Experimental Comparative Study MPPT between P&O and Sliding Control of a Small PV System

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Abstract- Several simulation studies of maximum power point tracking (MPPT) algorithms of solar systems are presented in the literature in order to purpose and explaining the advantages and disadvantages of each technique. The development of hardware technology has enabled us to easily implement and validate these techniques. The execution of the MPPT methods becomes very simple with low cost equipment, such as, open source electronic boards microcontroller-based and it is a good solution for autonomous embedded systems. This paper presents an experimental comparative study between two methods of MPPT P&O and sliding mode control (SMC) with an open source board. The main objective is to demonstrate the feasibility of proposed MPPT Algorithms and validate practically the SMC, with high internal and external disturbance. The MPPT techniques results compared with experimental characteristic PV curves based on tracer curves. The obtained experiment comparative P&O and SMC results show that, the proposed system MPPT controllers was very efficiency and very robust under high external disturbances.

Keywords MPPT P&O; MPPT SMC; Open source board; Solar PV generator; PV curves tracer.

1. Introduction

The fourth industrial revolution requires more and more the use of miniaturized, intelligent, and robust devices, while ensuring their energetic and control autonomy through renewable sources, such as solar energy [1,2].

The worldwide save of fossil energy is arriving at a critical state from one perspective, Furthermore, their consequences for ecological pollution that requires humanity to further exploit renewable energies [3,4].

Energy production is an issue of great importance for global consumption needs [5]. And to achieve this goal, two lines of research have been proposed, the first is based on the search for new sources of energy. The second based on the development of control techniques in order to increase the efficiency of maximum power extraction of the energy.

Solar energy has become one of the most used in the world, for its simplicity of exploitation and because it is clean energy [6]. However, the installation equipment of solar photovoltaic systems has high costs [7].

The PV curves characteristic depends on the climatic conditions and the variable load, which makes the efficiency of energy transfer between the generator and the load more difficult [8].

In addition, the operating point of the system is varied according to the values of the illumination, the temperature [9] and the value of the load [8,10]. The main objective for all MPP techniques is to keep this point at a maximum value of the generator power. And in order to extract this maximum point at the terminals of the PV generator, it is necessary to introduce an adaptation stage between the two stages, which is represented by a controllable converter DC/DC.

The problem of maximum power point (MPP) transfer of the PV generator to the load is a key point of our experimental comparative study between P&O and SMC.

To solve this problem, it is very important to operate the PV generator at the maximum power point (MPP), regardless of the climatic conditions and the value of the load.

Therefore, in the literature, several theories studies of MPPT algorithms have been proposed to compare them. Many researchers have proposed various methods for MPPT of PV, the simplest and most applied methods practically are the Perturb and Observe algorithm and Incremental conductance [11-13], In addition, other controllers robust exist like those based on neural networks compared with P&O [14,15] and on fuzzy logic with P&O [16-17].

However, when the majority of this type of work is limited to a theoretical study, we note that it is important for researchers to have an experimental study of comparison between a classic MPPT technique such as P&O and another more robust as the control by sliding mode, in order to check their properties and to validate them. The purpose of this paper is to validate the robustness of proposed SMC.

2. PV Generator Modelling

In this work, we have divided our system into three stages. The first stage consists of a small solar module generator of a Welion P-10W, the second presents by a boost DC/DC converter and the last it's a digital unit of MPPT controllers. The output of a boost converter is connected to a resistive variable charge as depicted in Fig.1. The technical parameters of the solar module generator is given by:

-Peak power ($P_{max} = 10\ W$)

-Open circuit voltage ($V_{oc} = 21.5\ V$)

-Short circuit current ($I_{sh} = 0.56\ A$)

-Max power voltage ($V_{mp} = 17.5\ V$)

To solve the problem of MPPT control of the system, it is necessary to have mathematical models of the PV generator and DC/DC boost converter first.

In this article, we take the simplest model of PV generator, where is presented by a current source I_{ph} in parallel to a diode linked to resistors in series R_s and in parallel R_p.

The mathematical expression of N_s cells linked in series is given by [8]:

$$I_{PV} = I_{ph} - I_s\left[exp\left(\frac{q(V_{PV}+I_{PV}R_S)}{N_sAk_BT}\right) - 1\right] - \frac{V_{PV}+I_{PV}R_S}{R_p} \quad (1)$$

Where

I_{PV} : The output current

I_s : The saturation current of the diode

T (K) : The temperature of the solar cell

The dynamic mathematical model of the DC/DC boost converter described by two equations:

$$\begin{cases} \frac{di_L}{dt} = \frac{V_{PV}-V_o}{L} + \frac{V_o}{L}.u \\ \frac{dV_o}{dt} = \left(-\frac{V_o}{RC_2} + \frac{i_L}{C_2}\right) - \frac{i_L}{C_2}.u \end{cases} \quad (2)$$

i_L: the current of the inductor L

V_o : the load voltage

C_2 : the output rectifier capacitor

R : the variable load and u is the switching input signal (control)

Table 1, offers the parameters of the static converter.

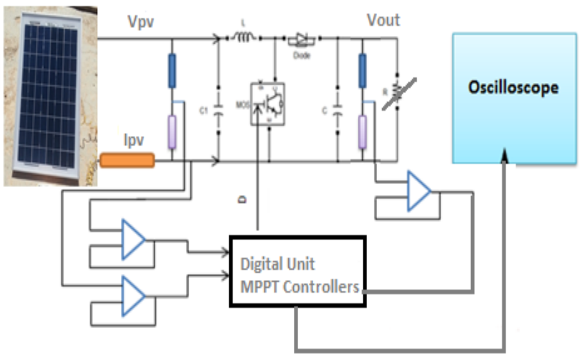

Fig. 1. PV system structure

Table 1. Appearance properties of accepted manuscripts

Inductor L	2.5 mH
Switching frequency f	62.5 kHz
Input capacitor C_1	470 µF
Output capacitor C_2	10 µF
Load R	460 Ω

3. Presentation of the MPPT Control

Sliding mode theory-based control is well known for its power and rapid dynamic response.

This control rule is divided into two parts, the first of which is the equivalent control $u_{eq}(t)$, and the second is the switching control $u_n(t)$which is defined from the attractive condition [8].

In this case, the sliding mode control is described by:

$$u = u_n + u_{eq} \tag{3}$$

To calculate these two elements of the sliding mode law, it is first necessary to propose the suitable sliding surface σ [8]. While our goal is to track the MPP of the photovoltaic module, which indicate the derivative of the photovoltaic power is equal to zero ($\frac{dP_{PV}}{dt} = 0$).

When the photovoltaic module works at its maximum power, one can write:

$$\frac{dP_{PV}}{dV_{PV}} = \frac{d(V_{PV}I_{PV})}{dV_{PV}} = I_{PV} + V_{PV}\frac{dI_{PV}}{dV_{PV}} = 0 \tag{4}$$

Therefore, the sliding surface can be chosen as

$$\sigma = \frac{dP_{PV}}{dV_{PV}} \tag{5}$$

This selection is established on the incremental conductance principle

$$\sigma = I_{PV}.dV_{pv} + V_{pv}.dI_{PV} = 0 \tag{6}$$

$$\sigma = I_{PV}.\frac{dV_{pv}}{dI_{PV}} + V_{\text{pv}}.\frac{dI_{PV}}{dI_{PV}} = 0 \tag{7}$$

$$\sigma = V_{pv} + I_{PV}.\frac{dV_{pv}}{dI_{PV}} = 0 \tag{8}$$

$$\frac{dV_{pv}}{dI_{PV}} = -\frac{V_{pv}}{I_{PV}} \tag{9}$$

If we use instantaneous resistance as $R = -\frac{dV_{pv}}{dI_{PV}}$ and incremental resistance as r=$\frac{V_{pv}}{I_{PV}}$, we can write:

$$\sigma = R(I_{PV}) - r(I_{PV}) \tag{10}$$

The derivative of the above expression is:

$$\frac{d\sigma}{dt} = \frac{dR(I_{PV})}{dt} - \frac{dr(I_{PV})}{dt} = \left[\frac{dR(I_{PV})}{dt} - \frac{dr(I_{PV})}{dt}\right] \cdot \frac{dI_{pv}}{dI_{PV}} \tag{11}$$

$$\frac{d\sigma}{dt} = \left[\frac{dR(I_{PV})}{dI_{PV}} - \frac{dr(I_{PV})}{dI_{PV}}\right] \cdot \frac{dI_{pv}}{dt} \tag{12}$$

Since $\frac{dR(I_{PV})}{dI_{PV}} - \frac{dr(I_{PV})}{dI_{PV}} \neq 0$, then:

$$\frac{d\sigma}{dt} = \frac{dI_{pv}}{dt} = 0 \tag{13}$$

$$\frac{dI_{PV}}{dt} = \left[-\frac{1-u_{eq}(t)}{L}V_0 + \frac{1}{L}V_{PV}\right] = 0 \tag{14}$$

Thus

$$u_{eq} = 1 - \frac{V}{V_o} \tag{15}$$

The nonlinear expression known as the switch command can be expressed as:

$$u_n = -k.sign(\sigma) \tag{16}$$

Where k a positive constant, its fundamental purpose is to guarantee the attractiveness of the sliding regime and to ensure the state of convergence. Finally, the sliding mode law may be written as [10]:

$$u(t) = \left(1 - \frac{V_{PV}}{V_0}\right) - k.sign(\sigma) \tag{17}$$

4. Design of the Test Bench and Experiments

Figure 2 depicts the laboratory prototype designed for these tests. And its functional block diagram used is exposed in the figure 3. An Arduino Mega board, low-cost real-time virtual instrument, is used in the experiment [8]. It includes a simple boost converter, one Welion PV module of 10W, a resistive load, an oscilloscope, an Arduino board, and a computer [18].

The MPPT controllers applied in this article measure the different parameters of PV system (I_pv,V_pv and V_output) by using the conditioners based on operational amplifier designed to isolate the control section with the power section. The I_pv is measured by using the resistance shunt [8].

Low-cost sensors are used to measure in real time the system current, the input and the output voltages of the converter. The recorded data will be saved in order to trace the P-V characteristic in Figure 4.

The figure 4 shows the plotting of P-V curves for three diverse irradiances using an Arduino card. The findings shown in Figures show that the real-time virtual tool established in this study is reliable and valid.

The Arduino card is linked to the small power operational amplifier to separate the control section with power section and to measure the several parameters of the photovoltaic panel. In adding, for tracing the curves a computer armed with Matlab-Simulink software or numerical oscilloscope is needed [19-20].

To confirm the effectiveness of the current control in sliding mode, practical tests of the robustness of the control despite an outside trouble that is the change of the load are presented (330Ω to 460Ω) [19].

Figures 5, 6, 7, 8, and 9 displays experimental curves found with the proposed MPPT controllers P&O compared with SMC by differing the load corresponding to a high square-shaped profile (high disturbance). These graphs are the growth of the following parameters (Duty cycle, Vpv, Ppv, Ipv and Vout).

we can see that the PV panel can be operating at its optimal mode against the presence of the outside perturbation at t = 2.6(sec) and at t = 7(sec). It is noticed that changing the load does not affect the output power.

This control method guaranteed that the PV maximum power was transmitted within this state, which means that it has achieved its main objective.

The tracking of the maximum PV power achieved using sliding mode current control (SMCC) is compared by P&O technique and the matching results are shown in Fig 10.

Fig. 2. The laboratory test bench

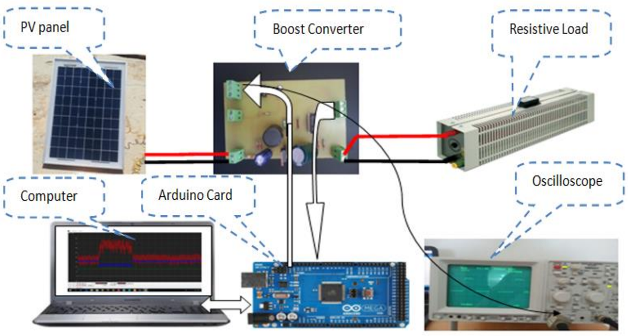

Fig. 3. Block diagram of the laboratory prototype

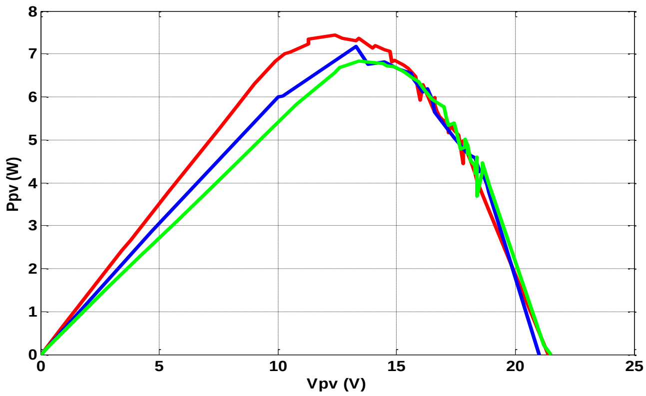

Fig.4. Power-voltage experimental curves

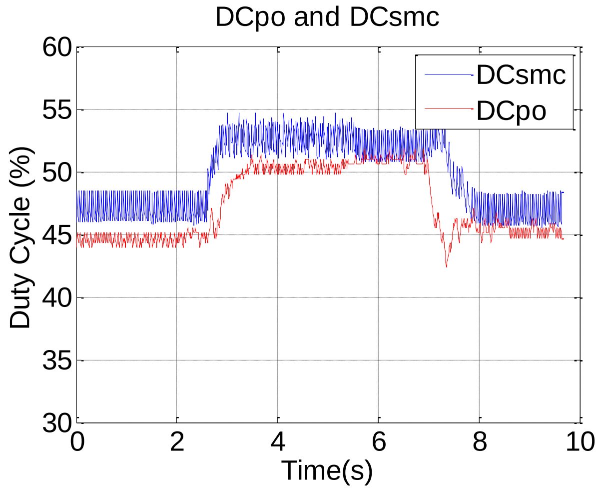

Fig.5. Experimental results P&O and SMC of Duty cycle (%)

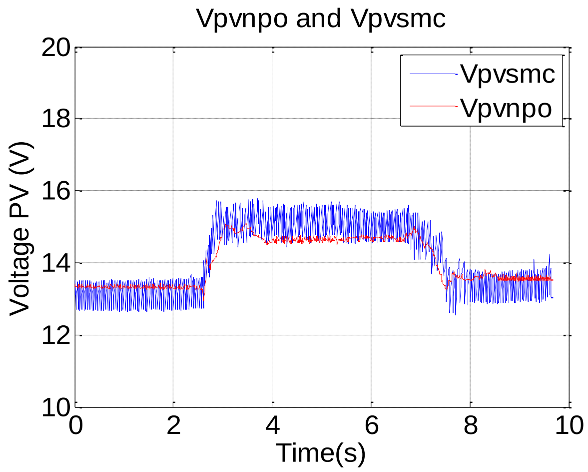

Fig.6. Experimental results P&O and SMC of PV voltage (V)

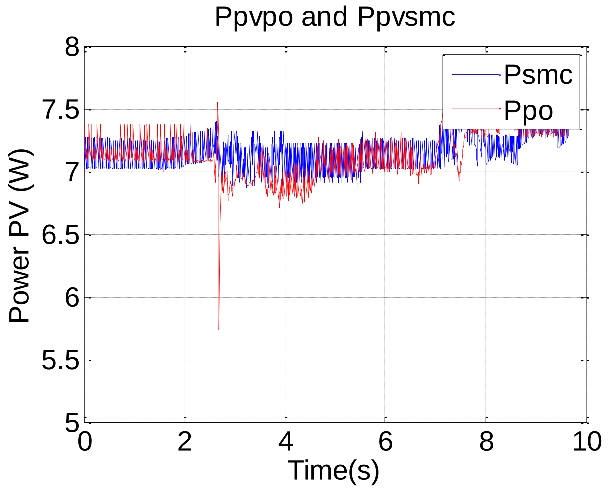

Fig.7. Experimental results P&O and SMC of PV power (W)

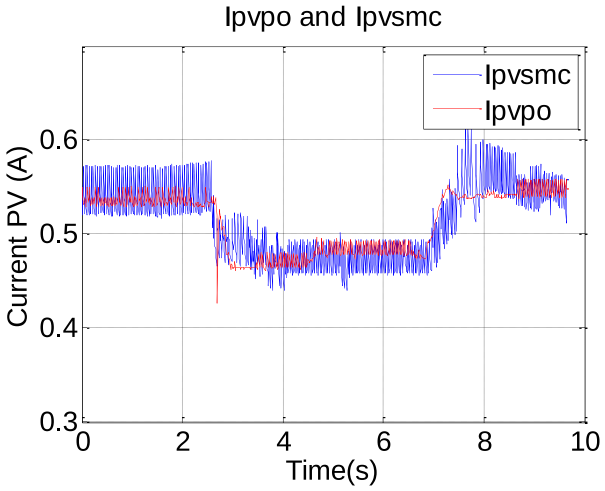

Fig.8. Experimental results P&O and SMC of PV current (A)

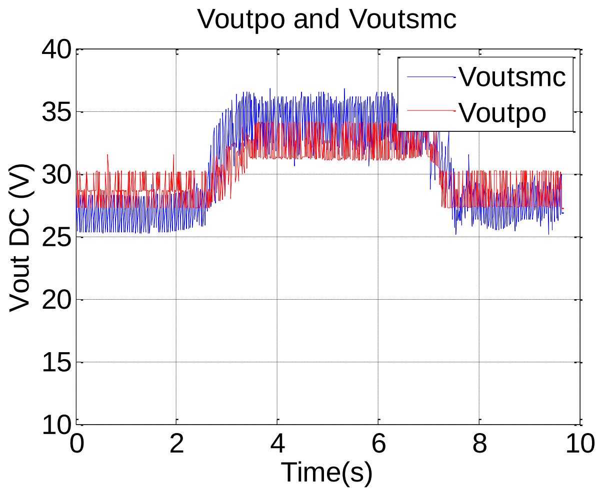

Fig.9. Experimental results P&O and SMC of PV output voltage (V)

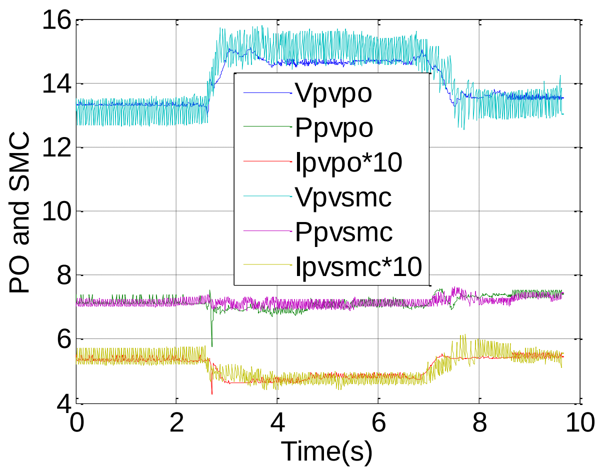

Fig.10. Experimental results P&O and SMC of PV

5. Conclusion

In this study, the experimental comparison of the conventional MPPT P&O technique with the sliding mode control was presented based on the open source Arduino board. In addition, the connection of the load with the PV of 10W module was carried out through the intermediary of the boost converters was controlled by P&O or SMC in order to ensure the maximum power transfer.

The system has been designed to respond to the embedded systems applications in isolated cities to ensure their energy autonomy.

Practical tests of PV variable measurements were carried out to plot the power/voltage characteristics with different climatic conditions. These characteristics were plotted to validate the two algorithms MPPT P&O and SMC.

The main result found by this study is the demonstration, the validation of the robustness and the speed of the SMC with respect to strong disturbances of varied load up to + 40% of its initial value. The experimental results found show that the SMC control is better compared to the P&O technique. As well as the ease of practical implementation of the SMC command on an Arduino board digital support, it is a convincing solution for researchers.

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