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PV array reconfiguration method under partial shading conditions

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ABSTRACT

This paper proposes a new reconfiguration method for photovoltaic arrays under partial shading conditions. With the application the method, the array can produce higher power by reconfigured connections of array. In the proposed method, each row of an array is formed by connecting the panels with close short circuit current levels as possible. A novel algorithm entitled configuration scanning algorithm is used to determine the all possible connection structures. This algorithm utilizes only short circuit current values measured at particular parts of the array. The proposed method has been tested in Matlab–Simulink environment under partial shading conditions. Results of the simulation show that the efficiency of the array is considerably increased with the presented reconfiguration method.

Introduction

The use of renewable energy sources has become very important as a result of increasing energy need and the environmental effects of fossil fuels. Photovoltaic (PV) modules are one of the most important renewable energy sources and their use is gradually increasing in regions that have a long sunshine duration and in rural areas. In order to be able to gain a higher solar power, PV arrays are formed by connecting the PV modules in series and parallel. However, the shadows of objects such as clouds, birds, buildings and trees on PV arrays reduce the sunlight that the array receive, inevitably resulting in a lower system efficiency.

PV modules need to be operated at the maximum power point (MPP) at varying heat, insolation and load levels for an efficient use. One way of increasing the PV array efficiency is to use maximum power point tracker (MPPT). MPPT is basically a dc–dc converter which utilizes an algorithm to determine the MPP of the current–voltage (*I*–*V*) or power–voltage (*P*–*V*) characteristic in varying environmental conditions. In order to improve conventional MPPT method, the step size of MPPT algorithm is taken variable instead of fixed [1]. However conventional MPPT methods can fail under partial shading conditions because of occurring more than one local maximas. To find global MPP among local maximas, soft computing technique is developed [2]. Another developed MPPT method is based on obtaining electrical characteristics of PV array. This method works effectively in partial shading conditions [3].

There are reported researches results showing that system efficiency of PV modules exposed to partial shading can be increased by applying some PV module reconfiguration algorithms [4]. In some of these studies, reconfiguration of array has been made by changing connections of all modules on the array [5,6]. In these methods which is called as electrical array reconfiguration module catalog information are used along with instant current and voltage information for each module. By using these data and calculating the current radiant intensity of the modules, the array is reconfigured to form new submodules with the modules that have similar insolation levels. The disadvantage of this method is the high number of possible connections since reconfiguration is applied to all the modules.

While a higher efficiency increase is provided with the reconfiguration of all modules in the PV array, quite many connection configurations are possible. In order to compensate this disadvantage, the array can be divided into two parts as the fixed part that consists of statically connected modules and adaptive modules part that can be attached to the fixed part with different configurations [7,8]. In this method, the currents of PV modules are calculated by using the measured voltage of fixed and adaptive parts, temperature of the array, and the catalog data. These currents are used in a bubble sort algorithm and reconfiguration of the array is applied.

In the presented another reconfiguration method, connections of all PV modules are reconfigured according to irradiance equalization strategy [9]. This method uses some optimizations to reduce possible connections number. However this number still high since all modules are reconfigured. The method had similar reconfiguration structure to [9] uses PV module equations and number of shaded modules to some calculations [10].

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In the presented method, the shaded modules are determined by measuring current and voltage of all modules in strings. All of these modules are connected to another bus by flexible switching matrix circuit and composed a new string. This string voltage is brought to nominal array voltage by dc–dc converter [11]. Another method tries to bring similar shaded modules to same string by high number switches [12]. This method is similar to [11] but uses more than one power bus and converter to get equal voltage for each string. In another method, all PV modules are reconfigured [13]. It is expected that a lot of switches are required to each module connect to another one. Additionally the algorithm consists of extra calculations to estimate module irradiations.

An optimal reconfiguration logic that utilizes mathematical formulas is proposed in [14]. Reconfiguration of the array is performed by using optimization techniques with the voltage values measured at each line and current values measured in all modules in the array. It is obvious that quite many sensors will be needed in this method.

In a reconfiguration method which uses "Rough Set Theory" based on ANN under the partial shading conditions, each PV module current in the array is compared to a reference value and proper switching signals are obtained in accordance with a certain rule. However, this method is complex and requires several measurements [15].

Load voltage and temperature parameters of the array are used as inputs to the algorithm which aims to reconfigurating an array with minimum number of switching [16]. The system simulated with four panels gives positive results at constant load but it has some disadvantages. It is difficult to obtain the parameters used in the algorithm and the performance drops when the conditions vary. In fuzzy logic controlled reconfiguration methods, selection of the most suitable connection configuration is aimed by using system and panel parameters [17,18].

Parallel connected modules that are in shade to the reconfigured PV array are proposed in [19,20] to take advantage of whatever power is available in these shaded pieces. In this way, degradation caused by shading effects is minimized. However, increased number of parallel modules in the array will raise the output current, casing in higher losses in conducting wires.

In this paper, a reconfiguration method is proposed to increase the efficiency under partial shading conditions. In the proposed method, PV system is divided into two parts, namely adaptive and fixed parts. A new developed configuration scanning algorithm that scans the array and decides how the adaptive parts can be attached to the fixed part to maximize the efficiency has been developed.

The main contributions of the proposed reconfiguration method as follows:

- The method require only short circuit currents where sensed particular nodes of array. Therefore there is no need parameter of PV panel and any additional calculations especially to estimate irradiances.
- The developed configuration scanning algorithm considers all possible connection configurations with defined terms. Thus the algorithm determines the proper configuration that has highest power under present shading conditions.
- The method needs minimum number of sensors comparing with other reconfiguration methods.

Validity of the method has been tested in a 3 × 4 PV array which is controlled by MPPT under partial shading conditions.

In the next section of the paper creation of the PV arrays and the shading effect on these arrays are explained. Then, proposed reconfiguration method and developed configuration scanning algorithm are explained. Finally, simulation results that show the effect of the proposed algorithm are given.

Connection of PV modules and PV array form

Connection in parallel

PV modules are connected in parallel between each other to form submodules. While the output voltage is equal in the submodule shown in Fig. 1, the output current is the total sum of module currents.

$$V_{out} = V_1 = V_2 = \cdots = V_n \tag{1}$$

$$I_{out} = I_1 + I_2 + \cdots + I_n = \sum_{i=1}^{n} I_i \tag{2}$$

The output power of submodule:

$$P_{out} = I_{out}P_{out} = \sum_{i=1}^{n} P_i \tag{3}$$

In this connection structure, as the bathos in any module will not affect the operation characteristics of other modules, all modules can transfer the power they generate to the output. In this way, the highest efficiency can be gained in any environmental conditions. The output voltage is equal to the module voltage in this connection structure and therefore it is low. Hence, the conversion ratio of converter which is going to be used to increase the voltage needs to be high. This affects the efficiency of converter in a negative way. Also, as the output current needs to be high, line losses are significant.

Connection in series

In the strings which consist of series connection of PV modules, a higher output voltage is obtained. In a string shown in Fig. 2, the currents of modules are equal to each other, and output voltage is the sum total of mudul voltages.

$$I_{out} = I_1 = I_2 = \cdots = I_n \tag{4}$$

$$V_{out} = V_1 + V_2 + \cdots + V_n = \sum_{i=1}^{n} V_i \tag{5}$$

The output power of string:

$$P_{out} = I_{out}P_{out} \tag{6}$$

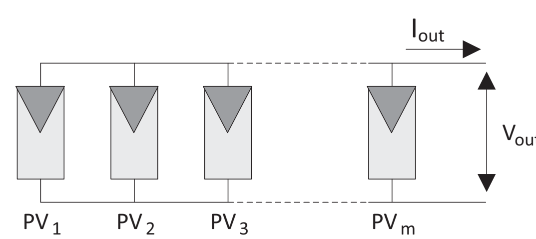

Fig. 1. Parallel connected PV modules.

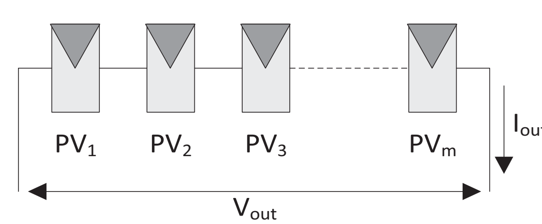

Fig. 2. Series connected PV modules.