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Detection and assessment of partial shading in photovoltaic arrays

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Abstract

The paper presents a methodology for detection and assessment of partial shading conditions in photovoltaic (PV) arrays based on artificial neural networks (ANN) as a preliminary step toward automatic supervision and monitoring. The PV array is modeled under normal and partial shading conditions for performance comparison. ANN is designed, trained, and tested for full identification of the partial shading condition. One ANN detects the presence of partial shading and distinguishes it from the uniform change in environmental conditions. If the first ANN detects partial shading on the PV array, other two ANN agents determine the shading factor and infers the number of shaded modules of the array, consequently. Results show excellent performance of ANN on the detection and assessment of partial shading.

Keywords: Photovoltaic arrays; Partial shading; Artificial neural networks

1. Introduction

Renewable energy has recently attracted increasing attention of the researchers due to cleanliness, on-site availability, and absence of greenhouse gas emission (Salem and Awadallah, 2014). The power of sun light is converted into DC electricity through photovoltaic (PV) cells which are usually made of semiconductor materials. The PV cells are connected in series to form a module of typically 36, 60, or 72 cells. The modules are then assembled in different series and parallel configurations to form an array at the desired output voltage and current. The output power of a PV array is conditioned via power electronic circuitry before being consumed by local loads or injected into power grids.

The output characteristics of the PV arrays are dependent on solar irradiation and cell temperature as the independent variables of the system. However, solar irradiation on a certain array may not be uniform due to partial shading caused by the shadows of passing clouds, trees, or nearby buildings. Many researchers have studied the characteristics of PV arrays under partial shading condition. A mathematical model is developed in Matlab environment and experimentally

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verified for partially shaded solar panels (Patel and Agarwal, 2008). A Simulink model utilizing SimPowerSystems blockset is also developed to model the PV array under the same condition (Said et al., 2012). Artificial neural networks (ANN) are exploited to estimate the *I–V* characteristics under partial shading conditions (Dolan et al., 2011).

It is found from these publications, and others, that the *P–V* curve under partial shading, unlike normal operation, has multiple peaks, whose number depends on the array topology, making maximum power point tracking (MPPT) more challenging. In Karatepe et al. (2007), a novel power compensation and MPPT control system is presented for PV arrays under complicated non-uniform irradiation conditions. The proposed system is based on forward biasing bypass diode of shaded modules by monitoring dynamic resistance and voltage of PV modules. Another MPPT, taking into account shading effects and utilizing a multi-stage buck-boost chopper circuit, is introduced in (Bellini et al., 2010). It proposes a new MPPT algorithm to maximize the power produced in any given ambient/junction temperature and solar irradiation levels.

Provision of early automatic diagnosis of PV arrays with quick and efficient responses is highly necessary and has been studied by many researchers (Chao et al., 2008; Davarifar et al., 2013; Houssein et al., 2010; Syafaruddin et al., 2011; Rezgui et al., 2014). Since the accuracy, fast computation and simplicity are imperative issues in this kind of study, ANN, as an intelligent technique, can be a prominent solution.

Detection and assessment of partial shading is vital for monitoring and supervising purposes as well as invoking appropriate model predictive control MPPT algorithms. A simplified expression could be used to monitor the equivalent thermal voltage in order to detect partial shades on small areas (Sera et al., 2009). In Spataru et al. (2012), fuzzy inference systems are employed to detect partial shading through the associated increase in series resistance of partially shaded cells. Therefore, it appears that the available literature lacks a straightforward method of partial shading detection and assessment based on direct simple measurement of array performance.

The present paper introduces a methodology based on ANN for the automatic detection and assessment of partial shading conditions in PV arrays. The real-time detection and full assessment of the proposed technique help initiate appropriate MPPT algorithm and avoid local overheating of cells. Moreover, it is considered one of the crucial steps toward automatic supervision and system monitoring.

The research assumes that the PV array is initially operating at maximum power point under normal conditions of uniform solar irradiation and cell temperature at all modules. A change in the output power of the array may be due to a consistent change in irradiation or temperature on the whole array, or may be due to partial shading where some modules receive less irradiation than others. A partial shading detection ANN is developed to distinguish between the two cases. If partial shading is detected, the condition is fully assessed by determining the shading factor and number of shaded modules. Therefore, other two ANN operate to assess the condition in case partial shading is characterized by the detection ANN. The design, training, and testing phases of ANN development are meant to be completed offline; then, it should be implemented on fixed-point microprocessor to perform the detection and assessment tasks online.

2. PV modeling and problem formulation

A solar cell can be modeled with a current source in parallel to a diode, a shunt resistor to provide a path for leakage current, and a series resistor to account for power loss associated with cell current, Fig. 1(a). The cell current is expressed as:

$$I_c = I_{ph} - I_{os}\,[e^{\frac{q}{AKT}(V_c+I_cR_s)} - 1] - \frac{(V_c + I_cR_s)}{R_{sh}} \tag{1}$$

where I_c is the cell current (A), I_{ph} is the light-generated current, or photocurrent (A), I_{os} is the reverse saturation current of the diode (A), q is the electron charge (C), A is the ideality factor of the diode, K is the Boltzmann constant (J/K), T is the cell temperature (K), V_c is the cell voltage (V), R_s is the series resistance (Ω), and R_{sh} is the shunt resistance (Ω).

The photocurrent is dependent on the solar irradiation and cell temperature, and is given as:

$$I_{ph} = \lambda\,[I_{sc} + k_i(T - T_r)] \tag{2}$$

where λ is the solar irradiation (as a ratio of 1000 W/m^2) (suns), I_{sc} is the cell S.C. current at a 25 °C and 1000 W/m^2 (A), k_i is the S.C. current temperature coefficient (A/K), T and T_r are the actual and reference temperature (K).