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Application of Adaptive Sliding Mode Control on a PV system

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***Abstract*—The PV system has a non-linear current-voltage characteristic which depends on the variations in temperature and solar irradiation, therefore it is necessary to track the maximum power so the PV system perform at it best .Hence in order to achieve and maintain the MPP this paper propose a robust tracking controller, an adaptive sliding mode control. The system includes a PV panel, DC/DC boost converter, a load and a MPPT controller that generate the duty cycle that goes to the boost converter. The proposed controller is compared to a SMC (sliding mode control) and a classic P&O algorithm. The system is simulated in MATLAB/SIMULINK and the results show a high level of efficiency.**

***Keywords*— MPPT controller, DC/DC boost converter, PV panel, SMC (sliding mode control), adaptive sliding mode control, P&O algorithm, MPP.**

I. INTRODUCTION

The worldwide demand of energy has increased significantly and nowadays renewable energy techniques for power production are more reliable. Photovoltaic, is one of the methods of renewable energy that generate electrical power by converting solar irradiation into direct current, has received a great attention especially in remote arrays where it is difficult to transport fuel and the installation of new energy line can be very expensive. However PV system is known for the non-linear relationship between the current and the voltage. There is a unique point on the P-V characteristic at which the photovoltaic cell produces maximum power. Therefore the PV systems require a specialized control algorithm to track the MPP maximum power point available at all time, otherwise the system could be unsustainable [1].

Many MPPT methods have been developed such as Hill climbing, Incremental inductance and Perturb and Observe, those are the conventional control techniques.

On the other hand unconventional techniques such as fuzzy logic, artificial neural network and sliding mode control, which can provide more stability and robustness, have been widely used and developed [2].

Generally, the SMC offer good robustness and transient performance, however it uses a control law with large gains which causes the undesired chattering, the latter can excite high-frequency dynamics and leads to instability, while the control system is in the sliding mode. To eliminate the chattering we propose an adaptive sliding mode control, with only one adaptive gain parameter. The stability and robustness of the proposed method are proven, by comparing the ASMC to the SMC and a classic P&O.

The paper is organized as follow; in section 2 we present the PV system with all its components, in section 3 we describe the proposed controller plus the SMC and the P&O, in section 4 the simulation results are discussed. And finally in section 5 the conclusions.

II. SYSTEM DESCRIPTION

As we mentioned previously, the PV system contains a PV panel a DC/DC boost converter, a load and a MPPT controller. In this section we are going to try to present each component separately, except for the MPPT which is discussed in section 3.

A. PV Panel

The basic diagram of a PV cell is shown in Fig. 1 [3] [4].

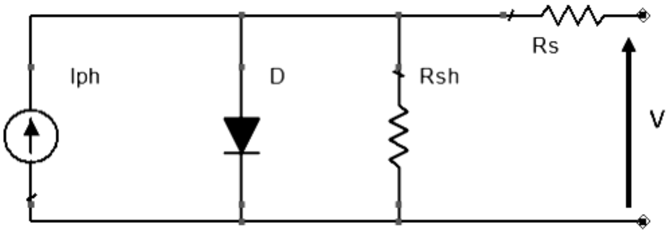

Fig. 1 PV cell equivalent circuit

Based on Fig. 1 the mathematical PV panel is given by the equation (1):

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$$I_{pv} = N_p I_{ph} - N_p I_0 \left[\exp\left(\frac{V_{pv} + \frac{N_s}{N_p} I_{pv} R_s}{\frac{N_s}{N_p} n V_T}\right) - 1\right] - \frac{V_{pv} + \frac{N_s}{N_p} I_p}{\frac{N_s}{N_p} R_{sh}} \tag{1}$$

Considering $N_p = 1$ and $N_s = 36$, and *Rs =0* and *Rp* the equation (1) became:

$$I_{pv} = I_{ph} - I_0 \left[\exp\left(\frac{V_{pv} + N_s I_{pv} R_s}{N_s n V_T}\right) - 1\right] - \frac{V_{pv} + N_s I_{pv} R_s}{N_s R_{sh}} \tag{2}$$

Where I_{pv} and V_{pv} are the current and voltage, respectively the module

I_{ph} : The photovoltaic current, A. I_0 : Reverse saturation current, A. R_s : Series resistance of the cell, Ω. R_{sh} : Shunt resistance of the cell, Ω. $V_T = \frac{kT}{q}$: Thermal voltage, V. k: Boltzmann constant (k = 1, 38.10^{-23} J/K). q: the electron charge (q = 1,602.10^{-19} C). T: the module temperature, K . n: the diode ideality factor (n = 1.62).

Fig.2 and 2 represent the characteristic I(V) and P(V) successively Which represents the non-linearity of the system.

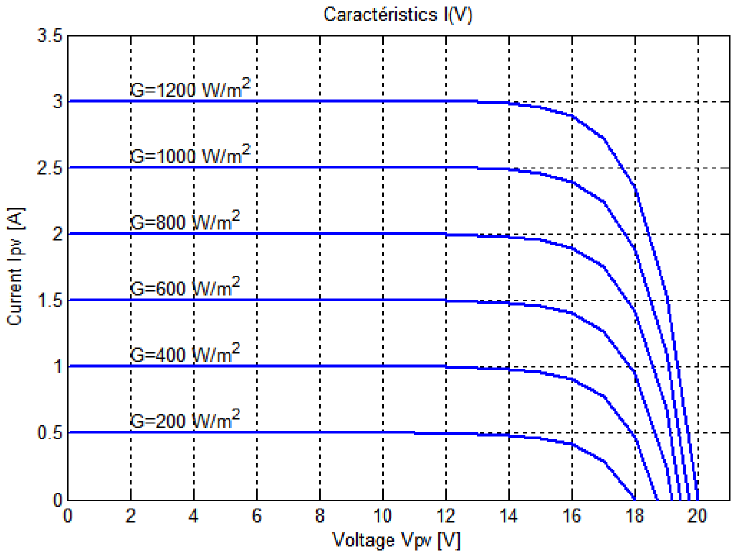

Fig. 2 I(V) characteristic

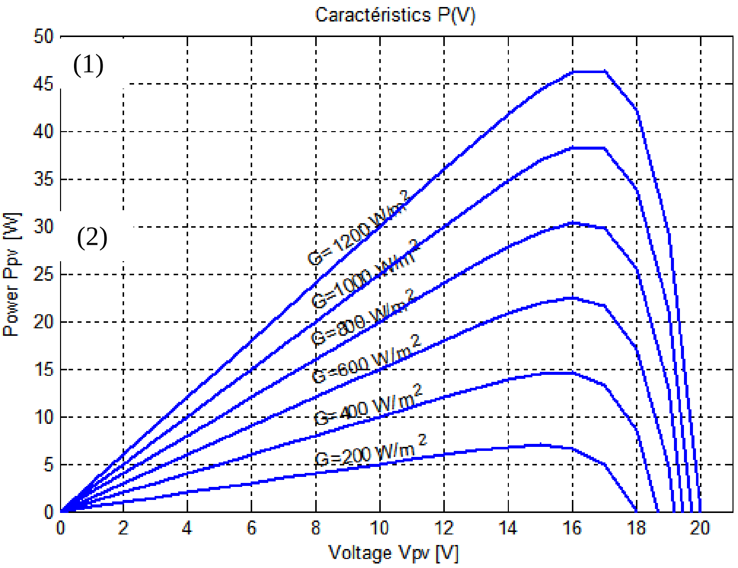

Fig. 3 P(V) characteristic

B. *DC/DC boost*

The Fig. 2 shows the equivalent circuit of a DC/DC boost converter.

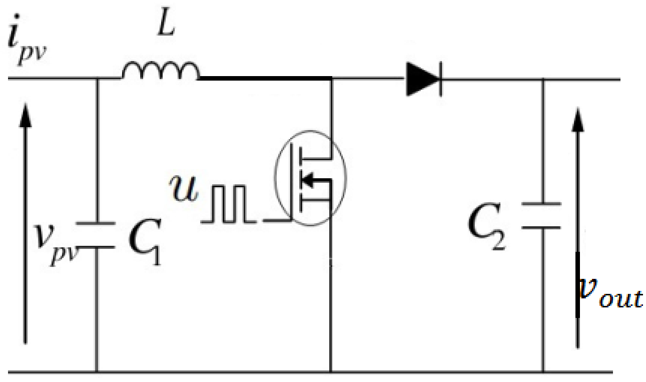

Fig. 4 Boost converter

Based on switching position the DC/DC boost converter is described by the following set of equations:

When the switch is ON:

$$L\frac{di_L}{dt} = v_{pv} \tag{3}$$

$$C_2\frac{dv_{out}}{dt} = -\frac{v_{out}}{R} \tag{4}$$

When the switch is OFF:

$$L\frac{di_L}{dt} = v_{pv} - v_{out} \tag{5}$$

$$C_2\frac{dv_{out}}{dt} = i_L - \frac{v_{out}}{R} \tag{6}$$

Where L, C2, and R are the inductance of the input circuit, capacitance of the output filter, and the output load resistance, respectively.

From (4)–(7), we get the averaging state equations over the duty cycle *u* as:

$$\frac{di_L}{dt} = \frac{v_{pv}}{L} - (1-u)\frac{v_{out}}{L} \qquad (7)$$

$$\frac{dv_{out}}{dt} = \frac{i_L}{C_2} - (1-u)\frac{v_{out}}{C_2 R} \qquad (8)$$

C. Battery:

The battery has two mode of operation : charge and discharge, the battery in charge mode when the input current is positive, and in discharge mode when the current is negative, the battery is characterized by some parameters :

- The initial state of charge: SOC [5].
- Number of 2V cells in series : nsb
- The maximum state of charge (SOCm)
- Charge and discharge efficiency: nbat
- Battery self-discharge rate: D

The equivalent circuit of battery is given as follow :

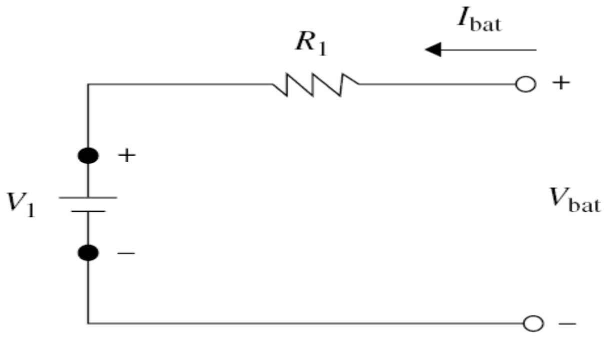

Fig. 5 Equivalent circuit of the battery

The modeling of battery voltage is represented by:

$$V_{bat} = V_1 + I_{bat} * R_1 \qquad (9)$$

In the charge mode:

$$V_1 = [2 + 0.148 * SOC(t)] * nsb \qquad (10)$$

$$R_1 = \frac{0.758 + \frac{0.1309}{[1.06 - SOC(t)] * n_{st}}}{SOCm} \qquad (11)$$

In the discharge mode:

$$V_1 = [1.926 + 0.124 * SOC(t)]n_{st} \qquad (12)$$

$$R_1 = \frac{0.19 + \frac{0.1037}{[SOC(t) - 0.14] * n_{st}}}{SOCm} \qquad (13)$$

III. CONTROL DESIGN

The control circuit takes voltage and current feedback and generates the duty cycle; this last defines the output voltage of the Boost converter.

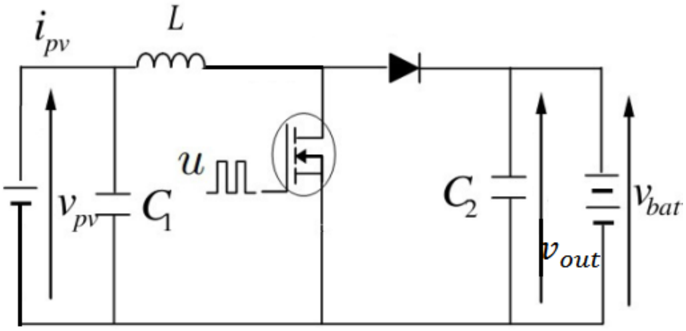

Fig. 6 Equivalent circuit of a PV system based on a Boost converter

A. SMC

The design of the control can be obtained in two important steps [6]:

- The choice of the sliding surface:
- The MPP is determined when:

$$\frac{\partial P_{pv}}{\partial V_{pv}} = 0 \qquad (14)$$

Therefore, the sliding surface is defined as:

$$s = \frac{\partial P_{pv}}{\partial V_{pv}} = \frac{\partial I_{pv}^2 R_{pv}}{\partial V_{pv}} = I_{pv} + V_{pv}\frac{\partial I_{pv}}{\partial V_{pv}} = 0 \qquad (15)$$

- The determination of the control law [7]:

The structure of the sliding mode control consists of two parts: the first one deal with the equivalent control quantity u_{eq}, which, and the second the stabilization controller u_n :

$$u = u_{eq} + u_n \qquad (16)$$

The equivalent control suggested by Slotine and Li (2005) is determined from the following condition [8]:

$$\frac{\partial s}{\partial t} = \left(\frac{\partial s}{\partial i_L}\right)\left(\frac{\partial i_L}{\partial t}\right) = \left(\frac{\partial s}{\partial i_L}\right)\left(\frac{v_{pv}}{L} - (1-u)\frac{v_{out}}{L}\right) = 0 \qquad (17)$$

$$\frac{v_{pv}}{L} - (1-u_{eq})\frac{v_{out}}{L} = 0 \qquad (18)$$

$$u_{eq} = 1 - \frac{v_{pv}}{v_{out}} \qquad (19)$$

The stabilization part of the control u_n can be a linear function of the sliding surface s:

$$u_n = -k_s . sgn(s) \tag{20}$$

k_s is a positive constant which is determined by the user. Thus the control is given by:

$$u = u_{eq} - k_s . sgn(s) \tag{21}$$

$$u = \begin{cases} 1 & if\ u_{eq} - k_s . sgn(s) \geq 0 \\ 0 & if\ u_{eq} - k_s . sgn(s) \leq 0 \end{cases} \tag{22}$$

Stabilization study, we use Lyapunov function given by [9]:

$$V = \frac{1}{2} s^2 \tag{23}$$

The derivative of this function is:

$$\dot{V} = s\dot{s} < 0\ \forall\ s \neq 0 \tag{24}$$

B. ASMC

Although SMC can offer good robustness it uses a control law with large gains which causes the undesired chattering and therefore high-frequency dynamics and leads to instability. In this section we propose an adaptive sliding mode control that can tune the controller gain to eliminate the chattering phenomena [10].

The modified control law is proposed as:

$$u = u_{eq} + u_{ad} \tag{25}$$

Where u_{eq} is the same equivalent control presented in SMC and u_{ad} is the adaptive modified term.

$$u_{ad} = -\tilde{T} . sgn(s) \tag{26}$$

Defining the adaptation error as

$$\tilde{T} = \bar{T} - T \tag{27}$$

The parameter $\bar{T}$ is estimated by using the adaptation law

$$\dot{\bar{T}} = \frac{1}{\gamma} \|s\| \tag{28}$$

Where γ is a positive constant.

The Lyapunov function is defined as [11]:

$$V = \frac{1}{2} s^2 + \frac{1}{2} \gamma \tilde{T}^2 \tag{29}$$

The derivative has to be:

$$\dot{V} = s\dot{s} + \gamma \tilde{T} \dot{\bar{T}} < 0\ \forall\ s \neq 0 \tag{30}$$

C. P&O

We have chosen to compare the SMC and ASMC to the algorithm P&O due to its simplicity and the fact that it's the st used method. Fig. 3 shows the flowchart of P&O.

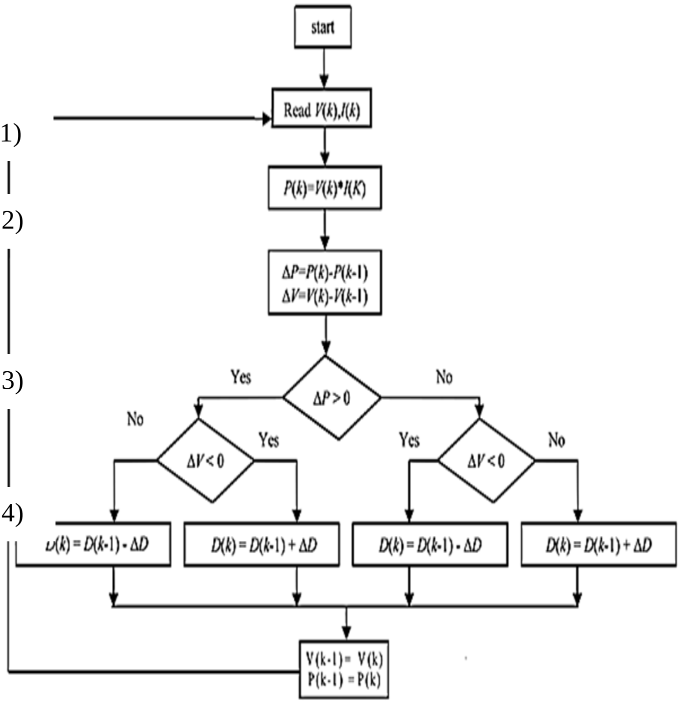

Fig. 7 P&O flowchart

IV. SIMULATION RESULTS

Fig.7 represent the PV system with MPPT controller.

The system is simulated in MATLAB/Similink and Fig.9 and Fig.10 represent the results of the output voltage and the power produced by the PV system with fixed temperature at 25° and variable solar irradiation.

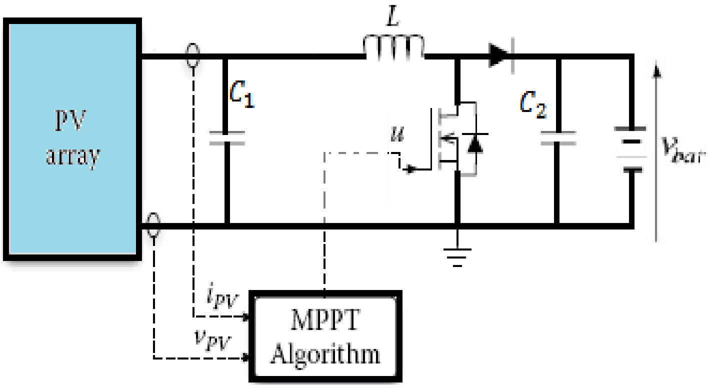

Fig. 8 Photovoltaic system with MPPT controller

Fig.8 represents the input irradiation.

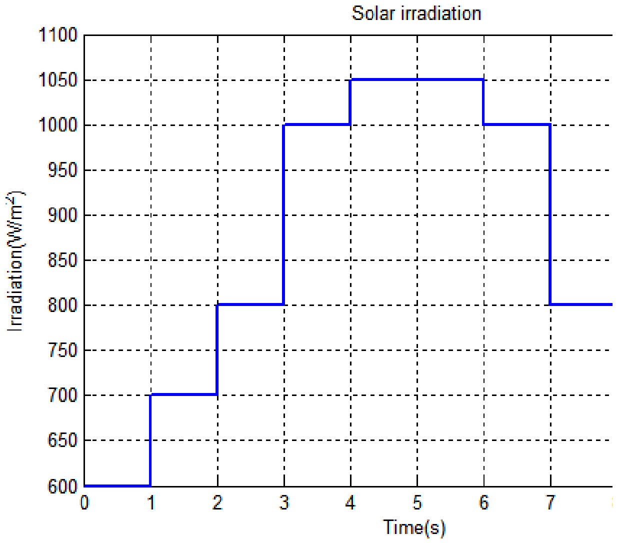

Fig. 9 Solar irradiation

Figure 10 and 11 represent the development of the PV voltage and power successively under deferent solar irradiation and a temperature of 25°.

We can see that the preferment of both ASMC and SMC is much better than that of the P&O, regarding the level and the stability of both the voltage and the power.

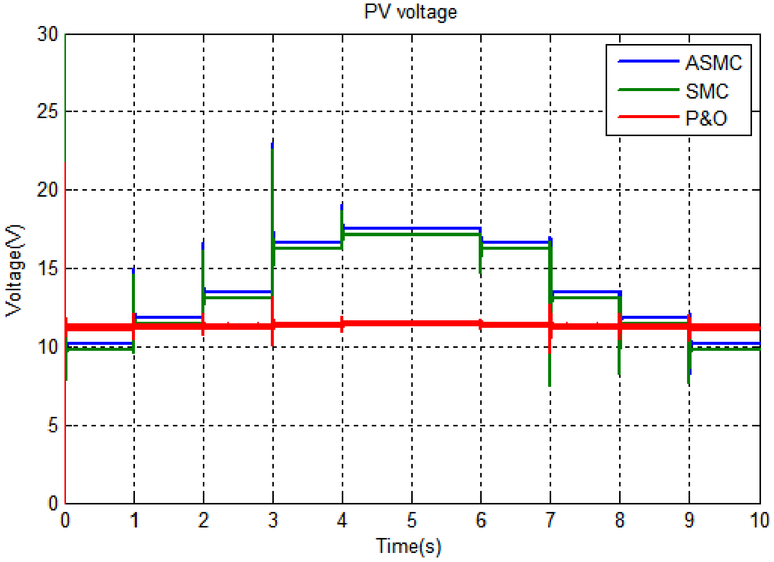

Fig. 10 PV output voltage

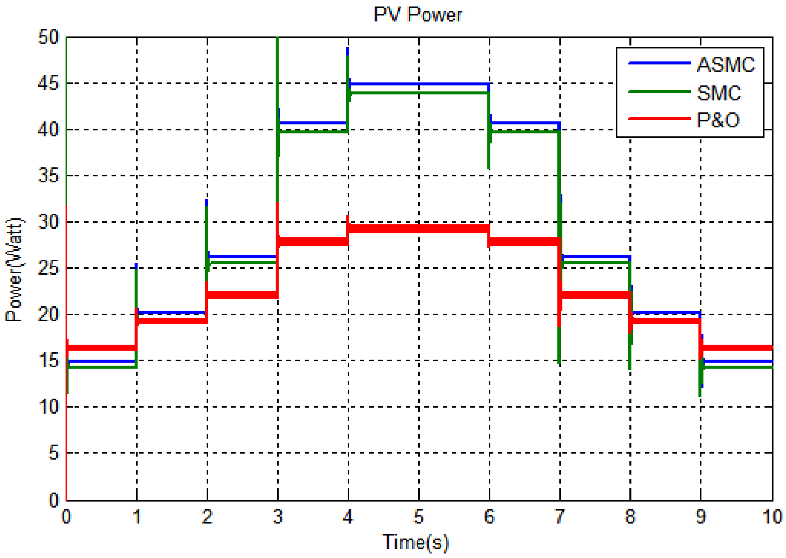

Fig. 11 PV Power

Figure 12 represent the PV power for a unique solar irradiation of 1000 W/m^2 and temperature of 25°, in order to better see the deference between ASMC and SMC.

The level of power is slightly higher for ASMC than the SMC and we can see that there is more oscillations for the SMC in the beginning.

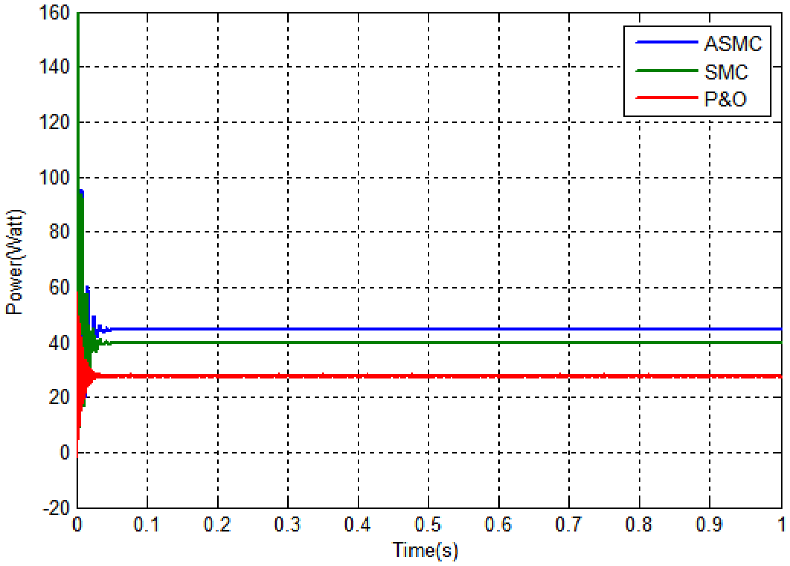

Fig. 12 PV power for solar irradiation 1000w/m^2

V. CONCLUSIONS

A PV system that includes a PV panel, DC/DC boost converter, a load and a MPPT controller has been modeled and simulated in MALLAB/Simulink and the results are represented in paragraph 4.

As can be seen from the results the tow controller ASMC and SMC give better performance than the P&O regarding the increase of the power and the stability.

Comparing the ASMC and SMC it is clear that adding the adaptation improves the performance of the system.

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