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Mismatch losses minimization in photovoltaic arrays by arranging modules applying a genetic algorithm

Samad Shirzadi *, H. Hizam, Noor Izzri Abdul Wahab

Department of Electrical and Electronic Engineering, University Putra Malaysia, 43400 UPM Serdang, Malaysia
Centre of Advanced Power and Energy Research, Faculty of Engineering, University Putra Malaysia, 43400 UPM Serdang, Malaysia

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Abstract

Photovoltaic (PV) arrays consist of series and parallel connections of PV modules. Difference in current–voltage (I–V) characteristics among a batch of modules form an array causes power losses in PV systems referred to as mismatch losses. These power losses are conventionally reduced by module sorting techniques which sort modules based on an I–V parameter such as short circuit current, current at maximum power or maximum power. This work introduces a new method that employs genetic algorithm (GA) to find an arrangement of modules in an array which minimizes mismatch losses more effectively than conventional methods do. Extensive simulations are applied to adapt a GA to the problem of mismatch losses, find the arrangement and demonstrate its superiority over module sorting techniques in terms of mismatch losses decrement and energy yield increment. Instructions for practical application of the suggested method are also provided.

Keywords: Mismatch losses; Genetic algorithm; Module sorting techniques; Photovoltaic

1. Introduction

Based on statistical information acquired from International Energy Agency (IEA) Key World Energy Statistics in 2006, yearly energy consumption of the world counts for around 140,000 TW h and it is predicted to increase up to 60% more than this amount till 2030 (Freris and Infield, 2008). The growing energy demands, finitude of fossil fuels, and environmental issues have motivated human beings to seek for other energy resources. A while after the invention of the first silicon PV cell at American Bell Laboratories in 1954 (Quaschning, 2009), solar PV energy found its position as a reliable and sustainable energy resource. An outstanding increase in global installed capacity, from 5 GW in 2005 to 40 GW in 2010, stands behind the commercial prosperity of PV industry (Bortnikov et al., 1981). One issue among several issues toward well utilization of PV systems is power losses due to a phenomenon called mismatch which is the subject of this study. As depicted in Fig. 1, statistics available on ISI web of science show that mismatch power losses in PV systems is still a hot topic in academic researches due to considerable number of publication and increasing number of citations it has gotten since 2003.

In PV generators, PV arrays convert photo-energy of sun irradiation to electrical energy in DC form. A PV array consists of series and parallel combination of PV modules.

* Corresponding author at: Department of Electrical and Electronic Engineering, University Putra Malaysia, 43400 UPM Serdang, Malaysia. Tel.: +60 129761733.

E-mail addresses: shirzadi1983@gmail.com (S. Shirzadi), Hashim@eng.upm.edu.my (H. Hizam), izzri@eng.upm.edu.my (N.I.A. Wahab).

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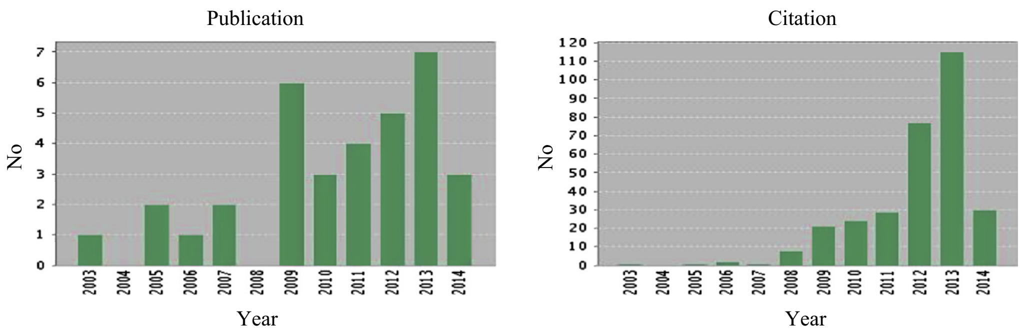

Fig. 1. Publications on mismatch power losses (left) and citations of mismatch power losses (right).

The same way PV modules are composed of PV cells. This modular nature of PV systems, is advantageous when it helps to wire the system up to desirable level of current, voltage and power. But the fact that PV modules with the same brand and same ratings are not exactly identical, turns the modularity of PV systems to be disadvantageous when it causes sort of power losses known as mismatch losses which are recognized by several research works (Bucciarelli, 1979; Chouder and Silvestre, 2009; Picault et al., 2010). Since PV modules are fabricated in the factory, further investigation and modification in cell level requires damaging the module encapsulation. So investigating mismatch losses mitigation techniques among cells inside modules is of PV module manufacturers' interest whereas such investigation among modules in arrays is of system operators and installers interest. This paper deals with mismatch losses among modules at array level.

Module sorting techniques are regular methods for minimizing mismatch losses in PV arrays in which modules are sorted in arrays by one of their characteristic parameters. This paper elaborates these techniques and reviews the mechanism of mismatch losses to propose a more effective solution. The proposed solution applies a GA to find the optimal arrangement of modules in an array, considering array output power as an objective function to be maximized. The arrangement of modules obtained by the GA is then compared to the arrangements obtained by the sorting techniques in terms of mismatch losses and energy yield.

Understanding electrical configuration of PV arrays, difference in PV modules characteristics and mismatch losses mechanism are inevitable steps toward comprehending the problem of mismatch losses in PV arrays and subsequently devising solutions to this problem. Second and third sections elaborate these steps. Section four reviews the conventional treatments for mismatch losses. Section five explains the hypothesis of this study. Sixth section is devoted to the methodology of the work. Sections seven and eight provide results and conclusions respectively.

2. PV array configurations

There are different possible configurations of PV modules in a PV array such as series parallel (SP), bridge link (BL) and total cross tied (TCT) Ramaprabha and Mathur, 2012. SP configuration which is the most practically used configuration is considered in this study. In this configuration connected modules in series form strings and connected strings in parallel form an array. Obviously all modules per each string work at the same amount of current and all strings in an array work at the same amount of voltage at a time. So it is simply concluded from Kirchhoff laws that the string voltage equals the summation of modules voltage in strings, the array current equals the summation of strings current and array's voltage equals the voltage of every string. An array of 40 modules and 4 strings with SP configuration is depicted in Fig. 2 as an example.

3. Mismatch losses

As previously mentioned, differences in PV modules characteristics together with modularity of PV arrays cause mismatch losses in PV arrays. These differences are discussed in first subsection and second subsection explains how these differences cause mismatch losses.

3.1. Differences in PV modules characteristics

A group of modules of the same brand and same nominal ratings are not exactly identical. Their differences are understood by comparing and contrasting their characteristic parameters such as fill factor (FF), maximum power (P_{MPP}), current at maximum power (I_{MPP}), voltage at maximum power (V_{MPP}), short circuit current (I_{SC}) and open circuit voltage (V_{OC}). Difference in module characteristic parameters is called *I–V* mismatch, since it results in different electrical performance. *I–V* mismatch comes from either temporary or permanent sources as classified in Fig. 3. Shading or non-uniform illumination might happen by fallen leaves of trees, scattered clouds moving over the PV

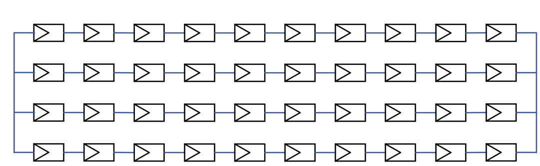

Fig. 2. SP configuration of an array of 40 modules in 4 strings.