A Sliding Maximum Power Point Tracker for a Photovoltaic System

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1. Brief introduction

This paper proposes a control strategy of a Maximum Power Point Tracking (MPPT) of a photovoltaic (PV) system. The system includes a photovoltaic array, a DC/DC converter and a DC/AC inverter connected to a load. The proposed strategy is based on the sliding mode control and it allows a direct control of power converter. The stability as well as the robustness of the system will be evaluated. This work is motivated by the need to use the maximal power of PV generator, which is a special source of energy that has a non-linear current-tension characteristic (I-V) dependent of temperature and solar irradiance. Some reliable simulation results are provided in this paper in order to demonstrate the efficiency of the proposed approach.

Key words: Photovoltaic system, boost converter, sliding mode control, maximum power point.

2. Introduction

This work analyses the control of an off-grid PV system, sometimes called a stand-alone system. This system consists of a PV array, a DC/DC converter, an inverter and a load. The control should guarantee that the PV array output power will be transformed with high efficiency to the load.

In order to archive this maximum power point (MPP) of the PV arrays, it is necessary to maintain it at their optimum points operating. This characteristic is difficult to reach because the PV array exhibit interesting dynamical properties. PV modules have nonlinear voltage-current characteristics, and there is only one PV operation point with a maximum output power under particular conditions of solar radiation and temperature. Such properties have attracted the interest of this work in the search a control that improves its dynamic performance.

Many methods have been developed to determine the MPP. Midya applied a dynamic MPP tracker to PV appliances, and Kuo proposed a single-stage MPP controller using the slope the power versus voltage, [1-2]. Other approach is based on a variable structure control applied to a buck converter, [3]. Too, there is an approach based on a perturbation and observation method, where the reference voltage varies periodically when the MPP is reached, [4].

In this analysis, the DC/DC converter is used as maximum power point tracker. The control signal is generated to control the switch state. 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 DC/DC converter power input. A sliding mode controller has been designed to search this maximum power point.

3. System Description

Photovoltaic generator performance can be determined trough the power-voltage curve, figure 1. The knowledge of these characteristic curves, for different irradiations and temperatures, allows valuing the maximal power delivered as well as corresponding efficiencies. The equation that relates current and voltage in a photovoltaic cell is:

$$I_{PV} = I_l - I_o\left(e^{q\frac{(V_{PV}+R_s I)}{\eta K T_K}} - 1\right) - \frac{V_{PV} + R_s I}{R_{sh}} \qquad (1)$$

Where I_{PV} and V_{PV} are cell output current and voltage, I_0 is the cell reverse saturation current; I_L is the light-generated current; R_s and R_{sh} are series and shunt resistances, q is electronic charge, K is Boltzmann's constant, and T_K is cell temperature in K.

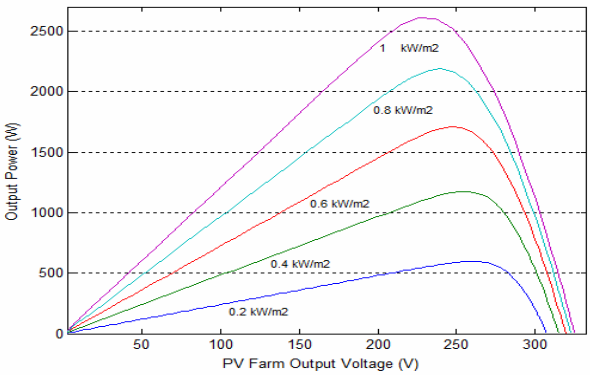

Fig. 1. Power-voltage PV module characteristics

The condition of the maximum power point is given by:

$$\frac{\partial}{\partial V_{PV}}\left[I_{PV}\cdot V_{PV}\right] = I_{PV} + \frac{d}{dV_{PV}}\left[I_{PV}\right]\cdot V_{PV} = 0 \qquad (1)$$

In order to adapt the array photovoltaic to a large voltage range, the PV MPPT system adopts step down-up DC-DC converter topology system, figure 2.

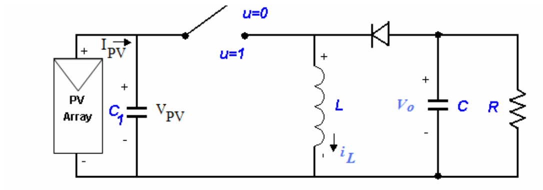

Fig. 2. Buck-boost converter

This converter can be modeled as follows.

$$\frac{dV_{PV}}{dt} = \frac{I_{PV}}{C_1} - \frac{i_L}{C_1}u \qquad (2)$$

$$\frac{di_L}{dt} = -\frac{v_O}{L} + \frac{u}{L}(V_{PV} + v_O) \qquad (3)$$

$$\frac{dv_O}{dt} = (\frac{i_L}{C} - \frac{v_O}{RC}) - \frac{ui_L}{C} \qquad (4)$$

where i_L is the current across the inductor, v_0 is the voltage in the capacitor C. Parameters R, L, C_1 and C are supposed to be known constants. $u \in \{0,1\}$ defines the switch position.

When buck-boost converter is used in PV applications, the voltage input change continuously with atmospheric conditions. Therefore, the duty cycle should change to track the maximum power point of photovoltaic array. Considering the condition of MPPT the following sliding surface $S(.)$ is proposed:

$$S(.) = I_{PV} + \frac{d}{dV_{PV}}[I_{PV}] \cdot V_{PV} = 0 \qquad (5)$$

The switch control signal can be selected as

$$u = \begin{cases} u^+ & para \quad S(x) > 0 \\ u^- & para \quad S(x) < 0 \end{cases} \qquad (6)$$

Assuming (5) as sliding surface and imposing the invariance conditions $S(x)=0$ and $dS(x)/dt=0$ in (2) leads to the following expression of the equivalent control $u_{eq}(x)$:

$$u_{eq} = \frac{I_{PV}}{i_L} \qquad (7)$$

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., $i_L > 0$. The expression described above allows obtaining the ideal model of closed loop control systems and to demonstrate that the system could reach global stability.

4. Simulation results

The proposed design scheme was implemented in ®Matlab/Simulink and SimPowerSystem. PV array has been modelled with 30 PV modules, connected in series and parallel. In order to allow the interaction between a DC/DC converter and the PV array, a simulation model for a PV array has been developed, including the dependence of the PV array output with the irradiance and temperature. The proposed design scheme was tested connecting a load of 0.5 KW, and radiation steps in PV array. Simulation results have been observed in each case to view the influence of the sliding mode control in power and index modulation.

Figure 3 shows the evolution of the current, voltage and power PV array for 1000 W/m^2 and for successive irradiance steps applied at t=0.06 seg (800W/m^2) and t=0.12 seg (600 W/m^2).

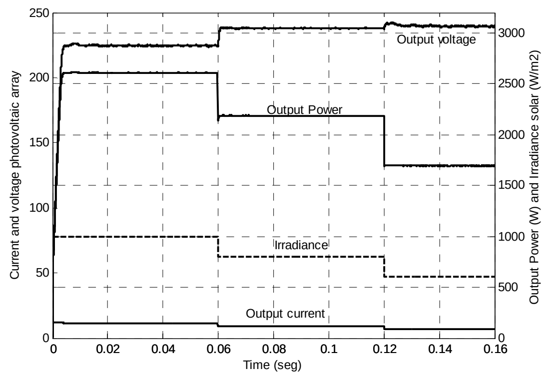

Fig. 3. Evolution of V_{PV}, I_{PV} and P_{PV}

The 400 V obtained at boost converter are applied to an IGBT two-level inverter to generate a sinusoidal output voltage of 50 Hz. The IGBT inverter is controlled with a PI regulator in order to maintain to 230 Vrms, 50 Hz at the load terminals.

5. Conclusions

In this paper, a sliding mode control of the boost converter has been analyzed. The reported controller uses the output power of the PV array and the output voltage of the converter to calculate the switching signal. The control law provides voltage regulation at the converter output, and guarantees the maximum power point of the PV array. This control law can be easily implemented by means of standard operational amplifiers, analog multipliers and digital devices in an experimental platform.

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