Le 2ème Séminaire International sur les Energies Nouvelles et Renouvelables
The 2nd International Seminar on New and Renewable Energies
Unité de Recherche Appliquée en Energies Renouvelables,
Ghardaïa – Algérie 15, 16 et 17 Octobre 2012

Robust Maximum Power Point Tracking Method for PV

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***Abstract*— This paper proposes a control strategy of a maximum power point of a PV system using the high order sliding mode (super twisting algorithm) method. This approach guarantees the some robustness and dynamic performances of traditional first-order SMC algorithm. Simulation results are presented to verify the performance of the proposed method.**

***Keywords*— Photovoltaic cells, Maximum power point tracking, DC-DC Boost, Sliding mode control, Robustness,**

I. INTRODUCTION

The photovoltaic system (PV) has attracted much attention due to the oil and environment pollution in recent years [1]-[4]. Its merits are:

- inexhaustible ;
- pollution-free ;
- abundant ;
- silent and with no rotating parts, and size-independent electricity conversion efficiently

The main drawback is that:

Form an operational point of the view, a photovoltaic array experiences large variations of its output power under intermittent weather conditions. These phenomena may cause operational problems at a central control centre in a power utility, such as excessive frequency deviations, spinning reserve increase, etc.;

Its initial installation cost is considerably high.

Integrating the PV power plant with other power sources such as diesel backup [2], fuel cell backup [3] , battery backup [1],[3] super conductive magnetic energy storage backup are ways to overcome variations of its output power problem

An important consideration in the operation of a photovoltaic system is to achieve the maximum output power by means of continuously adjusting the PV array operating point for the given conditions. Various maximum power point tracking algorithms to fulfill this task are being considered or are currently used in PV applications to obtain as much generation power as possible.

Several maximum power point tracking (MPPT) algorithms have been proposed from time-to-time [12-11]. Some of the popular schemes are the hill climbing method [1], incremental conductance method [12], constant voltage method [9.12] and modified hill climbing method [10].

Sliding Mode Control (SMC) is a non-linear control technique derived from variable structure control system theory and developed by UTKIN [20]. Such control solution has several advantages such as simple implementation, robustness and good dynamic response.

Variable structure control (VSC) method for PV conversion system was proposed and evaluated by numerical study in [16]. Further study was also proposed in [13], [17] and [18], however, these approaches required reference current for control law synthesis and may lead to a lack of robustness to operation conditions.

But the chattering phenomenon, originated by the interaction between parasite dynamic and finite-frequency switching control is the main disadvantages of this technique of control [23][25]. To avoid chattering some approaches were proposed [24][26][27]. Consequently, the characteristics of robustness and accuracy of the VSC system are no longer assured. To reduce the chattering phenomenon and to preserve the main advantages of the sliding mode technique, in [28] [29] a novel class of SMS algorithm, called the second-order SMC algorithm has been proposed.

In this paper, the sliding mode controller has been designed to search maximum power point and an adequate DC/DC converter output voltage. The control circuit adjusts the duty cycle of the switch control waveform for maximum power point tracking as a function of the evolution of the power input at the DC/DC converter. In this control system, it is necessary to measure the PV array output voltage and to change the duty cycle of the DC/DC converter control signal.

II. MODELING

A) *Photovoltaic Model*

Photovoltaic array (PV) arrays are built up with combined series/parallel combinations of PV solar cells [13], which are usually represented by a simplified equivalent circuit model such as the one given in Fig.1 and/or by Equation. (1).

During darkness, the solar cell is not an active device; it works as a diode, i.e. a p-n junction. It produces neither a current nor a voltage. However, if it is connected to an external supply it generates a current I_d, called diode (D) current or dark current. The diode determines the I-V characteristics of the cell.

$$V_{pv} = \frac{AKT_c}{e} \ln\left(\frac{I_{ph} + I_0 - I_c}{I_0}\right) - R_s I_c \qquad (1)$$

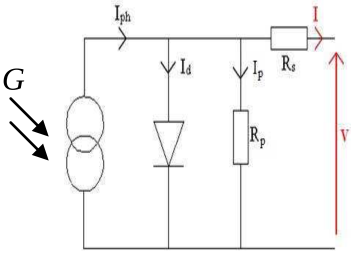

Fig.1 Simplified equivalent circuit PV model

Where e is the electron charge (1.602×10-19C), K is the Boltzmann constant (1.38 × 10-23 J/K), I_c is the cell output current (A), I_{ph} is the photocurrent, function of the irradiation level and junction temperature (5 A), I_0 is the reverse saturation current of diode (0.0002 A), R_s is the series resistance of cell (0.001 Ω), T_c is the reference cell operating temperature (25 °C), V_{pv} is the cell output voltage, V.

The PV characteristic in under different irradiance level and PV characteristic under different temperature are plotted in Fig.2. As illustrated in the figures, the open-circuit voltage (V_{oc}) is dominated by temperature, and solar irradiance has preeminent influence on short-circuit (I_{sc}). We can conclude that high temperature and low solar irradiance will reduce the power conversion capability.

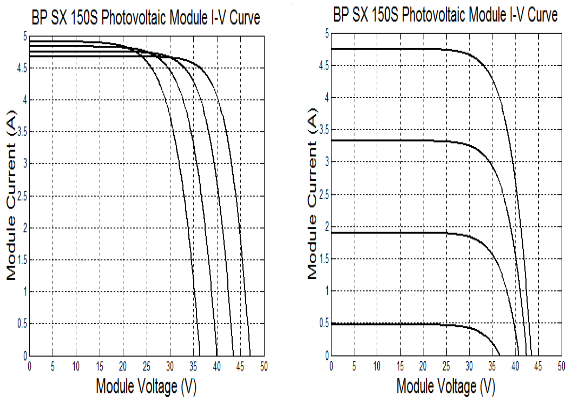

Fig. 2 PV characteristic under different temperature and irradiance.

Fig. 3 shows the influence of irradiance on the characteristic power - voltage (P (V)) of a photovoltaic cell.

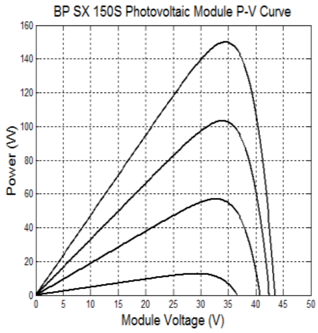

Fig. 3 PV characteristic under different irradiance (temperature =25°C).

III. DYNAMIC MODEL OF DC-DC BOOST CONVERTER

Fig .4 shows a DC-DC boost converter. It consists of a DC input voltage source (V_{pv}) a controlled switch (S_w), a diode (D), a filter inductor (L), filter capacitor (C), and a load resistor (R_L).

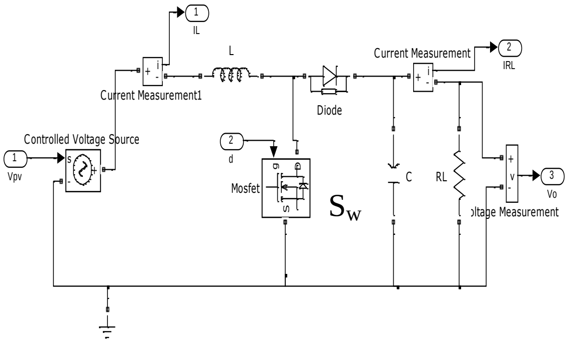

Fig.4 DC-DC boost converter.

The system can be written in tow sets of state equation depend on the position of switch S_w. if the switch is in position S_w=0, the differential equation can be written as:

$$\frac{di_{L_1}}{dt} = \frac{V_{pv}(i_L)}{L} - \frac{V_o}{L} \qquad (2a)$$

$$\frac{dV_{o_1}}{dt} = \frac{i_L}{C} - \frac{V_o}{CR_L} \qquad (2b)$$

The differential equation can be expressed as (3a) and (3b) if the switch is in position S_w=1

$$\frac{di_{L_2}}{dt} = \frac{V_{pv}(i_L)}{L} \qquad (3a)$$

$$\frac{dV_{o_2}}{dt} = -\frac{V_o}{CR_L} \qquad (3b)$$

By utilizing State Space Averaging method [15] can be combined into one set of state equation to represent the dynamic of the system.

Base on the idea of Pulse-Width Modulation (PWM), the ratio of the switch in the position 1 in a period is defined as duty ratio. Two distinct equation sets are weighted by the duty ratio and superimposed:

$$\dot{X} = (1-d)\dot{X}_1 + d\dot{X}_2 \qquad (4)$$

Where $\dot{X}_1 = \left[\dot{i}_{L_1} \quad \dot{V}_{o_1}\right]^T$, $\dot{X}_2 = \left[\dot{i}_{L_2} \quad \dot{V}_{o_2}\right]^T$ and $d \in \left[0 \quad 1\right]$ is the duty ratio. Hence, the dynamic equation of the system can be described by

$$\frac{di_L}{dt} = \frac{V_{pv}(i_L)}{L} - \frac{V_o}{L} + \frac{V_o}{L}d \qquad (5a)$$

$$\frac{dV_o}{dt} = \frac{i_L}{C} - \frac{V_o}{CR_L} - \frac{i_L}{C}d \qquad (5b)$$

Where C is the capacity, L is the inductance; R_L is the resistive load, $d \in \left[0 \quad 1\right]$is the ratio, which is also the control input. V_0 is the output voltage and i_L is the inductor current. Note the equivalent series resistance of the inductor and wiring resistance are neglected in the case, so i_L is assumed to equal to the PV current (I_{pv}). Equation (5) can be written in general form of the nonlinear time invariant system.

$$\dot{X} = f(X) + g(x)d \qquad (6)$$

IV. MPPT CONTROL APPROACH

As the supplied by the solar array depends on the insolation, temperature and array voltage, an important consideration in the design of efficient solar array systems is to track maximum power point correctly. The purpose of MPPT is to move the array operating voltage close to the MPP under changing atmospheric conditions.

A) Short review of 2-SMC

The sliding mode control consists of tow phase: first, we determine a sliding surface $s(x)$ upon which the control objectives are realised. Next, we derive a control law in order to bring the state trajectory to this output and maintain it there at all time [31].

In the case the problem is to generate a second order sliding mode on an appropriately chosen sliding surface and, thus, to constrain the trajectories system to evolve in finite time on $S = \{x : S = \dot{S} = 0\}$.

Consider a system whose dynamics is given by

$$\begin{aligned} \dot{x} &= f(x,t) + g(x,t)v \\ s &= s(x,t) \end{aligned} \qquad (7)$$

Where $x \in R^n$ is the system state variable.

$v \in R$ is the control

f, g are sufficiently smooth vector fields.

$S = S(x,t) \in R$ is the output function, called sliding variable .

By differentiating S with respect to time, t, we have:

$$\ddot{s} = \varphi_A(t,s,\dot{s}) + \phi(t,s,\dot{s})\dot{v}(t) \qquad (8)$$

The control v is bounded function $|v| \le V_{\max}$

The dynamics in Equation (8) are assumed to satisfy the following bounding conditions [28]:

$$0 < k_m \le |\phi(t,s,\dot{s})| \le K_M$$

$$|\varphi_A(x,t)| \le \beta_{0st}$$

The set $\{t, x, v : |s(t,x)| < s_0\}$ is the linear region

Where k_m, K_M and β_{0st} are some positive constants.

In this work the super twisting algorithm has been designed to search maximum power point and an adequate DC/DC converter output voltage.

The super twisting algorithm has the advantage of not require any knowledge of the derivative of the sliding variable $\dot{S}$. The control law comprises two continuous terms that, again, do not depend upon the first time derivative of sliding variable.

The algorithm can be defined by the following control law:

$$v_{st} = v_1 + v_2$$

$$\begin{cases} \dot{v}_1 = -\alpha_1 sign(s) \\ v_2 = -\alpha_2 |s|^\rho sign(s) \end{cases} \qquad (9)$$

With α_1, α_2 and ρ verifying the following inequality [29] and [30]:

$$\alpha_1 > \frac{\beta_{0st}}{k_m}$$

$$\alpha_2^2 \ge \frac{4\beta_{0st}K_M(\alpha_1 + \beta_{0st})}{K_m^2 k_m(\alpha_1 - \beta_{0st})} \qquad (10)$$

$$0 < \rho \le 0.5$$

The choice $\rho = 0.5$ ensures that he maximal possible for 2-Sliding realization real sliding order two is achieved.

By selecting the sliding surface as $\partial p / \partial I_{pv} = 0$, it is guaranteed that the system state will hit the surface and produce maximum power output persistently.

$$\frac{\partial P_{pv}}{\partial I_{pv}} = \frac{\partial I_{pv}^2 R_{pv}}{\partial I_{pv}} = I_{pv}\left(2R_{pv} + I_{pv}\frac{\partial R_{pv}}{\partial I_{pv}}\right) = 0 \tag{11}$$

Where $R_{pv} = V_{pv} / I_{pv}$ is the equivalent load connect to the PV, and I_{pv} the PV current, witch is equal to i_L in this case. The non-trivial solution of (11) is $2R_{pv} + I_{pv}\,\partial R_{pv} / \partial I_{pv} = 0$.

Hence, the sliding surface is defined as:

$$\underline{\underline{s}}\Delta 2R_{pv} + i_L \frac{\partial R_{pv}}{\partial i_L} \tag{12}$$

Based on the observation of duty cycle versus operation region as depicted in Fig. 5, the duty cycle output control can be chosen as:

$$d_{update} = \begin{cases} d + \Delta d \cdots s > 0 \\ d - \Delta d \cdots s < 0 \end{cases} \tag{13}$$

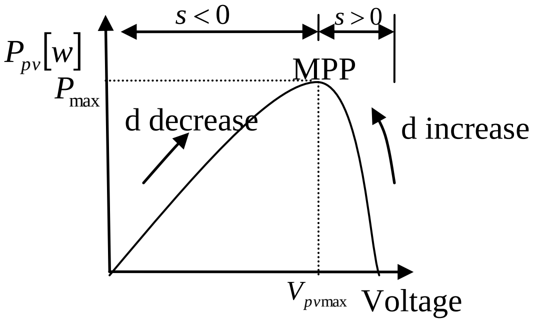

Fig. 5 duty cycle versus under operation region.

V. SIMULATION RESULTS

The diagram of the closed loop system for MATLAB and Simulink is shown in Figure 6, which includes the electrical circuit of the photovoltaic module BP SX 150S, whose characteristics are shown in Table.1, the DC-DC converter BOOST-type, and the MPPT algorithm. The photovoltaic module is modeled using the electrical characteristics to provide the current and voltage of the photovoltaic module output.

TABLE I
CHARACTERISTICS OF THE USED SOLOR MODULE BP SX 150S

Maximum power	150 W
Rated voltage	34.5 V
Open circuit Voltage	43.5 V
Rated current	4.4 A
Short circuit current	4.8 A

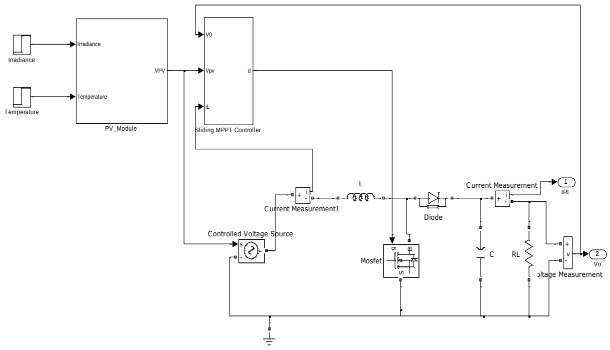

Fig. 6. Simulink block of the closed loop control of boost converter.

The proposed MPPT is evaluated from tow aspects: robustness to irradiance, temperature.

Fig.7 illustrates the tracking result with step irradiance, input (500 -1000w/m2) under the same temperature and load.

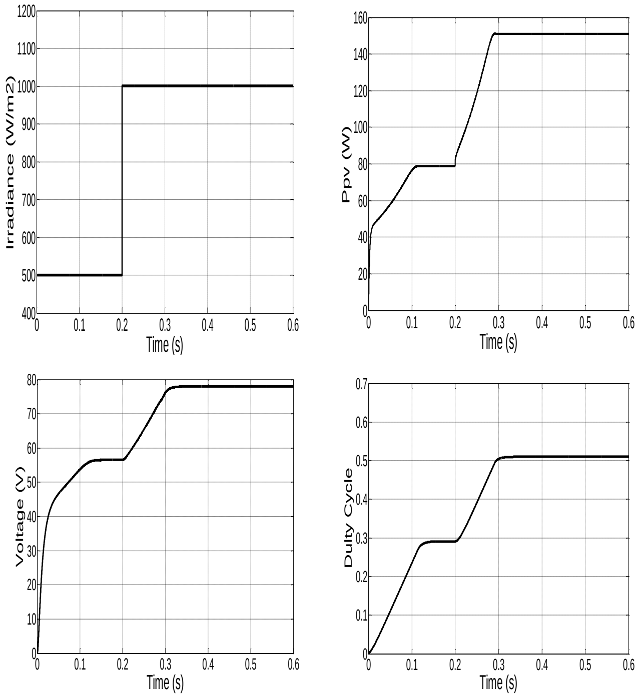

Fig. 7. Simulation with step irradiance change (500 to1000 W/m2, temperature = 25°C, $R_L = 42\Omega$).

Fig.8 depicts the system response under rapid temperature change.

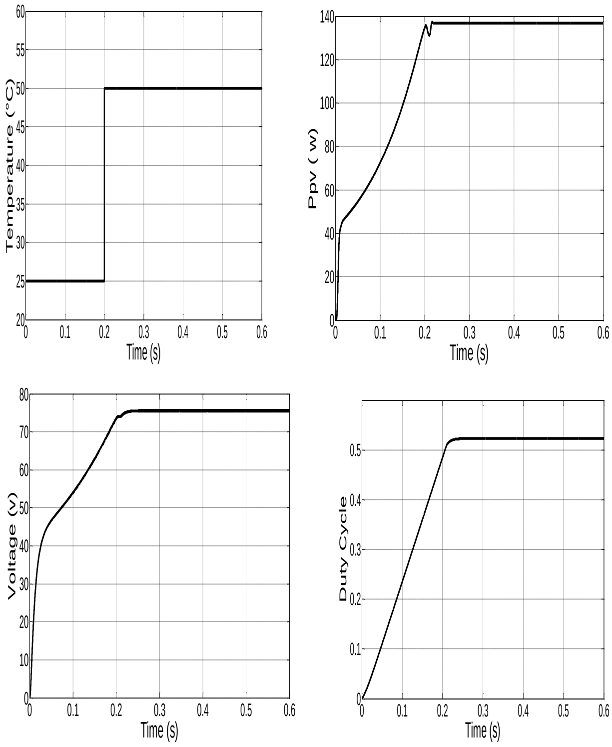

Fig. 8. Simulation with step temperature change (25 to 50 °C, $G = 1000 W/m^2$, $R_L = 42\Omega$).

VI. CONCLUSIONS

A robust maximum power point tracking controller is proposed for a photovoltaic generator. A sliding mode control design scheme is employed to find the controller structure and equations.

The simulation results show the validity of the sliding mode controlled boost converter model and the robustness of this control technique against changes in the load or variations in the input voltage.

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