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Control of a photovoltaic system by sliding mode based on backstepping

Abstract *In this article we have studied photovoltaic systems which are non-linear systems. Due to variations in the current-voltage characteristics of PV systems. In fact, we have described the sliding mode method and then we have combined it with the backstepping method. We have applied it to a well-determined PV system. shows that the sliding mode method based on backstepping is more efficient than that of the basic sliding mode.*

Streszczenie. *W tym artykule badaliśmy systemy fotowoltaiczne, które są systemami nieliniowymi. Ze względu na różnice w charakterystyce prądowo-napięciowej systemów fotowoltaicznych. W rzeczywistości opisaliśmy metodę trybu ślizgowego, a następnie połączyliśmy ją z metodą cofania. Zastosowaliśmy to do dobrze określonego systemu fotowoltaicznego. pokazuje, że metoda trybu ślizgowego oparta na krokach wstecznych jest bardziej wydajna niż metoda trybu ślizgowego podstawowego. (**Sterowanie systemem fotowoltaicznym w trybie ślizgowym opartym na backsteppingu**)*

Keywords: Boost converter, maximum power point tracking, Sliding Mode Control, Backstepping.
Słowa kluczowe: Konwerter doładowania, śledzenie maksymalnego punktu mocy, sterowanie trybem przesuwania, krok wstecz

Introduction

World consumption of electricity has occurred in recent years is strongly linked to the development of industry, transport and means of communication. Today, a large part of electricity production is produced from non-renewable resources such as coal, natural gas, oil and uranium. This will lead to a non-zero risk of depletion of these resources in the more or less short term [1]. This observation encourages the search for more and more innovative solutions to overcome the energy deficit and limit the negative impact on the environment. Thus, the development of non-polluting sources based on renewable energy is increasingly requested by both energy producers and public authorities.

Indeed, photovoltaics is considered a renewable energy source due to several advantages, including low operating cost, almost maintenance-free and environmentally friendly. Despite the high cost of solar modules, PV power generation systems have been commercialized in many countries due to its potential long-term benefits [2]. Moreover, financial schemes, for example feed-in tariff [3] and subsidized policies [4], have been implemented by various countries, resulting in rapid growth of the industry. To optimize the use of large arrays of PV modules, the Maximum Power Point Tracker (MPPT) is normally used in conjunction with the power converter (DC-DC converter and/or inverter). The objective of MPPT is to ensure that the system can always harvest the maximum power generated by the photovoltaic generators.

On the other hand, the control of nonlinear systems constitutes a very active field of research. The controls of advanced methods developed by several researchers (adaptive controller, predictive control, robust control, etc.) make it possible to meet the requirements of a certain number of highly non-linear systems such as photovoltaic systems. The development of a control strategy must ensure not only stability but also robustness in the presence of disturbing phenomena. These can be of an external nature (influence of the environment) or of an internal nature (errors of modeling or approximation). It is in this same niche that the methods of modeling and control by Sliding mode are positioned [5].

In this paper, the tracking of the maximum power point of our PV system has been studied for different irradiation variables. Our PV system consists of a photovoltaic panel, a Boost DC-DC converter, an MPPT control and a resistive load.

This article presents a study of a new command, the sliding mode command, optimized by the backstepping method.

We used this command to control the DC-DC converter using Matlab Simulink. In the following, we will present a modeling of the DC-DC boost converter. Next, we will describe the MPPT SMC command as well as the Backstepping command. And finally, our contribution is the combination between the two commands to improve the performance of the sliding mode method.

Modeling of the proposed system

As shown in Fig.1, our system consists of a Photovoltaic panel, a Boost converter controlled by the MPPT command and a resistive load [1].

Internal model control is based

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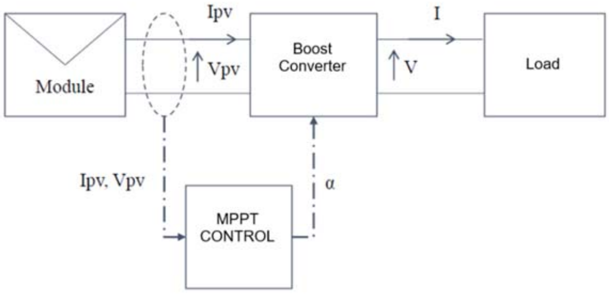

Fig.1. PV System

Where: Ip: the output currents of the PV system ; ; Vp: the output Voltage of the PV system; Vs: the output Voltage of the Boost converter

Boost converter

The average model is an approach allowing to model the converter by a continuous linear system [6].

The average model is obtained by considering the average of the two equations of state over a chopping period. Each circuit configuration of a converter is represented by a continuous linear model.

The mathematical expressions of the continuous dynamics are obtained by applying Kirchhoff's laws which describe the behavior of the converter in each of the configurations. The input of the models is the supply voltage Ve and the control variable is the duty cycle.

(1) $$\begin{cases} \dot{x} = A_1 x + B_1 V_e \\ y = C_1^T x \end{cases} \quad pour\ u = 1$$

If the switch is open

(2) $$\begin{cases} \dot{x} = A_2 x + B_2 V_e \\ y = C_2^T x \end{cases} \quad pour\ u = 0$$

Where x represents the state vector, Ve the input voltage and y the output to be controlled. The model called average model is then obtained by averaging the two state equations with the duty cycle d, which gives a single state representation [7].

(3) $$\begin{cases} \dot{x} = Ax + AV_e \\ y = C^T x \end{cases}$$

Or

(4) $$\begin{cases} A = dA_1 + (1-d)A_2 \\ B = dB_1 + (1-d)B_2 \\ C^T = dC_1^T + (1-d)C_2^T \end{cases}$$

The validity of this model is only assured if the cut-off frequency fc of the system is much lower than the switching frequency f (fc/f <<1) [9]. This representation considers, of course, the state vector x and the input Ve, but also d.

The duty cycle then becomes the input to the system in the sense of the command. This representation is nonlinear and is more precisely bilinear: product of the state vector with the command and the input voltage with the command [10].

A linear model can therefore always be obtained by linearizing the latter around a point of equilibrium (steady state). Let us denote each variable as the sum of a permanent value (DC component) and a variation around this value (AC component) noted with a hat, for example.

(5) x (t) = x(t) + xˆ(t)

Steady state is calculated by taking xˆ(t) = 0, ce qui donne.

(6) $$x = -A^{-1}BV_e$$

And

(7) $$y = -C^T A^{-1} B V_e$$

Provided that the matrix A is invertible. Ve represents the value of the supply voltage in steady state and the matrices A, B and C are expressed as a function of the value of the duty cycle at equilibrium d et d ' =1-d:

(8) $$A = dA_1 + d'A_2$$

(9) $$B = dB_1 + d'B_2$$

(10) $$C^T = dC_1^T + d'C_2^T$$

- Ideal Boost Converter

Structure

The electrical circuit of the Boost converter is shown in fig.2:

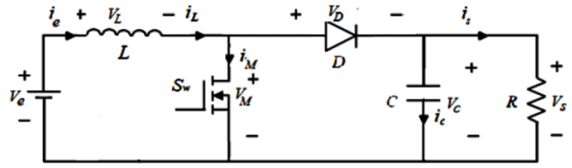

Fig.2. Boost Converter Schematic

In a Boost converter, the input source is a current source and the load is a voltage load [9].

Principle of operation

The switch is closed during the fraction dT of the chopping period T. The current in the inductance increases gradually, it stores energy, until the end of the first period. When the transistor is blocked, the diode ensures the continuity of the current in the inductor.

The energy stored in this inductance is then discharged into the capacitor and the load resistor.

- Instant model

The equivalent circuit of the Boost converter is shown in fig.3.

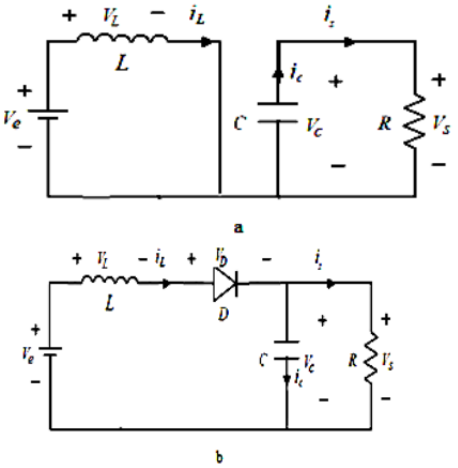

Fig.3. Boost converter equivalent circuits: (a) Sw closed, (b) Sw open.

Over the interval t 0 <t <t 0 +dT , Sw is closed and D is blocked. We obtain:

(11) $$l\frac{di_L}{dt} = V_e$$

And

(12) $$C\frac{dV_c}{dt} = -\frac{V_c}{R}$$

The linear model which represents the first configuration of the circuit described in fig.3.a is given by:

(13) $$\begin{bmatrix} \frac{di_L}{dt} \\ \frac{dV_C}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ V_C \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_e$$

Over the interval t_0 +dT < t<t_0 +T, S_w is open, diode D is on. We obtain:

(14) $$l\frac{di_L}{dt} = V_e - V_c$$

And

(15) $$C\frac{dV_C}{dt} = i_L - \frac{V_C}{R}$$

The linear model which represents the second configuration of the circuit described in fig.3.b is given by:

(16) $$\begin{bmatrix} \frac{di_L}{dt} \\ \frac{dV_C}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ V_C \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_e$$

- Medium model

The general average model equation that governs the operation of the Boost converter is:

(17) $$\begin{bmatrix} \frac{di_L}{dt} \\ \frac{dV_c}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{(1-d)}{L} \\ \frac{(1-d)}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_e$$

Sliding Mode Control (SMC)

Sliding mode control (SMC) is a multivariable control that has the advantage of being able to be applied without approximation to nonlinear systems with discontinuities (i.e. VSS, variable structure systems). Since the operation of the choppers is based on switching, this command seems a priori particularly suitable for controlling the photovoltaic generator. We will detail the theoretical principles and methods of application.

We want to apply a command to a system that can be nonlinear and present discontinuities, expressed in a state model by:

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

Or

$x \in R^n$ is the state vector, and $x \in R^m$ the command input.

Principle of sliding mode

This method then consists of approximating the output value of the system and making the system evolve along the sliding surface using a discontinuous command. There are two categories of slip mode.

The system tends towards the switching surface shown in Fig.4 and slips on this surface which implies that the system has reached the hyper slip surface.

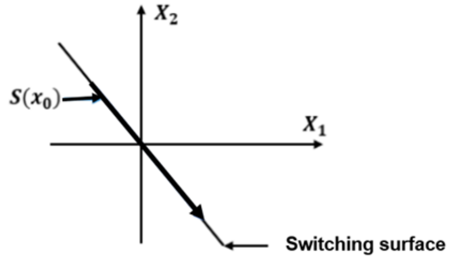

Fig.5. Ideal sliding mode

MPPT control of a PV system by sliding mode

The PPM maximum power point condition is given by:

(19) $$\frac{dP_{pv}}{dV_{pv}} = 0$$

Here Ppv, Vpv, Ipv is the power, voltage, and current of GPV The first step in designing the control is choosing the switching surface, which can be chosen as follows:

(20) $$S(x) = \frac{dP_{pv}}{dV_{pv}} = I_{pv} + V_{pv}.\frac{dI_{pv}}{dV_{pv}}$$

If the operating point is to the left of the PPM, the control must move it towards the sliding surface by increasing the voltage, this is only possible if, on the other hand, if the operating point is to the right of the PPM, the control must move it towards the sliding surface by decreasing the tension, and this is only possible if. For this, the switching control law adopted is that presented by the equation:

(21) $$u = \begin{cases} 1 & pour\ S > 0 \\ 0 & pour\ S < 0 \end{cases}$$

which can be written by:

(22) $$u = \frac{1}{2}\left(1 - sign(S)\right)$$

Hybrid control

Hybrid control Sliding mode-backstepping. In recent years, some lines of research have focused on approaches to hybrid control of DC-DC converters [11]. The hybrid aspect of a command is given by the simultaneous presence of two or more linear and non-linear techniques. Classically, hybrid controls switch between different operating modes where each mode is represented by its own dynamic law. Hybrid controls are predominant in the field of power electronics and in particular on DC-DC power converters which are characterized by a variable structure (due to the change of the circuit topology according to the on or off states of the transistors and diodes) [12].

This part presents the sliding mode method to optimize with the backstepping command as seen previously the SMC method can better improve its performance, the parameters (S, λ) can be obtained using the BS method.

In this section, we develop a backstepping controller based on the sliding mode approach. We define the first and the second backstepping variable as follows:

(23) $$z_1 = x_1 = q_e = q_c q$$

(24) $$z_2 = x_2 - \alpha_1$$

(25) $$x_2 = \omega_s^0$$

α_1 is a virtual control law.
The sliding surface is defined as follows:

(26) $$S = \dot{q_e} + w q_e$$

We consider the following Lyapunov functions.

(27) $$V_1(z_1) = \frac{1}{2} z_1^T z_1$$

(28) $$V_2(z_1, z_2) = V_1(z_1) + \frac{1}{2} S^T S$$

The derivative of V_2 with respect to time is expressed by:

(29) $$\dot{V}_2 = z_1^T \dot{z}_1 + S^T \dot{S}$$

We choose the derivative of the surface which satisfies the condition $\left(S^T \dot{S} < 0\right)$as follows

(30) $$\dot{S} = -\alpha_1 sat(S) - \beta_1 S = q_c \ddot{q} + W q_c \dot{q}$$

Simulations Results

In this paper we have studied the convergence and the speed of the sliding mode method based on backstepping. We simulated our system using MATLAB/Simulink® software for different irradiations and a constant temperature equal to 25°C.

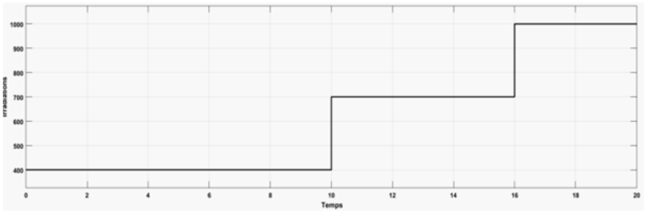

Fig.6. The different irradiation values

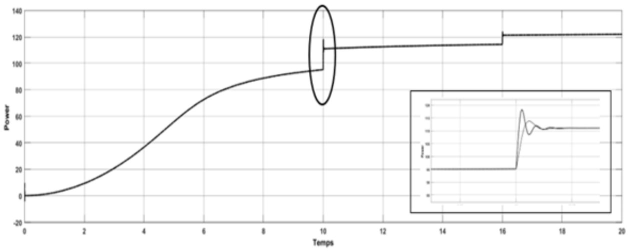

Fig.7. Optimum power of the PV system for varying conditions of irradiation

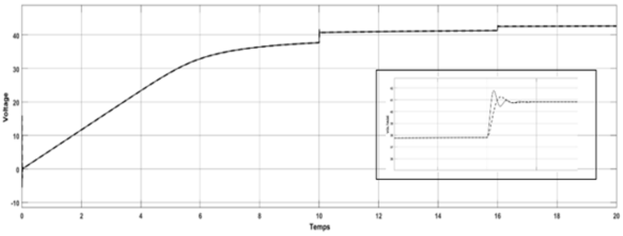

Fig.8. Optimum voltage of the PV system for varying conditions of irradiation.

After the simulation we find that the SMC method gives us an acceptable result from a stability point of view. But if we compare it with the SMC method based on backstepping we conclude that the latter is more efficient and faster.

Conclusion

After the simulation we find that the SMC method gives us an acceptable result from a stability point of view. But if we compare it with the SMC method based on backstepping we conclude that the latter is more efficient and faster.

In this paper we have manipulated a new method called SMC method based on backstepping after having presented the basic SMC method. We used his two methods to extract MPPT from the energy from the PV panel.

We find that the SMC method when combined with BS became faster and more stable.

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