Low cost and high efficiency experimental MPPT based on Hill Climbing approach

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Abstract : *Power point tracker algorithms play an important role in the optimization of the power and the efficiency of a photovoltaic generator. This work presents a experimental study of performance of Hill Climbing algorithm to track maximum power point on the PV panels. The boost converter is used between the solar panel and load. To validate this approach, the Hill Climbing approach is implemented in Simulink/Matlab and is validated by experimental test. The results of simulation and experimental test show the effectiveness of this approach.*

Key words: *Hill climbing, Maximum Power Point Tracking, Photovoltaic, Boost converter*

1. Introduction

The solar photovoltaic found its utility in applications for small scale, autonomic and isolated or unconnected systems but also for high power PV installations or stations. Photovoltaic energy is a source of interesting energy: it is renewable, inexhaustible and nonpolluting, so that, it is more and more intensively used as energy sources in various applications. Nevertheless, to satisfy industrial, commercial and exploiting constraints link to the cost, the system should present a good exploitation of all the photovoltaic modules and a high general efficiency.

For that, it is necessary to extract the maximum of power from the photovoltaic generator, i.e. the maximum of the power delivered by the PVG, not directly droved by the load. A good profitability of the PVG can be carried out if it works to the maximum of the available solar power all the time.

However, the maximum power point (MPP) varies according to several parameters like the solar irradiation Ψ, the temperature T, the nature of the load, the technology of the PV cells and the shadowing of the panels from various sources (falling leaves, dust...). In a current solar photovoltaic system, we can consider the random existence of these parameters [1].

Nevertheless, associated with a voltage converter, e.g. a DC-DC one as in this study, the PVG requires a permanent maximum power production.

Thus, whatever the weather conditions (temperature and irradiation) and whatever the load, the control system of the converter must place the system at the optimal power point (Ipv_{opt}, Upv_{opt}). Nevertheless, the operating point of the generator on the I-V curve is dynamically modified; the MPPT must get the MPP (maximum power point) at any moment and must maintain PVG power in the neighborhoods of this point and to produce power with the higher efficiency [2].

In this paper, a simulation and experimental study of Hill climbing MPPT algorithm is developed to maximize the power of a solar generating system. This objective is achieved by modulating the pulse width of the switch control signal (increasing or decreasing the duty ratio of the switching converter).

The rest of the paper is organized as follows. The dynamic model of the solar generating system is described in Section II. In Section III, a problem overview is explained. In Section IV, an algorithm of different MPPT is detailed. Simulations results, experimental results and conclusion are presented in Section V and VI respectively.

2. MPPT system modeling

The solar generation model consists of a PV array module, dc-to-dc boost converter and a battery as shown in Fig1 and Fig 3. The converter transfers power from the PV array terminals to the battery bank, indirectly controlling the voltage of the PV array panel and thus the array power generation [3].

A. PV model :

PV array is a p-n junction semiconductor, which converts light into electricity. When the incoming solar energy exceeds the band-gap energy of the module, photons are absorbed by materials to generate electricity [4].

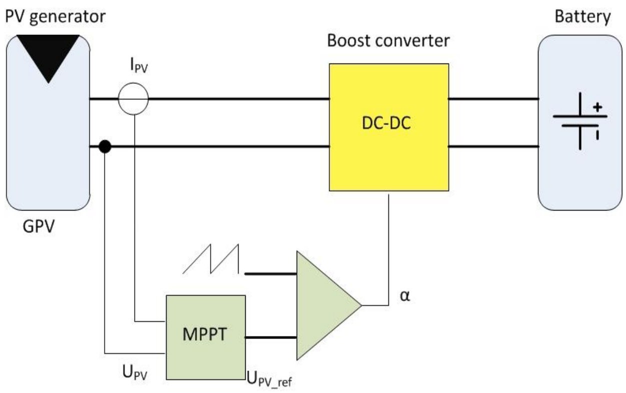


Fig 1. Photovoltaic generation model

The equivalent-circuit model of PV is shown in Fig 2. In this model, it consists of a light-generated source, diode, series and parallel resistances.

B. BOOST model :

The dynamic model of the solar generation system presented in fig 3 can be expressed by an instantaneous switched model as follows [4]:

$$c_1.\dot{u}_{pv} = i_{pv} - i_L \qquad (1)$$

$$L.\dot{i}_L = u_{pv} - (1-u).v_b \qquad (2)$$

where *L* and i_L represents the dc-to-dc converter storage inductance and the current across it, v_b is the voltage of the storage battery and *u* 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:

$$c_1.\dot{\bar{u}}_{pv} = \bar{i}_{pv} - \bar{i}_L \qquad (3)$$

$$L.\dot{\bar{i}}_L = \bar{u}_{pv} - d'.\bar{v}_b \qquad (4)$$

where $\bar{u}_{pv}$ and $\bar{i}_{pv}$ are the average states of the output voltage and current of the solar cell , $\bar{i}_L$ is the average state of the inductor current , d' is the limited duty ratio function of the off-state of the switched control signal *u*.

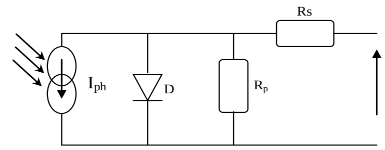


Fig. 2 Equivalent model of PV cell

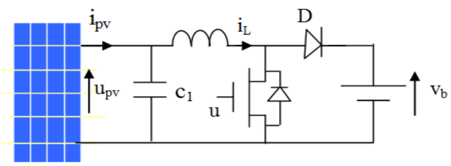


Fig 3. Boost converter connected to PV array generator

C. Operating principle of the boost converter

The theoretical study of the dc-dc converter in continuous conduction leads to the curves of figure 4.

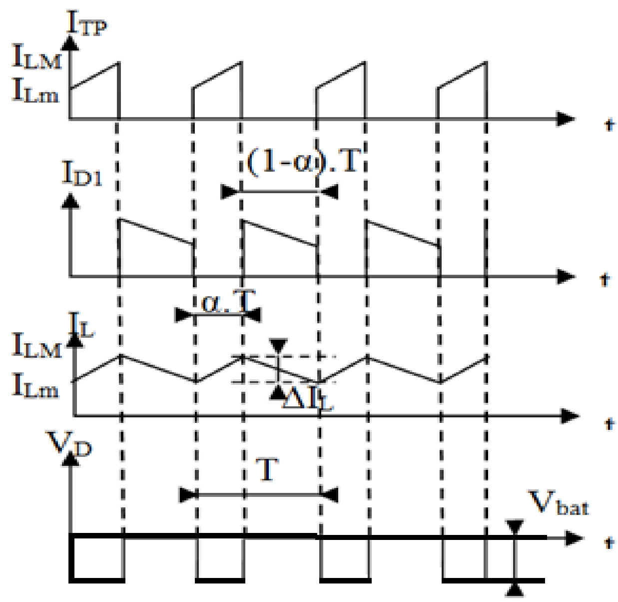


Fig 4. Evolution of the state variables (I_{TP}, I_{D1}, I_L, V_D) of the boost converter in continuous conduction

where I_{TP} and I_L are the current of the Mosfet transistor and the current across the storage inductance respectively. V_D and I_D represents the voltage and current of the diode.

3. Problem Overview

The problem considered by MPPT techniques is to automatically find the optimal point (V_{mpp}, I_{mpp}) at which a PV array should operate to obtain the maximum power output P_{mpp} under a given temperature and irradiance. Most techniques respond to changes in both irradiance and temperature, but some are specifically more useful if temperature is approximately constant. Most techniques would automatically respond to changes in the array due to aging, though some are open-loop and would require periodic fine-tuning. In our context, the array will typically be connected to a power converter that can vary the current coming from the PV array [1]. Fig. 5 shows the characteristic power curve for a PV array and the optimal point.

4. Hill Climbing approach

Hill climbing involves a perturbation in the duty ratio of the power converter. 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 [5]. From Fig. 5, it can be seen that incrementing (decrementing) the voltage increases (decreases) the power when operating on the left of the MPP and decreases (increases) the power when on the right of the MPP. Therefore, if there is an increase in power, the subsequent perturbation should

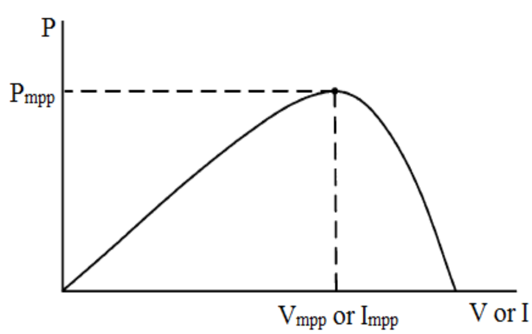


Fig. 5 PV array power curve

be kept the same to reach the MPP and if there is a decrease in power, the perturbation should be reversed. This algorithm is presented in Fig. 6. The process is repeated periodically until the MPP is reached. The system then oscillates around the MPP. The oscillation can be minimized by reducing the perturbation step size. However, a smaller perturbation size slows down the MPPT. A solution to this conflicting situation is to have a variable perturbation size that gets smaller towards the MPP [6].

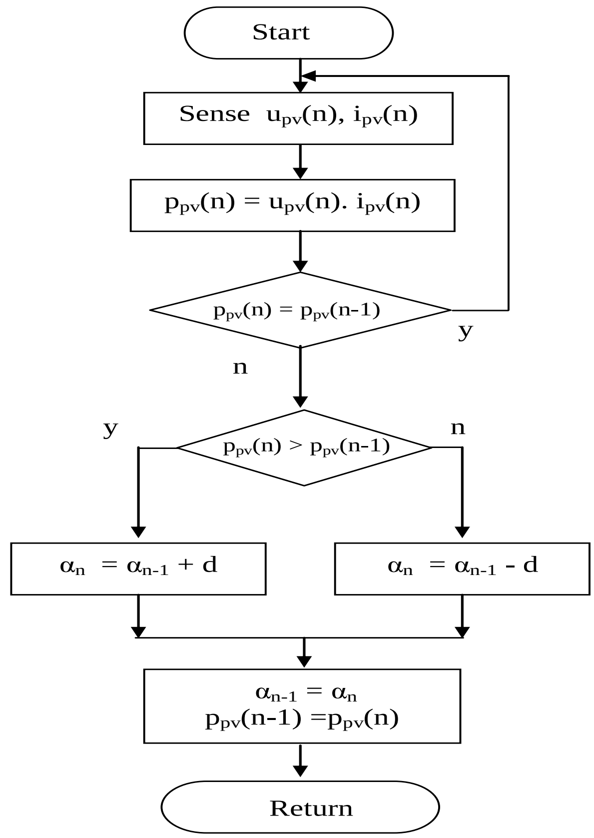


Fig 6. The flowchart of Hill climbing algorithm

5. Simulation results

The PV model, boost converter model, and the studied MPPT algorithm are implemented in Matlab/Simulink. In this study, RSM-60 PV module has been selected as PV power source, and the parameter of the components are chosen to deliver 1000 watt (maximum of power generated by 36 panel based on RSM-60). The specification of the control parameters and the main characteristics of the PV module are summarized in Table I and Table II respectively.

In this study, we evaluate the Hill Climbing algorithm from aspects: speed, accuracy and ripple to fast changing of irradiance (1000W/m^2 to 600 W/$m^{2)}$ under the same temperature (T=25 °C) as illustrated in fig 7.a.

TABLE I

CONTROL PARAMETERS USED IN THE SIMULATION

Parameters	Value	Unit
v_b	24	V
c_1	2	µF
c_2	4700	µF
L	0.002	H

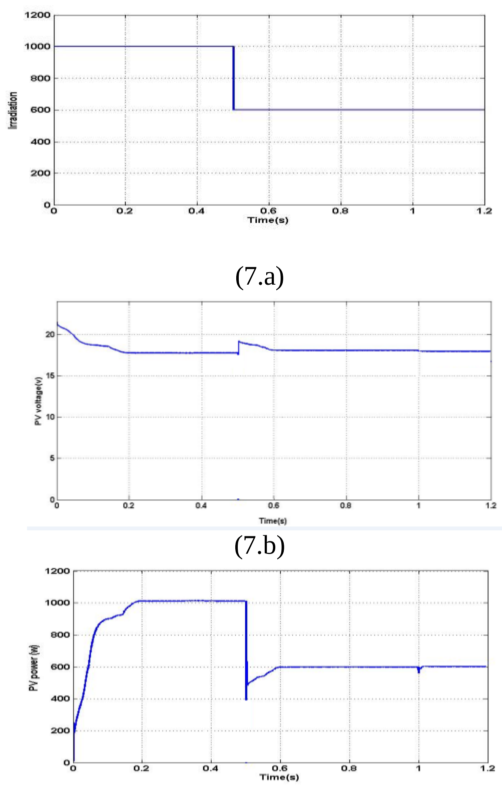
TABLE II

MAIN CHARACTERISTICS OF THE PV GENERATION SYSTEM

Maximum power	P_{max}	60 w
Output voltage at Pmax	V_{max}	16v
Open-circuit voltage	V_{oc}	21.5v
Short circuit	I_{cc}	3.8A

Figure 7.b shows the voltage of the photovoltaic panel in the response for the step irradiance input. The system reaches steady state of both irradiance levels within the order of 200 milliseconds. In this case, the the amplitude of the ripple around the MPPT is very low (<0.1V) for the low and high radiation. This figure shows that the time of tuning the MPP when the irradiation change rapidly is less than 50 milliseconds.

Figure 7.c shows that the system reaches the maximum point at the transient time for a reasonable time (about 200ms). the powers extracted according to the irradiation change are similar to the theoretical values.



(7.a)

(7.b)

(7.c)

Figure 7. (a) Irradiation, (b) PV voltage, (c) PV power

6. Experimental results

The proposed boost converter is implemented in between a solar panel and load as shown in Figure 8. This system is able to deliver power with output storage such as battery.

The control card based PIC 16F877 incorporated in this system is responsible for the MPPT algorithm and implementation. Using current and voltage sensors, the MPPT is able to adjust the duty cycle of the dc-dc boost switch to draw the maximum possible power out of the PV array at a given insolation. A general overview of the MPPT network is explored below (Figure 8 and 9).

The MPPT algorithm has been programmed into microcontroller PIC16F877, which is responsible for sampling of the output voltage and current of the solar panel. The micro-controller runs the HILL CLIMBING algorithm and it provides the signals to the control of switching devices of the Boost converter.

The switching device of the converter is composed by Transistor of the type (IRF250N). The converter also has an inductor of $2mH$, an electrolytic capacitor of $1000\mu F/100V$ and a fast diode power (BYT 30P).

The composition of the experimental set can be described, basically, as (figure 9) :

- A Solar Panel, model RSM60, comprising 36 rectangular cells of polycrystalline silicon with maximum power of 60 W; open circuit voltage of 21.5 V, short-circuit current of 4.2 A; maximum voltage of power 16 V and current of maximum power of 3,75 A;
- A Boost converter as previously described;
- An acquisition system and measuring for the input voltage and current of the solar panel (LEM LA50, LV25);

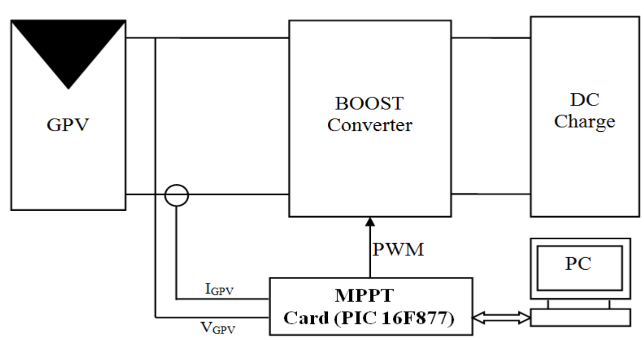


Figure 8 : Experimental MPPT system

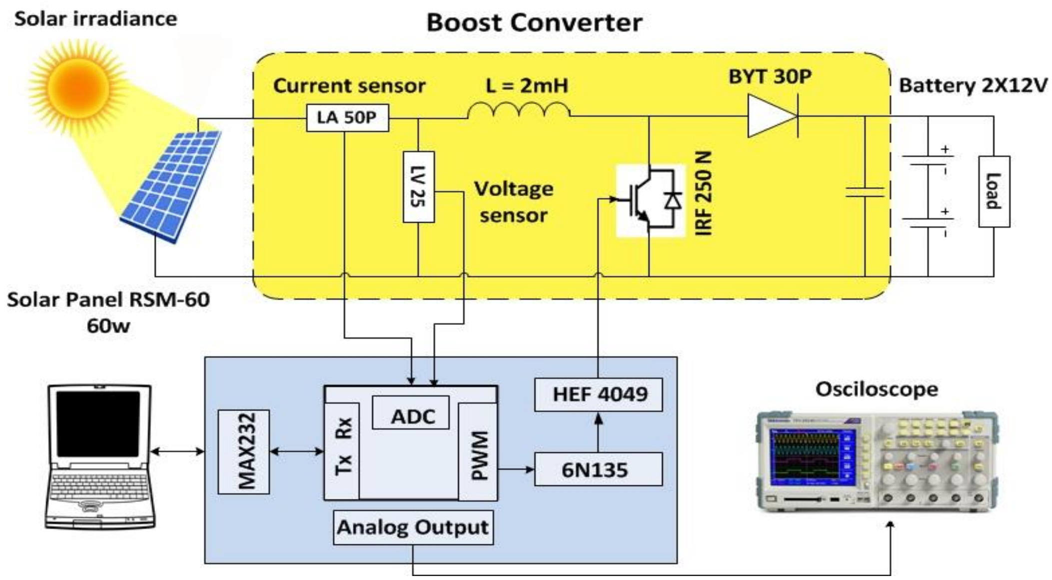
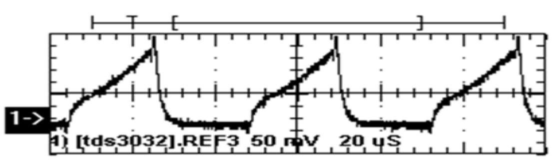


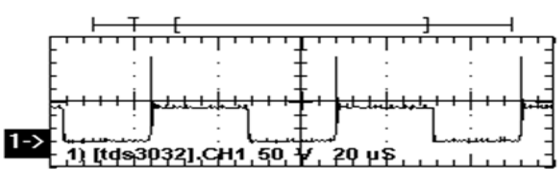
Figure 9 : Block diagram of experimental setup

- Resistive load of 5Ω and battery 24VDC (two 12V battery in series).
- A computer is used to view and save the measurements.
- A card based on PIC 16F877 to control the PV system.
- A oscilloscope to save and view the experimental results (Tektronix 3032).

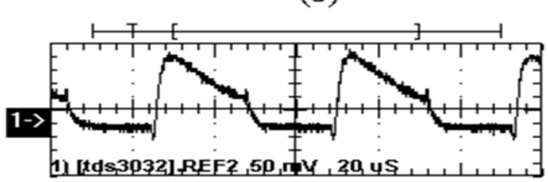
Fig. 9 shows the diagram blocks of experimental PV system. The experimental results are given in Figure 10 and 11. We note that these results are similar to the theoretical results shown in Figure 4.



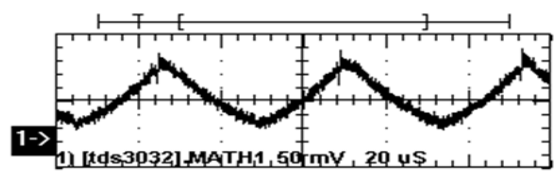
(a)



(b)



(c)



(d)

Figure 10 (a) Current in the transistor Tp, (b) Voltage across the transistor Tp (c) current in the diode, (d) current in the inductance L

The test of MPPT algorithms was conducted on Average irradiance 1000w/m^2, average temperature: 30°C) and the power source was the PV array (VOC = 21,5V, ISC = 4,2A). According to the voltage and current of the PV array, the microcontroller computes the output and generates the duty cycle given by the PWM pin which is applied to the MOSFET driver.
The converter duty cycle is adjusted such that maximum PV array output power is extracted under all operating conditions and transferred to load (battery and resistor.
Figure 11 (a,b and c) show PV array output power obtained by application of the proposed method, the hill climbing technique. As can be seen from Figure 11 shows that the MPPT controller based on the proposed method successfully reached the maximum power point with fast convergence (within 20 seconds). We also see that the photovoltaic voltage is regulated to 15V on steady state. we noticed that the PV voltage is close to the value given by the manufacturer (16V).

Experimental results are very close to the theoretical results which shows that the Hill climbing MPPT approach is validated in this paper.

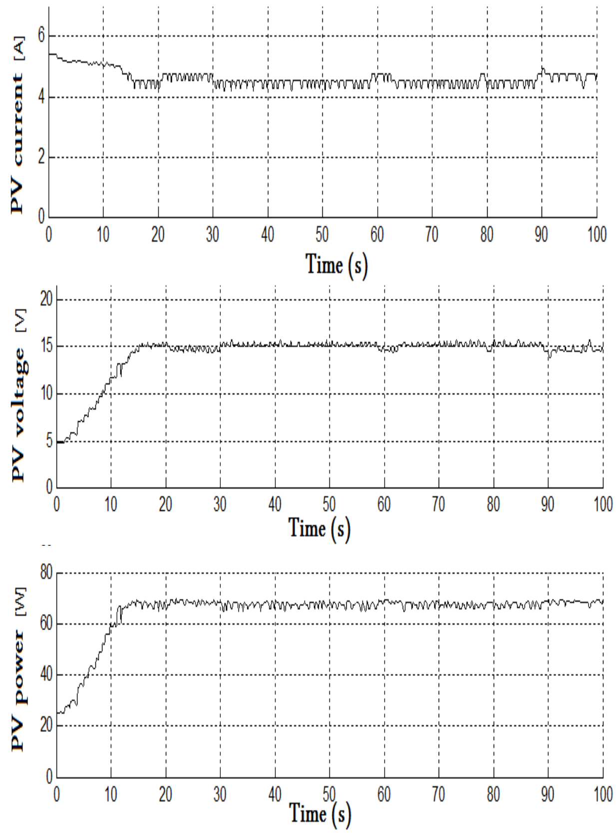


Figure 11. (a) PV current, (b) PV voltage, (c) PV power

CONCLUSIONS

In this paper, a MPPT technique for solar PV battery charger system using Hill Climbing algorithm has been developed. Solar energy is captured by a PV array and delivered into a DC load through a DC to DC boost converter which performs the function of tracking the MPP. The system is controlled by a microcontroller (PIC 16F877). The comparison with theoretical and experimental Hill Climbing technique has shown that the proposed method offers advantages of simplified hardware configuration, low cost and fast convergence to reach the MPP.

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