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Increasing efficiency of photovoltaic systems under non-homogeneous solar irradiation using improved Dynamic Programming methods

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ABSTRACT

The paper presents a complete technique, based on the combination of algorithms, devoted to minimize losses and increase efficiency of Total Cross Tied (TCT) connected photovoltaic (PV) systems under non-homogeneous solar irradiation, based on irradiance equalization criterion. Irradiance equalization is achieved by changing the connections of the solar panels adaptively by a dynamic switching matrix so that total solar radiation on parallel circuits is the most equalized.

In this paper, the authors introduce two algorithms. The first one is SmartChoice (SC) algorithm, which is combined with Dynamic Programming (DP) in order to create a hybrid method and obtain better results as compared to established methods for irradiance equalization. The second one is the control algorithm improvement method from Munkres' Assignment Algorithm (MAA) that helps to increase processing speed and lengthen the lifetime of the solar power system by 56% compared with the older MAA.

By emulating and experiencing the operation of the PV system under non-homogeneous irradiation condition, obtained results show efficiency and benefits of the proposed method applied to the solar power system operation while lengthening the lifetime of the switching matrix.

1. Introduction

Power crisis is becoming prominent issue, not only endangering the global economic growth but also international security and peace. Fossil power source, an extremely precious present that nature grants for society, is gradually exhausting. Thus, renewable energy has become a hot topic on the international agenda. The European Union has committed to reduce the emissions of greenhouse gas by at least 20% below the level in 1990 and by almost 100% by 2050. Consumption coverage from renewables must also reach 20% by 2020 and almost 100% by 2050.

In this context, solar power plays an important role due to the fact that it is a green source. The solar power generates electricity from solar irradiation without emitting direct carbon dioxide and greenhouse gas. Besides, electrical power supply from power plants to remote consumption locations can be very costly especially in developing countries. Small solar power plants may solve these issues by bringing power sources to be near the power charging station to minimize or replace completely the usage of generators that use diesel fuel. This will bring long-term public economic benefits without any environmental and economic cost. On the other hand, building a solar power plant needs a more expensive investment as compared to other power plants (i.e. hydropower plant, thermal power plant, etc.). Although Levelized Cost of Energy is progressively reducing (Adnan, 2015) driven by the reduction of the cost of modules. Researchers on solar power technologies in the near future is now promoted strongly to reduce power production costs to make it competitive with other power resources (International Energy Agency, 2013; Lynn, 2011). In recent scientific papers, a big amount of publications is devoted to algorithms development, architectures and control techniques in applications of the PV system for Maximum Power Point Tracking (MPPT) (Veerachary et al., 2002; Alireza et al., 2013; Balato et al., 2016; Liu et al., 2014; Zhao et al., 2015; Chen et al., 2015; Zhang et al., 2015).

However, during operation, there are many cases in which PV panels in the solar power plants can receive non-homogeneous radiation levels. The causes may be a lot such as shadow due to clouds, trees, houses and antenna pole. This results in inefficiency

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Nomenclature

avg	average sum of irradiance on the row after reconfiguration
DES	Dynamic Electrical Scheme
EI	Equalization Index
N	number of panels
i	row index
I-V	current-voltage
j	column index
m	number of rows
MPP	maximum power point
MPPT	maximum power point tracker
n_i	number of modules that are parallel connected of the row i
G	total irradiance
P-V	power-voltage
G_i	total irradiance of the row i
G_{ij}	irradiance value of module located on row i and column j
PS	partial shading
PV	photovoltaic
TCT	total-cross-tied
MAA	Munkres' Assignment Algorithm
DP	Dynamic programming
SC	Smartchoice

in operation of most of techniques on MPPT (Femia et al., 2012) leading the falling of the output power. Moreover, it can cause hot-spot phenomenon at shaded solar cell panels, thus damaging directly solar cells (Woyte et al., 2003; Shams El-Dein et al., 2012).

Effects due to partial shading (PS) of the PV system are given in Woyte et al. (2003) and in; Shams El-Dein et al. (2012). When in shading, the system is not only subjected to possible damage but also to misleading phenomena for the MPPT algorithm. The latter indeed will find many sub optimal working points.

With respect to this phenomenon, power loss of the solar power system is divided into two parts: recoverable loss and non-recoverable loss. At present, operative techniques for recovering losses could be grouped into the following main three categories:

- Distributed MPPT;
- Multilevel inverters;
- Photovoltaic array reconfiguration.

An exhaustive description of distributed MPPT and the employment of multilevel inverters is beyond the scope of this article, based on the array reconfiguration. One main research scope for power losses recovery is to develop the reconfiguration strategy of the solar power system (Velasco et al., 2005; Belhachat and Larbes, 2015; Nguyen and Lehman, 2008; Alahmada et al., 2012; Velasco et al., 2009; Obane et al., 2012; Storey et al., 2012; La Manna et al., 2014). The reconfiguration is an efficient rearrangement of connections of solar panels in order to increase the output power and protect the equipment when the system is working under non-homogeneous solar irradiation conditions. For instance, when one or more solar panels in the connection circuit is shaded, the generated power will be decreased causing an increase of the power losses in the system (Delinea et al., 2013).

In Riva Sanseverino et al. (2015), authors offered Dynamic programming (DP) method to find out the optimal connection configuration for PV panels and used Munkres Assignment Algorithm (MAA) to find out the best switching configuration in order to increase the lifetime of the switching matrix. Through analysis and simulation, these proposed methods obtained better results than those presented in Velasco et al. (2009), Storey et al. (2012) and Romano et al. (2013).

In this paper, authors initially propose a new heuristic algorithm, Smart Choice, which, combined to DP, improves the selection of the arrangement of the panels. The paper then introduces an improvement to the MAA that produces a computation time reduction. Finally, extensive simulations prove the efficiency of the proposed algorithms and finally a prototype allows to assess the effectiveness and accuracy of the proposed overall technique.

2. Reconfiguration strategy for TCT topology

Reconfiguration strategy for TCT topology is shown in details in Riva Sanseverino et al. (2015). The TCT topology (Fig. 1a) combined with a Dynamic Electrical Scheme (DES) switching matrix (Romano et al., 2013) (Fig. 1b) allows, through switching operations, to move from the initial TCT interconnection to a new TCT interconnection with any configuration (Fig. 1c).

Ampere meter and voltmeter are installed at each PV panel to measure current and voltage. Based on the current and the voltage measured from each PV panel, the formula to calculate the

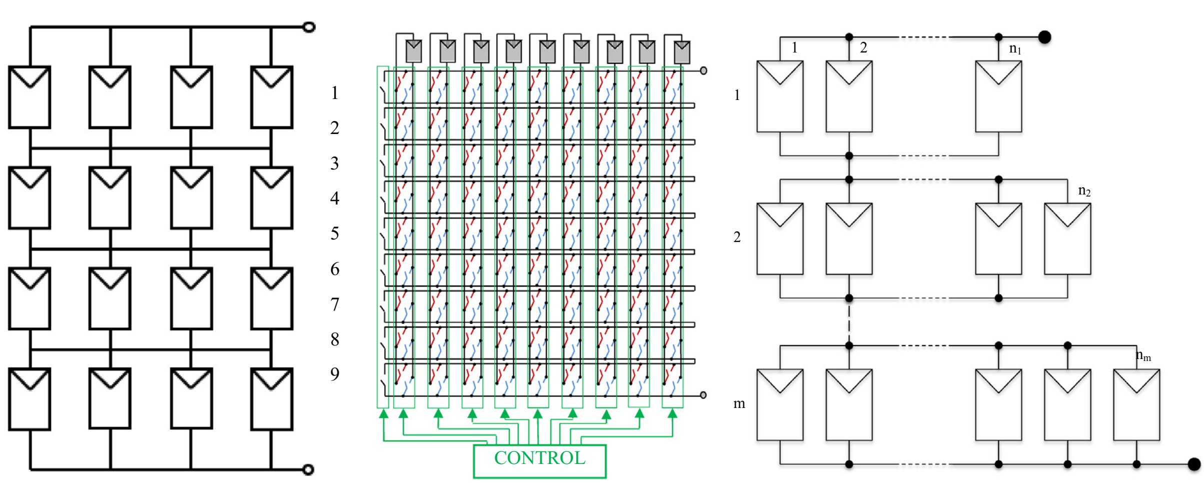

Fig. 1. (a) TCT topology; (b) Dynamic Electrical Scheme (DES) switching matrix (Romano et al., 2013), (c) generator topology.