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Voltage band based global MPPT controller for photovoltaic systems

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Abstract

This paper presents a new maximum power point tracking algorithm for PV systems useful in case of non-uniform irradiance conditions. This algorithm takes into account the number of bypass diodes in a PV string to calculate the voltage bands associated with the peak power points that appear in the power–voltage characteristic of the PV system. The main contribution of this study is to state that the global maximum power point can be tracked by considering only the possible voltage bands which can be found by using the proposed analytical equation in a simple manner. The algorithm is based in the evaluation and analysis of these voltage bands and in the selection of the PV system voltage related to the maximum power point of work. The proposed algorithm has been validated by means of simulation and also in an experimental study.

Keywords: Photovoltaic array; Global MPPT; Bypass diodes; Non-uniform irradiance

1. Introduction

The growing concern about the increase in energy demand and dwindling reserves of fossil resources have made renewable energy sources more popular in recent years (Gooding et al., 2013; Mastromauro et al., 2012). Photovoltaic (PV) energy is one of the most promising alternative energy resources. Moreover, it is environment friendly and requires little maintenance cost. PV modules are usually connected in series and parallel to reach the desired levels of voltage and current. Under uniform conditions of irradiance, all PV modules connected in series in a PV array will give the same output current. Unfortunately, one or more PV modules are shaded sometimes due to the dust, trees, surrounding buildings, clouds, etc. (Picault et al., 2010). Thus, the shaded PV module produces less photocurrent and acts as a load. The power dissipated in form of heat by non-shaded PV modules may damage cells in PV module if bypass diodes are not used (Kouchaki et al., 2013; Jung et al., 2013). This effect is known as hot spot. Manufacturers integrate bypass diodes into their PV modules in order to protect PV cells from hot-spot effects (Kadri et al., 2012). However, another problem arises on electrical characteristic of PV array when bypass diodes are used. The power–voltage (*P–V*) curve exhibits multiple peaks as several locals and one global (Chong and Zhang, 2013). Under uniform solar irradiance conditions, the *P–V* characteristics of PV array exhibit a unique operating point where the power is maximum. This is known as the maximum power point, or MPP. The impedance adjustment between PV array and load is carried out through a DC/DC converter to operate at the corresponding MPP (de Brito et al., 2013; Roshan and Moallem, 2013). Conventional MPP tracking (MPPT) algorithms can easily be trapped at local MPPs under non-uniform

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irradiance conditions. This leads to an increase of power losses (Deline et al., 2013) and thereby decreases the efficiency of PV system (Drif et al., 2012; Elgendy et al., 2012; Heydari-doostabad et al., 2013). There are different MPPT techniques such as constant voltage (CV) method, perturb and observe (P&O), incremental conductance (IC), MPP locus characterization, fixed duty cycle, beta method, temperature method, artificial neural network (ANN), fuzzy logic (FL), and particle swarm optimization (PSO) (de Brito et al., 2013; Al Nabulsi and Dhaouadi, 2012).

In recent years, the concept of maximizing PV system efficiency under non-uniform irradiance operating conditions has become a challenging problem since building integrated PV systems (BIPV) are very often subjected to partial shading conditions. Koutroulis and Blaabjerg (2012) propose a new method which is based on controlling the DC/DC power converter such that it behaves as a constant input-power load in order to track the global MPP of PV arrays. The PV modules are arranged based on the Su Do Ku puzzle pattern by Rani et al. (2012) to distribute the effect of shading over the array, therefore the occurrence of shading on modules in the same row is reduced. In another study, a modified quadratic maximization MPPT algorithm is proposed on a moving vehicle for the PV system (Ko and Chao, 2012). Bianconi et al. (2013) present a current-based technique by sensing the current of the capacitor placed in parallel with the PV generator. Alahmad et al. (2012) propose a reconfigurable architecture for PV system to maximize the generated power under operating conditions such as shading, soiling, mismatches, and module failure among others. Moreover, intelligent techniques are used in the MPPT problems (Shaiek et al., 2013). An improved MPPT method is proposed by using a modified PSO algorithm in the literature (Ishaque et al., 2012). Furthermore, artificial neural network (ANN) (Sheraz and Abido, 2012; Syafaruddin et al., 2012; Younis et al., 2012; Kulaksız and Akkaya, 2012) and fuzzy logic based MPPT algorithms (Bidram et al., 2012; Houssamo et al., 2013) are also utilized. On the other hand, the distributed MPPT (DMPPT) architecture based on a DC/DC converter for each PV module is applied as an alternative to the traditional MPPT methods (Poshtkouhi et al., 2012; Jiang et al., 2012). DMPPT architectures are supposed to solve any mismatching problem. However, this is not always feasible (Alonso et al., 2012). Determination of optimal PV array configuration for a given shading condition is an alternative and effective approach for maximizing the efficiency of partially shaded PV arrays (Tian et al., 2013). Thus, novel approaches or methods should be developed to improve the system efficiency. In that manner, the analysis of the electrical behavior of PV arrays is a very important issue to get some crucial clues when developing novel strategies for reducing the negative effect of partial shading.

In this paper, a novel method called as voltage band based MPPT is presented. This method takes into account the PV array configuration and the number of bypass diodes to determine the voltage bands associated with the peak power points that appear in the P–V characteristic of the PV array. The main contribution of this study is to state that the global MPP can be tracked by considering only the possible voltage bands associated with peak power points present in the P–V characteristic. This novel method presents an expression that allows obtaining these voltage bands in any conditions of irradiance and temperature. The effectiveness of the proposed algorithm is presented by means of simulation and experimental studies.

2. Modeling of a PV module

A photovoltaic module can be modeled by using single-diode equivalent circuit as shown in Fig. 1 (Villalva et al., 2009). The relationship between output current and voltage is given by the following nonlinear implicit equation:

$$I = I_{ph} - I_o\left(\exp\left(\frac{q(V + IR_s)}{nkT}\right) - 1\right) - \frac{V + IR_s}{R_{sh}} \tag{1}$$

where I_{ph} is the light-generated photocurrent, I_o denotes the reverse saturation current of diode, q, n, and k are the electron charge, diode ideality factor, and Boltzmann constant, respectively. T is the temperature of the module, R_s is the series resistance, R_{sh} is the shunt resistance. I and V are current and voltage outputs of the module, respectively.

Ambient air temperature can be used to find the operating PV module temperature as follows (Mattei et al., 2006; Skoplaki and Palyvos, 2009)

$$T = T_{air} + \frac{NOCT - 20}{800} \cdot G \tag{2}$$

where T_{air} is ambient air temperature, $NOCT$ is normal operating cell temperature (800 W/m^2 solar irradiance and 20 °C air temperature), and G is the irradiance level in W/m^2.

Manufacturers usually integrate bypass diodes for every 12 or 18 cells to a PV module as seen in Fig. 2. Although bypass diode numbers in a PV module is of great importance under partial shading conditions (Silvestre et al., 2009), this parameter is not taken into account in most studies. In this study, the PV modules are modeled with their own bypass diodes according to the technical data

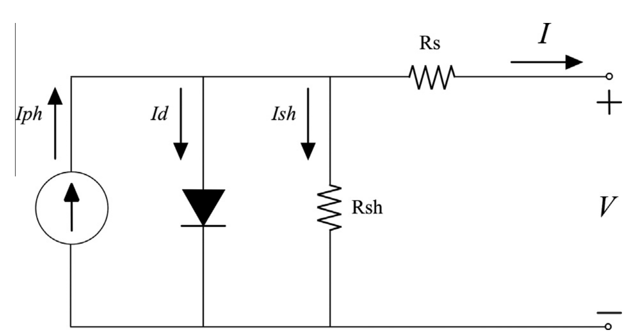

Fig. 1. Photovoltaic cell electrical equivalent circuit.