Modulated Hysteresis Current Control of a Grid Connected Photovoltaic System

Djamila Rekioua, Toufik Rekioua
Laboratoire LTII, Département de Génie Electrique
Faculté de Technologie, Université de Bejaia
Bejaia, Algeria
dja_rekioua@yahoo.fr

Abstract—**In this paper a control of a photovoltaic system connected to the grid is presented. The main components of the studied system are solar arrays connected through a DC bus to a grid side inverter. Due to the instantaneous changing of solar irradiance and temperature, maximum power point tracking (MPPT) is integrated in the inverter control. The energy generated by the grid photovoltaic system is sent to the power grid. This is accomplished through an efficient DC/AC conversion where the MPPT is integrated in the inverter control which ensures the control of the active and reactive power level injected to the grid. To overcome undesirable drawbacks of hysteresis current control, and to obtain a constant switching frequency, in this paper we applied a modulated hysteresis control. The simulation results under Matlab/Simulink show the control performance of grid connected photovoltaic system.**

Keywords—Photovoltaic systems, MPPT, Constant Switching frequency, Grid, Inverter control.

I. INTRODUCTION

Photovoltaic energy has increased interest in electrical power applications, since it is considered as an essentially inexhaustible and broadly available energy resource. However, the output power induced in the photovoltaic modules depends on solar irradiance and temperature of the solar cells. Therefore, to maximize the efficiency of the renewable energy system, it is necessary to track the maximum power point of the PV array. The PV array has a unique operating point that can supply maximum power to the load [1-2]. This point is called the maximum-power point (MPP). The locus of this point has a non-linear variation with solar irradiance and the cell temperature. Thus, in order to operate the PV array at its MPP, the PV system must contain a maximum-power point tracking (MPPT) controller [3-16]. In recent years, fuzzy logic controllers (FLC) are widely used for finding the MPP [17-23]. The inputs of fuzzy controller are error and its variations; the output is the duty ratio of DC / DC converter or its variation. The fuzzy controller introduced in [7] uses dP_{pv}/dI_{pv} and its variation $\Delta(dP_{pv}/dI_{pv})$ as inputs., calculates the duty ratio of the MPPT converter in the first reference and the variation of this in the last two references. While the fuzzy controller in [1] considers the variation of duty cycle as output but replaces dP_{pv}/dI_{pv} by varying the power of the photovoltaic panel.

In this paper, we present control of a grid connected photovoltaic system. The MPPT control is integrated in the inverter control. The FLC technique is applied to the studied system and a comparison is made. The energy generated by the grid photovoltaic system is sent to the power grid. This is accomplished through an efficient DC/AC conversion where the MPPT is integrated in the inverter control which ensures the control of the active and reactive power level injected to the grid. Hysteresis Current control is used. This control is very simple but it has the main drawback of variable switching frequency [1]. To overcome this problem, a modulated hysteresis control is applies in this paper [20]. The principle is to superpose an adequate triangular signal having the desired switching frequency to the reference current. The new modulated reference current is then compared to the calculated current in hysteresis controller. The simulation results under Matlab/Simulink are presented.

II. PROPOSED SYSTEM CONFIGURATION

Fig 1 shows the proposed system configuration to interface the photovoltaic array with the power grid.
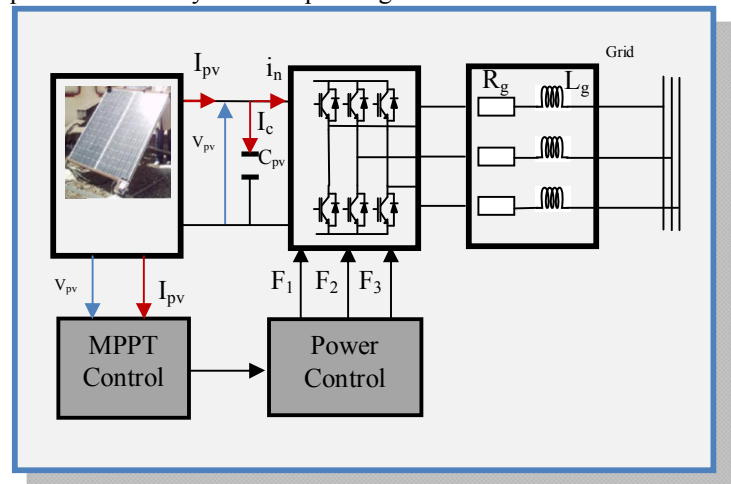

Figure 1. Proposed system configuration

A. Photovoltaic generator

In literature, there are several mathematical models that describe the operation and behavior of the photovoltaic generator. In this paper, we use a model with a very simple resolution. It requires only four parameters namely I_{sc}, V_{oc}, V_{mp} and I_{mp} [1].

$$I_{pv} = I_{sc}\left\{1 - C_1\left[\exp\left(\frac{V_{pv}}{C_2.V_{oc}}\right) - 1\right]\right\} \qquad (1)$$

With:

$$C_2 = \frac{\left(\dfrac{V_{mpp}}{V_{oc}}\right) - 1}{\ln(1 - \dfrac{I_{mpp}}{I_{sc}})} \qquad (2)$$

$$C_1 = (1 - \frac{I_{mpp}}{I_{sc}})\exp(-\frac{V_{mpp}}{C_2.V_{oc}})$$

The simple relationship of power for a photovoltaic module is

$$P_{pv} = I_{sc}\left\{1 - C_1\left[\exp\left(\frac{V_{pv}}{C_2.V_{oc}}\right) - 1\right]\right\}.V_{pv} \qquad (3)$$

The bloc diagram of the PV model under matlab/Simulink is given in Fig.2.
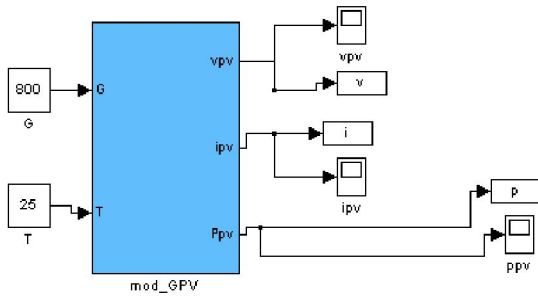

Figure 2.   Bloc diagram of PV model

Fig 3 shows the influence of irradiance G and temperature T_c on the electrical characteristics.
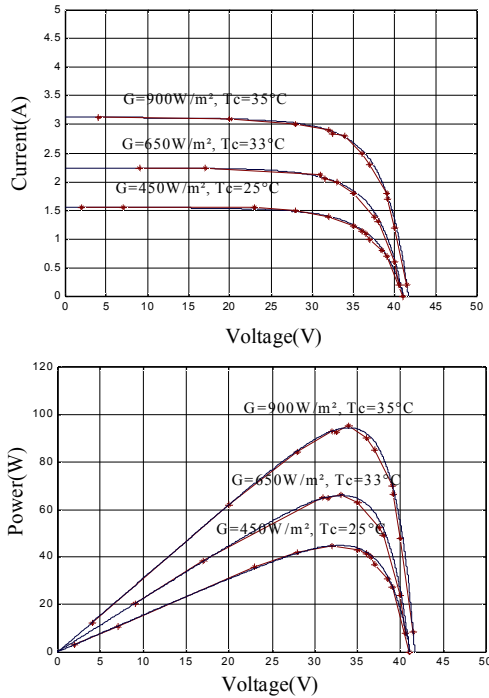

Figure 3.   Effects of solar irradiance and temperature changing

B. MPPT control

Fuzzy logic controller is introducing to determine the operating point corresponding to maximum power for different insolation levels and temperature. In this case, inputs of the fuzzy logic controller are power variation ΔP_{pv} and voltage variation ΔV_{pv}. The output is reference voltage variation $\Delta V_{pv,ref.}$ In order to converge towards the optimal point, rules are relatively simple to establish. These rules depend on the variations of power ΔP_{pv} and voltage ΔV_{pv}. In accordance with Table.1, if the power P_{pv} increased, the operating point should be increased as well. However, if the power P_{pv} decreased, the voltage $V_{pv,ref}$ should do the same.

TABLE I.   FUZZY RULE TABLE [2].

ΔP_{pv} / ΔV_{pv}	BN	MN	SN	Z	SP	MP	BP
BN	BP	BP	MP	Z	MN	BN	BN
MN	BP	MP	SP	Z	SN	MN	BN
SN	MP	SP	SP	Z	SN	SN	MN
Z	BN	MN	SN	Z	SP	MP	BP
SP	MN	SN	SN	Z	SP	SP	MP
MP	BN	MN	SN	Z	SP	MP	BP
BP	BN	BN	MN	Z	MP	BP	BP

From these linguistic rules, the MPPT algorithm contains measurement of variation of photovoltaic power ΔP_{pv} and variation of photovoltaic voltage ΔV_{pv} proposes a variation of the voltage reference $\Delta V_{pv,ref}$ according to Eq.4. [1-2].

$$\begin{cases} \Delta P_{pv} = P_{pv}(k) - P_{pv}(k-1) \\ \Delta V_{pv} = V_{pv}(k) - V_{pv}(k-1) \\ V_{pv-ref}(k) = V_{pv}(k-1) + \Delta V_{pv-ref}(k) \end{cases} \qquad (4)$$

Where: $P_{pv}(k)$ and $V_{pv}(k)$ are the power and voltage of the photovoltaic generator at sampled times (k), and $V_{pv,ref}(k)$ the instant of reference voltage.

The power variation (ΔP_{pv}) is either in the positive direction or in the negative one. The value of ΔP_{pv} can also be small where on the contrary large. This control allows the research of the optimum point while being based on the expert observations. From these judgements, the reference photovoltaic voltage $V_{pv,ref}$ is increased or decreased in a small or respectively large way in the direction which makes it possible to increase the power P_{pv}. If a great increase in the voltage V_{pv} involves a great increase in the power P_{pv}, we continue to strongly increase the reference voltage V_{pv}. If a great increase in the voltage V_{pv} involves a reduction in the power P_{pv}, we decrease the reference voltage $V_{pv,ref}$ to obtain a fast increase in the power P_{pv}. If a reduction in the voltage V_{pv} involves a weak increase in the power P_{pv} then we get closer to the optimal reference voltage which is the beginning of stabilization. When insolation and temperature vary, the same types of rules are applied to track the maximum power point. The structure of fuzzy logic controller is shown in Fig.5. (G_1, G_2 and G_3 are the adaptatives gain).
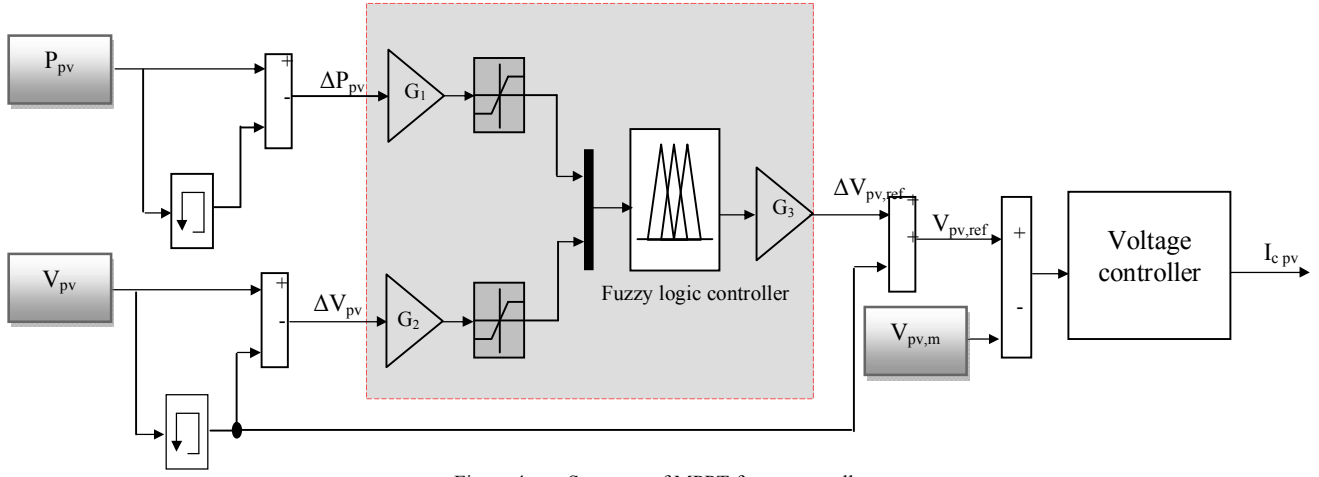
Figure 4. Structure of MPPT fuzzy controller.

In Fig.5, we present PV array characteristics from changed in temperature (T_c) at constant insolation. The open circuit voltage (V_{oc}) decrease when temperature increases, the maximum power point change according to the variation of temperature. It is clear that the operating point of this system operates closer to a maximum power point for variations in insolation and temperature.
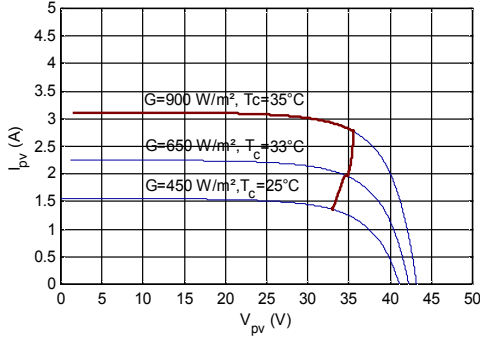
(a) Current-voltage characteristic of a PV module for different insolation.
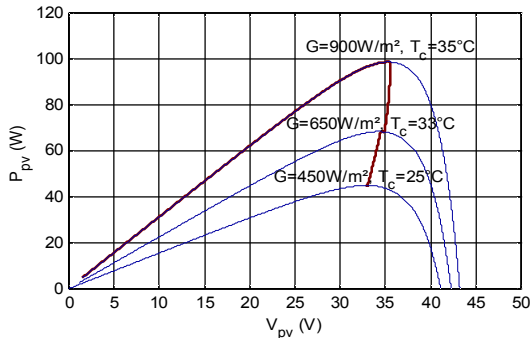
(b) Power-voltage characteristic of a PV module for different insolation.
Figure 5. Electrical characteristics with fuzzy logic controller

C. Power control

The control principle consists in adjusting the active power supplied to the grid to its reference value P_{ref} and the reactive power Q_{ref} to zero in order to fix the power factor at the unit. The active power reference is deduced by controlling the direct bus voltage with a proportional integral corrector generating the current reference I_{cref} to the capacitance (Fig.4).

We have:

$$i_n = F_1 i_{g1} + F_2 i_{g2} + F_3 i_{g3} \tag{4}$$

F_1, F_2 and F_3 are logic functions according to the switch states given by the grid link control and i_a, i_b and i_c are the three phase currents supplied to the grid.

The inverter is modeled as:

$$\begin{pmatrix} v_{g1} \\ v_{g2} \\ v_{g3} \end{pmatrix} = \frac{V_{pv}}{3}\begin{pmatrix} -2 & 1 & 1 \\ 1 & -2 & 1 \\ 1 & 1 & -2 \end{pmatrix}\begin{pmatrix} F_1 \\ F_2 \\ F_3 \end{pmatrix} \tag{5}$$

v_{g1}, v_{g2} and v_{g3} are the three phase voltages of the DC/AC inverter. Then the filter, constituted of R_g and L_g, links these voltages to E_1, E_2 and E_3, which are the three phase voltages of the grid, through the following relation:

$$\begin{pmatrix} v_{g1} \\ v_{g2} \\ v_{g3} \end{pmatrix} = R_g\begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} + L_g\frac{d}{dt}\begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} + \begin{pmatrix} E_1 \\ E_2 \\ E_3 \end{pmatrix} \tag{6}$$

Hence, we can express P_{ref} as:

$$P_{ref} = P_{pv} - P_c \tag{7}$$

Active and reactive power references P_{ref} and Q_{ref} are given by the following equations:

$$P_{ref} = E_d . I_{gdref} + E_q . I_{gqref}$$
$$Q_{ref} = E_q . I_{gdref} - E_d . I_{gdref} \tag{8}$$

Where: E_d, E_q are the Park components of E_1, E_2, E_3 .the voltages in (d,q) reference frame.

We obtain the references current:

$$I_{gdref} = \frac{P_{ref} . E_d + Q_{ref} . E_q}{E_d^2 + E_q^2}$$
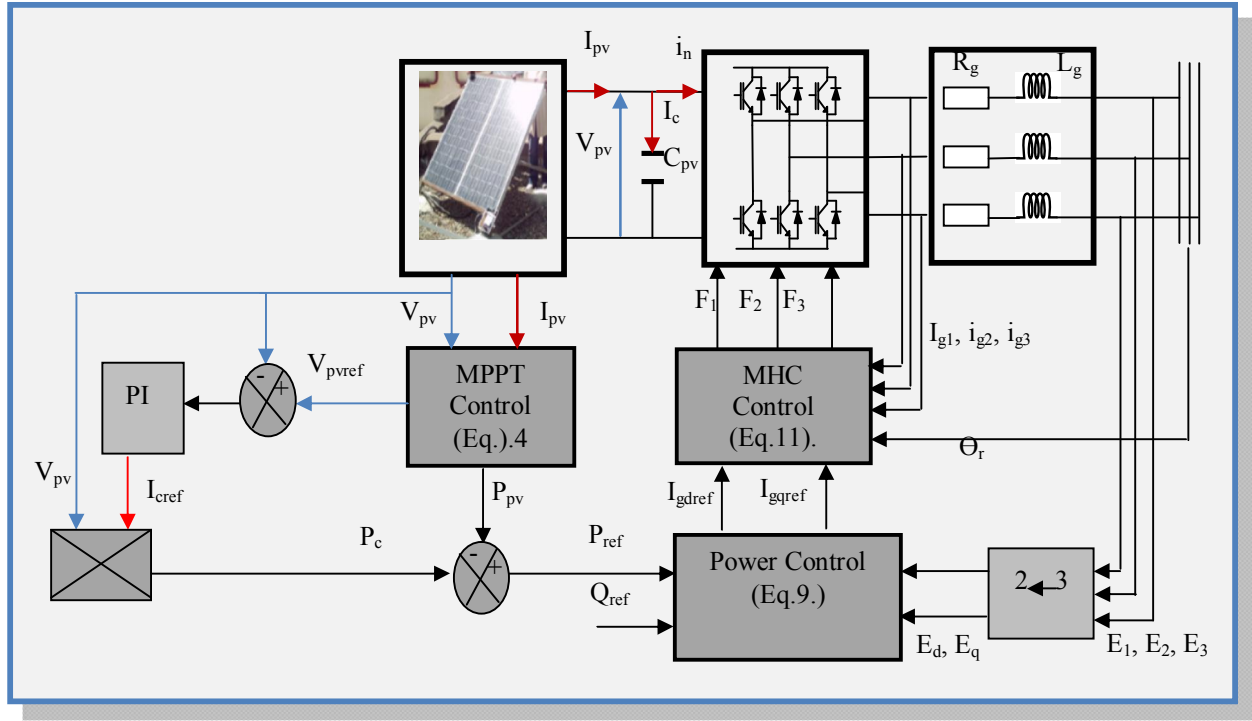$$I_{gqref} = \frac{P_{ref} . E_q + Q_{ref} . E_d}{E_d^2 + E_q^2} \tag{9}$$

Figure 6.   Proposed system configuration

The MPPT algorithm optimizes the reference voltage (V_{pvref}) for maximum power tracking. This voltage represents the input reference of the PI controller, which performs the DC bus voltage. The reference power (P_{ref}) represents the amount of active power produced by the photovoltaic generator interfaced to the main utility through the inverter, and Pc the power of capacitor C_{pv}; while Q_{ref} represents amount of reactive power desired to be injected into or absorbed from the main utility. In the present case, the inverter is operating at unity power factor (Q_{ref}=0) therefore no reactive power is exchanged and the total power extracted from the PV generator is injected to the grid.

D. Modulted hysteresis control (MHC)

The modulated hysteresis current control technique is used, it permit a constant switching frequency in the inverter. This control consists to add to the reference current i_{ref} a triangular signal i_{tr}, with frequency f_{tr} and amplitude A_{tr}. The frequency f_{tr} must be choosing equal to desired switching frequency of the semiconductor.

$$i_{mod}^* = i_{ref} + i_{tr} \qquad (10)$$

With i_{ref} the reference current, i_{tr} is the triangular signal, i_{mod}^* is the modulated reference current.

The hysteresis controller is defined by its band width B_H which borders i_{ref}*. In this way, the upper and the lower limit shown in Fig. 7 are obtained. The switches states are determined by the intersection points between the measured current i_m and the obtained limits. The switching strategy is a function of the reference current waveform. The desired switching period will

be equal to the period of the triangular signal T_{tr}. In order to impose the switching frequency, the measured current variation during a half period $T_{tr}/2$ should not exceed the difference between the maximum of the upper limit and the minimum of the lower one [4].

In the case where the measured current will have only two intersections with the hysteresis band limits during every half period $T_{tr}/2$ of the triangular signal, these points determinate the switching times of the voltage inverter
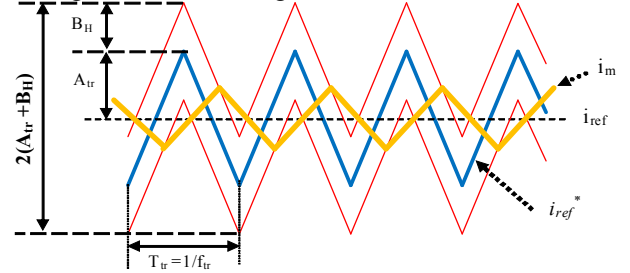

Figure 7.   Determination of the switches states

A_{tr} and B_h can be calculated by the following equation [20]:

$$\left(\frac{di}{dt}\right)_{max} = \frac{(\Delta I)_{max}}{(T_{tr}/2)} \langle \frac{2.(A_{tr}+B_h)}{T_{tr}/2} = \frac{4.(A_{tr}+B_h)}{T_{tr}} \qquad (11)$$
$$= 4.f_{tr}.(A_{tr}+B_h)$$

III.   SIMULATION RESULTS

The proposed system has been modeled and simulated under Matlab/Simulink. The photovoltaic power is about

17.85 kW (see Table 1.) and we use FLC algorithm to maximize the power. The inverter current is controlled by using MHC (A_{tr}=2.1, f=5 kHz and B_H =0.1.)

TABLE II.   SOLAR PANEL PARAMETERS NT175E1

| 6 strings of 17 series connected each, connected in parallel.	
Maximum power P_m	175 W
Current at maximum power point I_{mpp}	4.95 A
Voltage at maximum power point V_{mpp}	35.4 V
Short-circuit current I_{sc}	5.4 A
Open circuit voltage V_{oc}	44.4 V
Current temperature coefficient α_{sc}	0.053 mA/°C
Voltage temperature coefficient β_{oc}	156 mV/°C
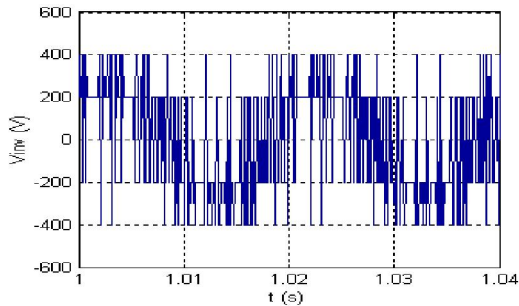
(a). With classical hysteresis control
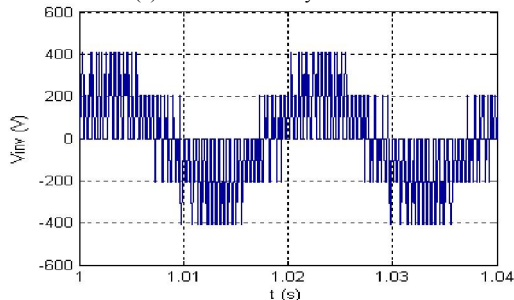
(b). With modulated hysteresis control,
Figure 8.   Output voltage inverter
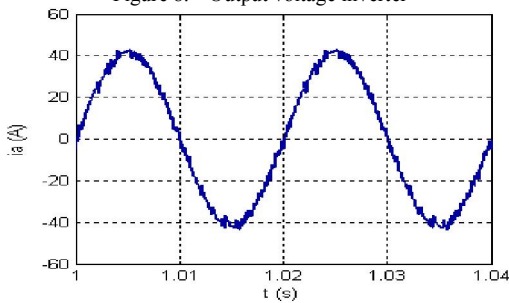
(a). With classical hysteresis control
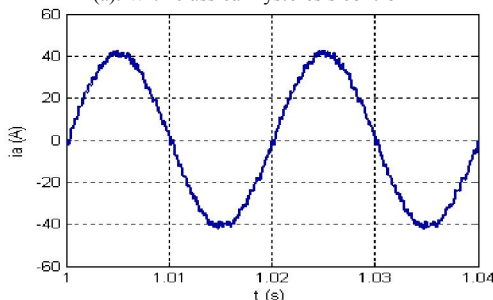
(b) With modulated hysteresis control

Figure 9.   Current injected into the grid

We can observe that voltage and current are in phase which means that the maximum of power extracted from the PV array can pass into the grid and system operates at unity power factor (Q_{ref}=0) with no reactive power exchange. Then, the system can provide energy to a utility grid with low harmonics compared to the classical control one.

IV.   CONCLUSION

A control of a photovoltaic system connected to the grid has been presented. It is based on fuzzy logic theory, where the MPPT is integrated in the inverter control. We have used a fast and steady fuzzy logic MPPT controller. It adjust appropriately the optimal increment's magnitude of voltage required for reached the optimum operating voltage and it makes it possible to find the MPP in a shorter time runs compared to conventional methods. Also to impose a constant switching frequency, we have used modulated hysteresis control (MHC) for the current control. The obtained results show that MHC controller gives less THD of grid current compared to the classical controller. The grid photovoltaic system is continuously operating at the MPP and the system can provide energy to the utility grid with low harmonics and unit power factor.

REFERENCES

[1]   D. Rekioua, E. Matagne "Optimization of photovoltaic power systems: Modelization, Simulation and Control, " 2012 Series: Green Energy and Technology. Ed Springer

[2]   S. Lalouni, D. Rekioua, T. Rekioua, E.Matagne "Fuzzy logic control of stand-alone photovoltaic system with battery storage " *J Power Sources*, 2009;193 (2): pp.899-907.

[3]   A. Yazdani "A Control Methodology and Characterization of Dynamics for a Photovoltaic (PV) System Interfaced With a Distribution Network," *IEEE Trans On Power Delivery*, 2009; 24(3): pp.1538-1555.

[4]   S. Lalouni, D. Rekioua,"Optimal control of a grid connected photovoltaic system with constant switching frequency, " 2013 Energy Procedia V36, 2013, pp.189–199.

[5]   L. J.L. Santos, F. Antunes, A. Chehab and C. Cruz "A Maximum Power Point Tracker for PV Systems Using a High Performance Boost Converter "*Solar Energy*, 2006; 80(7): pp.772-778.

[6]   J. Alonso-Martínez, J. Eloy-García and S.Arnaltes "Control of a Three-Phase Grid-Connected Inverter for Photovoltaic Applications with a Fuzzy MPPT Under Unbalanced Conditions"*13th European Conference on Power Electronics and Applications,* 2009, pp.1–7.

[7]   C.Y. Won, D.H. Kim, S.C. Kim, W.S. Kim and H.-S. Kim "A new maximum power point tracker of photovoltaic arrays using fuzzy controller" *In 25th Annual IEEE Power Electron*. 1994, pp.396-403.

[8]   H. Al-Atrash, I. Batarseh, K. Rustom"Statistical modelling of DSP-based hill-climbing MPPT algorithms in noisy environments" *IEEE APEC 2005*, pp.1773 – 1777.

[9]   J-A. Jiang, T-L Huang, Y-T Hsiao and C-H. Chen"Maximum power tracking for photovoltaic power systems" *In J. of Science and Engineering,* 2005; 8(2): pp.147-153.

[10]   F. Chekired, C. Larbes, D. Rekioua, F. Haddad, "Implementation of a MPPT fuzzy controller for photovoltaic systems on FPGA circuit", 2011 Energy Procedia, 6 , pp. 541-549

[11]   M. Veerachary, T. Senjyu, K. Uezato "Neural-network-based maximum-power-point tracking of coupled inductor interleaved-boost-converter-supplied PV system using fuzzy controller" *IEEE Trans. Ind. Electron*,2003, pp.749–758.

[12]   M. Taherbaneh, H. Ghafori fard, A.H Rezaie, S. Karbasian " Combination of fuzz maximum power point tracker and sun tracker for

deployable solar panels in photovoltaic systems" *Proc. FUZZ-IEEE* 2007, pp.23-36.

[13] I.H. Altas and A.M. Sharaf "Novel maximum power fuzzy logic controller for photovoltaic solar energy systems", *Renewable Energy*, 2008; 33(3): pp.388-399.

[14] I. Hamzaoui, F. Bouchafaa., A .Hadjammar. "Investigation of the behavior of a three phase grid connected photovoltaic system to control active and reactive power with DPC"*Energy Procedia* 2011, 6: pp.493–502.

[15] M.G. Simoes, N.N. Franceschetti "Fuzzy optimization based control of a solar array. *IEE Proc. Electr. Power Appl.*1999, 146(5): pp.552-558.

[16] N.Patcharaprakiti, S.Premrudeepreechacharn, Y.Sriuthaisiriwong "Maximum power point tracking using adaptive fuzzy logic control for grid connected photovoltaic system. " *Renewable Energy* 2005; 30(11): pp.1771-1788.

[17] S. Anushuman, G. Arindam and J.Ainash "Hysteresis current control operation of Flying Capacitor Multilevel Inverter and its Application in Shunt Compensation of Distribution System"*IEEE Trans on Power Delivery* 2007; 22 (1): pp. 396-405.

[18] K. Punitha, D. Devaraj, S.Sakthivel"Adaptive Hysteresis Current Control of Inverter for Solar Photovoltaic Applications. "*International Journal of Innovative Technology & Creative Engineering* 2011; 1(3): pp.25-33.

[19] C. Mukul "New Techniques for Inverter Flux Control." *IEEE Trans. On Industry applications* 2001; .37(3): pp.880-887.

[20] R. Abdelli, D. Rekioua and T. Rekioua "Performances improvements and torque ripple minimization for VSI fed induction machine with direct control torque. " *ISA Transaction* 2011; 50(2): pp.213-219.

[21] B.Borowy and Z. Salameh "Methodology for the Optimally Sizing the Combination of a Battery Bank and PV Array in a Wind/PV Hybrid System. "*IEEE Trans. on Energy Conversion* 1996; 11(2): pp.367-375.

[22] M. Nikraz, H. Dehbonei, C.V. Nayar"A DSP-Controlled PV System with MPPT."*Australian Power Engineering Conference, Christchurch* 2003, pp. 1–6.

[23] S Farinwata, D. Filev and R. Larguer, Eds. "*Fuzzy Control: Synthesis and Analysis,* "John Wiley, 1999.