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Achievement of MPPT by finite time convergence sliding mode control for photovoltaic pumping system

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ABSTRACT

In this paper, a new finite time stability approach is proposed for controlling the Maximum Power Point Tracking (MPPT) process. This approach is based on variable structure sliding mode technique. While standard Sliding Mode Control (SMC) forces the system to converge to the reference value in infinite time, the proposed method, Finite Time Sliding Mode Control (FTSMC), ensures the convergence in a given finite time. As a result, FTSMC ensure a fast error tracking capability. For the validation of this strategy, a Photovoltaic (PV) water pumping system is considered and intended to maintain this system operating at Maximum Power Point (MPP). A DC/DC power converter is inserted between the Photovoltaic Generator (PVG) and DC motor by the duty cycle, which is considered to be the control variable. Some simulation results are given for comparison with standard SMC and Perturb and Observe (P&O) methods.

1. Introduction

Electricity generation from renewable energy sources (e.g. solar, wind…) is the most effective step towards an eco-friendly sustainable society. The use of photovoltaic as power source for pumping is considered as one of the most promising areas of PV application. The efficiency of the PV pumping system depends on several climatic factors such as: the solar insolation, the ambient temperature and the state of the solar panels (Hamrouni et al., 2008). However, to increase the efficiency of PV, the system must operate at MPP (Premrudeepreechacharn and Patanapirom, 2003). The MPP can be tracked through different MPPT algorithms, which control the switching converter in order to obtain the maximum power under different conditions (Daoud and Midoun, April 2010; Petrone et al., 2012; Reisi et al., 2013).

However, the position of the MPP in the I–V curve is not known as priority. It should be located, by complete model calculations or by a search algorithm. The situation is further complicated by the fact that the MPP depends on a nonlinear way on insolation and temperature, the curves show easily nonlinear characteristics which are solidly influenced by ambient changes (Brito et al., 2011).

MPPT works as an embedded system (combination of hardware and software) in which DC-DC converter works as hardware part, and control algorithm acts as software part of MPPT. This combination defines the efficiency of PV system (Coelho et al., 2012). In fact, the MPPT problem is to adjust the PV operating point, such that the PV power supplied by the PV system is maximized. In the presence of modelling errors, electrical noise, external disturbances and model parameter variations, the characteristic curve of a photovoltaic solar cell, which is the fundamental element of the PV system, exhibits a nonlinear current-voltage characteristic, and then an effective MPPT scheme, which ensures a robust and accurate tracking, should be designed. There are many MPPT methods that have been proposed in the literature, some of them are based on the well-known principle of (P&O) Villalva et al., 2009; Elgendy et al., 2012, on SMC method (Miao et al., 2004; Arteaga Orozco et al., 2010), artificial neuronal networks (Ramaprabha et al., 2009), the fuzzy logic (Kottas et al., September 2006), the genetic algorithm (Salam et al., 2013; Chaouachi et al., 2010) and evolutionary algorithms (Ishaque and Salam, 2011), which due to its capability to handle non-linear objective functions.

The P&O is the most widely used algorithm due to the simplicity of practical implementation. Its main advantages are simple structure and ease of implementation. But it has limitations that reduce efficiency of MPPT. In the lower solar irradiance cases, it is difficult to determine the exact location of MPP, and the output power is oscillating around the MPP reducing the generated power and material time life due to vibrations (Egiziano et al., 2006; Femia et al., 2005; Kamala Devi et al., 2017).

Abbreviations: MPP, maximum power point; PV, photovoltaic; MPPT, maximum power point tracking; DC, direct current; P&O, perturbation and observation; SMC, sliding mode control; FTSMC, finite time sliding mode control; PVG, photovoltaic generator; MOSFET, metal oxide semiconductor field effect transistor

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Sliding mode control is one of the effective nonlinear robust control approaches. It provides system dynamics with an invariance property to uncertainties, once the system dynamics are controlled in the sliding mode (Utkin, 1993; Astrom and Wittenmark, 1995; Antonio Cortajarena et al., 2017; Kchaou et al., 2017). The first step of sliding-mode control design is to select a sliding surface that models the desired closed-loop performance in state space variable. Then, design the control which forces the system state trajectories towards the sliding surface and stay on it. The advantages of this control are various and important such as high precision, good stability, simplicity, invariance and robustness (Slotine and Li, 1991; Chiu et al., 2012).

The design of control law is a very important problem in control systems. Robust tracking controllers based on the SMC scheme have been proposed in Dahhani et al. (2016), Jouni et al. (2007), Ameziane et al. (January 2013), Yatimi and Aroudam (2016). These control laws can achieve asymptotic stability and provide good tracking results. However, these controllers were designed based on an asymptotic stability analysis which implies that the system trajectories converge to the equilibrium with infinite settling time. Finite time control usually demonstrate superior properties, such as faster convergence rate, higher accuracy, better disturbance rejection property and robustness against uncertainties (Wang et al., 2012; Du et al., 2011; Farkous and Tissir, 2016). Although, many research papers dealing with MPPT problem have been stated, there is no results in the literature that can guarantee the convergence of the power to the maximum neighbourhood in a pre-specified finite time. This motivates our work.

The main idea of this research paper is to design a controller based on FTSMC concept, so the tracking errors of a photovoltaic pumping will converge to zero in pre-specified finite time T_f. Therefore, photovoltaic power converges to its maximum value in the pre-specified finite time T_f. A comparison between FTSMC, SMC and P&O is carried out to ensure the robustness of the developed method. Simulation results show that the proposed approach gives better performance, faster and higher-precision tracking performance.

This paper is organized as follows: the introduction is in the Section 1, whereas the Section 2 presents a description and mathematics modelling of photovoltaic pumping system. The Section 3 describes a sliding mode control approach. In Section 4, the proposed method FTSMC is presented. Finally, the paper is ended by simulation results and conclusion.

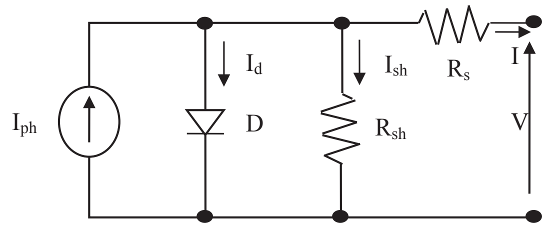

Fig. 2. PV Cell.

2. Description, mathematics modelling of photovoltaic pumping systems and problem statement

The PV studied system is composed by a PV generator, DC/DC converter, DC motor and a centrifugal pump (shown in Fig. 1), the MPPT is insured by the control unit through the DC/DC duty cycle.

2.1. Photovoltaic generator model

The PV cell can be represented in Fig. 2:

The characteristic of PV cell is given by, Reisi et al. (2013), Zhao et al. (2015), Yıldıran and Tacer (2016):

$$I_p = I_{ph} - I_o[\exp(A(V_p + R_s.\ I_p)) - 1] - \frac{V_p + R_s.\ I_p}{R_{sh}} \tag{1}$$

With:

$$I_{ph} = [I_{SC} + K_I(T - T_r)]\frac{\lambda}{1000} \tag{2}$$

$$I_o = I_{or}\left[\frac{T}{T_r}\right]^3\left[\exp\left(\frac{qE_{GO}}{\gamma k\left(\frac{1}{T_r} - \frac{1}{T}\right)}\right)\right] \tag{3}$$

$A = \frac{q}{\gamma NKT}$

I_{ph}: generated photocurrent (A).
I_o: Cell reverse saturation current (A).
I_{SC}: Short circuit current (A) at 1 kW/m^2 and 298.15°K.
I_{or}: Cell saturation current (A) at T_r.
R_s: Internal PV cell series resistance (Ω).
R_{sh}: Internal PV cell parallel resistance (Ω).
K_I: Temperature coefficient (°K) at I_{SCR} (short-circuit current at reference condition).

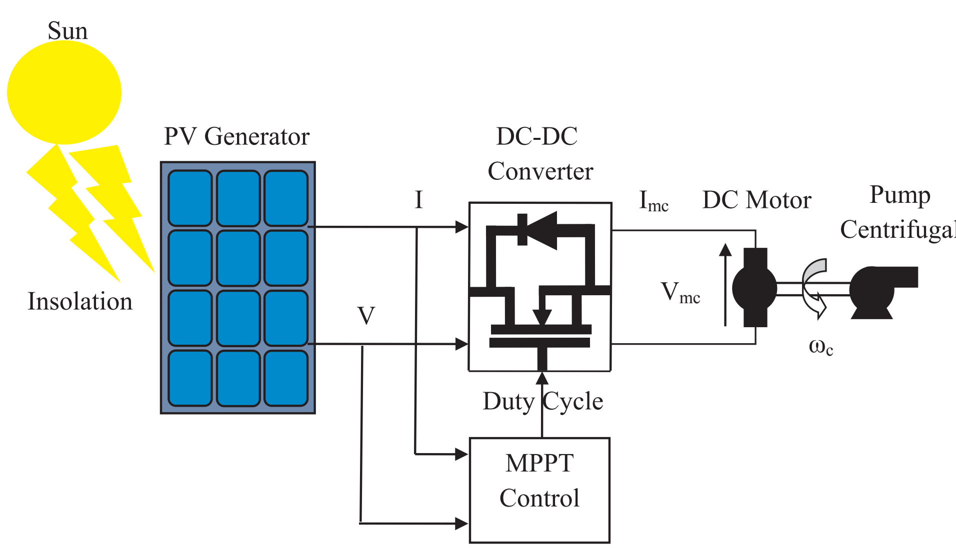

Fig. 1. Block diagram of PV pumping system.