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Sliding mode controller for a photovoltaic pumping system

A ElOugli[1], S Miqoi[2], M Boutouba[3] and B Tidhaf[4]

Laboratory of Embedded Electronic Systems and Renewable Energy
University of Mohamed I,Oujda, Morocco

Email: a.elougli@yahoo.fr

Abstract. In this paper, a sliding mode control scheme (SMC) for maximum power point tracking controller for a photovoltaic pumping system, is proposed. The main goal is to maximize the flow rate for a water pump, by forcing the photovoltaic system to operate in its MPP, to obtain the maximum power that a PV system can deliver.And this, through the intermediary of a sliding mode controller to track and control the MPP by overcoming the power oscillation around the operating point, which appears in most implemented MPPT techniques. The sliding mode control approach is recognized as one of the efficient and powerful tools for nonlinear systems under uncertainty conditions.The proposed controller with photovoltaic pumping system is designed and simulated using MATLAB/SIMULINK environment. In addition, to evaluate its performances, a classical MPPT algorithm using perturb and observe (P&O) has been used for the same system to compare to our controller. Simulation results are shown.

1. Introduction

Water pumping system is used in rural areas, where the water sources are spread over many miles of land and power lines are limited and the installation of a new transmission line and a transformer is expensive, so to operate in general renewable energy is recommended. Photovoltaic energy is among the most used renewable energy and has the greatest potential for development.PV generation systems have two major problems; the conversion efficiency of electric power generation is low (in general less than 17%, especially under low irradiation conditions), and the amount of electric power generated by solar arrays changes continuously with weather conditions. Moreover, the solar cell (I-V) characteristic is nonlinear and varies with irradiation and temperature. There is a unique point on the (I-V) or (P-V) curve of the solar array called MPP, at which the entire PV system operates with maximum efficiency and produces its maximum output power. The location of the MPP is not known, but can be located, either through calculation models, or by search algorithms [1, 2]. Therefore MPPT techniques are needed to maintain the PV array's operating point at its MPP.

In this paper we are representing simple photovoltaic water pumping system and we are using a sliding mode control as MPPT to generate the voltage reference to which the PV system should operate. The paper is structured as follows: paragraph 2 is a description of the PV system used, paragraph 3 introduces the concept of sliding mode control and applying it on our system plus a brief representation of the P&O controller and paragraph 4 present the simulation results on Matlab that are discussed, finally we have a conclusion.

2. PV pumping system modelling

Our photovoltaic pumping system consists of a PV panel, a DC-DC Boost converter, a DC motor and a water pump.Figure1 shows the equivalent circuit of the boost system based on PV with water pump. The system's average model is given in the equation (1) [3, 4]:

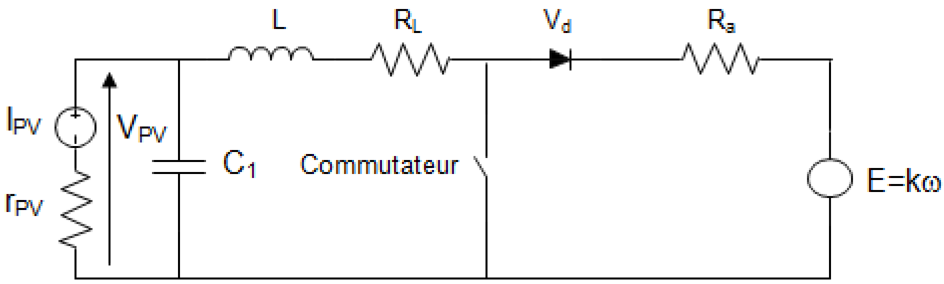

Figure 1. The equivalent circuit of the PV pumping system.

$$\begin{cases} \frac{di_L}{dt} = \frac{V_{pv}}{L} - \frac{(R_a+R_L)}{L} i_L + \frac{(R_a-R_m)i_L+V_d+k\omega}{L} u - \frac{V_d}{L} - \frac{k}{L}\omega \\ \frac{dV_{pv}}{dt} = \frac{I_{pv}}{C_1} - \frac{i_L}{C_1} \\ \frac{d\omega}{dt} = \left(\frac{k}{j} - \frac{k}{j}u\right) i_L - \frac{k_2}{j}\omega - \frac{k_1}{j} \end{cases} \quad (1)$$

where V_{pv} and i_{pv} designthe PV panel voltage and current respectively. L, R_L and i_L are the self-inductance, resistance and current. R_m is a resistance characterizing IGBT lost. C_1, V_d and ω are the input capacitance, the diode forward voltage and DC-motor speed. R_a,j,k,k_1 and k_2 are the DC-motor electric resistance, the moment of inertia of the rotor, the electromotive force constant, the disturbance input and the damping coefficient. u is the control input.The values of each of these parameters are listed in the table blow.

Table 1. System parameters.

Model	*Bosch Solar Module c-Si 60*	R_L	0.5 Ω
Power	180 Wp	R_a	3.254 Ω
V_{MPP}	30.30 V	**L**	6.8 10^{-3} H
I_{MPP}	7.76 A	C_1	6.2 10^{-3} F
V_{oc}	36.8 V	**J**	0.004 $kg.m^2$
I_{sc}	8.45 A	k_1	0.1$kg.m^2$.rad/sec
k_2	0.0114 $kg.m^2/sec^2$	**k**	0.333 V.sec/rad
R_m	17.5 mΩ		

3. MPPT

The control circuit takes voltage and current feedback and generates the duty cycle D; this last defines the output voltage of the Boost converter.

3.1. Sliding mode control

Siding Mode Control is a nonlinear control solution and a variable structure control (VSC). It was proposed by Vladim UTKIN in (Utkin, 1977). The advantages of SMC are various and important: high precision, good stability, simplicity, invariance, robustness… [3, 4]. The design of the control can be obtained in two important steps:

•The choice of the sliding surface. Representation of the system state:

$$\frac{d}{dt}\begin{pmatrix} i_L \\ V_{pv} \\ \omega \end{pmatrix} = \begin{pmatrix} -\frac{(R_a+R_L)}{L} & \frac{1}{L} & -\frac{k}{L} \\ -\frac{1}{C_1} & 0 & 0 \\ \frac{k}{j} & 0 & -\frac{k_2}{j} \end{pmatrix}\begin{pmatrix} i_L \\ V_{pv} \\ \omega \end{pmatrix} + \begin{pmatrix} \frac{(R_a-R_m)i_L+V_d+k\omega}{L} \\ 0 \\ -\frac{k}{j} i_L \end{pmatrix} u + \begin{pmatrix} -\frac{V_d}{L} \\ \frac{I_{pv}}{C_1} \\ -\frac{k_1}{j} \end{pmatrix} \quad (2)$$

$$\dot{x} = f(x) + b(x)u + d \quad (3)$$

The vector state is:

$$x = \begin{pmatrix} i_L \\ V_{pv} \\ \omega \end{pmatrix} \quad (4)$$

The MPP is determined when:

$$\frac{\partial P_{pv}}{\partial V_{pv}} = 0 \quad (5)$$

$$\frac{\partial P_{pv}}{\partial V_{pv}} = \frac{\partial I_{pv}^2 R_{pv}}{\partial V_{pv}} = \frac{I_{pv}}{R_{pv}}\left(2R_{pv} + I_{pv}\frac{\partial R_{pv}}{\partial I_{pv}}\right) = 0 \quad (6)$$

Where $R_{pv} = \frac{V_{pv}}{I_{pv}}$is the equivalent load connect to the PV andI_{pv} is the PV current.

$$2R_{pv} + I_{pv}\frac{\partial R_{pv}}{\partial I_{pv}} = 0 \quad (7)$$

So the sliding surface is defined as:

$$S = 2R_{pv} + I_{pv}\frac{\partial R_{pv}}{\partial I_{pv}} \quad (8)$$

•The determination of the control law.As we can see in figure2, the duty cycle output control can be chosen as:

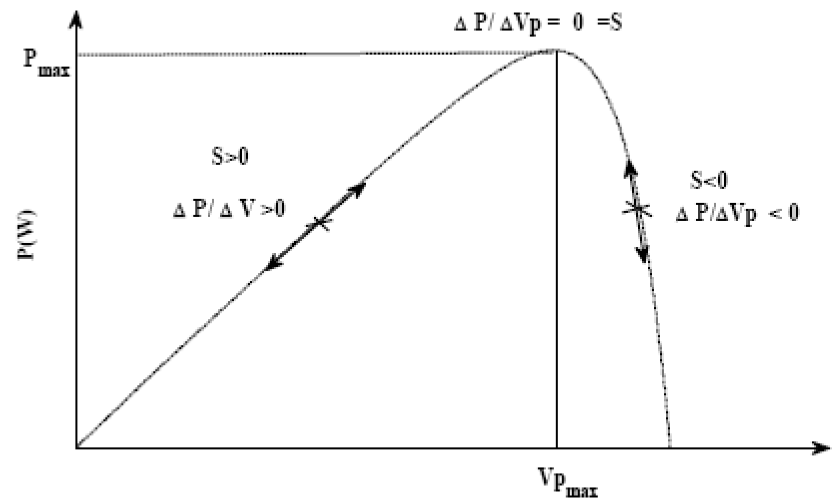

Figure2. Sign of the sliding surface at different positions of the graph P-V.

We have $D = uandD_{eq} = u_{eq}$

$$D = \begin{cases} D - \Delta D fors > 0 \\ D + \Delta D fors < 0 \end{cases} \tag{9}$$

With :

$$\Delta D = u - u_{eq} \tag{10}$$

The equivalent control suggested by Slotine and Li (2005) is determined from the following condition:

$$\dot{s} = \left[\frac{\partial S}{\partial x}\right]^T \dot{x} = \left[\frac{\partial S}{\partial x}\right]^T (f(x) + b(x)u + d) = 0 \tag{11}$$

The equivalent control is:

$$D_{eq} = -\frac{\left[\frac{\partial S}{\partial x}\right]^T (f(x))}{\left[\frac{\partial S}{\partial x}\right]^T b(x)} \tag{12}$$

Since the range of duty cycle must lies in$0 \le D_{eq} \le 1$, the real control signal is proposed as:

$$D = \begin{cases} 1 & for D_{eq} - \lambda * sign(S) \ge 1 \\ D_{eq} - \lambda * sign(S) for & 0 < D_{eq} - \lambda * sign(S) < 1 \\ 0 & for D_{eq} - \lambda * sign(S) \le 0 \end{cases} \tag{13}$$

$\lambda$is a positive scaling constant.

3.2. P&O

We have chosen to compare the SMC to the P&O method due to the fact that it is the most used method to control the MPP in the industry, it is known for its simplicity and efficiency. The characteristics of PV panel are measured and then induce a small perturbation on the voltage (or current) to analyse the resulting power variation.Figure3 shows the flowchart of the algorithm for P&O as it should be implemented.

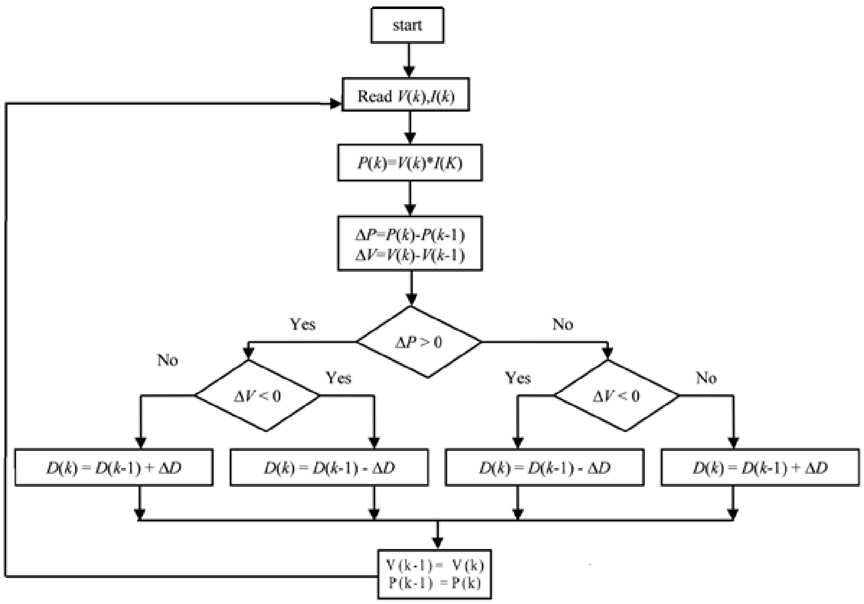

Figure 3. Chart of the algorithm P&O.

4. Results

The results of the MPPT and the speed of the DC motor are taken for a whole day.Figure 4 and figure 5present the climatic conditions on one day (temperature and solar irradiance).

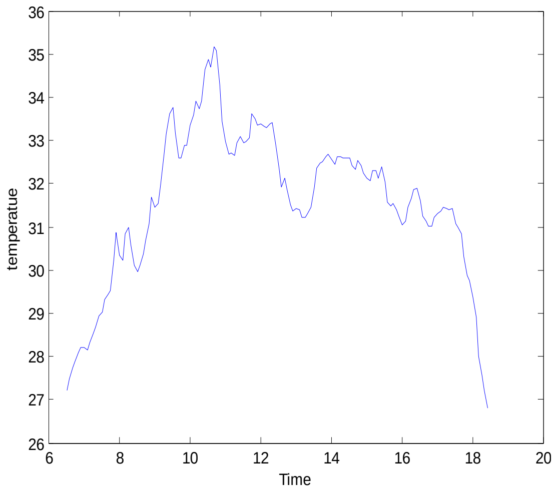

Figure 4. Temperature for the day.

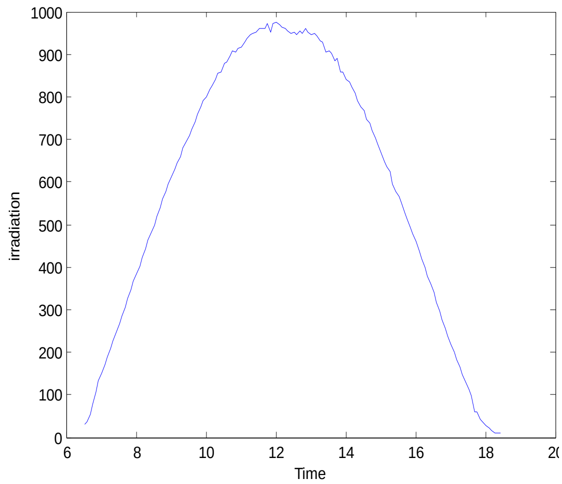

Figure 5. Irradiation for the day.

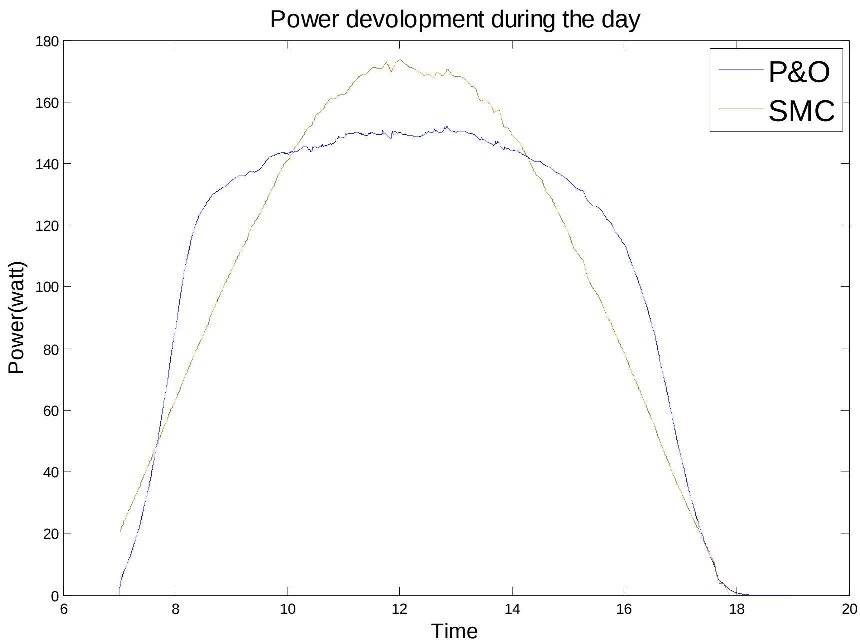

Figure 6. The Power for the day.

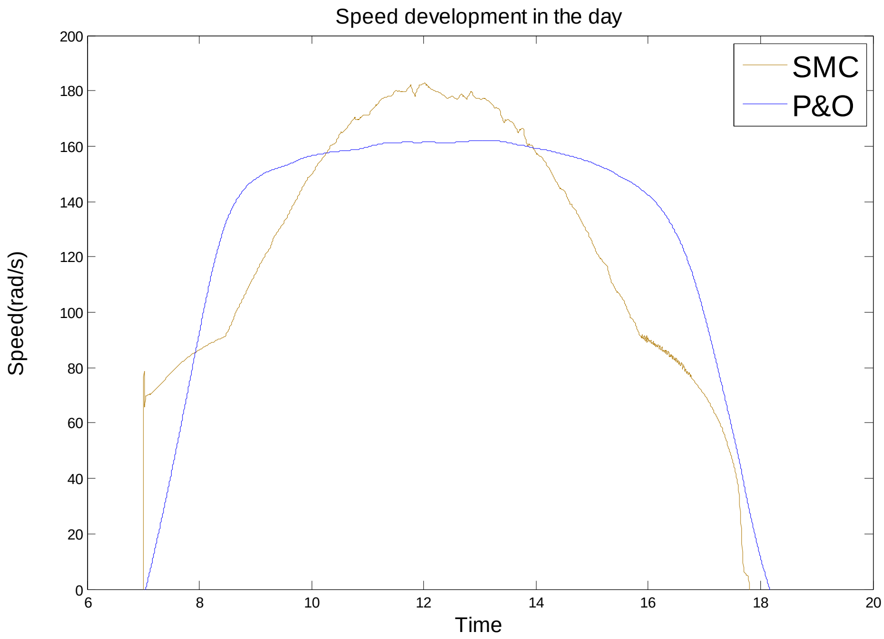

Figure 7. The DC motor speed for the day.

Figure6 and figure 7 represent respectively the development of the Power and the DC motor Speed during day.

5. Conclusion

This paper represents a comparison between two methods of control: P&O and sliding mode control which have been both designed and simulated for the proposed system.It is clear from the results that the sliding mode control gives better performance at tracking the maximum power point, therefore a higher speed for the DC motor and flow rate for the pump.

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