array is used as a source for the maximum power point tracker system. The PV array makes use of the equations of a typical solar cell. The typical model of a solar cell is shown in Fig. 5. The current and voltage of the solar cell is given as follows [1][2][3][4]:

$$\mathrm{Icell} = \mathrm{Iph} - \mathrm{ID} - \frac{\mathrm{Vcell} + \mathrm{RsI_{cell}}}{\mathrm{Rp}} \qquad (1)$$

$$\mathrm{ID} = \mathrm{I_{sat}}\left\{\exp\left[\frac{q}{KT}(\mathrm{V_{cell}} + \mathrm{RsI_{cell}})\right] - 1\right\} \qquad (2)$$

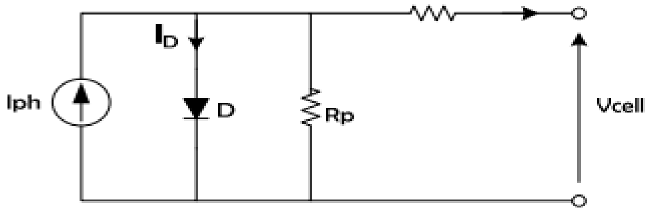

Fig .1. Solar cell equivalent model.

Where

I_{cell} and V_{cell} are the cell output current and voltage. The definitions of the parameters are given in table 1. The equivalent circuit for the solar cells arranged in Np parallel and Ns series is shown in fig.6, array current and array voltage becomes [3][4]::

$$\mathrm{Ipv} = \mathrm{NpIph} - \mathrm{NpIsat}\left\{\exp\left[\frac{q}{KT}\left(\frac{\mathrm{Vpv}}{\mathrm{Ns}} + \frac{\mathrm{RsIpv}}{\mathrm{Np}}\right) - 1\right]\right\} - \frac{\mathrm{Np}}{\mathrm{Rp}}\left(\frac{\mathrm{Vpv}}{\mathrm{Ns}} + \frac{\mathrm{RsIPv}}{\mathrm{NP}}\right) \quad (3)$$

Where Np: represent the number of parallel modules. Note that each module is composed of Ns cells connected in series. ph p I N corresponds to the short circuit current of the solar array.

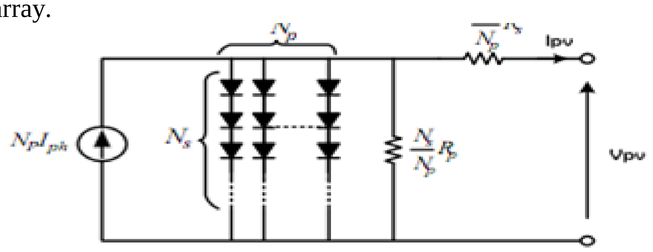

Fig.2.Electrically equivalent of solar array circuit (Ns series-Np parallel)

1. Mppt algorithm

A dc/dc converter (step up) serves the purpose of transferring maximum power from the solar PV module to the load. A dc/dc converter acts as an interface between the load and the PV array Fig. 3. By changing the duty cycle, the load impedance as seen by the source is varied and matched at the point of the peak power with the source so as to transfer the maximum power.

The relation between the input and the output voltages of the buck-boost converter is given as follows: [05][6][7][15][16].

$$Vout = \frac{1}{1-D} Vin \quad (4)$$

On applying Kirchhoff's laws, we find:

$$\begin{cases} L\dfrac{di}{dt} = -(1-D).V + E \\ C\dfrac{dV}{dt} = (1-D)i - \dfrac{V}{R} \end{cases} \quad (5)$$

I is the current through the inductance, the voltage across the capacitor, D is the duty ratio and Vpv is the voltage measured from the photovoltaic panel.

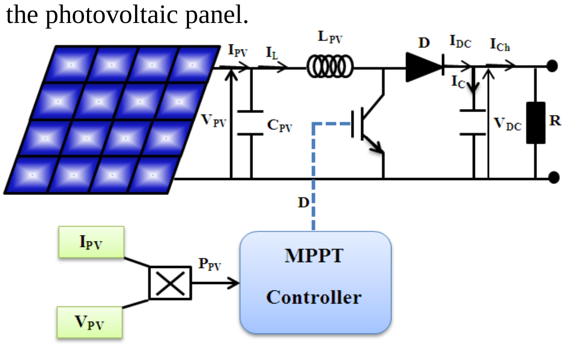

Fig.3 Diagramme en circuit d'un système photovoltaiique (PV-boost-MPPT)

2. Incremental Conductance (IC)

The disadvantage of the perturb and observe method to track the peak power under fast varying atmospheric condition is overcome by IC method [8]. The IC can determine that the MPPT has reached the MPP and stop perturbing the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between dl/dV and –I/V [8] This relationship is derived from the fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP. This algorithm has advantages over P&O in that it can determine when the MPPT has reached the MPP, where P&O oscillates around the MPP. Also, incremental conductance can track rapidly increasing and decreasing irradiance conditions with higher accuracy than perturb and observe [7]. One disadvantage of this algorithm is the increased complexity when compared to P&O [8].

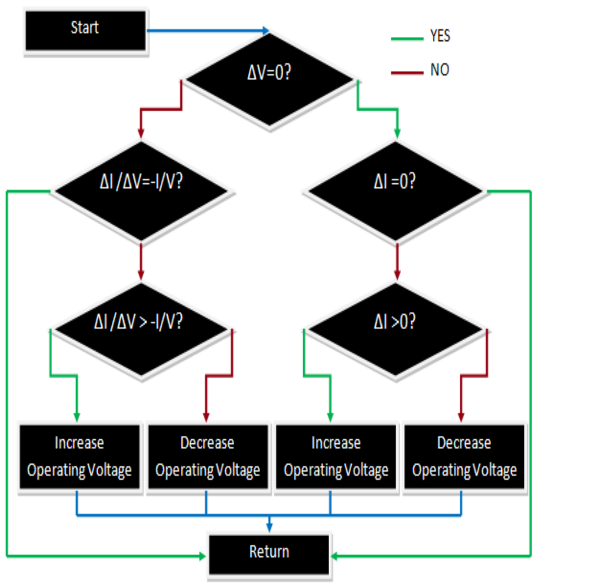

Fig 4. Flow chart of the incremental conductance algorithm

3. Modelling of a three-phase grid connected photovoltaic system

Schematic representation of the PV system injection to grid is shown in Figure 5.

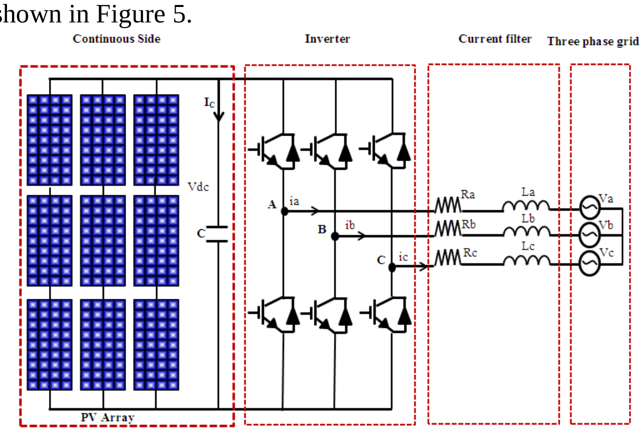

Fig. 5 Typical configuration of a grid connected photovoltaic system.

To analyze the system connected to the grid in Figure 3.7, standard Kirchhoff's voltage law is used, thus the voltage at the grid side of the converter can be described as [15]:

$$\begin{cases} Ea = L\frac{d}{dt}ia + Ria + va \\ Eb = L\frac{d}{dt}ib + Rib + vb \\ Ec = L\frac{d}{dt}ic + Ric + vc \end{cases} \quad (6)$$

$$Eabc = L\frac{d}{dt}iabc + Riabc + vabc \quad (7)$$

Where vabc are converter input voltages, while iabc are grid currents, Eabc are grid voltages, R and L are resistance and inductance respectively between the converter and the grid.

Three-phase currents and voltages are transformed in dq reference frame by means of abc to dq transformation, where ω is the system frequency in rad/s.

$$\begin{bmatrix} E_d \\ Eq \end{bmatrix} = L\frac{d}{dt}\begin{bmatrix} id \\ iq \end{bmatrix} + wL\begin{bmatrix} 0 & -1 \\ -1 & 0 \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + R\begin{bmatrix} I_d \\ I_q \end{bmatrix} + \begin{bmatrix} V_d \\ V_q \end{bmatrix} \quad (8)$$

After the transformation in dq reference frame, the voltage equations are:

$$\begin{cases} E_d = L\frac{d}{dt}i_d - wLi_q + v_d + Ri_d \\ E_q = L\frac{d}{dt}i_q + wLi_d + v_q + Ri_q \end{cases} \quad (9)$$

It can be observed that the d- and q-axes are decupled; they are only related to each other by means of ωLiq and ωLid terms. The power exchange in dq reference frame is given by:

$$P_{dq} = \frac{3}{2}(v_d i_d + v_q i_q) \quad (10)$$

4. Modelling of the inverter

The grid connection inverter consists on a three-phase voltage source inverter with three independent arms. Each one includes two switches which are complementary and controlled by the Pulse Width Modulation PWM.

The inverter's voltages (Va, Vb, Vc) are expressed in terms of the upper switches as follows [9][10][15]:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{V_p}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} K_1 \\ K_2 \\ K_3 \end{bmatrix} \quad (11)$$

K1, K2 and K3 are the controller signals applied to the switches.

The inverter's current Iinv is given by (12):

$$I_{inv} = K_1 I_a + K_2 I_b + K_3 I_c \quad (12)$$

Where, (Ia, Ib, Ic) are the currents to be injected to the grid.

5. The current control

The AC-side circuit equations in the synchronously rotating d-q reference frame are given by (13):

$$\begin{cases} V_d = E_d - L\frac{dI_d}{dt} - wLI_q \\ V_q = E_q - L\frac{dI_q}{dt} - wLI_d \end{cases} \quad (13)$$

Where:

Ed and Eq = The d- and q-axis components of the grid side voltage respectively

Vd and Vq = Those of the inverter voltage

ω = The system angular frequency To provide direct use of the sensed currents which present intrinsic error, (13) may be transformed to (14) using PI controllers:

$$\begin{cases} V_d = E_d - wLI_q - \mu_d \\ V_q = E_q - wLI_d - \mu_q \end{cases} \quad (14)$$

Where:

$$\begin{cases} \mu_d = (K_p + \frac{K_i}{S})(I_d{}^* - I_d) \\ \mu_q = (K_p + \frac{K_i}{S})(I_q{}^* - I_q) \end{cases} \quad (15)$$

Where, Kp and Ki are the proportional and integral gains of the PI controllers.

Thus, the diagram of current control with a PI regulator in synchronous d-q rotating can be illustrated by fig.6.

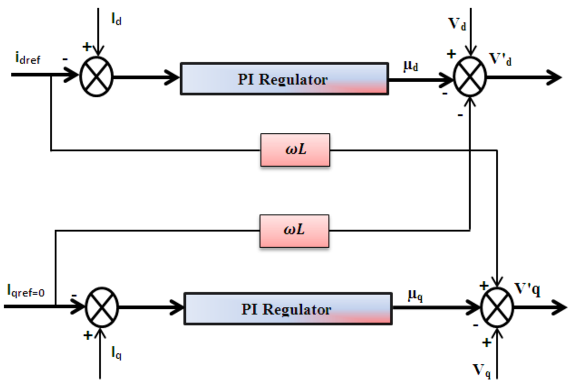

Fig. 6 Proposed current control scheme in synchronous d-q rotating

6. Design of voltage controller

The DC voltage is set by a PI controller that compares the actual dc bus voltage and the reference generated by the MPPT, and provides an active current reference in a synchronous reference frame attached at grid voltage vector.

The other component of current vector represents the reactive current and it can be fixed at the desired level for power factor or voltage control [11][12][13].

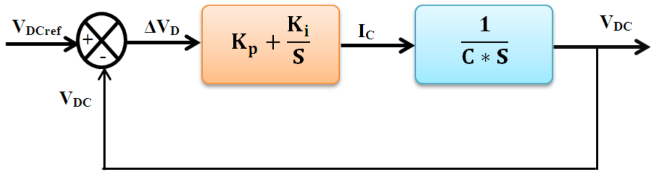

Fig. 7. Control loop of the DC bus voltage.

7. Modelling of the DC bus

The DC bus current Ic is given by (16):

$$I_C = C\frac{dV_{DC}}{dt} \qquad (16)$$

Dans le domaine de Laplace, l'équation précédente s'écrit :

$$I_C = C * S * V_{DC}\,,\, V_{DC} = \frac{i_C}{C*S} \qquad (17)$$

8. The phase locked loop

The PLL is an important and critical part of the system. Its aim is to give the voltage angle of the three-phase system (Ua Ub Uc Figure 2.4). This angle is then used for all the dq-transformations in the model.

The PLL used in this study is based on zero crossing voltage detection and the utilization of the quadrate of the input signals [14]:

• Ed*= 0: The synchronization signals based on this technique has a simple structure. By keeping Ed*= 0, the synchronous reference voltage component Ed is minimized and thereby the PLL will remain locked to the input voltages Eα and Eβ.

III.RESULTS

A complete Simulink-MATLAB simulation and controlling of the Grid Connected Photovoltaic System with the Voltage Oriented Control and the Maximum Power Point Tracking algorithm has been carried out with the following parameters:

• The PVG is composed of 20 series modules and 5 parallel modules. Those modules are amorphous. Each one presents the following characteristics: Nominal peak power: 60 WP, Nominal voltage: 17.1 V, Nominal current: 3.5 A, Open-circuit voltage: 21.1 V and Short-circuit current: 3.8 A

• The DC-bus capacitance: C = 200 10−3 F

• The grid filter: R = 3, L = 0.01 H

• The grid voltage: 220V/50 Hz

The simulation shows an excellent performance of both inverter and MPPT, with negligible fluctuation of the dc bus voltage, fast tracking of optimum operating point, and a unit power factor is achieved. Also ,The responses are more stable, more accurate and robust.

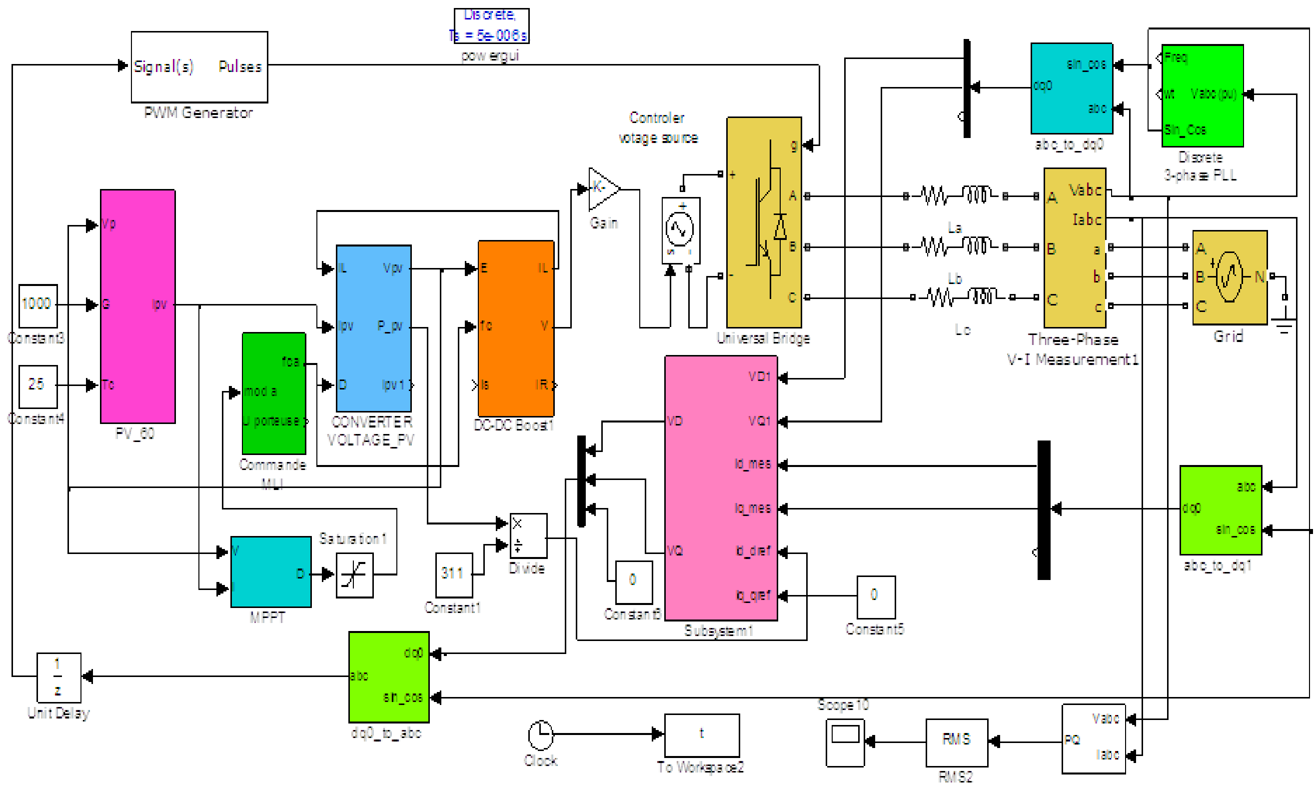

Fig. 8. Simulation model for PV three-phase grid-connected inverter

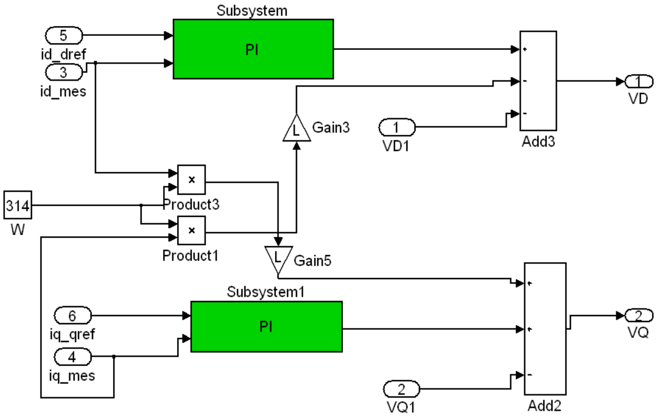

Fig. 9. Simulation model of PI current control

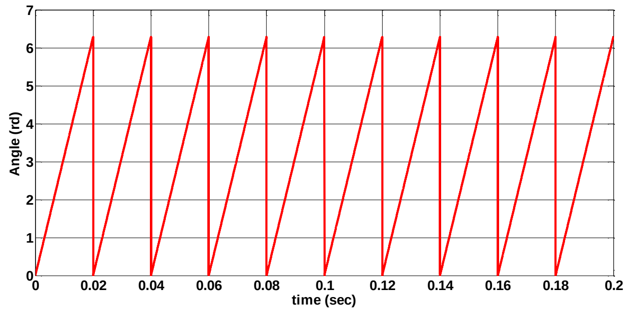

Fig. 10. The angle θ calculated by the PLL

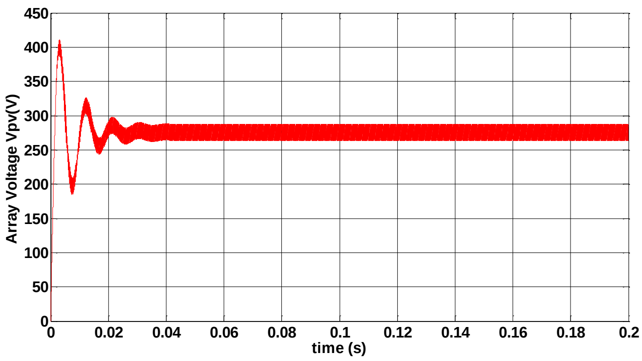

Fig. 11. Output Voltage of the solar panels

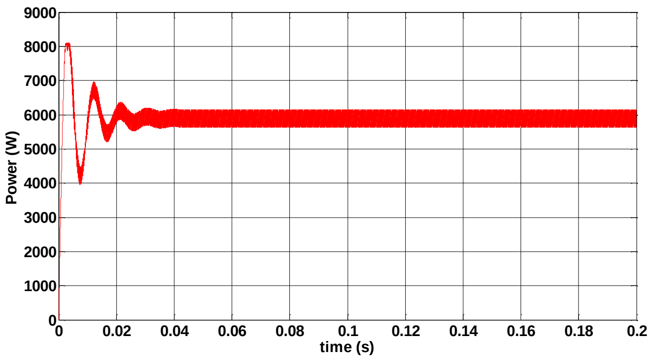

Fig. 12. Output power of the solar panels

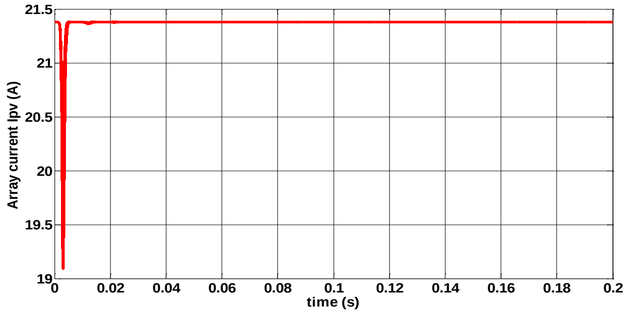

Fig. 13. Output Current of the solar panels

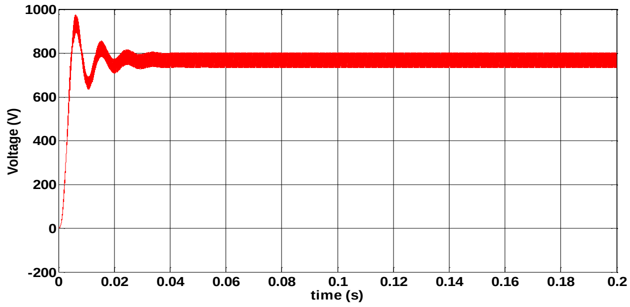

Fig. 14. The DC bus Voltage

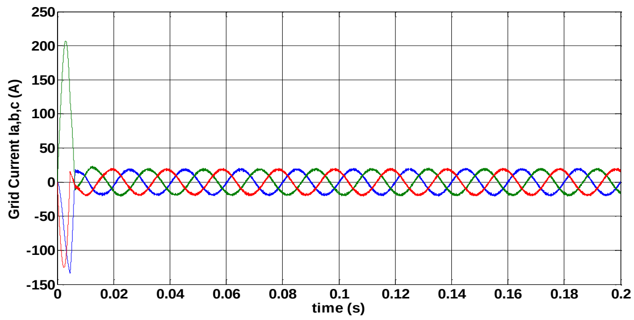

Fig. 15. Three phase grid current waveform

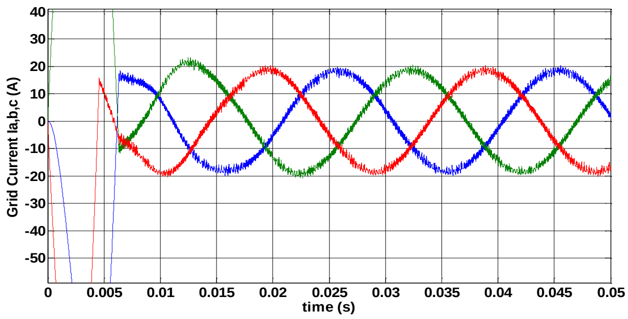

Fig. 16. Zoom of the three phase grid current waveform

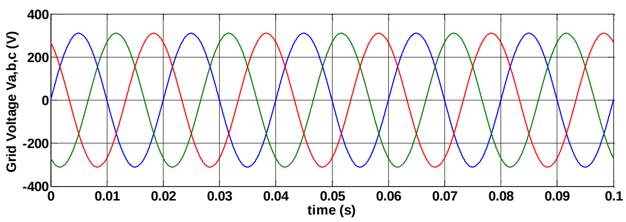

Fig. 17. Three phase grid Voltage waveform

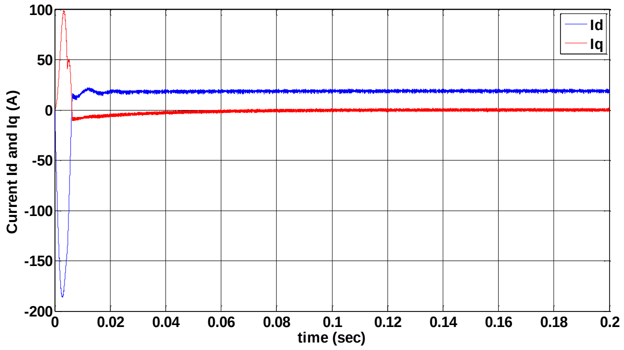

Fig. 18. Characteristics of active and reactive currents (Id and Iq)

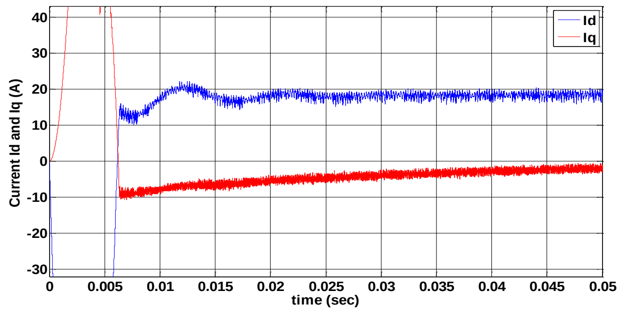

Fig. 19. Zoom of the Characteristics of active and reactive currents (Id and Iq)

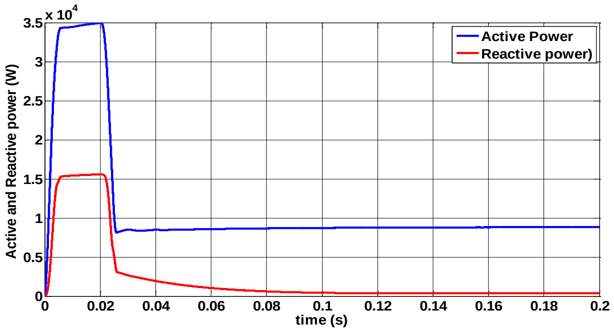

Fig. 20. Characteristics of active and reactive power (P and Q)

IV. CONCLUSION

This study is focused on the modeling and simulation of a grid connected photovoltaic system, optimized by Incremented Inductance approach and controlled by the PI control. The responses are more stable, more accurate and robust. The MPPT has proved its utility in tracking of the maximum power point and the optimization of the photovoltaic power generation.

The phase locked loop used in this study has proved its robustness and effectiveness in synchronization of the grid voltage and current.

References

1. V. Salas, E. Olias, A. Làzaro, A. Barrado, *"Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems"*, Solar Energy Material Solar Cells, 2006, 90:1555–78.
2. H.E.A. Ibrahim, *"Comparison Between Fuzzy and P&O Control for MPPT for Photovoltaic System Using Boost Converter"*, Journal of Energy Technologies and Policy, Vol.2, No.6, 2012.
3. T. Esram, P. Chapman, *"Comparison of photovoltaic array maximum power point tracking techniques,"* IEEE Transactions on Energy Conversion, 2007, 22:2.
4. Ahmed. M, Fares,Belal A. Abo Zalam Salwa G. El Nashar, Haitham Aka1, *« Comparison Between Different Algorithms for Maximum PPT in Photovoltaic Systems and its Implementation on Microcontroller »*, Journal of Energy Technologies and Policy, Vol.3, No.5, 2013.
5. Subiyanto, Mohamed, A., Hannan, M.A., *"Photovoltaic Maximum Power Point Tracking Controller Using a New High Performance Boost Converter", Int. Rev. of Electr. Eng.* 5(2010), 6, 2535-2545.
6. Rym Marouani and Abdelkader Mami, *"Voltage Oriented Control Applied to a Grid Connected Photovoltaic System with Maximum Power Point Tracking Technique"*, American Journal of Applied Sciences 7 (8): 1168-1173, 2010.
7. S .Lalouni, D. Rekioua,"*Optimal Control of a Grid Connected Photovoltaic System with Constant Switching Frequency*", Energy Procedia 36 (2013) 189 – 199.
8. Hassaine, L, Olias. E, Quintero.J, Haddadi. M, "*Digital Power Factor Control and Reactive Power Regulation for Grid-Connected Photovoltaic Inverter*", *Renewable Energy*, 34(2009), no. 1, 315-321.
9. Salas.V, Olias.E, "*Overview of State of Technique for PV Inverters Used in Low Voltage Grid-Connected PV Systems: Inverters Below 10kW*", *Renewable and Sustainable Energy Rev.*, 13(2009), 1541-1550.
10. Weidong.X, Nathan.O, and William.G.D, *« Topology Study of Photovoltaic Interface for Maximum Power Point Tracking »*, IEEE transactions on industrial electronics, vol. 54, no. 3, june 2007.
11. Kim, I.S., 2007. *"Robust maximum power point tracker using sliding mode controller for the three-phase grid-connected photovoltaic system*". Solar Energy, 81: 405-414. DOI: 10.1016/j.solener.2006.04.005.
12. Kim.s.k, j.h. jeon, c.h. cho, e.s. kim and j.b. ahn, 2009. *"Modeling and simulation of a grid-connected PV generation system for electromagnetic transient analysis*". Solar Energy, 83: 664-678. DOI: 10.1016/j.solener.2008.10.020.
13. Lee, S.H., S.G. Song, S.J. Park, C.J. Moon and M.H. Lee, 2008. "*Grid-connected photovoltaic system using current-source inverter*". Solar Energy, 82: 411-419. DOI: 10.1016/j.solener.2007.10.006.
14. Jianwu Cao,"*Analysis and Implementation of Grid-Connected Solar PV with Harmonic Compensation*", Thesis, le 04 Janvier 2011, Florida State University.
15. Rekioua.D, Matagne.E, *"Optimization of photovoltaic power systems: Modelization, Simulation and Control*, Green Energy and Technology", DOI: 10.1007/978-1-4471-2403-0, Springer-Verlag London Limited 2012.
16. Rekioua. D, Achour.A.Y, Rekiouaa. T, *"Tracking power photovoltaic system with sliding mode control strategy"*, 2013 , Energy Procedia.