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Performance enhancement of partially shaded PV array using novel shade dispersion effect on magic-square puzzle configuration

Anurag Singh Yadav [a,*], Rupendra Kumar Pachauri [b], Yogesh K. Chauhan [a], S. Choudhury [b], Rajesh Singh [b]

[a] Electrical Engineering Department, School of Engineering Gautam Buddha University, Greater Noida, Uttar Pradesh 201308, India
[b] Electronics Instrumentation and Control Engineering Department, College of Engineering Studies, University of Petroleum and Energy Studies, Dehradun 248001, India

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ABSTRACT

Partial shading conditions decrease the power output from PV arrays. In partial shading conditions the PV modules of the array receive the different solar irradiation, so the arrays exhibit multiple peaks in P-V and I-V characteristics hence mismatch loss occurs between the PV modules. This paper investigates the performance improvement in existing solar photovoltaic (PV) array by re-configurations of the array. The MATLAB/Simulink modeling of PV array configurations such as total cross-tied (TCT), proposed hybrid series parallel - total cross-tied (SP-TCT), bridge link- total cross-tied (BL-TCT), bridge link- honey comb (BL-HC), Magic Square (MS) and MS puzzle pattern based reconfiguration like Re-arranged total-cross-tied (RTCT), Re-arranged series parallel- total-cross-tied (RSP-TCT), Re-arranged bridge link- total cross-tied (RBL-TCT) and Re-arranged bridge link- honey comb (RBL-HC) is done. The performance of all these configurations has been investigated using P-V characteristics, power loss due to shading, fill factor and shading dispersion effect on maximum power point (MPP) for various shading patterns namely pattern-1 (vertical shading), 2 (horizontal shading) and 3 (diagonal shading). Extensive analysis is carried out on a 4×4 PV array configurations for these shading patterns. The power at MPP of MS and RTCT configurations is 2279 W more, mismatch power loss is 300 W less, and fill factor (FF) is 9.91 more than TCT configuration. The performances of proposed configurations are found superior for some cases of shading patterns.

1. Introduction

Recently, the crises of energy is experienced globally which motivated the development of renewable energy (RE) sources such as solar, wind, tides, bio-fuel and geothermal energy etc. based systems. Due to depleting fossil fuels and concerns of environmental pollution, the research on solar assisted power generation system is getting impetus (Bauwens and Doutreloigne, 2014).

The conversion efficiency of PV system is very low and it is challenging to enhance the performance of PV system under partial shading conditions e.g. moving clouds, building shadow, trees and telecom tower etc. In this context, different conventional PV array configurations e.g. series, series-parallel (SP), total-cross-tied (TCT), bridge-link (BL), honey-comb (HC) are reported for the system performance enhancement.

Rani et al. (2013) proposed a concept on partial shading. The investigation done with the TCT based PV arrays configuration arranged on the Su Do Ku puzzle pattern. The performance of the system is investigated for different shading patterns and the results show that positioning the modules of the array according to "Su Do Ku" puzzle pattern yields improved performance under partially shaded conditions. Alonso-Garcia et al. (2006) modeled a simulation model of a PV array string and investigations are carried out with shading effects. The recommendations are extracted as the increment of shading rate over one cell produces higher deformations in the I-V curves. Maki and Valkealahti (2014) investigated the effects of partial shading on maximum power points of Simulink model of a PV array, which composed of 18 series connected PV modules. Dorado et al. (2014) proposed a generalized, quick and simple method for modeling and simulating the electrical behavior of PV installations under any shading situation. For the investigation, series and series- parallel configurations are considered. Ahmad and Salam (2015) investigated the effect of partial shading on SP configuration of PV array. The energy losses are reduced by using the maximum power point tracking (MPPT) methods. Bai et al. (2015) checked the effect of partial shading

* Corresponding author.
E-mail addresses: er.anuragsingh046@gmail.com (A.S. Yadav), rpachauri@ddn.upes.ac.in (R.K. Pachauri), chauhanyk@yahoo.com (Y.K. Chauhan), schoudhury@ddn.upes.ac.in (S. Choudhury), rsingh@ddn.upes.ac.in (R. Singh).

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Nomenclature

V_C	cell voltage (V)	C_{SI}	irradiation coefficient for cell photocurrent
V_{OC}	open circuit voltage (V)	P_{array}	array power (W)
V_{cx}	new value of cell voltage (V)	T_C	cell temperature (°C)
C_{TV}	temp. coefficient for cell voltage	T_a	ambient temperature (°C)
C_{SV}	irradiation coefficient for cell voltage	T_x	actual temperature (°C)
β	open circuit voltage coefficient	S_c	reference solar irradiation level (W/m^2)
V_{mpp}	voltage at maximum power point (V)	S_x	actual solar irradiation level (W/m^2)
V_{mi}	module voltage at ith rows (V)	S_f	shading factor
V_{array}	array voltage (V)	G	actual solar irradiation level at PV module (W/m^2)
I_c	cell current (A)	G_{STC}	standard solar irradiation level at PV module (W/m^2)
I_{ph}	photocurrent (A)	e	electron charge (Coulomb)
I_0	diode current (A)	k	Boltzmann constant (J/K)
I_{SC}	short circuit current (A)	R_S	series resistance (Ω)
I_{phx}	new value of photocurrent (A)	n	numbers of PV modules
I_{mpp}	current at maximum power point (A)	m	numbers of shaded PV modules
I_R	row current (A)	A	curve fitting factor
I_{array}	array current (A)	FF	fill factor
I_m	module current at standard irradiance level G_{STC} (A)	PSC	partial shading conditions
γ	short circuit current coefficient	MS	magic square
C_{TI}	temp. coefficient for cell photocurrent		

and a study is carried out with the I-V and P-V curves. Belhachat and Larbes (2015) proposed a comprehensive study of partial shading on available PV array configurations such as Series, Parallel, Series–Parallel (SP), Total-Cross-Tied (TCT), Bridge-Linked (BL), and Honey-Comb (HC). The performance all PV array configurations are compared and found that the TCT configuration having the best performance in terms of highest maximum power and lowest relative power losses. A novel analytical approximation of the effect of inter-row shading on large photovoltaic (PV) arrays is investigated in terms of FF and power losses (Deline et al., 2013). Deshkar et al. (2015) reported genetic algorithm based reconfiguration is used for the arrangement of PV modules in a PV array. The system performance is analyzed for various shading conditions and it is proved that the proposed technique is superior and yields better results as compared to the TCT and Su-Do-Ku arrangement. The comparison between the experimental and simulation study has been done on the PV array in terms of P-V and I-V curves under the conditions of non-uniform irradiance (Ding et al., 2012; Gao et al., 2009; Pareek and Dahiya, 2014). Ishaque et al. (2011), Qi et al. (2014) investigated partial shading effect on SP configuration of PV array. Karatepe et al. (2007) investigated the effects of non-uniform solar irradiation on different interconnected configurations such SP, BL, TCT (2×6, 6×2, 4×3, 3×4 size) PV arrays. Malathy and Ramaprabha (2015), Pareek and Dahiya (2013) investigated the reduction in power output due to shading effect. For the investigations series, parallel, SP, TCT, BL, HC as well as a 'new' configurations are considered. It is found that TCT configuration is a better choice for this condition. Patel and Agrawal (2008) investigated the shading effect on 10×90 size of PV array with a random shading pattern. For performance, maximum power point tracking methods are adapted to achieve the GMPP. Patnaik et al. (2011) designed a SP 4×4 PV array configuration to investigate the effect of non-uniform irradiation.

Potnuru et al. (2015), Renaudineau et al. (2011) investigated the reduction in power losses in TCT based PV array configuration. Moreover, Su-do-Ku based puzzle pattern is used to compare with TCT configuration of size 36×36 PV array and 4×4 array of 9×9 micro-arrays. Proposed a concept on SP based PV array configuration with the various shading pattern. To achieve GMPP, the MPPT method is used. Renaudineau et al. (2011), Tabanjat et al. (2014) investigated the non- uniform irradiation effect on SP, TCT and HC configurations of PV array. Shirzadi et al. (2014) designed a PV arrays consist of series and parallel connections of PV modules. Power losses in PV systems referred to as mismatch losses due to partial shading. A new method that employed genetic algorithm (GA) to find an arrangement of modules in an array, which minimizes mismatch losses is discussed (Deshkar et al., 2015). Yadav et al. (2016) investigated the shading effect on PV array with puzzle shade dispersion method for SP, TCT, BL, HC, SP-TCT, BL-TCT and proposed NS-1 and NS-2 (non-symmetrical) PV arrays configurations. It is found that proposed configurations NS-1 and NS-2 are having better performance. Very limited work is reported on MS puzzle pattern based rearrangement of solar PV configurations (Namani et al. 2015). In this research paper, only PV characteristics are analyzed for different shading pattern namely short wide, long wide, short-narrow and long- narrow shading pattern.

The aim of this paper is to investigate the performance of the proposed novel symmetrical 4×4 PV array configurations in comparison to existing PV array configurations. The physical positions of conventional PV array such as SP, TCT, BL and HC configurations are rearranged in accordance with the MS puzzle pattern and this re-arrangement of PV modules are framing novel configurations such as RSP, RTCT, RBL and RHC. The novel PV array configurations are found superior with respect to performance indices such as locations of GMPP, power losses and FF under partial shading conditions.

2. Modeling of PV solar cell

PV array is formed by combining various PV cells to generate electrical power. The electrical equivalent circuit of single diode PV cell is shown in Fig. 1 as,

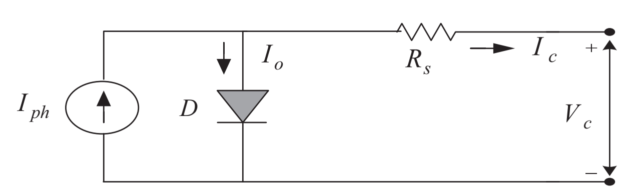

Fig. 1. Equivalent circuit of single diode PV system.