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Maximum power extraction in solar renewable power system - a bypass diode scanning approach☆

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ABSTRACT

The effectiveness of solar energy as a viable energy source is hampered by various factors including high cost of components and lowered operating efficiency due to partial shading. Partial shading reduces the output of not only the shaded part of the panel but also the other panels connected to the same photovoltaic (PV) array. This paper discusses the benefits of using a bypass diode based voltage drop measurement and maximum power point tracking (MPPT) system in the power generation of a PV array. An algorithm to find the global maximum power in short span of time is also presented. MATLAB is then used to perform the simulation of the proposed algorithm on a 3×3 photovoltaic array and the results are checked against actual outdoor tests to test the validity of the proposed method. The proposed method holds even when extended to any array combinations for practical applications.

1. Introduction

Deployment of renewable energy sources like solar is taking place at a rapid phase to mitigate the growing greenhouse gas emissions, the ill effects of which are seen every day around the world. However, solar power generation does suffer some drawbacks including but not limited to low conversion efficiency and reduction in output due to partial shading of the panel surface. In a solar photovoltaic (PV) array, partial shading by nearby trees, buildings, clouds, birds and dust greatly reduces [1] the other panel's power generation as well. So, maximum power point tracking (MPPT) method should constantly track the maximum power under partial shading conditions. But the existing MPPT algorithms such as perturb and observe (P & O) and incremental conductance (IC) do not extract the maximum possible power during shading.

During partial or uneven shading, the power versus voltage (P–V) characteristic curve of the PV array contains many peaks and as a result, the maximum power point (MPP) detected may not always be the global maximum power point (GMPP). To detect the absolute global maximum out of all MPPs, many researchers developed various techniques and algorithms. One of such techniques is a thermography based temperature distribution analysis [2], which estimates the voltage

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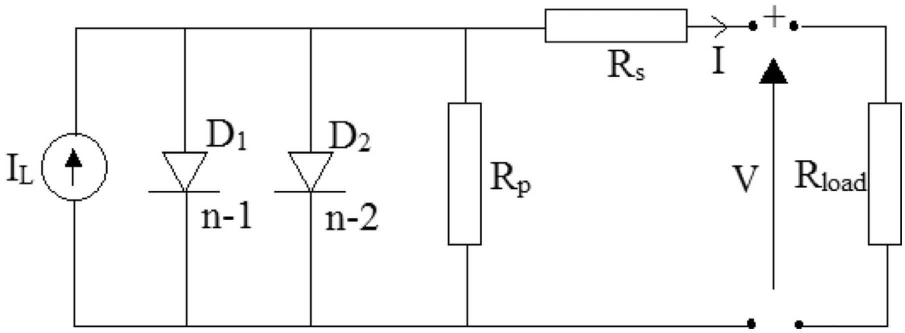

Fig. 1. Equivalent circuit of single solar cell using 2 diodes.

of the module by using a thermographic image. Depending on the shading and fault levels present, the temperature of the panel varies and by using this variation, the voltage of the panel is then calculated using a thermographic image [2]. A thermal camera is needed to do all these analyses but in the method paper proposed in this, the same voltage measurement is done just using voltage sensors across each bypass diode in the array. Bypass diodes are usually connected across the modules as a means to reduce the voltage imbalance that occurs during shading. Here in our technique, the same diodes are used to measure the GMPP through a bypass diode scanning algorithm which takes in real-time measurement of the voltage drop across each diode. Conventional bypass diode scanning mechanisms are more complex and time-consuming. If the number of panels and diodes increases, then the time per scanning will also increase. This drawback of time consumption is overcome by the proposed method. This characteristic based mechanism requires more memory space to store the data and in the literature, numerous methods and artificial intelligence based techniques have been proposed but they are not regarded satisfactory because of them taking more time and cost. In addition, this traditional bypass diode mechanism [3] based MPP tracking algorithms do not sense the voltage drop across the diodes to find the MPP. Physical reconfiguration of the modules takes place [4] during partial shading, which might provide maximum power but requires careful monitoring, more manpower and time [5]. Reconfiguration [6] by switching also causes loss of power due to the over usage of semiconducting devices. Conventional MPPT algorithms including P&O method and IC method are studied [7–11]. On comparing the performances and simplicity [12], P&O algorithm is found to be very simple but in case of performance, IC algorithm stands out. Both the algorithms can be used for this proposed technique depending on the requirements. Many artificial intelligent techniques which have been proposed to figure out MPP include artificial neural network (ANN) [13], particle swarm optimization (PSO) [14,15], artificial bee colony (ABC) [16], fuzzy logic (FL) [17], neural network (NN) [18,19] method. Some other methods have been proposed [20–25], for finding out MPP but, they are all either time consuming or requires more infrastructure. The methods existing in the literature are unsatisfactory in terms of cost, speed, effectiveness, and complexity.

The proposed method greatly reduces the time by using the bypass diode's voltage drop alone for partial shading level detection. In case of thermographic image-based processing, the processing time is high and it also demands high-cost components. No additional infrastructure is needed in the proposed method other than the voltage sensors. So, this method is more effective for tracking the maximum power in a short span during partial shading as well as normal condition. MATLAB is used for simulating the MPPT controller and DC-DC converter. The results from the simulation and practical verification assert our claim that the proposed bypass diode scanning algorithm provides a better performance than the conventional and existing techniques.

The rest of the paper is organized as follows: Modeling of a solar cell, the characteristics and the impacts of partial shading on a selected array arrangement is explained in Section 2. Section 3 explains the proposed bypass diode scanning algorithm and its practical verification is given in Section 4. Section 5 presents the simulation results and the comparative analysis. The conclusions are presented in Section 6.

2. Modeling of PV panel

The mathematical model of a solar module is developed in MATLAB/SIMULINK. The panel used for practical implementation is of polycrystalline type. The equivalent circuit of a solar cell using two diodes is shown in Fig. 1. The solar cell's I–V characteristic [23] is derived from accurate two exponential diode model and its current output can be derived as in Eq. (1).

$$I = I_L - I_0\left[e^{\frac{q(v+IR_S)}{n_1 kT}} - 1\right] - I_{01}\left[e^{\frac{q(v+IR_S)}{n_2 kT}} - 1\right] - \left(\frac{V + IR_s}{R_p}\right) \tag{1}$$

I_L - Light Induced Current
I_0 - First Diode's Saturation Current
I_{01} - Second Diode's Saturation Current
k - Boltzmann's Constant

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