

A fast and accurate maximum power point tracking for photovoltaic power generation system

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This paper concentrates on the modeling and control of an autonomous photovoltaic power electricity generation system. The system consists of a PV cell, a DC-DC Buck-boost converter used for Maximum Power Point Tracking (MPPT). As a consequence, the PV cell itself cannot maintain a constant DC voltage and function as a DC voltage power supply source. To overcome this problem, a DC-DC converter with the nonlinear control scheme, sliding mode control (SMC) may be used. The DC/DC Buck-boost converter controlled by using the sliding mode approach is used for tracking the maximum power point MPP. The proposed controller is robust to environment changes, load variations and it can be implemented effectively and economically.

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1. Introduction

Renewable energy technologies today are harness for electrical power generation which are reliable and cost competitive with the conventional fuel generators. Among various renewable energy technologies, the solar energy has several advantages like clean, power, unlimited, and provides sustainable electricity [1, 2].

The potential energy in Photovoltaic power generation system is inexhaustible, and it is possible as a long-term reliable and environmentally friendly source of energy. Photovoltaic power generation system can be used as an option to meet the objective of reducing emissions of carbon dioxide and to achieve renewable energy goals. In fact, in recent years, the world's photovoltaic power generation system installed rapidly increase in growth rate of 8 years in a row about 30% [3].

The transformation in electricity with the photovoltaic effect allows to bring basic energizing services (e.g. lighting, cold production, pumping...etc.) and to answer to many professional needs (e.g. relay radio, remote monitoring, lighting system...etc.). By its suppleness and its easiness of installation and maintenance, the photovoltaic energy is incontestably a technical and economical solution for the electrification in isolated site, either in the countries in development or in the industrialized countries. The photovoltaic solution also represents a sociological stake because, while bringing progress in isolated zones, it contributes to limit the rural exodus phenomenon [4].

The output power of PV cell is changed by

environmental factors, such as irradiance and temperature. Since the characteristic curve of a solar cell exhibits a nonlinear voltage-current characteristic, a controller named maximum power point tracker (MPPT) is required to match the solar cell power to the environmental changes [5].

Several studies have been performed by many authors proposes different strategies MPPT for a photovoltaic system. For example, the Perturb and Observe (P&O) methods, the Incremental Conductance (IC) methods, the Artificial Neural Network method, the Fuzzy Logic method, Open Circuit Voltage [6] etc...

This paper presents the modeling and the control of the solar source. This one consists of a MSX 60 panel connected to the continuous bus through a control chopper with MPPT technique. The adopted strategy is based on the sliding mode control.

2. MPPT system modeling

The studied system is of energetic type with a renewable (solar) energy source coupled to adaptation converters (maximum power point tracking, MPPT). These adapters are DC/DC converters with different structures.

The MPPT controller is basically a DC-DC converter that accepts a DC input voltage and outputs a DC voltage higher, lower or the same as the input voltage. Most MPPT controllers are based on either the buck converter (step-down), boost converter (step-up) or buck-boost converter.

Other types of DC-DC converters can be employed in the MPPT design for example, CuK converter and full-bridge converter [7]. These converters uses passive electronic components such as inductors and capacitors to control the energy flow from the solar module to the load by continuously opening and closing a switch. The switch is usually an electronic device that operates in two states: in the conduction mode (on) or in the cut-off mode (off).

For our system, the buck-boost converter is used as a DC power supply, to interface the PV output to the DC load and to track the maximum power point of the PV array where the input voltage varies with temperature and irradiance conditions.

2.1 Modeling of the photovoltaic generator PVG

In the case of an array with N_s series connected solar cells and N_p parallel connected panels, the array current may be related to the array voltage by (1), as in [8, 9].

$$I_{pv} = N_p I_{ph} - N_p I_s \left[\exp \left(\frac{V_{pv} + \left(\frac{N_s}{N_p} \right) R_s I_{pv}}{n_s a v_t} \right) - 1 \right] - \frac{V_{pv} + \left(\frac{N_s}{N_p} \right) R_s I_{pv}}{\left(\frac{N_s}{N_p} \right) R_p} \quad (1)$$

Where: I_{pv} , V_{pv} and P_{pv} are respectively the photovoltaic (PV) current, voltage and power. I_{ph} is the light-generated current and I_s is the reverse saturation current. R_s and R_{sh} are respectively the PV array series and shunt resistances. A is the ideality factor, K is the constant of Boltzman, T is the cell temperature, q is the electronic charge and V_T is the thermodynamic potential given by (2).

$$I_{ph} = [I_{sc}^* + k_i(T - T^*)] \frac{G}{G^*} \quad (2)$$

In ideal conditions, R_s is much smaller and R_{sh} is much greater, [9]. So, the nonlinear characteristic of the PVG in ideal conditions is given by (3).

$$I_{pv} = N_p I_{ph} - N_p I_s \left[\exp \left(\frac{V_{pv} + \left(\frac{N_s}{N_p} \right) R_s I_{pv}}{n_s a v_t} \right) - 1 \right] \quad (3)$$

Fig. 1 shows the different current-voltage and power-voltage characteristics of the MSX 60 PV module with varying atmospheric conditions.

2.2 Dynamic model of DC-DC Buck-Boost converter

The dynamic model of the buck-boost type DC-DC converter in state space form is obtained by the application of basic laws governing the operation of the system. The schematic diagram of DC-DC buk-boost converter is shown in Fig. 2. The dynamic equations of this converter can be written as [10]:

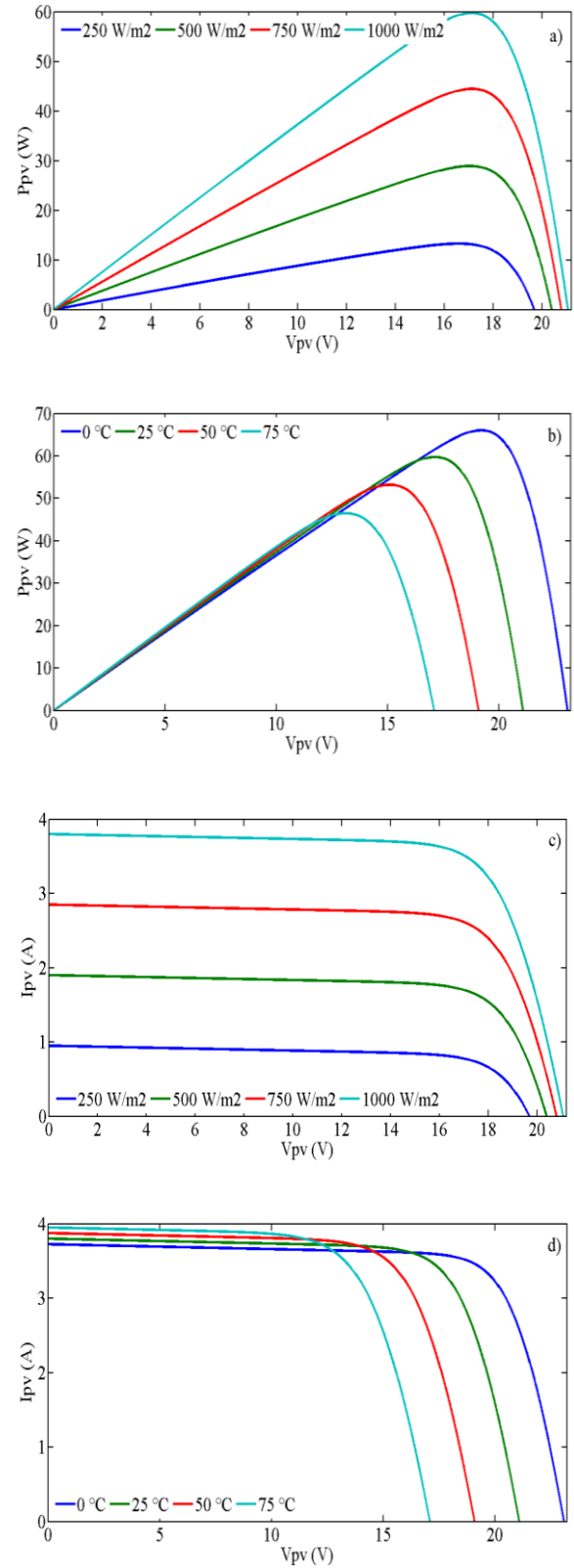


Fig. 1. Solar module characteristics: (a) power-voltage at different irradiance; (b) power-voltage at different temperature; (c) current-voltage at different irradiance; (d) current-voltage at different temperature.

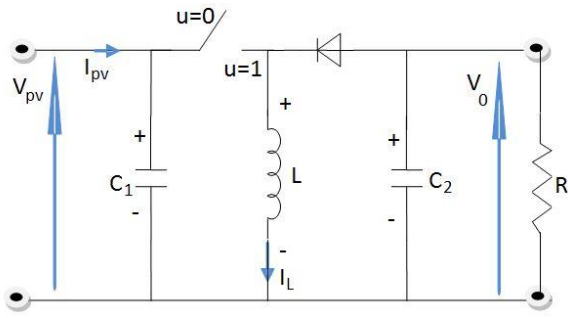


Fig. 2. Schematic diagram of DC-DC buck-boost converter.

$$\frac{dV_{pv}}{dt} = \frac{I_{pv}}{c_1} - \frac{i_L}{c_1} \cdot u \quad (4)$$

$$\frac{dV_0}{dt} = -\left(\frac{V_0}{RC_2} + \frac{i_L}{c_2}\right) + \frac{i_L}{c_2} \cdot u \quad (5)$$

$$\frac{di_L}{dt} = \frac{V_0}{L} + \frac{V_{pv}-V_0}{L} \cdot u \quad (6)$$

Where V_0 and i_L are the output capacitor voltage and inductor current, respectively. The control input u is the switch position function in the set of $\{0, 1\}$.

If we set $x = [x_1 \ x_2 \ x_3]^T = [V_{pv} \ i_L \ V_0]^T$, then the above expression can be written in general form of the non-linear time system as:

$$\dot{x} = \frac{dx}{dt} = f(x, t) + g(x, t) \cdot u + h \quad (7)$$

$$f(x) = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & \frac{x_3}{L} \\ 0 & -\frac{x_2}{c_2} & -\frac{x_3}{RC_2} \end{bmatrix}, g(x) = \begin{bmatrix} \frac{-x_2}{c_1} \\ \frac{x_1-x_3}{L} \\ \frac{x_2}{c_2} \end{bmatrix}, h = \begin{bmatrix} \frac{I_{pv}}{c_1} \\ 0 \\ 0 \end{bmatrix}$$

It is assumed that the buck-boost converter is working in continuous conduction mode (CCM), in which the average value of the inductance current never drops to zero due to load variations.

3. Sliding mode control design

The control system is depicted in Fig. 3.

The basic idea of the sliding mode control is firstly to attract the states of the system in a suitably selected area of state space, known under name of the sliding surface. Such that once that the system is in this area of state space, it has the desired behaviour. Then, the second stage consists in conceiving a control law which leads, in a finished time, the system towards this area and will maintain it in this one [11].

The function of the MPPT sliding mode controller is to ensure that the system delivers the maximum power to the load by varying the duty ratio of the buck-boost converter.

When the solar array is operating in its maximum output power state, we can get

$$\frac{dP_{pv}}{dV_{pv}} = \frac{dV_{pv} I_{pv}}{dV_{pv}} = I_{pv} + V_{pv} \frac{dI_{pv}}{dV_{pv}} \quad (8)$$

The switch function can be selected

$$S = I_{pv} + V_{pv} \frac{dI_{pv}}{dV_{pv}} = 0 \quad (9)$$

The switch control signal can be selected as

$$u = \begin{cases} 0 & \text{if } S > 0 \\ 1 & \text{if } S < 0 \end{cases} \quad (10)$$

Imposing the invariance conditions [12, 13]:

$$S(x) = 0 \text{ and } \frac{dS(x)}{dt} = 0 \quad (11)$$

Therefore, the equivalent control variable is shown below.

$$u_{eq} = \frac{I_{pv}}{i_L} \quad (12)$$

$$u = u_{eq} - k_n \cdot \text{sgn}(S) \quad (13)$$

$$u = \frac{I_{pv}}{i_L} - k_n \cdot \text{sgn}\left(I_{pv} + V_{pv} \frac{dI_{pv}}{dV_{pv}}\right) \quad (14)$$

Ideally, u_{eq} is a solution to the sliding mode control because it maintains the state on the sliding manifold at each instant. We conclude that a sliding regime will exist if the converter works in continuous conduction mode, i.e., $i_L > 0$.

4. Simulation results

In this paper a novel, patent pending technique for the maximum power point tracking of photovoltaic systems has been introduced. The approach is based on the sliding mode control technique.

Processing the energy obtained from the solar photovoltaic module is coming to the fore. The energy supplied by the module does not have constant values, but fluctuates according to the surrounding condition such as intensity of solar rays and temperature shown in the characteristics curves in Fig. 1. These supplies are therefore supplemented by additional converters. Here the solar photovoltaic system composed of a DC to DC converter connected to the resistive load.

The simulations were made for duration of 1.5 s, to illustrate the response of the PV system for three parameters: load, temperature and solar radiations. In each case, we let two parameters constant and we make a sudden variation for the third one at two instants 0.5 s and 1 s.

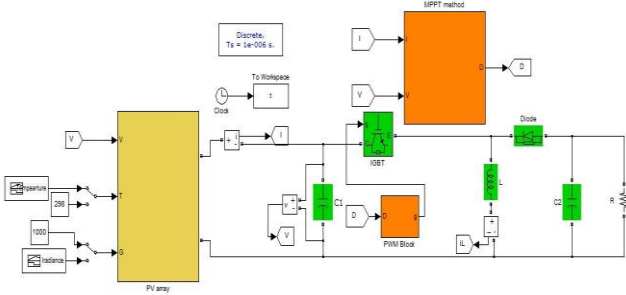


Fig. 3. Autonomous photovoltaic studied system.

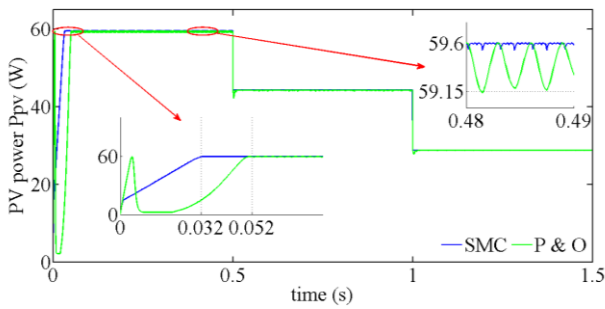


Fig. 4. Simulation results with solar radiation change (1000-750-500W/m², T=25°C, R=2Ω).

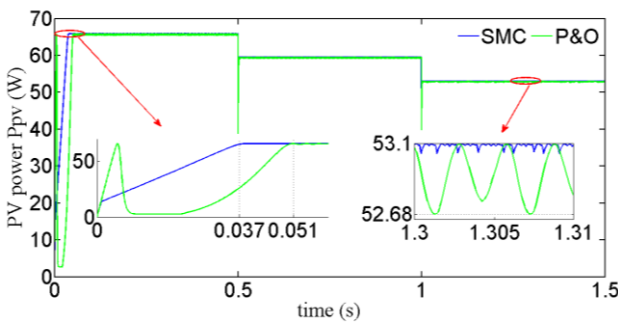


Fig. 5. Simulation results with temperature change (25-50-75 °C, G=1000 W/m², R=2 Ω).

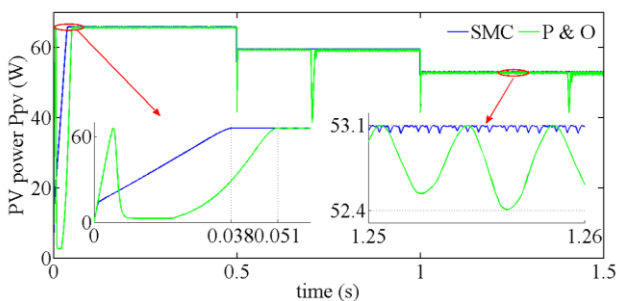


Fig. 6. Simulation results with load change (2-1.5-1 Ω, G=1000 W/m², T=25°C).

First, the proposed solar system with its controller was tested connecting a load of 2 Ω, temperature was set to be constant as 25°C and for successive irradiance steps applied 1000 W/m² at 0 s, 750 W/m² at 0.5 s, 500 W/m² at

1 s. The corresponding simulation results are shown in fig. 4.

Second, the proposed PV system was also tested under a constant solar irradiance of 1000 W/m², constant load of 2 Ω and a sudden change of temperature from 25 °C to 50 °C and then to 75°C. Fig. 5 illustrates the results of simulation with these conditions.

Third, the conditions of simulations will be constant solar irradiance of 1000 W/m², constant temperature of 25 °C and a rapid load change from 2 Ω to 1.5 Ω and then to 1 Ω. Fig. 6 shows these last results.

For each test, two zooms are illustrated, one at startup condition, other at steady state. It can be seen that the proposed MPPT has better performance than P&O method, both in the response time and in the static errors.

We can say that the PV array power is practically affected by the three parameters: irradiance; temperature; and load.

Among the three parameters of variation, one notes that the solar irradiance is the most influential parameter on the PV system.

Under the standard climatic conditions (G =1000 W/m², T=25°C), the PV panel generates an average of 60 W of power, 17.1 V of voltage and 3.5 A of current. This output value may change as the irradiance and temperature level changes as shown in Fig. 1.

For all the results above, the sliding mode approach reaches steady state much faster and with less fluctuations compare to the P&O MPPT techniques.

According to the obtained results, the tracking efficiency is not less than 95 %.

Therefore, the proposed method guarantees good tracking efficiency under different operating conditions.

5. Conclusion

In this paper, the modelling and control of autonomous photovoltaic power electricity generation system is proposed.

A power electronics converter has been included to allow the use of the PV array at its maximal power. The proposed model has been implemented under MATLAB-SIMULINK environment. It accounts for the important non-linear DC response of PV devices, and is simple, robust and flexible while existing models suffer from unnecessary complexities and from implementation difficulties in various software programs.

A control strategy based on sliding mode techniques was developed in order to regulate the power output of a solar system, which comprises photovoltaic generation, a buck-boost DC-DC converter which is able to operate in a wide range of output voltages and different loads demands.

Comparing with other techniques used in the past, the use of the proposed MPPT control improves the PV system performance. The results of simulation are present.

Appendix

P_{pv} : PV panel output power,
 V_{pv} : PV panel output voltage (V),
 I_{pv} : PV panel output Current (A),
 I_{ph} : Photocurrent (A),
 I_s : Reverse saturation current,
 R_s : Series resistance of the solar cell,
 R_p : Shunt resistance of the solar cell,
 N_s : Number of solar cells connected in series,
 N_p : Number of solar cells connected in parallel,
 a : Diode quality factor ,
 k : Boltzman's constant ($1.38 \cdot 10^{-23}$ J/K),
 T : Solar cell operating temperature (K),
 q : Charge of an electron ($1.60 \cdot 10^{-19}$ C),
 L : Inductance (0.5 mH),
 Input filters: $C_1=1000 \mu\text{F}$,
 Output filters: $C_2=470 \mu\text{F}$.

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