Nonlinear Controller and a Optimized Maximum Power Point Tracking In PV Power System

H. Abouobaida, M. Cherkaoui

Department of Electrical Engineering, Ecole Mohamadia d'ingenieurs,

Mohamed V University, Rabat,Morocco.

(Email: Hassan_abouobaida@yahoo.fr, Cherkaoui@emi.ac.ma)

Abstract - **This work presents a high performance Maximum Power Point Tracker (MPPT) optimized for fast changing conditions on the PV panels.**

The rapidly changing conditions are tracked by an optimized P&O MPPT method. with a variable step size for a solar array system. This approach adjusts automatically a step size by using four different step to the solar array operating point, thus improving the MPPT (Maximum Peak Power Tracking) speed and accuracy compared with the conventional method with a fixed step size when the irradiance or temperature are changing rapidly. It also allows to have a lower oscillations around the MPP in steady-state conditions. The simulations results show that the proposed MPPT provides a quick and accurate tracking even in fast changing environmental conditions.

The stability of the control algorithm is demonstrated by means of Lyapunov analysis. Representative numerical results demonstrate that the power system can be controlled to track the maximum power point of the photovoltaic array panel.

Keywords—**Maximum power point tracking , solar power generation, backstepping control, Lyapunov, PWM.**

I. INTRODUCTION

Dc-dc power converters are employed in a variety of applications, including power supplies for personal computers, office equipment, spacecraft power systems, laptop computers, and telecommunications equipment, as well as dc motor drives. The input to a dc-dc converter is an unregulated DC voltage. Very often, the success of a PV application depends on whether the power electronics device can extract sufficiently high power from the PV arrays to keep overall output power per unit cost low. The maximum power point tracking (MPPT) of the PV output for all sunshine conditions, therefore, becomes a key control in the device operation for successful PV applications. The MPPT control is, in general, challenging, because the sunshine condition that determines the amount of sun energy into the PV array may change all the time, and the current-voltage characteristic of PV arrays is highly nonlinear. From an automatic control viewpoint, a switched power converter constitutes an interesting case study as it is a variable-structure nonlinear system. Its rapid structure variation is accounted for using averaged models.

Based on these, different nonlinear control techniques have been developed. These include passivity techniques, feedback linearization, sliding mode [1] and flatness methods.

To track the MPP, different approach has been addressed in many literatures. Among these algorithms, hill-climbing [2], and perturb and observe (P&O) methods [3]. Hill climbing involves a perturbation in the duty ratio of the power converter, and P&O a perturbation in the operating voltage of the PV array. In the case of a PV array connected to a power converter, perturbing the duty ratio of power converter perturbs the PV array current and consequently perturbs the PV array voltage.

Alternative approach to overcome this defect is called the increment conductance (IncCond) method [4], which is based on the fact that the MPP is defined by $dP_{PV}/dV_{PV} = 0$. When $dP_{PV}/dV_{PV} > 0$ (or $dP_{PV}/dV_{PV} < 0$), then the operation point is on the left (or right) of the MPP, and should be tuned toward opposite direction, where P_{PV} denotes power output of PV and V_{PV} and I_{PV} are PV voltage and PV current, respectively. The expression of dP_{PV}/dV_{PV} can be replaced by measurable parameters $dI_{PV}/dV_{PV} + I_{PV}/V_{PV}$. However, both perturbation (or hill-climbing) and IncCond methods did not perform well during rapid changing of atmospheric conditions. Therefore, modified methods [5]-[6] have also been proposed to improve tracking performance. The algorithms mentioned above are sharing the same idea of searching for MPP. Since PV exhibits nonlinear I-V characteristics, solutions of MPP are difficult to be determined analytically. Another approach called proportional open-circuit voltage (or short-circuit current) is addressed in [7] which assumed that voltage (V_{mpp}) and current (I_{mpp}) of MPP is proportion to PV open-circuit voltage (Voc) and short-circuit current (Isc), respectively. However, the estimated V_{mpp} is only an approximation of true V_{mpp} and the proportional constant will change if the PV module ages, in other words, the performance degraded with time. Another approach is called (RCC: Ripple correlation control). RCC makes use of ripple to perform MPPT. RCC correlates the time derivative of the time-varying PV array power $\dot{P}$ with the time derivative of the time-varying PV array current $\dot{I}$ or voltage $\dot{V}$ to drive the power gradient to zero [8]-[9], thus reaching the MPP. if V or I is increasing ($\dot{V} > 0$ or $\dot{I} > 0$) and P is increasing ($\dot{P} > 0$), then the operating point is below the MPP ($V < V_{MPP}$ or $I < I_{MPP}$). On the other hand, if V or I is increasing and P is decreasing ($\dot{P} < 0$), then the operating point is above the MPP ($V > V_{MPP}$ or $I > I_{MPP}$). Combining these observations, we see that $\dot{P}.\dot{V}$ or $\dot{P}.\dot{I}$ are positive to the left of the MPP, negative to right of the MPP, and zero at the MPP. Therefore, the duty ratio control input is :

$$d(t) = -k.\int \dot{P}.\dot{V}.dt \quad \text{or} \quad d(t) = -k.\int \dot{P}.\dot{I}.dt$$

The problem of controlling switched power converters is approached using the backsteeping technique [10]. While feedback linearization methods require precise models and often cancel some useful nonlinearities, backstepping designs offer a choice of design tools for accommodation of uncertain nonlinearities and can avoid wasteful cancellations. The backstepping approach is applied to a specific class of switched power converters, namely dc-to-dc converters [11]. In the case where the converter model is fully known the backstepping nonlinear controller is shown to achieve the control objectives i.e. input voltage tracking with respect to climate change uncertainty.

In this paper, a control strategy is developed to maximize the power of a solar generating system. The control objective is to determine the maximum power operating point (MPOP) by tracking a desired array voltage which can be achieved by modulating the pulse width of the switch control signal (increasing or decreasing the duty ratio of the switching converter). The desired array voltage is designed online using a optimized P&O MPP tracking algorithm [12]. The proposed strategy ensures that the MPP is determined and the tracking errors are globally asymptotically stable. The stability of the control algorithm is verified by Lyapunov analysis.

The rest of the paper is organized as follows. The dynamic model of the solar generating system is described in Section II. A backsteeping array voltage tracking controller is designed along with the corresponding closed-loop error system and the stability analysis of the closed loop error system is discussed in Section III. In Section IV, the numerical simulation results and concluding remarks are presented.

II. MPPT system modeling

The solar generation model consists of a PV array module, dc-to-dc Cuk converter and a load as shown in figure 1.

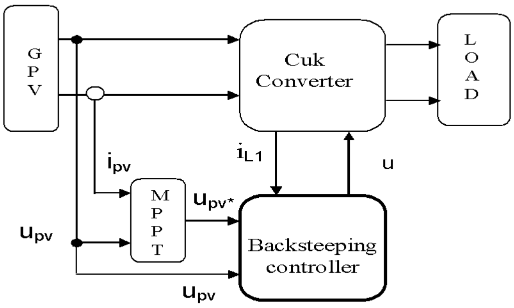


Fig.1. Solar generation model

The Cuk converter is a step-down/step-up converter based on a switching boost-buck topology. Essentially, the converter is composed of two sections, an input stage and an output stage. The schematic of the Cuk converter is presented in Figure 2.

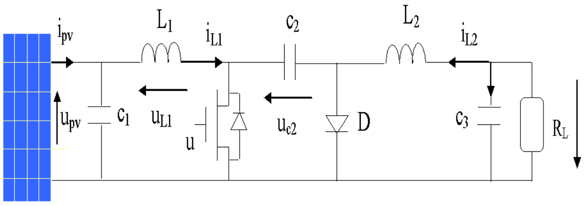


Fig.2. PV array connected to Cuk converter

A. PV model

The equivalent-circuit model of PV is shown in figure 3. This model consists of a light-generated source, diode, series and parallel resistances [13]-[14].

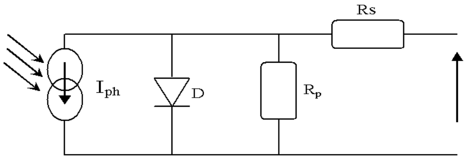


Fig.3. equivalent model of solar cell

B. BOOST model :

The dynamic model of the solar generation system presented in figure 2 can be expressed by an instantaneous switched model as follows:

$$c_1.\dot{u}_{pv} = i_{pv} - i_{L1} \tag{1}$$

$$L.\dot{i}_{L1} = u_{pv} - (1-u).u_{c2} \tag{2}$$

where L_1 and i_{L1} represents the dc-to-dc converter storage inductance and the current across it, u_{c2} is the voltage of the capacitor c_2 and u(t) is the switched control signal that can only take the discrete values 0 (switch open) and 1 (switch closed).

Using the state averaging method, the switched model can be redefined by the average PWM model as follows:

$$c_1.\dot{u}_{pv} = i_{pv} - i_{L1} \tag{3}$$

$$L.\dot{i}_{L1} = u_{pv} - \alpha.u_{c2} \tag{4}$$

where u_{pv} and i_{pv} are the average states of the output voltage and current of the solar panel, i_{L1} and u_{c2} are the average state of the inductor current and capacitor voltage respectively. α is the limited duty ratio function of the off-state of the switched control signal u(t).

III. Backstepping controller design

The control objective is to maximize the power extracted from a solar generating system by tracking a developed desired array voltage u_{pv}* using an optimised P&O algorithm. Figure 4 and 5 show respectively a conventional and optimised P&O algorithm.

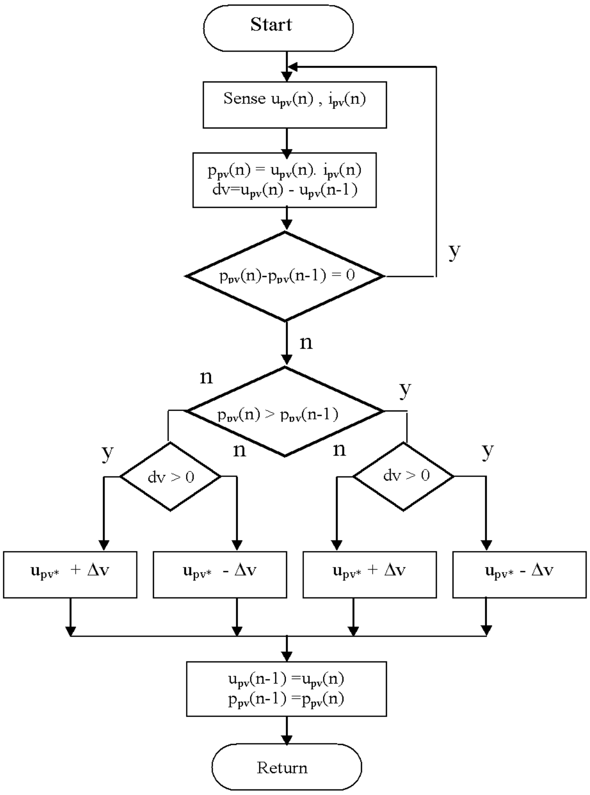


Fig.4. Flowchart of conventional P&O algorithm

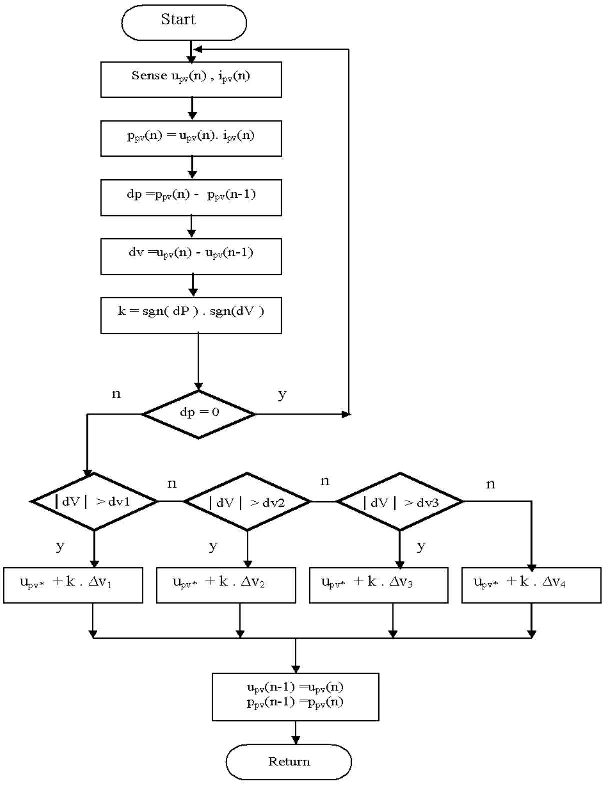


Fig.5. Flowchart of a optimised P&O algorithm

Step 1. Let us introduce the input error:

$$e_1 = u_{pv} - u_{pv}{}^* \qquad (5)$$

Deriving e_1 with respect to time and accounting for (3), implies:

$$\dot{e}_1 = \dot{u}_{pv} - \dot{u}_{pv}{}^* = (\frac{i_{pv}}{c_1} - \frac{i_{L1}}{c_1}) - \dot{u}_{pv}{}^* \qquad (6)$$

In equation (6), i_{L1} behaves as a virtual control input. Such an equation shows that one gets
$\dot{e}_1 = -k_1.e_1$ ($k_1>0$ being a design parameter) provided that:

$$i_{L_1} = k_1.c_1.e_1 + i_{pv} - c_1.\dot{u}_{pv}{}^* \qquad (7)$$

As i_{L1} is just a variable and not (an effective) control input, (7) cannot be enforced for all $t \geq 0$. Nevertheless, equation (7) shows that the desired value for the variable i_{L1} is:

$$\alpha_1 = i_{L_1}{}^* = k_1.c_1.e_1 + i_{pv} - c_1.\dot{u}_{pv}{}^* \qquad (8)$$

Indeed, if the error:

$$e_2 = i_{L_1} - i_{L_1}{}^* \qquad (9)$$

vanishes (asymptotically) then the control objective is achieved i.e. $e_1 = u_{pv} - u_{pv}{}^*$ vanishes in turn. The desired value α_1 is called a stabilization function.
Now, replacing i_{L1} by $(e_2 + i_{L1}{}^*)$ in (6) yields:

$$\dot{e}_1 = \frac{i_{pv}}{c_1} - \frac{(i_{L_1} + e_2)}{c_1} - \dot{u}_{pv}{}^* \qquad (10)$$

which, together with (10), gives:

$$\dot{e}_1 = -k_1.e_1 - \frac{e_2}{c_1} \qquad (11)$$

Step 2. Let us investigate the behaviour of error variable e_2. In view of (4) and (9), time-derivation of e_2 turns out to be:

$$\dot{e}_2 = \dot{i}_{L_1} - \dot{i}_{L_1}{}^* = \frac{u_{\mathrm{pv}}}{L_1} - \frac{\alpha.u_{c_2}}{L_1} - \dot{i}_{L_1}{}^* \qquad (12)$$

From (8) one gets:

$$\dot{\alpha}_1 = \dot{i}_{L_1}{}^* = k_1.c_1.\dot{e}_1 + \dot{i}_{pv} - c_1.\ddot{u}_{pv}{}^* \qquad (13)$$

which together with (12) implies:

$$\dot{e}_2 = \frac{u_{\mathrm{pv}}}{L_1} - \frac{\alpha.u_{c_2}}{L_1} - k_1.c_1.\dot{e}_1 - \dot{i}_{pv} + c_1.\ddot{u}_{pv}{}^* \qquad (14)$$

In the new coordinates (e_1,e_2), the controlled system in (3)-(4) is expressed by the couple of equations (11) and (14). We now need to select a Lyapunov function for such a system. As the objective is to drive its states (e_1,e_2) to zero, it is natural to choose the following function:

$$v=\frac{1}{2}.e_1^2+\frac{1}{2}.e_2^2 \qquad (15)$$

The time-derivative of the latter, along the (e_1,e_2)-trajectory, is:

$$\dot{v} = e_1.\dot{e}_1 + e_2.\dot{e}_2$$

$$\dot{v} = -k_1.e_1^2 - k_2.e_2^2$$

$$+e_2.\left[\frac{u_{pv}}{L_1}-\frac{\alpha.u_{c_2}}{L_1}-k_1.c_1.\dot{e}_1-\frac{e_1}{c_1}-\dot{i}_{pv}+c_1.\ddot{u}_{pv}{}^*+k_2.e_2\right] \qquad (16)$$

where $k_2>0$ is a design parameter and $\dot{e}_2$ is to be replaced by the right side of (14). Equation (16) shows that the equilibrium $(e_1,e_2)=(0,0)$ is globally asymptotically stable if the term between brackets in (16) is set to zero. So doing, one gets the following control law:

$$\alpha=\frac{L_1}{u_{c_2}}\left[\frac{u_{pv}}{L_1}-k_1.c_1.\dot{e}_1-\frac{e_1}{c_1}-\dot{i}_{pv}+c_1.\ddot{u}_{pv}{}^*+k_2.e_2\right] \qquad (17)$$

IV. SIMULATION RESULTS :

The PV model, a optimized P&O algorithm and backstepping controller are implemented in Matlab/Simulink as show in figure 6. In the study, RSM-60 PV module has been selected as PV power source, and the parameter of the components are chosen to deliver maximum 1kW of power generated by connecting 16 module of RSM-60 in parallel. The specification of the system and PV module are respectively summarized in table 1 and table 2.

TABLE I
CONTROL PARAMETERS USED IN THE SIMULATION

parameters	VALUE	Unit
k_1	100	
k_2	1000	
R_L	10	Ω
c_1	220	µF
c_2	47	µF
L_1	0.004	H
L_2	0.004	H

TABLE II
MAIN CHARACTERISTICS OF THE PV GENERATION SYSTEM

Maximum power	OUTPUT VOLTAGE AT P_{MAX}	Open-circuit voltage	Short current circuit
60w	16v	21.5v	3.8A

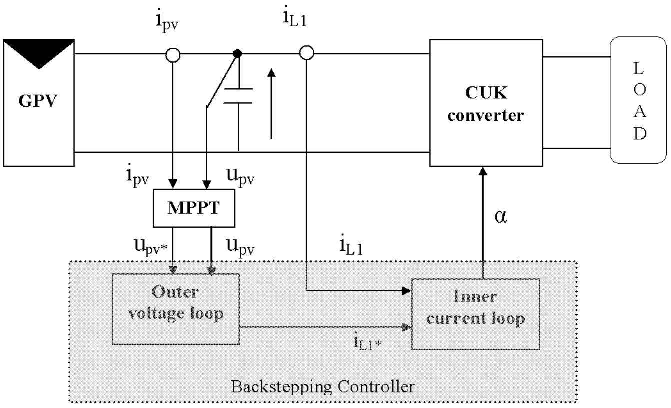


Fig.6. Backstepping controller design for Cuk converter

A Matlab® simulation of the PV system, the backstepping controller and the proposed P&O MPPT has been carried out using the following parameters:

- Cuk switching frequency: 25kHz

The proposed MPPT is evaluated from tow aspects: speed and accuracy to track maximum power of photovoltaic generator in fast changing of irradiance and temperature. In each figures, two different values of irradiance and temperature are introduced in order to show the performance of this algorithm.

Figure 7 show the tracking result with step irradiance input 500 to 1000W/m^2 under the same temperature (T=25°C). The system reaches steady state of both irradiance levels within the order of milliseconds, which is is more accurate compare to the conventional MPPT algorithm.

Figure 8 depict the system response under rapid temperature change of temperature from 25 to 45°C under the same radiation (G=1000 W/m^2).

Notice that according to figure 7.c and figure 8.c, the maximum power point is always reached after a smooth transient response (approximately 0.1second unlike in the conventional MPPT which this time is equal to 0.5 second). Notice that the power of photovoltaic generator reaches the commanded value according to external perturbation.

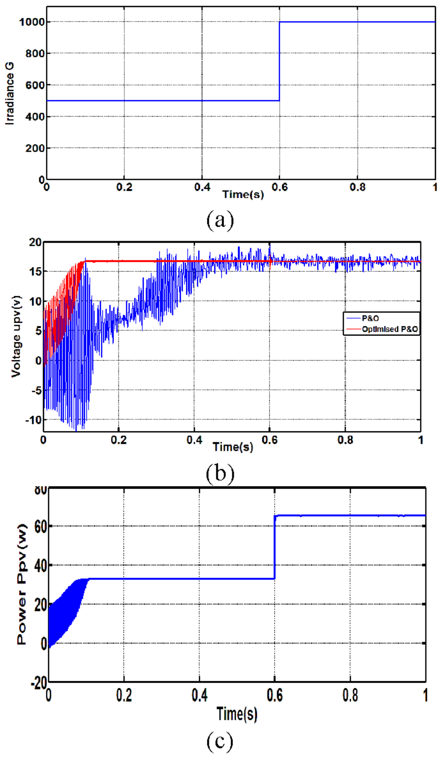
In the figure 7.b and 8.b, the output voltage of PV generator is achieved quickly after the transient period following each change in reference values of radiation or temperature. We also note the absence of the ripples in the photovoltaic voltage then conventional MPPT. Indeed, in the conventional MPPT voltage, the ripple in photvoltaique voltage is 3 volts for high radiation and about 2 volts for low radiation, but in the proposed MPPT, this ripple is limited to less than 0.5 volts regardless of the solar radiation.

In the conventional method, we note that the ripple is increased for low radiation (low temperature) because the curve of the PV generator output voltage presents a multi-point maximum (curve almost flat).

In all the results obtained, the proposed algorithm shows great efficiency to extract the maximum power with good speed and a small oscillation around the point of maximum power in comparison with the conventional MPPT algorithm in variable weather conditions.

CONCLUSIONS

An optimized P&O algorithm has been developed for a solar generating system to maximize the power extracted from a photovoltaic array in varying weather conditions. This approach adjusts automatically a step size to the solar array operating point, thus improving the MPPT (Maximum Peak Power Tracking) speed and accuracy compared with the conventional method using fixed step size when the irradiance or temperature are changing rapidly, and lower oscillations around the MPP in steady-state conditions. To track the optimal voltage, a nonlinear controller is developed to modulate the duty cycle of the Cuk converter. The proposed controller is proven to yield global asymptotic stability with respect to the tracking errors via Lyapunov analysis. Simulation results are provided to verify the effectiveness of this approach.



(a)

(b)

(c)

Fig.7. simulation with constant temperature T= 25 °C
(a) step irradiance change (500 ►1000 W/m^2),
(b) photovoltaic voltage, (c) PV power

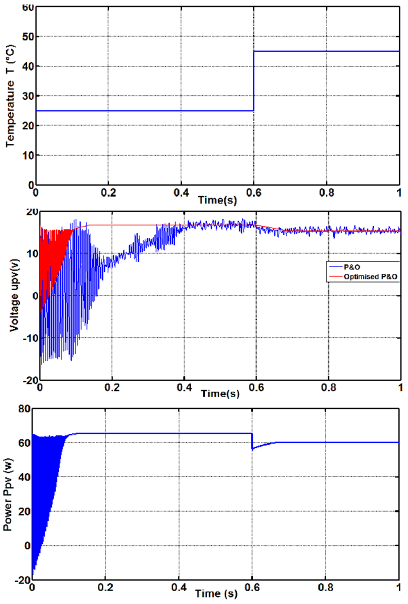


Fig.8. simulation with constant irradiation G = 1000 w/m^2,
(a) step temperature change (25°c ► 45 °c),
(b) photovoltaic voltage, (c) PV power

References

[1] Chen-Chi Chu , Chieh-Li Chen , " Robust maximum power point tracking method for photovoltaic cells: A sliding mode control approach", Solar Energy ,Vol. 83, 2009, pp. 1370-1378

[2] W. Xiao and W. G. Dunford, "A modified adaptive hill climbing MPPT method for photovoltaic power systems," in Proc. 35th Annu. IEEE Power Electronics, 2004, pp. 1957–1963.

[3] L. Egiziano, N. Femia, D. Granozio, G. Petrone, G. Spagnuolo, and M. Vitelli, "Photovoltaic inverters with Perturb & Observe MPPT technique and one-cycle control," in Circuits and Systems Proceedings IEEE International Symposium, 2006

[4] Jae Ho Lee; HyunSu Bae; Bo Hyung Cho, "Advanced Incremental Conductance MPPT Algorithm with a Variable Step Size", Power Electronics and Motion Control Conference EPE-PEMC 12th International, 2006.

[5] Sera, D.; Teodorescu, R.; Hantschel, J.; Knoll, M. "Optimized Maximum Power Point Tracker for Fast Changing Environmental Conditions", IEEE Transactions on Industrial Electronics, pp. 2629 – 2637, 2008.

[6] N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli, "Optimization of Perturb and Observe maximum power point tracking method", IEEE Transactions on Power Electronics, pp. 963–973, 2005.

[7] Trishan Esram, Patrick L. Chapman," Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques ", IEEE Transactions on energy conversion, JUNE 2007.

[8] H.Abouobaida, M.Cherkaoui, "Ripple correlation MPPT and Robust Controller for Grid-Connected Photovoltaic Systems", journal of electrical engineering - (in press).

[9] Trishan Esram,, Jonathan W. Kimball, Philip T. Krein, Patrick L. Chapman and Pallab Midya, "Dynamic Maximum Power Point Tracking of Photovoltaic Arrays Using Ripple Correlation Control", IEEE Transactions on power electronics, pp.1282–1291, SEPT 2006.

[10] H.Abouobaida, M.Cherkaoui, M.Ouassaid, "Robust Maximum Power Point Tracking for Fast Changing Environmental Conditions", International Review on Modelling and Simulations, Vol. 4 no. 1 - (Part B), February 2011, pp. 391-396

[11] Khalil, H. K., 1996, Nonlinear Systems, 2nd ed.,Prentice Hall, New York, USA.

[12] H.Abouobaida, M.Cherkaoui, "New Maximum Power Point Tracker for Fast Changing Environmental Conditions", IEEE International Conference on Multimedia Computing and Systems (ICMCS'11), 7-9 April 2011 - Ouarzazate, Morocco

[13] Campbell, R.C , A Circuit-based Photovoltaic Array Model for

Power System Studies, Power Symposium, 2007. NAPS '07. 39th North American, pp 97 – 101, Sept. 30 2007-Oct. 2 2007.

[14] Y.T. Tan, D.S. Kirschen, and N. Jenkins, "A Model of PV Generation Suitable for Stability Analysis," IEEE Transaction on Energy Conversion, 2004.

Hassan Abouobaida was born in Rabat, Morocco, in 1974. He received the « Diplôme d'ENSET » in Electrical Engineering from Ecole Normal Supérieur de l'Enseignement Technique, Mohamedia in 1998, and the « Diplôme DESA », in Electrical Engineering from Ecole Mohammadia d'Ingénieur, Université Mohamed V , Rabat, Morocco, in 2007. He is currently teacher in IBN SINA Technical School, Kenitra , Morocco. His research interests power electronics, control systems and renewable energy.

Mohamed Cherkaoui was born in Marrakech, Morocco, in 1954. He received the diplôme d'ingénieur d'état degree from the Ecole Mohammadia, Rabat, Morocco, in 1979 and the M.Sc.A. and Ph.D. degrees from the Institut National Polytechnique de la Loraine, Nancy, France, in 1983 and 1990, respectively, all in Electrical Engineering.

During 1990-1994, he was a Professor in Physical department, cadi Ayyad university, Marrakech, Morocco. In 1995, he joined the Department of Electrical Engineering, Ecole Mohammadia, Rabat, Morocco, where is currently a Professor and University Research Professor. His current research interests include renewable energy, motor drives and power system. Dr. Cherkaoui is a member of the IEEE.