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A new maximum power point method based on a sliding mode approach for solar energy harvesting

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HIGHLIGHTS

- Create a simple, easy of implement and accurate V_{MPP} estimator.
- Stability analysis of the proposed system based on the Lyapunov's theory.
- A comparative study versus P&O, highlight SMC good performances.
- Construct a new PS-SMC algorithm to include the partial shadow case.
- Experimental validation of the SMC MPP tracker.

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ABSTRACT

This paper presents a photovoltaic (PV) system with a maximum power point tracking (MPPT) facility. The goal of this work is to maximize power extraction from the photovoltaic generator (PVG). This goal is achieved using a sliding mode controller (SMC) that drives a boost converter connected between the PVG and the load. The system is modeled and tested under MATLAB/SIMULINK environment. In simulation, the sliding mode controller offers fast and accurate convergence to the maximum power operating point that outperforms the well-known perturbation and observation method (P&O). The sliding mode controller performance is evaluated during steady-state, against load varying and panel partial shadow (PS) disturbances. To confirm the above conclusion, a practical implementation of the maximum power point tracker based sliding mode controller on a hardware setup is performed on a dSPACE real time digital control platform. The data acquisition and the control system are conducted all around dSPACE 1104 controller board and its RTI environment. The experimental results demonstrate the validity of the proposed control scheme over a stand-alone real photovoltaic system.

1. Introduction

The fluctuations of rising oil prices and increasingly worrying degree of pollution contrasted with the new provisions of sustainable development make alternative and renewable energy sources more attractive. Economic incentives and huge advancement in electronic technology promote the use of photovoltaic systems. These systems present a simple and convenient solution from an economic point of view. The use of a converter on these photovoltaic systems is even more compelling as it increases their efficiency and reduces their costs.

This work analyses the control of a stand-alone PV system. The success of a PV application depends on weather conditions where the power electronic devices help to increase the efficiency of the PV generator (PVG). Extracting maximum power from the PVG is a challenge. Maximum power point tracking (MPPT) controller accuracy is a key control in the device operation for successful PV applications. In general, a PV system is typically built around the following main components as shown in Fig. 1:

(1) PVG that converts solar energy into electric energy.
(2) DC–DC converter that manipulates produced DC voltage by the PVG to feed a load voltage demand.
(3) Digital controller that drives the converter commutations accordingly to a MPPT capability.
(4) A load.

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Nomenclature

G, G_{ref}	global, reference insulation (W/m^2)
I_p, V_p	cell output current and voltage
R_p, R_s	cell parallel and series resistance (Ω)
n, Eg	solar ideal factor and band gap energy (eV)
Irs	reverse diode saturation current (A)
K_{SCT}	short circuit current temperature (A/K)
T_c, T_{c_ref}	cell junction and Reference temperature (°C)
β, D	Boltzmann constant (1.38e−23) and duty cycle
Ns, Np	number of series and parallel modules
ns	number of series cells
k'	PS-SMC crisp value

In general, the MPPT control is challenging because the conditions that determine the amount of sun energy into the PVG may change at any time. As such, the PV system can be considered as non-linear complex.

Numerous MPPT methods have been developed and implemented in previous studies including [1], perturb and observe (P&O) [2], incremental conductance (Inc-Cond) [3], fractional open-circuit voltage and short circuit current [3], fuzzy logic controller (FLC) approaches [4], and Adaptive neuro fuzzy inference system, etc. [5]. These algorithms consist of introducing a crisp value, positive or negative (decrease or increase), all around the actual PVG operating point. From the previous power point position, the trajectory of the new command value helps the algorithm to decide on the command output value. These techniques have high tracking accuracy under stable conditions. It however still reveals some trade-offs between tracking speed and tracking reliability when load values or weather conditions rapidly change.

The sliding mode controller has recently attracted considerable attention from researchers due to several advantages [6,7], the main advantage of the SMC is its implementation simplicity, robustness, and great performance in different fields such as robotics [8] and motor control [9]. This work interest focused on the use of SMC in the photovoltaic fields by maximizing the power generated from the PV panels while maintaining the system stability.

This paper proposes a new design of stable SMC for PV system control. The proposed control methodology is built into two steps in order to control a PV system. The first step consists of an estimator synthesis of V_{ref}. This last corresponds to the (MPP) working voltage $V_{ref} = V_{MPP}$. The second is to perform the system tracking based on the developed SMC regulator for a boost converter and according to the estimated voltage value.

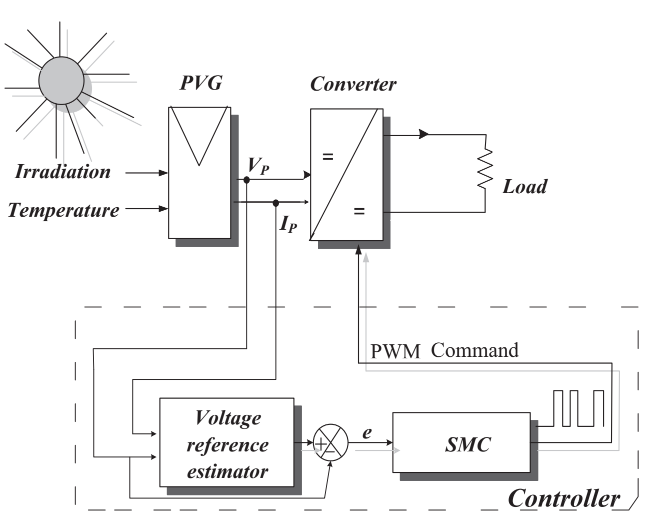

Fig. 1. Synoptic diagram of PVG system.

In previous work [5], the (V_{ref}) value can be provided only after the drawing of panel characteristics; however, this value will be valid only for a short period, so any change in weather will cause a change in its characteristics and as a result a change in the value of V_{MPP}. This method, as consequence, is valid only after determination of the right value of V_{MPP} [10,11]. The main objective in this work is to construct an MPP voltage-reference estimator that meets the MPP. The estimator is designed specifically in order to compute on-line the optimal voltage value V_{MPP}. In this paper, the proposed SMC uses the error between the measured voltage of the PV module and the voltage generated by the voltage reference estimator to adjust continuously the duty cycle (D) of the DC–DC Boost converter in order to eliminate this error. The reference voltage value is generated online with no need to know the actual irradiation. The PV system topology proposed is shown in Fig. 1. As shown in Fig. 1, the SMC algorithm directly generates the PWM signal. It has the benefit of avoid the use of the PWM commutation signal (Saw signal). It also permits the direct building of a PWM output signal toward the converter IGBT Gate. The SMC overcomes the limitations with other algorithms such as P&O [12] and Inc [13] which generates a duty cycle control value comparable to saw signal to uphold a PWM IGBT drive signal.

The performance of a photovoltaic module is highly affected by the partial shaded condition [14]. The PVG under partial shading makes maximum power point (MPP) tracking difficult; generally, there will exist multiple local MPPs, and their values will change as rapidly as the illumination [15]. Finding a solution to this problem ensures PVG power reliability and strengthens its economic rationale. Installers have an interest in resolving this issue. Many installers carefully design installations to avoid structural shading [16]. Installers could make a relatively effective strategy in order to avoid partial structural shading by carrying out a precise study of the proposed photovoltaic (PV) site of installation. The loss of energy caused by the PS is difficult to predict because it depends on several variables including internal module-interconnections [17].

Researchers and engineers developed an electronic solution to this problem by identifying and harvesting the maximum power of each panel individually using power optimizer technology [18], however, this method increases the cost of the installation. In addition, most MPPT are not able to get the maximum power point under these conditions.

Unconventional techniques have been recently widely used in literature for PS condition; authors in [19] use an MPPT managed by an adaptive neuro fuzzy inference system. Researcher in [20] uses ANN as an MPPT method for shading conditions. Although ANN and ANFIS have a good performance, they also present some drawbacks especially in rapid variation. Therefore, its robustness requires a huge database and consequently a long computing time and a large amount of memory. A speed/accuracy trade-off is therefore inevitable [21]. As a solution to this problem, the PS-SMC algorithm is proposed as the simple solution that is easiest, quicker, and most effective.

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