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Bidirectional flyback based isolated-port submodule differential power processing optimizer for photovoltaic applications

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ABSTRACT

Partial shading brings many serious problems in the solar photovoltaic system (SPV) such as the significant reduction in power harvest, hot spots, and the emergence of the multiple maximum power points (MPPs). This paper presents a bidirectional flyback converter (BFC) based isolated-port differential power processing (DPP) architecture at the submodule level. Bidirectional flyback converters (BFCs) are designed for submodules with both discontinuous condition mode (DCM) and continuous condition model (CCM) modes for light-load and heavy-load conditions to improve the efficiency. The voltage equalization with open-loop control is adopted for each BFC, this control method keeps the voltage in primary and secondary of the BFCs equal and it does not require additional voltage or current sensors. It's simple, easy-to-implement and well suited for low-cost integrated hardware scheme. Both simulation and experimental results for an isolated-port DPP regulated 72-cells photovoltaic (PV) module under various partial shading scenarios were provided. It shows that this structure can distinctly mitigate the energy loss in a PV system, increase output power harvest, and achieve high efficiency under partial shading condition. The measured efficiency with the isolated-port DPP structure was 90.23% under severe shading condition. The measured output power improvement under severe mismatch condition was high up to 43.1%.

1. Introduction

In the real world, photovoltaic (PV) panels are connected in series to form a string generating a high DC voltage, and then these strings are connected in parallel to create an array for building photovoltaic grid power generation system. The whole PV systems are presenting a high-power conversion efficiency but have been proved significantly reduced for output energy harvesting under non-ideal real-world conditions (Mäki and Valkealahti, 2012). The loss is mainly caused by the mismatch among PV cells, which may be generated by either external factors (partial shading, dust gathered, and angle differences) or internal factors such as manufacturing process and PV cells degradation (Bai et al., 2015; Mai et al., 2017; Lappalainen and Valkealahti, 2017). The mismatch among PV cells will not only cause the loss of energy but also bring hotspot effects, which eventually affects the reliability and lifetime of PV modules. Bypass diodes are widely used to prevent the failures due to the hotspot. Typically, one bypass diode can protect one PV substring with 20–24 cells. However, the reduction of output power is also significant since the bypassed PV cell substring is unable to work properly and the string current is also affected by a small number of shaded PV cells (Kim et al., 2016; Daliento et al., 2016). Fig. 1(a) illustrates the string current flow path of a PV module with three bypass diodes parallel-connected under mismatch conditions among the submodules, where submodules PV2 and PV3 are shaded with less insolation compared with PV1. With the conventional method, the module output power is affected due to partial shading, and subsequently, three peaks are observed in the power-voltage (P-V) curve, including a global maximum power point (GMPP) and multiple local maximum power points (LMPPs), as shown in Fig. 1(b). Classical MPPT techniques such as incremental conductance (Radjai et al., 2014; Tey and Mekhilef, 2014), beta method (Li et al., 2016) and perturbation & observe (P & O) (Rezk and Eltamaly, 2015) are unable differentiate the GMPP and LMPPs. Furthermore, the bypassed PV cells cannot output power properly, which could not be recovered by the GMPP tracking (GMPPT) algorithms.

Some new architecture such as DC power optimizers (DCPO) and differential power processing (DPP) are proposed to solve these issues (Du and Lu, 2011; Solórzano and Egido, 2014; Khan and Xiao, 2016, 2017). DCPO is PV-panel-level converters, connected in a cascaded architecture to keep each panel working on its MPP to mitigate the

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Nomenclature

I_{string}	string level current
V_{module}	module voltage
$I_{pri,i\ (i=1,2,3)}$	primary current of bidirectional flyback converter
$I_{sec,i\ (i=1,2,3)}$	secondary current of bidirectional FLYBACK converter
$V_{sub,i\ (i=1,2,3)}$	terminal voltage of submodule
V_{sec}	secondary voltage of bidirectional flyback converter
$i_{g,i\ (i=1,2,3)}$	output current of submodule
$V_{pri,i\ (i=1,2,3)}$	primary voltage of bidirectional flyback converter
C_{pri}	primary capacitor of bidirectional flyback converter
C_{sec}	secondary capacitor of bidirectional flyback converter
Q_{pri}	primary device of bidirectional flyback converter
Q_{sec}	secondary device of bidirectional flyback converter
$P_{DPP,\max}$	maximum output power with DPP structure
$P_{MPPT,\max}$	ideal maximum output power
δ	power loss percentage
N_s	number of cells
V_{mpp}	voltage at maximum power point (MPP)
V_{oc}	open-circuit voltage
E_g	band energy
R_p *ddResistanc*	shunt resistance P
P_{mpp}	maximum power
I_{mpp}	current at MPP
I_{sc}	short-circuit current
R_s	series resistance
P_{DPP}	system output power by using DPP
P_{MPPT}	system output power by using MPPT
SIM	simulation
EXP	experiment

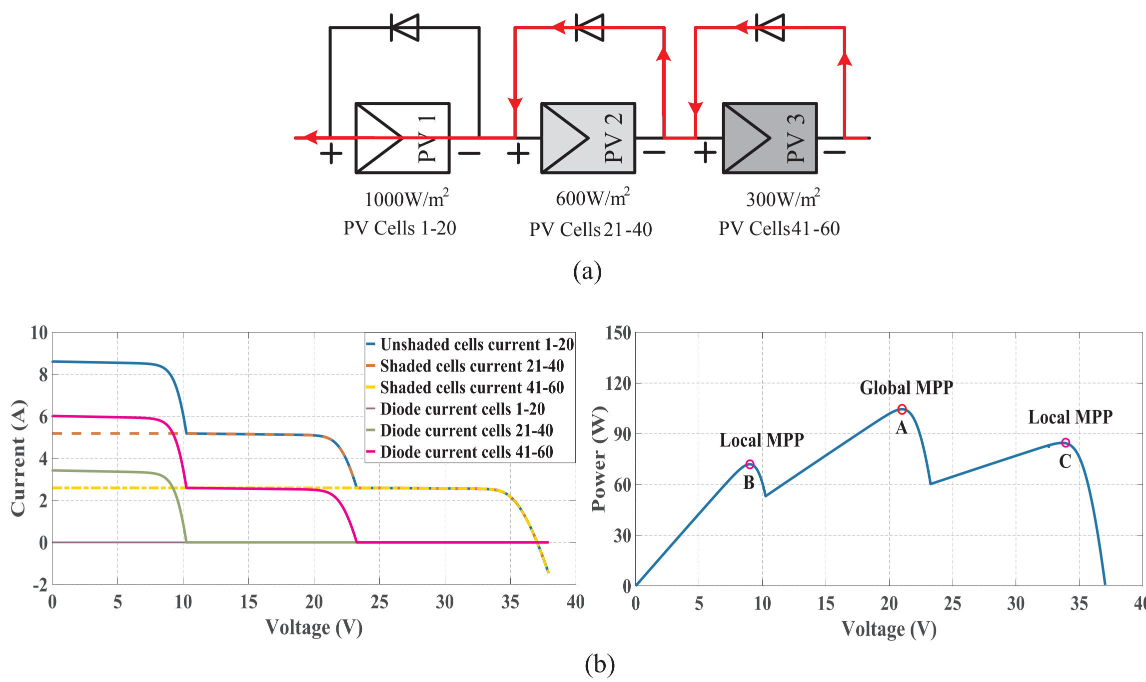

Fig. 1. PV module under partial shading condition: (a) string current flow path and (b) the characteristics of I-V and P-V curves.

mismatch. In DCPO architecture as shown in Fig. 2(a), the converters are required to process the full power generated by each PV panel that the architecture efficiency depends on the effectiveness of the converter. Differential power processing (DPP) architecture is proposed to solve the submodule-level mismatch problem, which provides a way to overcome mismatch problem among PV modules by enabling each PV element connected in a series string to work on its MPP. More specific introduction to the DPP concept in photovoltaic application can be

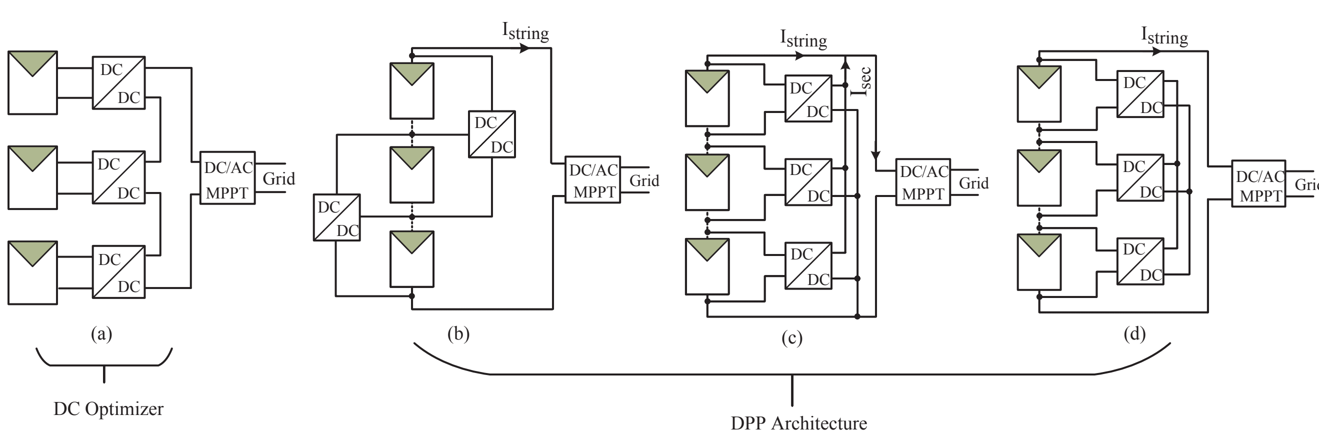

Fig. 2. (a) DC optimizer architecture, (b) PV-PV DPP architecture, (c) PV-to-non-isolated port bus DPP architecture, (d) PV-to-isolated port bus DPP architecture.