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A novel reconfiguration procedure to extract maximum power from partially-shaded photovoltaic arrays

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ABSTRACT

This paper presents a new reconfiguration procedure, named power comparison technique (PCT), to extract maximum power from photovoltaic arrays. PCT introduces optimum configuration and maximum power point (MPP) of photovoltaic arrays in partial shading conditions. PCT finds absolute MPP and its corresponding configuration via comparing whole peaks of power-voltage (P-V) curve of a photovoltaic (PV) array. This will ensure that the right-hand peaks of absolute MPP have been removed. This logic comes to help algorithm of MPP tracking to identify the absolute peak. This approach is applicable for any topology of PV arrays (series-parallel and total-cross-tied, here). Simulations show better (or at least equal) reconfiguration results by the proposed method in comparison to the previous works reviewed. Results represent about 8% increase in mean output power based on the studied cases.

1. Introduction

Due to limited sources of fossil-based energies and their environmental harms, electric power generation by renewables have been increased rapidly in recent years. In addition to potential of renewable energy sources and their eco-friendly nature, economic competitiveness of them is grown continuously.

Solar radiation is the main source of energy for the earth hence, direct conversion of light to electricity is one of the promising technologies to supply the world. Solar cells and photovoltaic (PV) modules have increasing efficiency, decreasing cost and no moving part thus their utilization is increased year by year. Recent worldwide rapid growth of photovoltaic systems is depicted in Fig. 1 (http://www.ren21.net/status-of-renewables/global-status-report/).

A PV system uses some PV arrays and a few auxiliaries to transmit produced electricity to load in a suitable form (Rekioua and Matagne, 2012). To optimize power transmission capability from PV array to load, an impedance matching power conversion unit (PCU) is used named maximum power point (MPP) tracking unit (Fig. 2a). Any change in system condition (solar irradiation, temperature and load, for example) deviates the system from its optimized working point on characteristic curve of PV array (Fig. 2b). MPP tracking unit moves the system to a new working point that is optimal for the latter condition using algorithms such as P&O[1], IC[2] or other methods.

In general, a PV array is comprised of some series and parallel modules. Difference between maximum power of a PV array and the sum of the maximum powers of its modules is called mismatch losses (Lorente et al., 2014). This phenomenon may be permanent as a result of production tolerance, performance demotion and module cracking, or temporary because of irradiance difference received by PV modules (Lorente et al., 2014). Irradiance is radiant solar power received by a surface per square meter (https://www.nasa.gov/mission_pages/sdo/science/solar-irradiance.html). The mismatch caused by the changes in irradiance level is called partial shading (PS) of the PV array (Fig. 3a) (http://blog.aurorasolar.com/content/images/2016/10/Article4_Figure1.jpg; http://www.builditsolar.com/Experimental/PVShading/P1030391.JPG). In series-connected modules, the current flowing through all modules are the same. In the case of a partially shaded string, the modules that cannot provide the string current are short-circuited by bypass diodes to enable proper string current flow and protect the shaded modules from operating in reverse bias voltages (Tabanjat et al., 2015). Partial shading and misleading Losses (partial-shading-induced MPP tracking losses) for a typical PV array represented in Fig. 3b. For example, about 5–10% PV energy waste occurs in Germany and Japan due to partial shading (Drif et al., 2008; Garcia et al., 2009). 3–4% power loss is reported because of partial shading in Spain

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[1] Perturb and observe
[2] Incremental conductance

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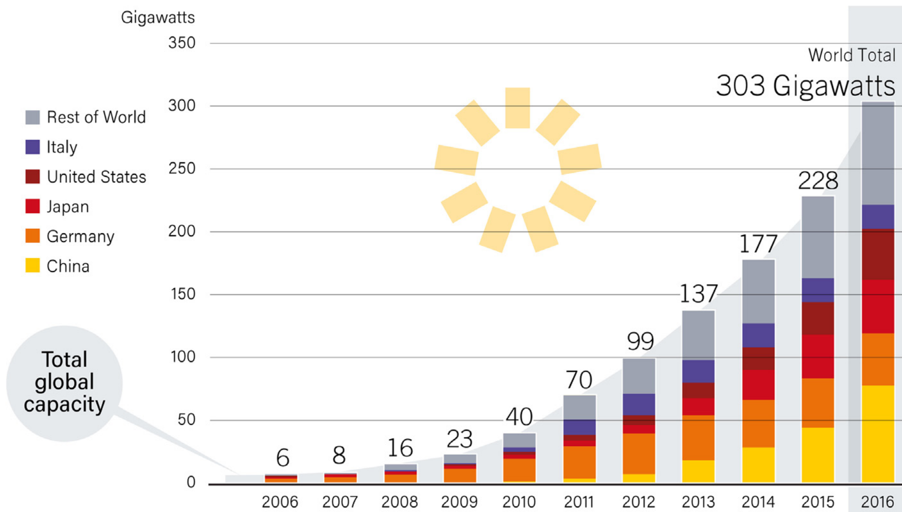

Fig. 1. "Solar PV Global Capacity, by Country and Region, 2006–2016". (http://www.ren21.net/status-of-renewables/global-status-report/).

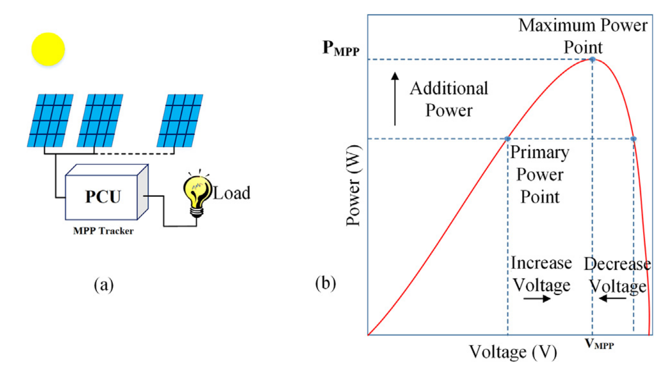

Fig. 2. A typical PV system: (a) PV system including PCU (MPP tracking), (b) Effect of MPP tracking on PV working point.

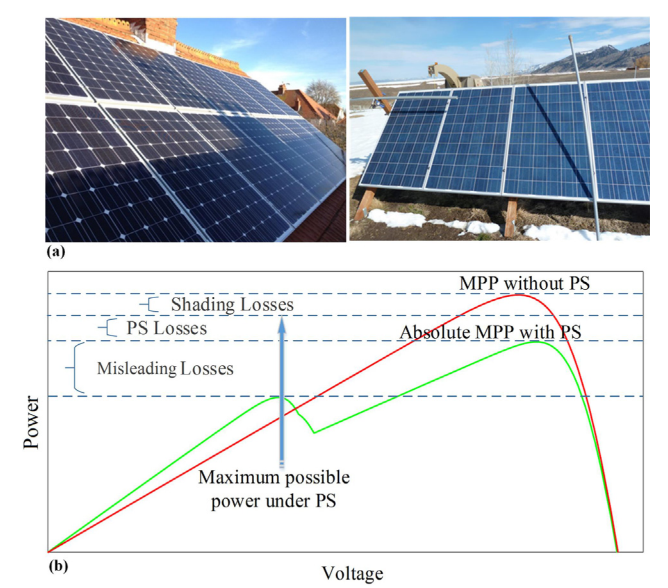

Fig. 3. (a) Examples for partial shading, (b) Shading, partial shading, and misleading losses for a photovoltaic array.

(Garcia et al., 2009). In addition to partial shading losses, misleading of MPP tracking causes more power losses because of creation of several local peaks in power-voltage (P-V) curve (Shams El-Dein et al., 2013).

There are two groups of techniques to remove or at least alleviate the above mentioned problems caused by partial shading of PV arrays; passive techniques and active techniques.

1.1. *Passive techniques*

Using bypass diodes can protect PV arrays from hot spot effect and reduce PS losses (Drif et al., 2008; Braun et al., 2016). Common connections that usually used for PV modules are Series-Parallel (SP), Total-Cross-Tied (TCT) and bridge-linked (BL) connections (Fig. 4). As an approximate method, switching between these connections can be used to approach MPP (Drif et al., 2008; Hayoun and Arrigoni, 2010).

1.2. *Active techniques*

Usual active techniques for PS conditions are as follows:

1.2.1. *Using multi-tracker converters*

In this approach, an independent MPP tracking is used for any set of PV array with the same shading (Sanseverino et al., 2015). This approach is not cost effective because of high number of converters used.

1.2.2. *Using micro converters*

This method leads to good power conversion efficiency but its cost is very high (Hayoun and Arrigoni, 2010).

1.2.3. *Reconfiguration of PV modules*

Modules used in a PV array can be reconfigured through existing switches between them. There are several reconfiguration algorithms for TCT and SP connections.

There are some reconfiguration methods which are based on equalized distribution of radiation in each row of TCT connections (Fig. 5) that need radiation Sensors to increase output electrical power (Shams El-Dein et al., 2013; Sanseverino et al., 2015; Pareek and Dahiya, 2016).

In some articles, PV array is divided into fixed and reconfigurable parts of modules (Nguyen and Lehman, 2008a, 2008b; Liu et al., 2010; Parlak, 2014; Karakose and Baygin, 2014; Velasco et al., 2008; Cheng et al., 2010). Parlak proposed a method to arrange PV modules to reach equal short circuit currents in each row of TCT topology to reduce number of switches (Fig. 6) (Parlak, 2014). Due to the small percentage of variable part of array, there is not enough possibility to reach optimal configuration.

In (Deshkar et al., 2015), genetic algorithms have been used to accelerate the reconfiguration process for TCT topology but it is