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A novel maximum power point tracker based on analog and digital control loops

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Abstract

In this paper, a new maximum power point tracking (MPPT) system for photovoltaic applications is presented. The proposed system consists of two analog loops, a current and a voltage loop, built around a boost converter and a digital loop for the computation of the maximum power point. The analog loops provide a fast response to sudden changes of irradiance conditions while the digital loop, enhancing the accuracy, allows the implementation of various MPPT algorithms and facilitates the integration of additional control and monitoring features. Different existing systems are simulated and compared. A small signal model for the proposed system is developed and a novel compensation method is found. The compensation is designed in such a way that it makes the system independent of the input panel used and also of the load connected at the output. In order to have fast simulation results, a macromodel is developed allowing comparison between different algorithms. Furthermore the "perturb and observe" (P&O) algorithm is improved to obtain a better response for changing irradiance conditions.

Keywords: Solar panel; MPPT; Current loop; Voltage loop; Small signal model; P&O algorithm

1. Introduction

The economic reasons, environmental concerns and political implications are the main causes that led to the search for alternative ways of obtaining electrical energy. With global warming on the rise, it is natural that scientific research is more and more oriented towards renewable energies development. Photovoltaic (PV) energy has attracted more attention in the last few years as it meets the requirements of being environmentally compatible and resource conserving.

When connecting the solar array to the load, the solar panel characteristic has only one point where the panel provides the maximum power for the given environmental conditions (irradiance and temperature): it is called the maximum power point (MPP). Generally if the load is directly coupled with the solar array, the operation point does not coincide with the maximum power point. To fulfill the load demand, direct connection of the load to the solar array leads to over sizing the solar panels thus increases the cost of the entire system. To solve the problem, a DC–DC converter with an automatic duty cycle control is usually inserted between the solar panel and the load. The MPP computing system will modify the duty cycle and implicitly the input impedance of the converter until the system reaches the maximum power point.

There are multiple ways of achieving impedance matching for the solar panel to the load: a general diagram is presented in Fig. 1. The system is composed of a MPP

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computing system and a DC–DC converter. The DC–DC converter acts as an impedance matching circuit. The MPPT computing system measures the input voltage and the input current and computes the power in order to control the DC–DC converter input impedance (Yu et al., 2004). The storage device can be either a battery or a super capacitor.

For several years, research has been focusing on various MPPT control algorithms to draw the maximum power from the solar array. Among them, the "constant voltage control" method, the "perturb and observe" method with fixed and variable step sizes, the "incremental conductance" method and the "fuzzy logic" control have drawn attention (Yu et al., 2004). Various papers describe the advantages and disadvantages of these algorithms.

Two versions of the P&O algorithm are developed (Enrique et al., 2009; Leyva et al., 2006). The system development aims at simplicity, reliability and cost. The P&O method, also known as the "hill climbing method", presents oscillations around the MPP. This is not the only problem of this method. It is also hard to acquire the maximum power point in low irradiance conditions because the peak in the power characteristic (P–V) of the solar panel drops when the irradiance decreases. To solve the oscillations problem around the MPP, the incremental conductance algorithm can be used. In Tafticht et al. (2007) a Buck is used as DC–DC converter based on incremental conductance with variable step. After the MPP is reached, the step is reduced to a lower value to minimize the oscillations around the MPP. In Sokolov and Shmilovitz (2008), a method to accelerate the convergence time of conventional MPPT algorithms is presented. The power converter presented is controlled in such a way that it reflects a virtual load toward the PV array. The system then brings the operating point near the MPP and the fine tuning with P&O or incremental conductance is applied.

MPPT systems with fuzzy logic and neural networks control are presented in Hiyama et al. (1995a,b), Zhang and Bai (2008), Won et al. (1994), Pang et al. (2008). These methods need much more processing time and computational power than the classical control because of the necessity to find control rules for the maximum power tracker.

A comparison between the different types of classical algorithms with different power stages is presented in Hua and Shen (1998), Kerekes et al. (2006), Fermia et al. (2007), Nobuyoshi et al. (2006), Hohm and Ropp (2003), Esram and Chapman (2007).

After the study of the chaotic behaviour and the harmonics of nonlinear dynamics systems (in particular power converters), we are now interested in designing the maximum power point tracking system for photovoltaic applications (Morel, 2005, 2008).

This paper presents a new maximum power point tracker (Fig. 2) which improves the step response of the entire system based on the implementation of two analog loops together with a digital control one.

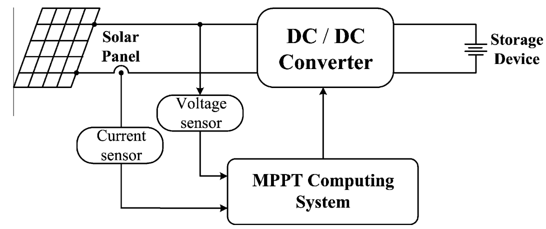

Fig. 1. Solar power system.

The paper also presents improved versions of the P&O algorithms tested with the new architecture. The proposed algorithms use a three step search tracking method to reduce the oscillations around the MPP. A small signal model of the system is determined and a compensation method is presented. The compensation method makes the system stability independent of the solar array and of the environmental conditions (irradiance and temperature). In order to reduce the simulation time, a macromodel of the new system is developed. The simulated results are then compared with the ones from the experimental development kit.

2. Simulation results

2.1. Solar panel model

The major factors that influence the electrical design of the solar arrays are: the sunlight intensity and the load connected to the system. Modeling the solar panel is necessary for an easy development of a MPPT system. The model is developed from Eq. (1) describing the PV cell equivalent circuit:

$$I_S = I_{ph} - I_D - I_{sh} = I_L - I_0 \cdot \left[\exp\left(\frac{V_S + I_S \cdot R_S}{a}\right) - 1\right] - \frac{V_S + I_S \cdot R_S}{R_{sh}} \quad (1)$$

where I_L is the short-circuit current of PV panel; I_0 is the saturation current of the diode; R_S, R_{sh} are the series and shunt equivalent resistances; a is a parameter that has to be determined by approximating the theoretical curve with the experimental one.

A solar panel model based on a general solar model of Fig. 3a and Eq. (1), developed in PSIM, is presented in Fig. 3b.

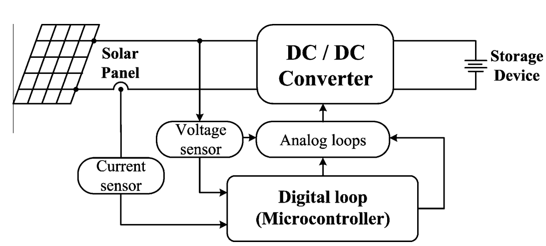

Fig. 2. Proposed system diagram.