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Performance enhancement of PV system using proposed array topologies under various shadow patterns

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ABSTRACT

In this paper, a comprehensive study is carried out on the solar photovoltaic (PV) array topologies under diagonally shading scenario. The aim of extensive analysis is to investigate the power mismatch losses in PV array under non-uniform irradiations. The partial shading affects not only power but also exhibits extreme non-linearity along with multiple maximum power points on P-V and I-V characteristics. The investigation is based on designing of the optimal layout of PV modules in a array to extract maximum power under partial shading conditions (PSCs). In this context, a novel structure (NS) of PV array is designed and compared with the classical configurations such as total cross-tied (TCT), hybrid series-parallel-total cross-tied (SP-TCT), bridge link-total cross tied (BL-TCT) and bridge link-honey comb (BL-HC) under considered shadowing scenario. The modeling of all the considered PV array configurations has been done in MATLAB/Simulink environment. The performance of proposed NS configuration is found superior for some cases of shading effect. NS configuration of PV array has minimum power losses and improved fill factor (FF) as compared to others under PSCs.

1. Introduction

Energy crisis is experienced worldwide, which inspired the development of renewable energy sources e.g. photovoltaic, wind turbine, bio-fuel and geothermal energy systems, etc. Due to exhausting fossil fuels and environmental pollution issues, the researchers explored more sustainable energy sources (Bishop, 1988). Today, PV based power generation is attaining more popularity due to its eco-friendly feature. Recently, the deteriorating performance during PSCs is a partial shading condition is a matter of research (Kovach and Schmid, 1996).

The PV based power system are facing many challenges like variation of short circuit current (I_{sc}) of PV cell due to non-uniform irradiation. The main causes of occurring PSCs on PV array are dust accumulation and shadow caused by tree, pole, building and passing clouds. The shading has predominant effect on PV modules performance in an array, which thereby minimizes the produced power. For the performance enhancement of PV based power generation system, the numbers of PV modules are connected in some pre-defined configurations (Quaschningt and Hanitscht, 1996). In these situations, it is inspiring task to enhance the performance as well as reducing the effect of PSCs. These research aspects make the extensive study to assess the impacts of PSCs on PV array performances (De-Blas et al., 2002). The effect of shading on the P-V and I-V characteristics is shown in Fig. 1.

The various types of existing configurations of PV array are observed in terms of their performance, reliability, and scope of implementation in available literature (Kaushika and Gautam, 2003; Karatepe et al., 2007; El-Dein et al., 2011, 2013; Bindram et al., 2012; Villa et al., 2012; Mohammadnejad et al., 2016; Buddala et al., 2013; Lun et al., 2014; Rani et al., 2013; Pareek and Dahiya, 2014, 2016; Vijayalekshmy et al., 2015a, 2015b, 2016; Braun et al., 2016; Belhachat and Larbes, 2015; Celik et al., 2015; Malathy and Ramaprabha, 2015a, 2015b; Deshkar et al., 2015; Potnuru et al., 2015; Yadav et al., 2016a, 2016b; Yadav et al., 2017; Nguyen and Lehman, 2008; Parlak, 2014; Storey et al., 2014; Picault et al., 2010; Moballegh and Jiang, 2014; Kumar et al., 2016). An exhaustive study is offered, which is related to the accuracy, robustness, efficiency and execution of each method.

In Kaushika and Gautam (2003) and Karatepe et al. (2007), the electrical characteristics of PV array interconnections such as SP, TCT and BL (9×4, 6×6, 2×6, 6×2, 3×4 and 4×3) are

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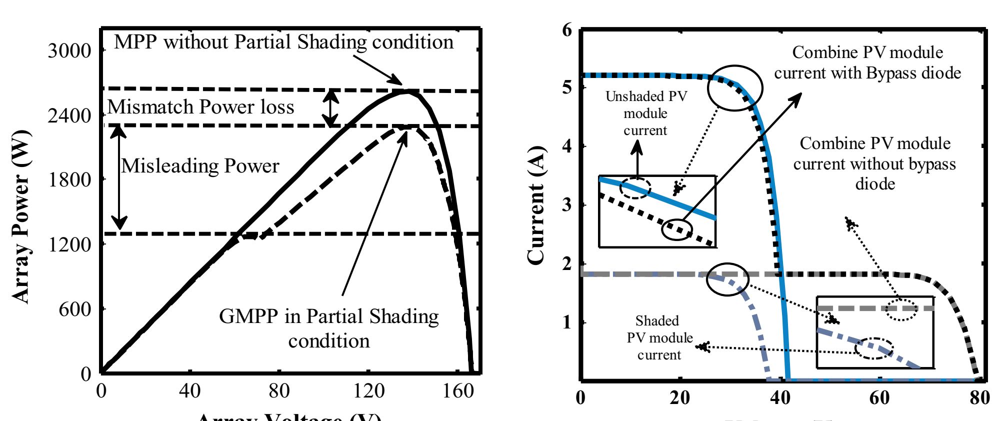
Nomenclature

V_C	cell voltage (V)
V_m	module voltage (V)
V_A	array voltage (V)
V_{OC}	open circuit voltage (V)
V_{OC_m}	module open circuit voltage (V)
V_{OC_A}	array open circuit voltage (V)
V_{cx}	new value of cell voltage (V)
C_{TV}	temperature coefficient for voltage
C_{SV}	irradiation coefficient for voltage
V_{mpp}	voltage at maximum power point (V)
I_C	cell current (A)
$\mathrm{I_m}$	module current (A)
I_A	array current (A)
I_{ph}	photocurrent of cell (A)
I_{ph_m}	module photocurrent (A)
I_{ph_A}	array photocurrent (A)
I_O	cell diode current (A)
I_{O_m}	module diode current (A)
I_{OA}	array diode current (A)
I_{SC}	cell short circuit current (A)
I_{SCm}	module short circuit current (A)
I_{SC_A}	array short circuit current (A)
I_{phx}	new value of photocurrent (A)
I_{mpp}	current at maximum power point (A)
I_R	row current (A)
C_{TI}	temperature coefficient for cell photocurrent
C_{SI}	irradiation coefficient for cell photocurrent
P_{array}	array power (W)
T_C	cell temperature (°C)
T_a	ambient temperature (°C)
T_x	actual temperature (°C)
S_C	reference solar irradiation level (W/m^2)
S_x	actual solar irradiation level (W/m^2)
e	electron charge (Coulombs)
k	Boltzmann constant (J/K)
R_S	series resistance (Ω)
R_{S_m}	module series resistance (Ω)
R_{S_A}	array series resistance (Ω)
N_P	parallel connected PV cells
N_S	series connected PV cells
N_{S_m}	series connected PV modules
N_{P_m}	parallel connected PV modules
A	ideality factor
FF	fill factor
PSCs	partial shading conditions
MP	maximum power
GMP	global maximum power
MPP	maximum power point
GMPP	global maximum power point
LMPP	local maximum power point
STC	standard test condition

Greek letters

α_s	slope of the change in the cell operating temperature
β_T	open circuit voltage coefficient
γ_T	short circuit current coefficient
δ	maximum power temperature coefficient by manufactures

investigated under shading effect. Moreover, the obtained results of TCT configuration are compared with other configurations in terms of maximum power at GMPP and FF. The authors of El-Dein et al. (2011), Bindram et al. (2012), Villa et al. (2012), Mohammadnejad et al. (2016) have investigated 6 × 4, 5 × 3 sizes of SP, BL, TCT and HC configurations of PV array under PSCs. Among all the array configurations, TCT has minimum power losses. PV modules are arranged in series, parallel, SP, TCT, BL and HC configurations and performance has been investigated for different shading scenario in Buddala et al. (2013), Lun et al. (2014). The authors of El-Dein et al. (2013) investigated SP, TCT, BL, Half Reconfiguration Photovoltaic Array (HRPVA) and Full Reconfiguration Photovoltaic Array (FRPVA) of size 6 × 4 PV array under PSCs. The performance of HRPVA is found superior than considered other configurations. In Rani et al. (2013), the authors investigated that the physical locations of the 9 × 9 size PV modules are connected in array and this arrangement has been configured based on Su-Do-Ku puzzle pattern to distribute the shading effect over the entire array, which shows the best performance. In Pareek and Dahiya (2014, 2016), Vijayalekshmy et al. (2015a), Braun et al. (2016), SP, TCT and BL array interconnections are considered for the investigation under shading effect and minimum power losses are found in TCT configuration. In Belhachat and Larbes (2015) and Celik et al. (2015), the existing PV array configurations e.g. series,



(a) P-V characteristics (b) I-V characteristics

Fig. 1. P-V and I-V characteristics under PSCs (Yadav et al., 2017).