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A NEW MPPT CONTROLLER FOR PHOTOVOLTAIC SYSTEM BASED ON HIGH ORDER SLIDING MODE APPROACH

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Abstract— **The photovoltaic energy is now considered as an important source of electricity and renewable energy in general. However it is an unstable source of power since it presents a nonlinear current-power characteristic that depends on the variable climatic conditions as the illumination and the temperature. Consequently this leads to the variation of the maximum power point (MPP)'s position. Therefore, this work will deal with this problem of power optimization by using a robust technique called a high order sliding mode algorithm which is proposed to track the maximum power point in spite of model uncertainties and meteorology condition variations. A detailed description of the tracking approaches' theoretical analysis is presented. The proposed MPP tracking algorithm has been validated through an extensive simulation work under MATLB/SIMULINK package. Based on the obtained results, we can note a great effectiveness in terms of output power optimization. Moreover, this new MPPT controller resolved the well known chattering problem and succeeded to ensure a great robustness and stability against the rapid external disturbances variation and the parametric uncertainties of the photovoltaic systems.**

I. INTRODUCTION

Due to the both price oil rising and higher energy consumption, a great interest in green and renewable energy sources has taken a big part in the new research. Renewable energy seems to be clean, plentiful and reliable it includes solar energy, which in particular, could be considered as one of the most promising energies with a very high rate in the world. The photovoltaic is a solar energy application that has received much attention with many feasible applications [1-6].

The operating power of photovoltaic modules depends on the climatic conditions as solar illumination, temperature besides the load impedance [4]. Then, in order to extract the maximum output power from the photovoltaic modules, an MPPT algorithm is required [2]. There are many different MPPT approaches that have been addressed in many researches [1-6]. Among the most important algorithms, appears the perturb and observe (P O) tracker which is commonly used [1] and [2]. It is based on perturbing the converter duty cycle and then observing the power output variation. This algorithm is relatively simple to implement. However, it occurs a problem in the steady state; that makes the working point oscillates around the maximum power point [1]. Therefore, an alternative approach called increment conductance is adopted to overcome this defect [2]. Both PO and increment conductance schemes did not provide better performances during an abrupt variation of the system disturbances. Moreover, another approach based on the proportional open circuit voltage Voc or short circuit current ICC is suggested in [3]. It is assumed that the optimal photovoltaic voltage and current are proportional to the open circuit voltage and short circuit current respectively by some coefficients. So by measuring open circuit voltage, it is possible to bring the photovoltaic module to the maximum working point. In effect, the estimated optimal voltage is just an approximation of the true optimal one. As a matter of fact the open circuit voltage changes with temperature [3]. Besides, the proportional constant will change if the photovoltaic module ages. So as a result, the performance of this approach will degrade with time.

A photovoltaic generator can be considered as a nonlinear complex system and due to the variable climatic condition which changes the system operating points; the research for an optimal solution will be difficult to be built analytically. In this fact, many nonlinear control methods have been adopted in order to improve the control performances against the different disturbances and uncertainties .As for example the artificial intelligence techniques [3] and [6], sliding mode control (SMC) [7 -14], predictive control [15], back stepping [16] ...etc. Among these nonlinear control methods, the SMC method is well known for its invariant properties to the internal parameter variations and external disturbances, these advantages can ensure a perfect tracking performance despite of the parameters and model uncertainties. However, the SMC occurs a problem, in fact this approach needs an infinite switching frequency which is so difficult even impossible to realize in real time. For finite switching frequencies, oscillations appear on the state variables and on the switching function [14].

In order to overcome the consequences of this phenomenon, a new control approach, called the high order sliding mode control, has been investigated in [7]. In this work, a new MPPT algorithm for PV systems based on the second order sliding mode approach is synthesized and well detailed.

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II. PV Panel Characteristic

Photovoltaic cell is basically a p - n semiconductor junction diode [1]. It allows a direct conversion of light energy into electricity from the sun's rays. The p - n junction, which is the core of the photovoltaic cell, has the capability to absorb the solar radiation and then make the photon carry an energy exceeding the material forbidden band, thus, giving rise to an electron hole pair. When a load is connected to the cell's terminals, the electrons will migrate from the negative region back to the holes in the positive region giving by this rise to create a potential difference. Then, a direct current flows through it until light beam stops. Its equivalent circuit model is shown in Fig. 1, it is constituted of a light generated current source, a parallel diode and a couple of resistance.

The series resistance is relatively small and a parallel one is infinitely large. These two resistances are ignored in order to simplify the simulation work. The photovoltaic characteristic under solar radiation and temperature are given (1) in terms of output current and voltage [1-2]:

$$I = I_{ph} - I_D \left[e^{\left(\frac{}{q} K_b\, T\, A\, V\right)} - 1 \right] \tag{1}$$

The generated photocurrent I_{ph} is given as:

$$I_{ph} = \frac{G}{G_r} \left[I_{scr} + K_i \left(T - T_r \right) \right] \tag{2}$$

The diode saturation current is given by:

$$I_D = I_{rr} \left[\frac{T}{T_r} \right]^3 e^{\left[\frac{q\, E_g}{K_b\, A} \left(\frac{1}{T_r} - \frac{1}{T} \right) \right]} \tag{3}$$

Where q is the elementary charge, K_b is the Boltzmann's constant,A is the diode ideality factor, T_r=298K is the reference temperature, G_r=1000 W/m^2,and G (W/m^2) are the reference and the input light radiations respectively, I_{scr} and I_{rr} are the short circuit and diode saturation currents at standard test conditions respectively,$K_i$is the temperature coefficient of current and E_g is the band gap energy semiconductor. Based on the equations (1) - (3), the photovoltaic system model has been implemented using Matlab/Simulink package. Fig. 2 shows the power - current characteristics of the photovoltaic system according to the different temperature (a) and irradiation (b) levels. These curves show that the output power of the photovoltaic system has nonlinear aspect and it is quite influenced by the variable climatic conditions. It can be noticed that at fixed irradiation and cell temperature, there is a lonely maximum power point for the photovoltaic system.

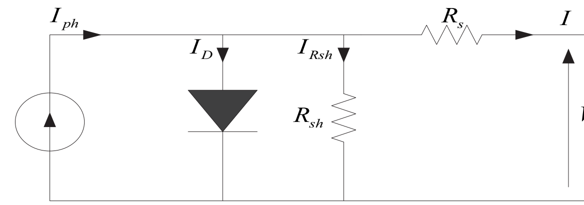
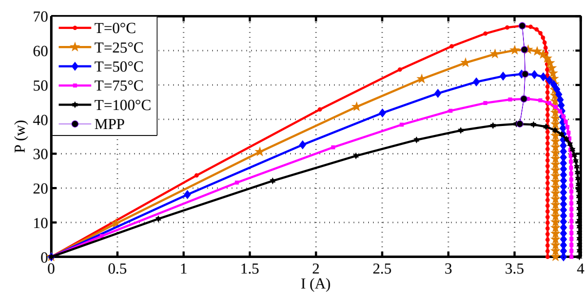
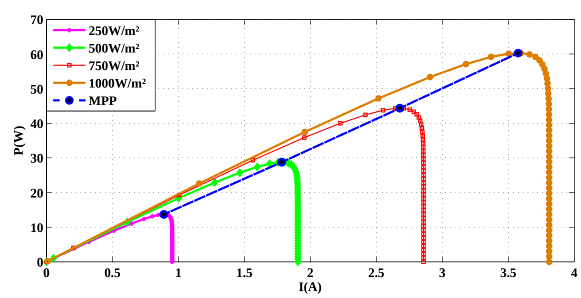


Fig. 1. Equivalent model of a solar cell.

In order to track this point a specific tool is required to let the photovoltaic system produce a maximum energy.This can be achieved through MPPT controller using a variable duty cycle that is generated through a robust approach. In the following paragraph, an MPPT algorithm, based on second order sliding mode approach is proposed.



(a) Temperature change.



(b) Irradiance change.

Fig. 2. P-I characteristics under temperature and irradiance change.

III. MPPT Converter Modeling

For a PV system connected to a resistive load there is a necessity to insert a DC/DC converter. Fig. 3 shows the boost converter which is characterized as follows: When the transistor T is opened *Sa*=0, the differential equation set can be expressed as:

$$\begin{cases} \dot{I} = \frac{V}{L} - \dfrac{V_{out}}{L} \\ \dot{V}_{out} = \frac{I}{C} - \dfrac{V_{out}}{C\, R_{load}} \end{cases} \tag{4}$$

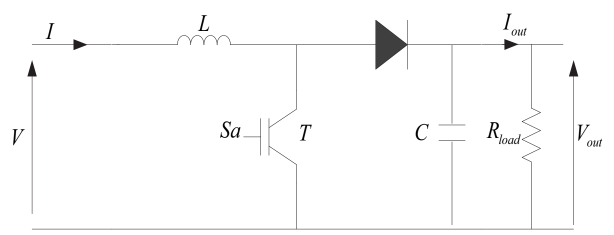


Fig. 3. MPPT boost converter diagram.

When the transistor T is closed *Sa*=1, the differential equation set can be written as:

$$\begin{cases} \dot{I} = \frac{V}{L} \\ \dot{V}_{out} = -\frac{V_{out}}{C\,R_{load}} \end{cases} \quad (5)$$

By using the state space averaging method principle, the system dynamic is then represented with one set of state equation.

$$\begin{cases} \dot{I} = \frac{V}{L} - \frac{V_{out}}{L} - \frac{V_{out}}{L}\alpha \\ \dot{V}_{out} = \frac{I}{C} - \frac{V_{out}}{C\,R_{load}} - \frac{I}{C}\alpha \end{cases} \quad (6)$$

Here α is the duty cycle, *C* is the capacity, *L* is the inductance and R_{load} is the resistive load. The system described by (6) can be written in the general form of an uncertain nonlinear system.

$$\dot{x} = f(x) + g(x)\,\alpha \quad (7)$$

IV. Second Order Sliding Mode Control Approach

The concept of higher order sliding mode control approach has been suggested in the eighties in order to overcome the problem of the chattering phenomena [7-14]. Let us consider an uncertain nonlinear system defined as:

$$\dot{x} = f(t,x,u) \quad (8)$$

Where x(t) $\epsilon\ \Re^n$ is the state vector, u $\epsilon\ \Re^m$ is the control vector and *f (t,x,u)* is a function supposed sufficiently differentiable. A sliding mode is considered of r^{th} order if the equalities (9) are satisfied [7].

$$S(t,x) = \dot{S}(t,x) = \cdots = \overset{(r-1)}{S}(t,x) = 0 \quad (9)$$

With *S(t,x)* is the switching surface. In the case of a second order sliding mode control, (10) must be verified.

$$S(t,x) = \dot{S}(t,x) = 0 \quad (10)$$

The switching surface derivative can be expressed as:

$$\dot{S}(t,x) = \frac{\partial S(t,x)}{\partial t} + \frac{\partial S(t,x)}{\partial x} f(t,x,u) \quad (11)$$

The second order derivative of the switching surface is:

$$\ddot{S}(t,x) = \frac{\partial \dot{S}(t,x)}{\partial t} + \frac{\partial \dot{S}(t,x)}{\partial x} f(t,x,u) + \frac{\partial \dot{S}(t,x)}{\partial u}\dot{u} \quad (12)$$

Let us define the ζ and γ variables

$$\zeta\,(x,t) = \frac{\partial \dot{S}(t,x)}{\partial t} + \frac{\partial \dot{S}(t,x)}{\partial x} f(t,x,u) \quad (13)$$

$$\gamma(t,x) = \frac{\partial \dot{S}(t,x)}{\partial u} \quad (14)$$

A new system can be established

$$\begin{cases} \dot{y}_1(t,x) = y_2(t,x) \\ y_2(t,x) = \zeta\,(t,x) + \gamma(t,x)\dot{u} \end{cases} \quad (15)$$

Moreover a new switching surface is proposed:

$$\sigma(t,x) = \dot{S}(t,x) + \lambda\, S(t,x) \quad (16)$$

The corresponding control signal can be expressed as

$$\dot{u}(t) = \dot{u}_{eq}(t) - M\, sign\,(\sigma(t,x)) \quad (17)$$

u_{eq} is determined from the following conditions (18).

$$\dot{\sigma}(t,x) = \ddot{S}(t,x) + \lambda\dot{S}(t,x) = 0 \quad (18)$$

With:

$$\ddot{S}(t) = \frac{\partial \dot{S}(t,x,u)}{\partial t} + \frac{\partial \dot{S}(t,x,u)}{\partial x}\dot{x}(t) + \frac{\partial \dot{S}(t,x,u)}{\partial u}\dot{u} \quad (19)$$

The equivalent control $\dot{u}_{eq}$ is then derived.

$$\dot{u}_{eq}(t) = -\frac{1}{\frac{\partial \dot{S}(t,x,u)}{\partial u}}\left[\frac{\partial \dot{S}(t,x,u)}{\partial t} + \frac{\partial \dot{S}(t,x,u)}{\partial x} f(t,x,u) + \lambda\,\dot{S}(t,x,u)\right] \quad (20)$$

The real control signal that must be applied to the system (7) is then deduced by integration.

$$u(t) = \int \dot{u}_{eq}(t)\,dt - \int M\, sign\,(\sigma(t,x))\,dt \quad (21)$$

V. A Second Order Sliding Mode MPPT Controller for Photovoltaic System

The efficiency objective of optimization for PV system can be accomplished by zeroing ∂P/∂I.

$$\frac{\partial P}{\partial I} = I\,(\frac{\partial V}{\partial I} + \frac{V}{I}) = 0 \quad (22)$$

The non trivial solution of (21) is $(^{\partial V}/_{\partial I} + ^{V}/_{I}) = 0$

Let's consider (22) the form of the sliding surface

$$S(t,x) = \frac{\partial V}{\partial I} + \frac{V}{I} \quad (23)$$

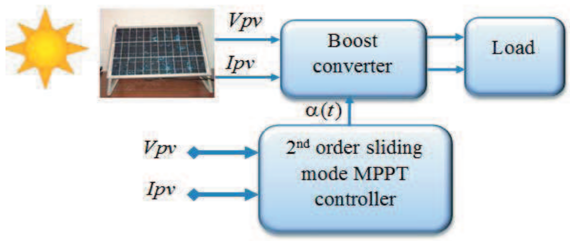


Fig. 4. MPPT system block diagram.

The first and second derivatives of the switching surface can be described as:

$$\dot{S}(t,x) = \left[\frac{\partial S(t,x)}{\partial x}\right]^T [f(x) + g(x)\,\alpha] \tag{24}$$

$$\ddot{S}(t,x) = \left[\frac{\partial \dot{S}(t,x)}{\partial x}\right]^T \dot{x} + \left[\frac{\partial \dot{S}(t,x)}{\partial \alpha}\right]^T \dot{\alpha} \tag{25}$$

Based on the detailed second order algorithm and the maximum power point tracking principle, the control signal that must be applied to the PV system is

$$\alpha(t) = \int \dot{\alpha}_{eq}(t)\,dt + \int M\,sign\,(\sigma(t,x))\,dt \tag{26}$$

In which,$\dot{\alpha}_{eq}$ and $\sigma(t,x)$ are given by (27) and (28).

$$\dot{\alpha}_{eq}(t) = -\frac{\left[\frac{\partial \dot{S}(t,x)}{\partial x}\right]^T \dot{x} + \lambda \dot{S}(t,x)}{\frac{\partial \dot{S}(t,x)}{\partial \alpha}} \tag{27}$$

$$\sigma(t,x) = \dot{S}(t,x) + \lambda\,S(t,x) \tag{28}$$

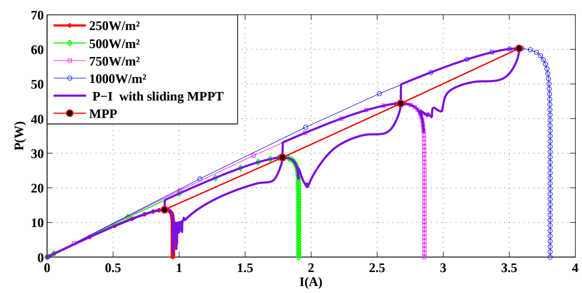
Since the range of the duty cycle must lie between 0 and 1 , the real control signal is defined as:

$$\alpha(t) = \begin{cases} 1 & if\ \alpha(t) \geq 1 \\ \alpha(t) & if\ 0 < \alpha(t) < 1 \\ 0 & if \alpha(t) \leq 0 \end{cases} \tag{29}$$

VI. Simulation Results

In order to validate the effectiveness of the proposed approach a computer simulations have been carried. In this fact, the PV generator, a Boost converter model and the proposed sliding mode MPPT controller The effect of changes in solar irradiation levels and temperature is observed by giving some stepwise that increments and decrements with 250W/m^2 and 25°C respectively. The results are presented in Fig. 5 and 6. As it is shown in Fig. 5(b) and Fig. 6(b), the Boost converter duty cycles follows the dynamics of the optimal ones. Thus, we can obviously conclude that the second order sliding mode MPPT algorithm is able to track the maximum power points despite of climatic conditions variations ((Fig. 5(a)) and (Fig. 6(a)). Moreover, the control signal is smooth proving that the chattering phenomena were resolved by using the second order sliding mode approach. Investigating the ability of the proposed MPPT algorithm to reject load disturbances, the system is initially operated at standard test conditions (25°C and G=1000W/m^2). A sudden step increase of the load value with and are applied at 0.5s and 1s respectively. Besides, a sudden step decrease of the load value with and are applied at 1.5s and 2s respectively. The obtained results are presented in Fig. 7. A rapid convergence of the sliding function is, equally, noticed (Fig. 7(b)). This induces that the maximum power point is reached despite of brutally load variations.

(a)



(b)

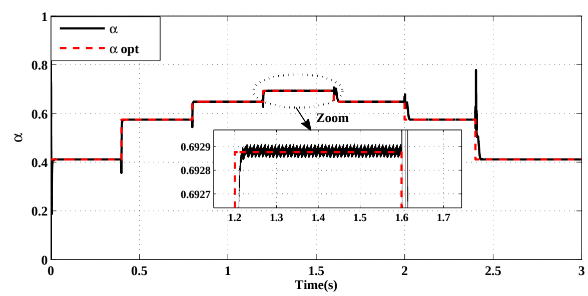


Fig. 5 Simulation results under step change in radiation levels: (a) System power and (b) Duty cycles.

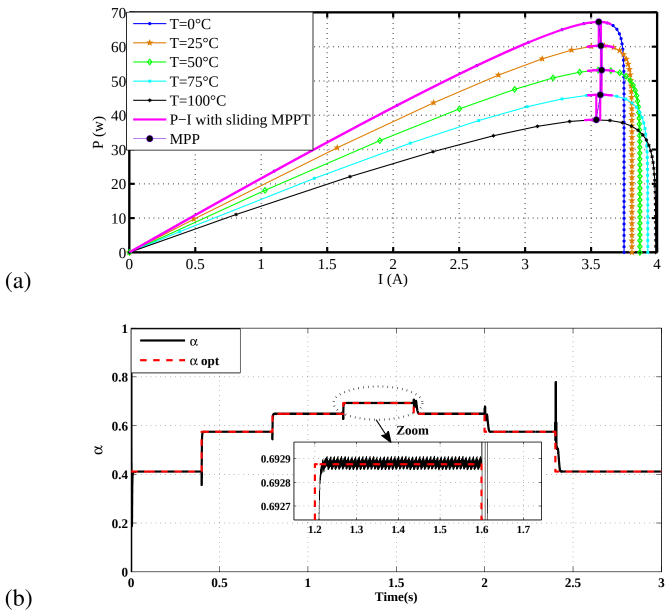


Fig. 6 Simulation results under step change in temperature levels: (a) System power and (b) Duty cycles.

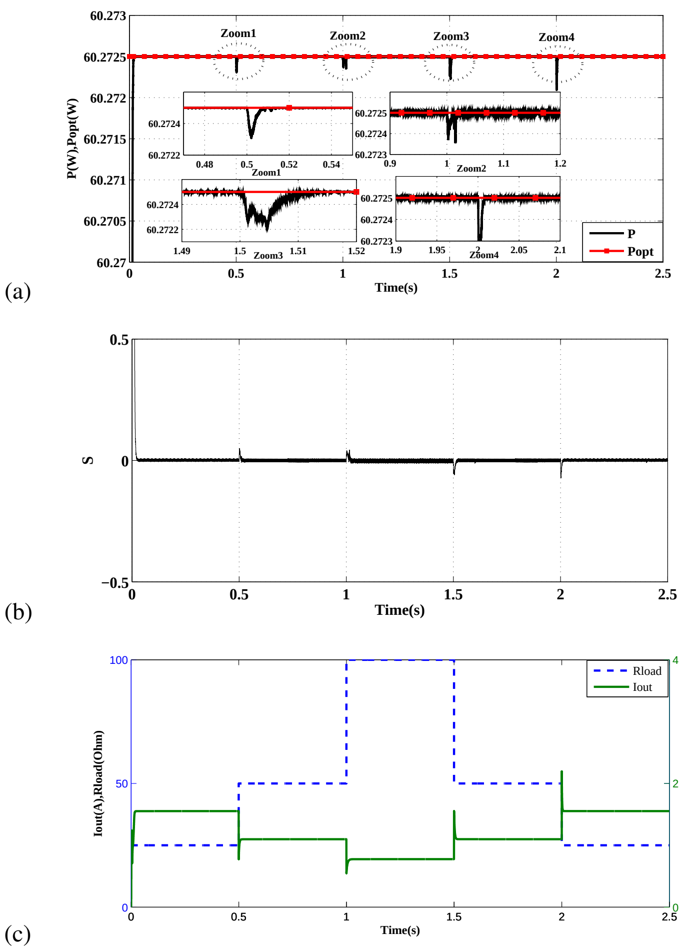


Fig. 5. Simulation results under step change in load value: (a) System power, (b) Duty cycles and (c) load values and load current.

VII. CONCLUSIONS

This paper deals with the problem of controlling power generation in PV systems. For that goal, a second order sliding mode approach is proposed to design the MPPT controller. The proposed MPPT tracker is validated across an extensive simulation work using Matlab/Simulink package. Numerical results show that the proposed MPPT controller is effective in terms of power optimization. Moreover, the control signal is smooth. Besides, the proposed MPPT ensure robustness against the temperature and solar irradiation even in the presence of load change PV system could reach and conserve the optimal operation.

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