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A photovoltaic panel emulator using a buck-boost DC/DC converter and a low cost micro-controller

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Abstract

In order to facilitate the design and testing of photovoltaic (PV) power systems, a PV emulator which models the electrical characteristic of a PV panel or array is needed. Among different approaches to modeling PV characteristic, namely the *I–V* curve, curve-fitting is a popular approach. Even though a single high-order polynomial equation may accurately represent the *I–V* curve, the process of derivation and implementation is rather complex. This paper hence proposes the use of piecewise linear approach which is easier to derive and implement in a low-cost micro-controller. A two-switch buck-boost DC/DC converter is selected as the PV emulator and is analyzed. Experimental results on a hardware prototype of the proposed PV emulator are reported to show the effectiveness of the approach.

Keywords: DC/DC converter; Photovoltaic; Micro-controller; Emulator

1. Introduction

The demand of photovoltaic (PV) power system installation has been increased over the past decade due to technological improvement, better environmental awareness, lowered system costs, governmental initiatives, rising electricity bills, etc. While these installed PV systems and products are operating properly, there are still ongoing issues to be investigated and solved. For example, reliability of PV power systems (Petrone et al., 2008), PV power generation analysis (Ishaque et al., 2011; Paraskevadaki and Papathanassiou, 2011) and electricity network performance (van der Borg and Jansen, 2003) due to partial shading, development of power electronics interfaces (Marsh, 2011, 2010), etc. All these research and development activities require a stable, repeatable and variable PV source for design and testing. Hence there is a need of a PV generator emulator.

The main task for a PV generator emulator is to reproduce the *I–V* curve of a practical PV panel. There are different approaches to performing this task. In Nagayoshi (2004), a p–n photodiode is used and a DC power amplifier increases the power level to match with that of a PV panel. However, this approach requires a light source and associated circuit to reproduce the *I–V* curves of a PV panel. In fact, a power electronics converter can mimic the *I–V* curve accurately with only a DC input voltage source (Mukerjee and Dasgupta, 2007). In Khouzam and Hoffman (1996), a AC/DC buck converter is used as the PV emulator to emulate a PV cell circuit model. However this approach requires the knowledge of the values of the parameters which are usually difficult to obtain. In fact, to model a PV panel, one may use the data available from the datasheet of the PV panel manufacturer and derive an analytical model to represent the *I–V* curves (Ortiz-Rivera and Peng, 2005).

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Look-up table and curve fitting are two popular approaches to implementing *I–V* curves of a PV panel by the power electronics converters. Look-up table would require a large memory storage of the micro-controller as large amount of panel data is stored if many *I–V* curves at different conditions and with high accuracy are implemented. Hence to implement look-up table in a low cost micro-controller which has limited memory space is usually difficult. Curve-fitting approach in general uses one or more polynomial equations to model an *I–V* curve and needs a digital controller with fast computational speed to find the solution. While this method requires less memory space, the non-linearity of the *I–V* curve requires the equations to be of higher orders which may increase the computational time substantially. A powerful DSP controller is usually needed to produce very fast and accurate results (Zhang and Zhao, 2010). Also the derivation process of the polynomial equations for different conditions such as insolation and temperature is rather troublesome. In order to use curve-fitting efficiently on a low-cost micro-controller, this paper introduces a PV emulator using multiple simple linear equations to mimic an *I–V* curve of the PV panel. This approach reduces computational time while maintaining sufficient accuracy and can be implemented in a low-cost 8-bit micro-controller. The paper is organized as follows: Section 2 describes the circuit and operation principle of the proposed PV emulator. Section 3 reports the experimental results of the emulator which models a BP Solar SX-10 PV panel. Section 4 discusses the limitations of the emulator and followed by the conclusions in Section 5.

2. Description of the PV emulator

2.1. System overview

The PV emulator, as shown in Fig. 1, consists of a DC input source, V_{in}, a DC/DC converter for shaping the output *I–V* curves of the PV panel, a micro-controller for sensing the output voltage v_{pv} and current i_{pv}, calculation and sending duty cycle command, and a gate driver for amplifying the incoming duty cycle command suitable for driving the power transistor (MOSFET in this case). The output load R_L is modeled as a variable resistor to represent an equivalent resistance of a maximum power point tracker (MPPT).

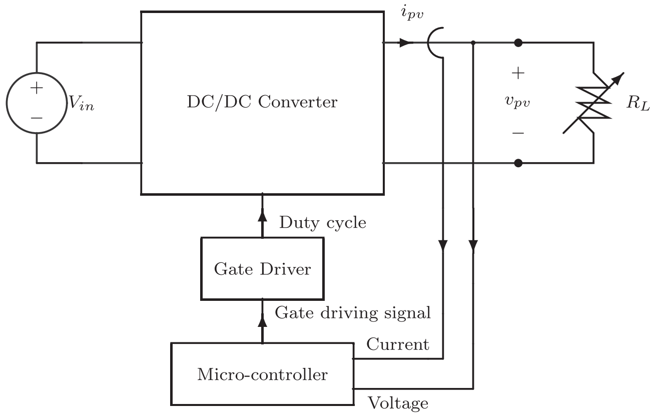

Fig. 1. Block diagram of the PV emulator.

2.2. Mathematical modeling of a PV panel

Apart from measuring an actual PV panel, one can also use an analytical model to represent the data in the datasheet from the manufacturer to obtain the *I–V* curves of a specific PV panel. In Ortiz-Rivera and Peng (2005), the authors have generated an analytical model for a PV panel which is adopted in this paper:

$$I(V) = \alpha \cdot I_{max} \cdot \tau_i \cdot \left[1 - exp\left(\frac{V}{b(\alpha \cdot \gamma + 1 - \gamma)(V_{max} + \tau_V)} - \frac{1}{b}\right)\right] \quad (1)$$

where α is the percentage of effective intensity of the light, b is the characteristic *I–V* curve constant, γ is the shading linear factor, τ_i is the rate of change with the temperature for the current (A/°C), τ_V is the rate of change with the temperature for the voltage (V/°C) and I_{max} is the ideal maximum current (when $V = -\infty$ at STC).

For this paper, a PV panel from BP Solar (Model: SX-10) is modeled. Assuming no shading and using $\alpha = 1$ and others values provided by the datasheet (BP Solar PC SX-10 data sheet, 2003), a numerical expression of this PV panel can be found:

$$I(V) = \frac{0.65}{1 - e^{-1/b}}\left[1 - \frac{V}{b \times 21} - \frac{1}{b}\right] \quad (2)$$

Using the maximum power point condition at 16.8 V and 0.59 A, the value of b can be calculated by (2) as 0.085. At 25 °C, (2) can be further simplified to:

$$I(V) = 0.65[1 - e^{(V/1.785 - 11.7647)}] \quad (3)$$

Similarly at 75 °C one can get:

$$I(V) = 0.6711[1 - e^{(V/1.445 - 11.7647)}] \quad (4)$$

Fig. 2 shows the MATLAB plot of the *I–V* characteristic curves of SX-10 PV panel Eqs. (3) and (4).

2.3. Two-line and multiple-line fitting approaches

To generate N number of fitting lines, $N + 1$ points from the curve need to be selected. To begin with, a two-line approach as shown in Fig. 3 is discussed. The two ends points from the curve are the open-circuit voltage (21 V, 0 A) and short-circuit current (0 V, 0.65 A). The third point is selected (16.8 V, 0.62 A) as the maximum power point (MPP) of the curve where the two lines converge. Therefore the two equations which represent the two lines are expressed as

$$I(V) = 0.65 - 0.004V \quad (5)$$

$$I(V) = 2.94 - 0.14V \quad (6)$$