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Novel current sensing photovoltaic maximum power point tracking based on sliding mode control strategy

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Abstract

A novel maximum power point tracking method based on a sliding mode control strategy is proposed to harvest the maximum power from solar panels more effectively by controlling the duty cycle of DC–DC buck converter to which they connect. This method utilises a sliding mode strategy to achieve fast tracking speed and reduced oscillation at steady state. Furthermore, unlike most of other methods which require feedback signals from both voltage and current sensors, this method only requires current feedback information to generate control actions; so reducing the capital cost and the complexity of the system. The system modelling, development of the sliding mode control method, definition of the sliding surface and an analysis of stability are presented in this paper. Numerical results demonstrated that compared with conventional perturbation and observation method, a much faster tracking speed and efficiency improvement up to 5% can be achieved.

Keywords: Sliding mode control; Photovoltaic system; Maximum power point tracking; Current sensor based

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1. Introduction

Global renewable energy demand has been increasing steadily. According to REN21 (2013), the percentage of renewable energy supply continued to rise throughout 2011 and 2012, supplying 19% of global final energy consumption, despite the international economic crisis. Among many renewable energy technologies, solar energy has the fastest average growth rate in the last five-year period. In 2012, the total global operating capacity of solar photovoltaic (PV) reached the 100 GW milestone, with total capacity of solar PV growing at rates averaging 60% annually since the end of 2007.

Solar cells typically possess a strong nonlinearity in their power characteristic behaviour. There exists a single operating point called the maximum power point (MPP), at which maximum power output is delivered under certain solar irradiation and cell temperature conditions. The positions of the MPP are dependent on the type of PV cells and are also strongly dependent on weather conditions. Hence prediction of the variation in MPP would be difficult because of the many varying and complex physical processes involved. As a result, if directly connecting PV cells to a load, there is the possibility that a mismatch occurs between current and voltage characteristics of the load and the MPP. Thus, tracking this point accurately becomes an important task in solar PV application, not

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only increasing the efficiency of the overall plant, but also reducing the number of panels required for a particular load demand, and ultimately reducing the capital cost (Hohm and Ropp, 2000). Several MPPT techniques have been proposed, including fractional method, perturbation and observation (P&O) method, incremental conductance (INC) method, intelligent control strategy such as fuzzy logic, neural network, extremum seeking control method, and other hybrid methods, as reviewed in Esram and Chapman (2007), Reza Reisi et al. (2013) and Subudhi and Pradhan (2013).

Among the MPPT strategies listed above, P&O and INC methods are most commonly adopted due to their simple implementation and reasonable tracking performance, both employing hill climbing mathematical methods. Changes in power output as a result of small adjustments (perturbations) in the voltage of the solar panel are observed; if the power output increases, further adjustments in the same direction are made, until power output no longer increases. However, both methods suffer from oscillations in power output, especially at steady state. The step size of the voltage perturbations is clearly a compromise between tracking speed during the transient state and efficiency loss caused by oscillation at steady state. Larger perturbation results in faster tracking speed but incurs large oscillation at steady state and vice versa. Furthermore, the P&O method has been shown to track in the wrong direction under sudden changes in solar irradiation, especially when the effect on power output of the irradiance change is greater than the perturbation applied (Zhang et al., 2013; Liu et al., 2013).

Another feature of P&O and INC methods is that they require feedback signals from both voltage and current sensors in order to calculate the power output which they seek to maximise. The power acts as the measured variable, used to generate the control effort (signal) and hence control duty cycle of the power electronics. This may require memory and computational devices, increasing the capital cost and complexity of the plant.

Some hybrid methods exist (Moradi and Reisi, 2011; Moradi et al., 2013; Zhang et al., 2013), which when integrated with predictive and/or adaptive strategies are claimed to have greater efficiency. However, such methods are frequently complex and may require considerable knowledge in control system design which may not be widely available. Such complexity may further increase the computational burden on the plant.

Sliding mode control (SMC) is a nonlinear control strategy derived from variable structure system (VSS) theory. In VSS, the control is allowed to change the system structure by switching from one set of continuous functions of state to another at any instant (Utkin, 1977). By doing so, it is possible to combine useful properties of different control structures and can even be made to possess new properties not presented in any of the structures utilised.

In variable structure control, two objectives are achieved by utilising a high-speed switching control law. First of all, the state trajectory is driven onto a user defined (hyper) surface in the state space which is referred as the sliding surface. It will remain on this surface for all subsequent time thereafter. Variable structure control is so called because during this process, the control system varies its structure from one form to another. The term sliding mode control is used to emphasize the importance of the sliding mode (Liu and Wang, 2011).

This technique possesses several advantages such as simple implementation, robustness and good dynamical response (Bartoszewicz, 2011). This technique has been successfully applied to power electronics systems such as DC–DC converters.

SMC for PV power conversion systems has been studied by numerical means in De Battista and Mantz (2002), and further studies include Jimenez et al. (2008), Brea et al. (2010) and Jimenez-Brea et al. (2010).

Previous work employing SMC in MPPT has focused on the power and its relationship to current and voltage. The choice of the sliding surface is normally based on the relationship such as $\frac{dP_{pv}}{dV_{pv}} = 0$ (Chu and Chen, 2009) or $\frac{dP_{pv}}{dI_{pv}} = 0$ (Yau and Chen, 2012). Three sensors, two current sensors and a voltage are generally required for control signal generation. As in other work Alqahtani and Utkin (2012), those methods have been proved as effective ways for MPPT.

The aim of the paper is to develop a novel SMC scheme that is simple to implement but also possess excellent transient and steady state performance. Furthermore, the sliding mode strategy only required current as a measured variable, which reduced system cost and the computation burden further.

2. System configuration and modelling

2.1. Model of photovoltaic system

A photovoltaic system may be modelled based on an equivalent circuit which consists of a current source in parallel with a diode and a serially connected resistor

Table 1
Nomenclature.

I_{pv}	PV current
V_{pv}	PV voltage
I_p	Photo current
I_s	Reverse saturation current
V	Voltage applied on the diode
ε_i	Ideality factor
V_t	Thermal voltage ($V_t = k_B T/q$)
k_B	Boltzmann constant, $k_B = 1.38 \times 10^{-23}$ J/K
T	Absolute temperature of the diode
q	Electron charge, $q = 1.6 \times 10^{-19}$ C
R_s	Equivalent series resistance
E	Irradiation
K_o	Temperature coefficient of short circuit current
V_g	Band gap voltage
$\frac{dV}{dI_{V_{oc}}}$	Coefficient generated from manufacturers' data sheet
M_r	Reference value of corresponding parameter M which can be found from the manufacturers' data sheet