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ScienceDirect

Solar Energy 110 (2014) 325–337

SOLAR ENERGY

www.elsevier.com/locate/solener

Implementation of a modified incremental conductance MPPT algorithm with direct control based on a fuzzy duty cycle change estimator using dSPACE

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Received 8 January 2014; received in revised form 9 September 2014; accepted 10 September 2014

Communicated by: Associate Editor Arturo Morales-Acevedo

Abstract

Maximum power point tracking (MPPT) is a necessary function in all photovoltaic (PV) systems. The classic incremental conductance (IC) MPPT algorithm is widely used in the literature. However, when large changes occur in the irradiance, the performance of this algorithm is degraded. To eliminate all of the disadvantages of the classic IC algorithm, we developed a new IC controller based on a fuzzy duty cycle change estimator with direct control. A fuzzy logic estimator (FLE) is used to estimate the new duty cycle used to track the PV array maximum power point. Compared with the fixed step IC MPPT method with direct control, the proposed algorithm reaches the MPP more accurately and faster during dynamic and steady-state conditions. A controlled Cuk DC–DC converter was implemented and connected to a SunTech STP085B PV panel to verify the accuracy of the proposed method. Matlab/Simulink was used for the simulation studies. Additionally, the algorithms were digitally implemented on the dSPACE ACE1104 platform. The results obtained confirm the advantages of the proposed algorithm.

Keywords: Photovoltaic; Fuzzy logic estimator; MPPT; Incremental conductance; Cuk; Fixed step

1. Introduction

The petroleum crisis and the increasing demand for energy, coupled with the possibility of the reduced supply of conventional fuels, has motivated progress in renewable energy research and applications. Among renewable energy sources, solar energy is currently considered to be the most useful natural energy source because it is abundant, clean and distributed over the earth. Solar energy is a primary factor in all other processes of energy production on earth (de Brito et al., 2013).

Despite these advantages, the efficiency of solar energy conversion is currently low, and the initial cost for its implementation is still considered high (de Brito et al., 2013; Fairley, 2011).

The efficiency of solar cells depends on many factors, such as the temperature, insulation, the spectral characteristics of the sunlight and the presence of dirt and shadows (Bratcu et al., 2011; Jain and Agarwal, 2007; Ji et al., 2011). Rapidly changing atmospheric conditions can reduce the photovoltaic (PV) array output power.

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http://dx.doi.org/10.1016/j.solener.2014.09.014
0038-092X/

Due to these disadvantages, the efficient design of a PV system is necessary. Maximum power point tracking (MPPT) is well-established algorithm in PV applications to extract the maximum power from the PV panel, in order to achieve maximum power transfer on every operating condition the maximum power from a PV panel by achieving the maximum power transfer under every operating condition (de Brito et al., 2013; Yu et al., 2002).

Many MPPT systems have been proposed in the literature. Some of the proposed systems are simple, such as those based on voltage and current feedback. However, these systems require periodic disconnection or short circuiting of the PV modules to measure the open-circuit voltage or the short-circuit current for reference, resulting in greater power loss (Liu et al., 2008). Other MPPT algorithms are more complicated, such as the perturbation and observation (P&O) algorithm (Abdelsalam et al., 2011; Femia et al., 2005; Petrone et al., 2011; Teulings et al., 1993; Wasynczuk, 1983; Yang et al., 2010; Zegaoui et al., 2011) and the hill climbing (HC) and incremental conductance (IC) algorithms (Kish et al., 2012; Kjaer, 2012; Liu et al., 2008; Xiao and Dunford, 2004; Xuesong et al., 2010). These algorithms are widely used due to their easy implementation and high tracking efficiency. All of these methods are based on the general rule that dP/dV should be positive on the left, negative on the right and zero at the MPP. The P&O and IC methods introduce a perturbation in the operating voltage of the PV array. The hill climbing strategy introduces a perturbation in the duty cycle of the power converter and is more attractive due to its simplified control structure (Alajmi et al., 2011a). Faster and more accurate MPPT controllers, such as those using neural network (NN) and fuzzy logic methods, have been developed (Ben Salah and Ouali, 2011; Chaouachi et al., 2010; Chiu, 2010; Kottas et al., 2006; Liu et al., 2013; Messai et al., 2011; Punitha et al., 2013a, 2013b; Rajesh and Mabel, 2014; Veerachary et al., 2003; Wu et al., 2000). In general, MPPT fuzzy logic controllers provide good performance under varying atmospheric conditions and exhibit better performance than other control methods (Esram and Chapman, 2007). The main disadvantage of the fuzzy logic controllers is their reliance on the designer's knowledge of the system.

The conventional IC MPPT is based on two independent control loops. The first loop uses the incremental and instantaneous conductance to generate the error signal, and the second is the closed loop with a proportional-integral (PI) controller to drive the error to zero (Esram and Chapman, 2007). In (Safari and Mekhilef, 2011), an IC method with direct control is proposed where the second loop is eliminated, and the duty cycle is adjusted directly in the algorithm. The control loop is simplified, and the computational time for tuning the controller gains is eliminated. The IC MPPT algorithm with direct control is characterised by a fixed convergence step, this design is able to track the PV array maximum power, improves the efficiency of the PV system and reduces the power loss and the cost of the system.

Despite these advantages of the fixed-step-size IC MPPT method with direct control, the method has the following disadvantages:

1. The method converges slowly to the optimal operating point (when using a small step size).
2. The oscillations in the PV power around the MPP in the steady state cause system power losses (when using a large step size).
3. Under variable weather conditions, the operating point diverges from the MPP.

In this paper, a new IC MPPT algorithm is proposed using direct control based on a fuzzy duty cycle change estimator. We use the fuzzy logic estimator to estimate the duty cycle change in a Cuk converter. First, the disadvantages of the fixed step IC method with direct control are investigated. Next, we proposed a new method that is able to exploit the benefits of fixed step IC with direct control (Safari and Mekhilef, 2011) and eliminates all the disadvantages mentioned above. Finally, experimental and simulation results are presented to demonstrate the efficiency and the stiffness of the proposed MPPT algorithm compared to the fixed step IC method with direct control.

2. PV panel model

The basic structural unit of a solar module is the PV cell. The equation for the model of the photovoltaic cell involves the relationship between the output voltage, V_{cell}, and the current, I_{cell}. To increase the output power of the system, solar cells are generally connected in series and/or in parallel to form PV modules. The main equation for a module's output current is (Ismail et al., 2013).

$$I = n_p I_{ph} - n_p I_{rs}\left[e^{\left(\frac{q(V+R_sI)}{A\cdot k\cdot T\cdot n_s}\right)} - 1\right] - n_p\left(\frac{q(V+R_sI)}{n_s\cdot R_{sh}}\right) \quad (1)$$

where R_s and R_{sh} are the solar cell series and shunt resistances, respectively; I: PV module output current; n_p: number of cell strings connected in parallel; I_{ph}: cell photocurrent (proportional to the solar irradiation); I_{rs}: cell reverse saturation current; k: Boltzmann constant; T: temperature in degrees Kelvin; V: PV module output voltage; n_s: number of PV cells connected in series; and q: electron charge.

The cell photocurrent is calculated as follows:

$$I_{ph} = [I_{rs} + k_i(T - T_r)]\frac{S}{100} \quad (2)$$

where k_i: short-circuit current temperature coefficient; T_r: cell reference temperature; and S: solar irradiation in milliwatts per square centimeter.