A Comprehensive Comparison of Two MPPT Techniques (P&O, SMC) for Photovoltaic Systems

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Abstract: This paper aims to study the behavior of different maximum power point tracking (MPPT) techniques applied to PV systems. In this work, we evaluate and compare perturbation and observation (P&O) and sliding mode control (SMC) techniques. a DC/DC boost converter is used between the PV system and load to transfer the maximum possible power. the conventional MPPT methods Perturb and Observe (P&O) cannot detect and track the highest peak. Thus, this causes an important loss of power, so a technique is suggested sliding mode control, which offers many benefits such as durability against parameter changes, minimal current output distortion, and excellent reference tracking. The simulation results shown in MATLAB confirm that the sliding mode control method allows to have a faster response compared to P&O, to reduce the steady-state fluctuations and better track the maximum power point with fewer power losses.

Keywords: Photovoltaic system, MPPT, P&O, SMC.

1. INTRODUCTION

The demand for electrical energy increases daily to cover human needs; the use of renewable energy is becoming the key solution to this serious energy crisis and environmental pollution [1]. Algeria has great potential for solar energy because it has a vast desert area and very high solar radiation. For this reason, the optimal solution to energy production in our study is solar energy [2]. Photovoltaic systems use cells to convert solar radiation into electricity. When light shines on the cell, it creates an electric field across the layers, causing electricity to flow. The larger the intensity of the light, the greater the flow of electricity [3]. However, the power generated by PV systems is an irregular energy source presenting two major problems: (a) low efficiency, and (b) the nonlinear output characteristic owing to the intermittent nature of solar PV systems, like variation of solar insolation and temperature [4]. a DC/DC boost converter is used between the PV system and load to transfer the maximum possible power. The maximum power is obtained by operating the converter using the power tracking algorithm MPPT. which can be categorized into the indirect method and direct method, direct methods include the methods, which use the voltage and current measurement of the PV panel, the most popular direct techniques are perturbation and observation (P&O), hill climbing (HC), and incremental conductance (IC), fuzzy logic (FL), artificial intelligence (AI), Sliding Mode Control (SMC) [5]. the most important advantage of these methods is that they are independent of PV characteristics, temperature, and radiation level while tracking the maximum power point. The indirect method includes curve fitting, look-up table, open circuit voltage, and short circuit current [6]. In indirect techniques, the maximum power is tracked in two steps: the first one is used for controller parameter optimization, and the second one is for power tracking using one of the direct MPPT methods. Among indirect techniques in the literature, we can cite, genetic algorithm-artificial neural networks (GA-ANN), and particle swarm optimization of a fuzzy logic controller (PSO-FLC).[7] In this work, different MPPT control strategies are studied and developed for photovoltaic systems to improve their efficiency. The P&O MPPT algorithm encounters a serious problem such as oscillations at the MPP due to continuous perturbations and reduced efficiency. Further, it is sensitive to changing atmospheric conditions. To tackle the problems associated with P&O MPPT, the researchers suggested many ways to improve the performance of the control, including, slidingmode controller (SMC), for

MPPT designers because it inherits robustness of tracking control, which speeds up the MPP convergence. Moreover, it brings stability against load uncertainties and the system 's nonlinearity. From the results obtained it can be seen that the sliding mode controller performs well compared to MPPT with P&O. The sliding mode control allows to have a faster response compared to P&O, to reduce the steady-state fluctuations and to better track the maximum power point with fewer power losses.

2. MODELING OF PHOTOVOLTAIC SYSTEM

The equivalent diagram of the real photovoltaic cell takes into account parasitic resistive effects due to manufacturing and is shown in figure 1, this equivalent diagram consists of a diode (d) characterizing the junction, a current source (Iph) characterizing the photo-current, a series resistor (Rs) representing the losses by Joule effect, and a shunt resistor (Rsh) characterizing a leakage current between the upper gate and the rear contact which is generally much greater than (Rs) [8].

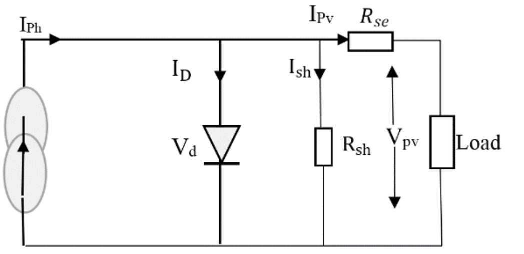

Fig.1Equivalent diagram of a photovoltaic cell.

The output current is given by the following equation:

$$I_{PV}=N_{sh}I_{ph}-N_{sh}I_0\left\{\exp\left[\frac{q\left(V_{pv}+\frac{N_s}{N_{sh}}I_{pv}R_{se}\right)}{a.k.T.N_s}\right]-1\right\}-\frac{V_{pv}+\frac{N_s}{N_{sh}}I_{pv}R_{se}}{\frac{N_s}{N_{sh}}R_{sh}} \quad (1)$$

Where, the cell reverse saturation current is related to the temperature (T) as follows:

$$I_0=I_{0r}\left(\frac{T}{T_r}\right)^3 \exp\left\{\frac{qE_G}{k.a}\left[\frac{1}{298}-\frac{1}{T}\right]\right\} \quad (2)$$

Similarly, the photocurrent Iph depends on the solar radiation (G) and the celltemperature (T)[2]:

$$I_{ph}=\{I_{scr}+k_i\ (T\text{-}298)\}\frac{G}{G_r} \quad (3)$$

With

I_{0r}; Reverse saturation current, I_D; Diode Current, **k_i**; Temperature coefficient of short-circuit current, **I_{scr}**; Current generated by the light at nominal condition, **k**; Constant of Boltzmann (1.38.10-23J / K), **q**; Charge of the electron (1.6.10-19C), a; p-n junction ideality factor, **EG**; Band gab and **G**, **Gr**; Real and reference solar radiation.

3. PERTURBATION AND OBSERVATION TECHNIQUE(P&O)

The perturbation and Observation (P&O) algorithm are the most used in the literature, especially in practice because of its ease of implementation. This method is based on performing a perturbation (increase or decrease) on the value of the output voltage or current of the system and comparing the output power of the system after the perturbation with the power of the system before the perturbation. When it changes the system voltage and its ability to increase (i.e.: $(((\Delta P_{pv})/(\Delta V_{pv}))>0)$, the control system will move the action point in the same direction (i.e., it makes a perturbation increasing), and in the case of $(((\Delta P_{pv})/(\Delta V_{pv}))<0)$ the system will move the work point in the opposite direction (i.e., it makes a perturbation decreasing). In the next perturbation, the system proceeds in the same manner. Figure 2. shows the variation of the duty ratio or voltage depending on the power. [9,10]

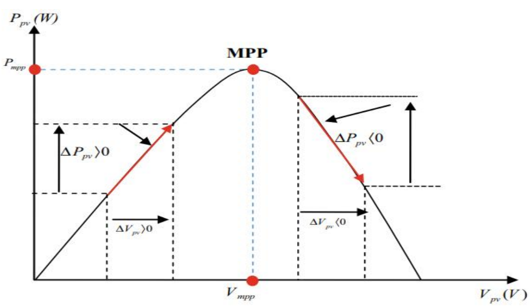

Fig.2 Functional characteristics of the P&O method.

The flowchart of the P&O algorithm is given in Figure 3

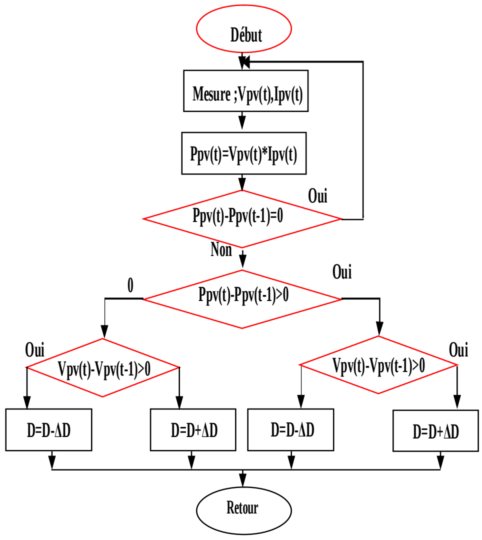

Fig.3Flowchart of the P&O MPPT algorithm.

4. SLIDING MODE CONTROL

Sliding mode control is a special mode of operation for systems with variable structure, where this technique consists of taking the state path of the system to the sliding surface and alternating it using appropriate switching logic to the equilibrium point (Fig.4). On the surface, the dynamics of the system is independent of that of the initial process, ensuring stability and robustness to large variations in system parameters [11].

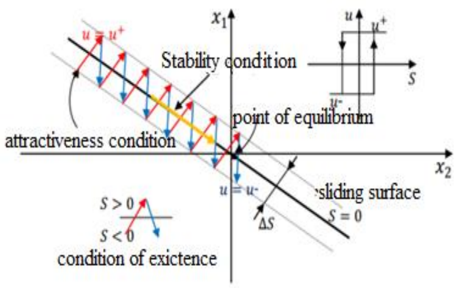

Fig.4. Principle of the sliding mode control.

The design of the control law can be summarized in three steps;

A. Selection of the sliding surface:

The general equation used to choose these sliding surfaces is given by;

$$S(X)=\left(\frac{d}{dt}+\lambda\right)^{r-1}\left(X^{d}-X\right) \quad (4)$$

With

λ: is a positive constant.

r: is the relative degree, equal to the number of times the output must be derived to bring up the control.

(X_d-X): the tracking error.

Where **X**: state variable of the control signal and **X_d**: is the desired signal.

B. The convergence conditions:

The convergence condition is defined by the Lyapunov equation which makes the surface attractive and invariant;

$$S(X)S(\dot{X})\langle 0 \quad (5)$$

C. Determination of the control law:

The control signal calculation is expressed by the following relation;

$$U = U_{eq} + U_n \quad (6)$$

Where Ueq is the equivalent control and Un is the switching control term.[12,13]

5. MPPT CONTROL BY SLIDING MODE OF PHOTOVOLTAIC SYSTEM

A. Selection of the sliding surface:

$$S(X)=\frac{dP_{pv}}{dV_{pv}} = I_{pv} + \frac{dI_{pv}}{dV_{pv}} V_{pv} = N_{sh}I_{sc} - \left(N_{sh}I_{sc} + \frac{N_{sh}I_{sc}}{a.k.T.N_s}\right)\exp\left(\frac{V_{pv} - N_s V_{co}}{a.k.T.N_s}\right) \quad (7)$$

B. The convergence conditions:

$$S(X)=\frac{dS}{dx_1}.\dot{x}_1 = 0 \quad (8)$$

C. Determination of the control law[14]:

$$U=\frac{I_{pv}}{I_L} - K.sign\left(I_{pv} + \frac{dI_{pv}}{dV_{pv}} V_{pv}\right) \quad (9)$$

6. SIMULATION RESULT

The photovoltaic module (SunPower SPR-400E WHT-D) is chosen for modeling and then simulation. It contains 54 monocrystalline silicon solar cells, and provides a rated maximum power of 21.6 KW. The characteristics of the PV system are shown in table 1:

Table1 Photovoltaic PV system proposed parameters.

Solar panel model	**Value**
Solar panel wattage	400.22W
Open circuit voltage for panel	85.3V
The voltage at MPP for panel	72.9V
Short circuit current for panel	5.87A
Current at MPP for panel	5.49A
No. of panels in series, No. of panels in parallel	9 in series, 6 in parallel
Boost converter inductance	0.5063 mH
Filter capacitance	2192 µF
Boost converter switching frequency	5 KHZ
Total power of system at MPP	400.22*9*6=21.6KW

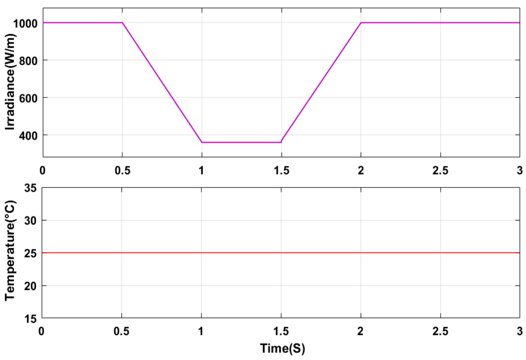

Fig.5 Irradiation and Temperature as a function of Time.

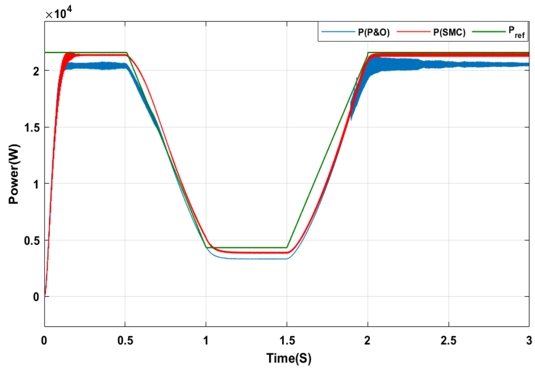

Fig.6PV system power response for different MPPT controllers.

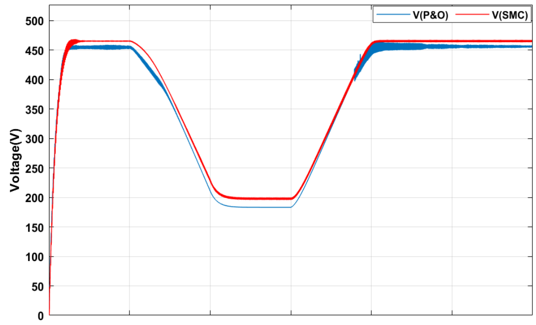

Fig.7. PV system voltage response for different MPPT controllers.

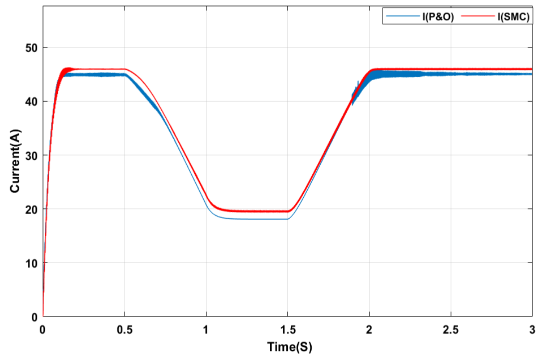

Fig.8 PV system current response for different MPPT controllers.

Then, the two MPPT tracking methods are studied; the method (P&O), the method using the sliding mode controller. Both systems are simulated under standard conditions for temperature T = 25°C and variable condition for solar irradiance as shown in figure (5). The purpose of these simulations is to visualize the offset of the operating point with respect to the MPP point. It is also used to evaluate losses due to oscillations around this point. From the results obtained, it can be seen that the sliding mode controller performs well compared to the MPPT with P&O. Sliding mode control allows for faster response to P&O, reduced steady-state fluctuations, and better tracking of the maximum power point with less power loss.

The following table summarizes the comparison between the MPPT with P&O control and MPPT with SMC applied to the system PV:

Control	P&O	SMC
Vmax	455	465
Oscillation	6	3.5
Response time	0.09	0.08
Pmax	20.5	21.4

7. CONCLUSION

In this work, different MPPT control strategies are studied and developed for photovoltaic systems to improve their efficiency. The results obtained by the sliding mode MPPT controller are better than that of the P&O MPPT controller, from the point of view of maximum point tracking and steady-state oscillation where the power losses are lower in the steady-state; this implies an improvement of the system efficiency.

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