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Mathematical analysis of total-cross-tied photovoltaic array under partial shading condition and its comparison with other configurations

Shahram Mohammadnejad [a], Ali Khalafi [a,*], S. Morteza Ahmadi [b]

[a] *Department of Electrical Engineering, Iran University of Science & Technology, Narmak, Tehran, Iran*
[b] *Photonics Laboratory, Physics Department, Iran University of Science & Technology, Narmak, Tehran, Iran*

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Abstract

The goal of this paper is to investigate total-cross-tied (TCT) configuration under partial shading condition. A full investigation requires mathematical analysis and simulation. An accurate mathematical analysis gives us a better understanding of how partial shading affects the output curves of the solar cell, so we first mathematically analyze the TCT (2×2) configuration under different partial shading conditions and then we check the mathematically analysis accuracy through Matlab simulation. All of the simulations in this paper are conducted using Matlab. We have used single diode solar cell model for mathematical analysis and the simulations. So we will explain how to acquire single diode solar cell model and its effective parameters. The better performance of TCT configuration among other configurations is why we have chosen this configuration to investigate under partial shading condition. The superiority of TCT configuration to other configurations like Honey-comp (HC), Bridge-linked (BL) and Series-parallel (SP) under different partial shading conditions is demonstrated and various aspects of these configurations in terms of output characteristics (maximum output power and power dissipation percentage) is displayed using Matlab simulation. All of the required inputs for simulations are extracted from standard photovoltaic cell datasheets.

Keywords: Partial shading; Total-cross-tied; Bridge-linked; Honey-comp; Series-parallel

1. Introduction

Solar cells will provide a huge amount of human's needed energy in future. Like other animals and plants, humans are dependent upon solar energy for feeding and keeping themselves warm. Solar cells are a simple and great way to use solar power. Solar cells which are unique in their kind, directly convert sunlight into electricity. Today, conducted researches in photovoltaic systems field are mainly focused in three sections: low cost, high efficiency and high reliability (Joshi et al., 2009).

One of the reasons that reduce solar cell reliability is inequality error regarding partial shading (Jiang et al., 2013). In recent years, many studies have been conducted all the effects of partial shading in photovoltaic systems operation (Deline et al., 2013; Di Vincenzo and Infield, 2013; Dolara et al., 2013). If solar panels cover a vast area, it is so much probable that some parts of the cells become shaded by any reason like trees' shadow, birds nesting on solar panels, passing clouds and neighboring tall buildings. In this situations, the shaded cells may act reversely and deplete power from other turned-on cells which reduces

* Corresponding author.
E-mail address: ali_khalafi70@yahoo.com (A. Khalafi).

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Nomenclature

I_{Cell}	current solar cell	T_{Cell}	solar cell temperature
I_D	diode current	V_{Cell}	solar cell voltage
I_L	irradiance current	V_{OC}	open circuit voltage
I_0	diode reverse saturation current	I_{sh}	short circuit current
k	Boltzmann's constant, 1.38×10^{-23} J/K	α	degree of shaded
n	diode ideality factor	s	the amount of irradiance
q	Electron charge, 1.6×10^{-19} C	P_M	maximum power point
V_M	maximum voltage point	I_M	maximum current point

solar cells output power and if the security measures are not considered, this may harm the solar cell or solar module.

Partial shading has more serious consequences like hot spots too. Hot spots lead to distractive effects that include flawing the glass or the cell, melting soldered parts and dismantling solar cells. So by considering all of these, it is justifiable to study partial shading (Dolara et al., 2013).

In order to overcome partial shading problems, by-pass diodes are used (Woyte et al., 2003). By-pass diodes are connected in parallel to photovoltaic cells and don't pass any current in normal conditions. When the photovoltaic cell is reversed biased by an external mean, the by-pass diode turns on and in low voltage passes a large current. Generally using a single by-pass diode for every cell is not economical and a by-pass diode is used for a cluster of cells. Therefore, various configuration for by-pass diode exists (Tam et al., 2014; Ziar et al., 2014).

Solar arrays of photovoltaic systems use various configuration to achieve desired voltage and currents (Ramaprabha and Mathur, 2012). Among these configurations, we can point to series-parallel (SP) configuration, total-cross-tied (TCT), Honey-comp (HC) and Bridge-linked (BL) (Fig. 1). In SP configuration, the modules are connected in series to each other to reach the required voltage and then these series connections are connected in parallel to each other. TCT configuration is formed by connecting all nodes of rows in SP configuration. In TCT configuration, the voltages of all nodes and also the sum of currents in different junctions are equal. In BL configuration, every four modules are connected to each other in the form of a rectifier bridge in which at first two modules are connected in series and then in parallel to each other. By modification of BL configuration, a new configuration named as HC is formed (Wang and Hsu, 2009, 2011). The advantages of BL and TCT configurations are combined in HC configuration.

There have been many studies conducted on comparison between different solar array configurations (SP, HC, BL and TCT) under partial shading conditions and in every study (Ishaque et al., 2011; Jazayeri et al., 2014; Ramaprabha and Mathur, 2012), the superiority of TCT configuration under partial shading conditions is proved through simulation, Now the need for mathematical analysis of these structures is sensed. The mathematical analysis of TCT configuration which gives us a better understanding of current–voltage and power–voltage curves under partial shading condition and can be used to determine the number of peaks, short circuit current and maximum power point under partial shading conditions without the need for simulation is presented in this paper. A good analysis needs simulations to be carried along mathematical calculations. This paper has taken this attitude for its analyzes. Section 2 investigates single diode solar cell model along with its effective parameters. Section 3 presents the mathematical relations of TCT 2×2 configuration under different partial shading conditions to better study the effects of shading in the configuration and the needed

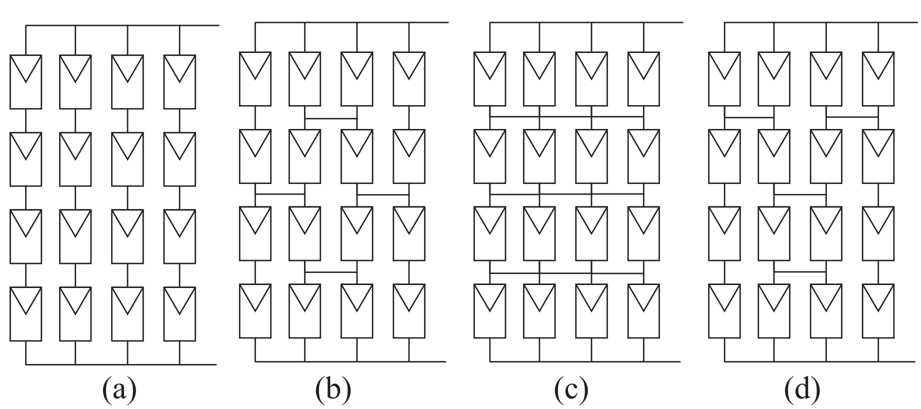

Fig. 1. Solar array configurations (a) SP, (b) BL, (c) TCT, (d) HC.