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Review of Distributed power electronics solutions for PV Generation systems

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Abstract Photovoltaic (PV) systems with traditional energy conversion architectures are frequently forced to tradeoff electricity generation and conversion effectiveness. A power electronics system architecture called differential power processing (DPP) parallelizes converters from DC to DC that used in the PV string to increase power output. The characteristics of this type of connection, such as its low rating for used converters and its minimal power loss, make DPP particularly appropriate for submodule-level maximum power point tracking (MPPT).

Since the DPP concept for PV systems was presented, Diverse algorithms for control and topologies have been developed and verified since the DPP concept for PV systems was first established, proving the advantages of DPP converter systems over current series string and full power processing converter solutions. The theory, practical use, and comparison of several series DPP connection topologies are all covered in this paper.

Keywords:. photovoltaic power, Differential power processing (DPP), Maximum power point tracking (MPPT), renewable energy.

1 Introduction

The world's energy demand is continuously growing, as has been seen in latest years. As a result, many renewable energy sources (RESs), including wind, solar, hydro, etc., are used [1]. Solar photovoltaics (PVs) are the freely available, plentiful, and most viable energy sources now in use, providing the humankind with a vast amount of energy [2]. Distributed, low power processing, submodule-integrated converters are used in differential power processing (DPP) designs to eliminate insertion losses while reducing mismatches in photovoltaic (PV) power systems [3] .

Particularly in traditional string or central inverter-based systems, the losses might be significant, like the system displayed in Fig. 1 (a) [4]. Full power processing (FPP) distributed power electronics have been used in a number of ways to mitigate these mismatch-related losses, including microinverters [see Fig. 1(b)] [5], or dc power optimizers (DCPO) [see Fig. 1(c)], which use MPPT at the level of the PV module, or even the level of the submodule[6].

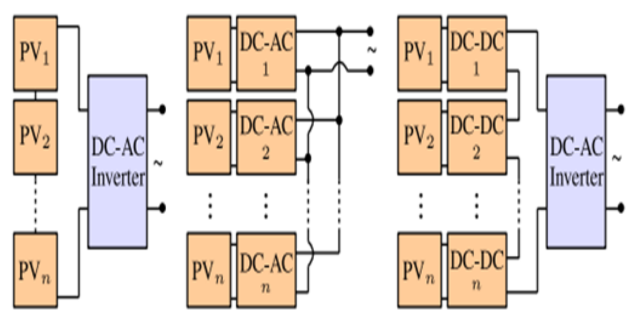

Fig. 1. Architectures for PV systems: (a) traditional system with single inverter, (b) system with microinverters or module-level dc-ac inverters, and (c) system with central inverter and cascaded dc-dc converters or dc power optimizers.

Differential power processing (DPP) architectures have been proposed more recently. There are two classes of these DPP architectures: PV-to-PV DPP topologies, as depicted in Fig. 2, interface adjacent PV string sections through converters, as illustrated in Fig. 2(a), and those where converters connect to buses (PV-to-bus), either through an isolated port or the PV output port, as depicted in Fig. 2(b) [3]. These DPP architectures share the same principle of operation: same size group of cells have a converter across them, Submodules, as they are referred to

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here, work to balance the current flowing across the group of submodules connected in series. Due to its major advancements over conventional methods in terms of efficiency, reliability, low-cost hardware implementation, and also the ability to be rated at low power levels, differential power processing (DPP) for PV applications has recently attracted a lot of attention [7]. This paper contains different sections to illustrate the significance of DPP, section I is the introduction of the paper, section II elucidates the principle of operation of DPP converters, section III illustrates a comparison between DCPOs and DPP, section IV explains local control and maximum power tracking, section V shows the various architectures of the series DPP.

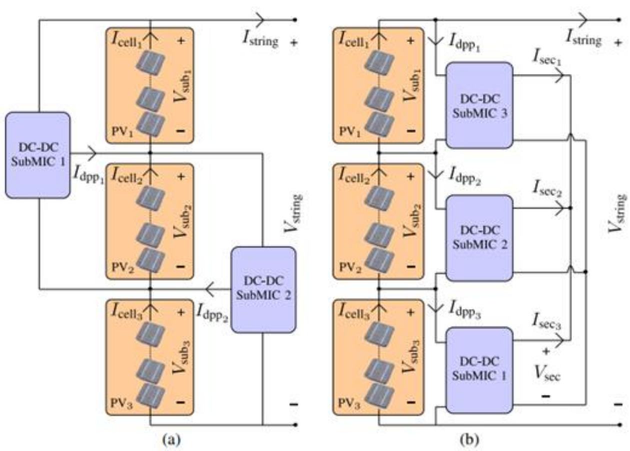

Fig. 2. DPP topologies: (a) PV-to-PV shuffling converters and (b) isolated-port PV-to-bus architecture.

2 Differential power processing

Enhancing PV energy conversion efficiency can be done by operating converters only when needed and only with the minimum amount of power necessary. By allowing each PV element in a series string to operate at its MPP by delivering only the often-negligible difference in the MPP current between two neighboring PV elements, differential power processing offers a way to avoid the sacrifices made in the past, shown conceptually in Fig. 3. There is no need for a power exchange if there is no mismatch. More generally, with a limited MPP mismatch, every local MPP can be reached by using only a tiny portion of the total power produced. The series string is intact, and the bulk of the power travels in a straight line. A differential converter serves as a controlled current source with a limited rating [8].

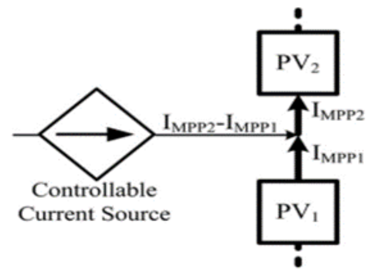

Fig. 3. To enable series PV elements to operate at different current levels, differential power converters serve as controllable current sources.

The power generated may be transferred directly to an output like an inverter connected to the grid, without further processing when the MPPs of series PV elements match. The inverter only processes power once, preventing local conversion loss if there are multiple local Maximum power points. Due to this, differential converters only use processing power if there is a mismatch in the MPP current of the series PV modules. If the MPP currents are matched, differential converters are not necessary (i.e., have no output current). Contrasted with cascaded dc-dc converters, A central inverter is followed by dc power optimizers, as in Fig. 1(c), that is required to process all PV power under all operational conditions [9, 10].

3 Comparison of the DC stage efficiency of the DPP system and the DC power optimizer system

A dc power optimizer (DCPO) system's system efficiency is primarily constrained by its dc-dc converters; however, the DPP system decouples the system's efficiency from the dc-dc converter's performance. To more clearly demonstrate how the DCPO and DPP systems compare in terms of efficiency, Fig. 3 displays a numerical example of a PV module with three submodules that has a small mismatch; the three submodules have a normalized radiation of 100%, 90%, and 80%, respectively.

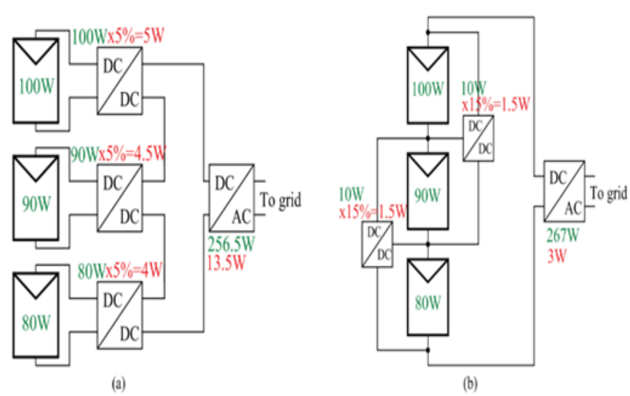

Fig. 4. (a) DC Power Optimizer. (b) DPP.

Submodule MPPT can be performed using either a dc optimizer or a DPP converter to eliminate mismatches. A summary of both systems' analyses of their dc stage efficiency is illustrated in Table I. Keep in mind that the DPP converters are anticipated to operate in a moderate load condition, whereas the DCPOs are anticipated to perform mostly at full load, we assume that the dc optimizers will be more efficient converters than the DPP converters. However, as shown in Table I, the DPP system's overall dc stage efficiency is significantly higher.
Submodule-level DPP has been frequently suggested to be used directly on utility-scale PV arrays, or to be combined with module-level dc optimizers, or microinverters, because of the aforementioned merits [11].

Table I
Efficiency of DC stages is compared. [11].

Device	DCPO	DPP
Scheduled total PV power [W]	270	270
overall power processed [W]	270	20
Converter effectiveness [%]	95 %	85 %
dc stage power loss [W]	13.5	3
stage effectiveness [%]	95 %	98.9 %

4 local control and maximum power point tracking

For local control, differential power processing is effective. Differential converters can increase each PV element's output power using only local information. The converters may benefit from additional protection and supervision measures [8]. Utilizing local data, There are several maximum power point tracking (MPPT) methods that can be used [12]. Certain MPPT algorithms might not be as effective when used with differential converters. A fractional open-circuit voltage approach, for instance, would not be the ideal option because it necessitates opening the main circuit channel. Simple, when power conversion is managed at the submodule level, reduced power overhead solutions might be viable [13].

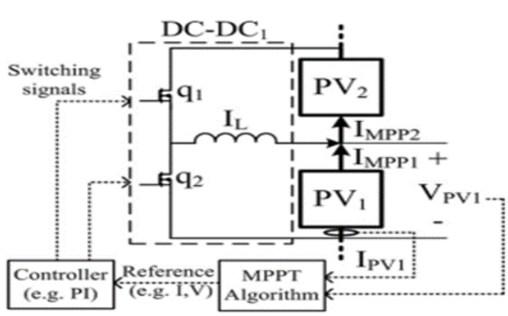

Fig. 5. Maximum tracking of power points under local control

The local controller's responsibility is to maximize the output of each individual PV element, as depicted in Fig. 7. The perturb-and-observe (P&O) technique is used in this work in its most basic form. At each PV element, local measurements of voltage and current are taken on a regular basis. These measurements will show the local controller whether power has risen or fallen since the previous step. The method can update a duty ratio value or just produce a reference for a compensator. The average voltage of the PV element that operates at the local MPP is controlled by the duty ratio of the switches. Since the I-V curve is a one-to-one mapping function, the PV element must be producing its MPP current if it is functioning at its MPP voltage. The system's requirement to balance the flow of charge leads to the differential converter current. If the average current of a differential converter is near to zero, it can be turned off to save energy [8].

5 series DPP architectures

To increase the performance of DPP converters in PV systems, recent research has focused on developing a variety of designs and topologies, improving converter design, and developing reliable and effective system control mechanisms. However, Every DPP architecture has drawbacks and compromises.

2.1 PV to Bus

Each DPP converter in the series DPP PV-bus architecture is connected to the system bus through a PV element, as shown in Fig. 6. Every PV element has a bidirectional DPP converter that can supply or drain the current necessary to maintain the MPP functionality of the PV element. The PV current for a perfect array of n PV element is defined by

$$I_{SS} = I_{PV,K} - I_{DPP,K} \tag{1}$$

For k = 1, 2, 3…n, where I_{SS} is the current substring, I_{PV} is the PV current, and I_{DPP} is the input current for the DPP. The following equation determines the return current I_r

$$I_r = \sum_{K=1}^{n} \frac{V_{PV,K} I_{PV,K}}{V_{bus}} \tag{2}$$

Where V_{bus} is the voltage of the string bus, and V_{PV} the voltage of the PV. The string current is then:

$$I_{string} = I_{SS} + I_r \tag{3}$$

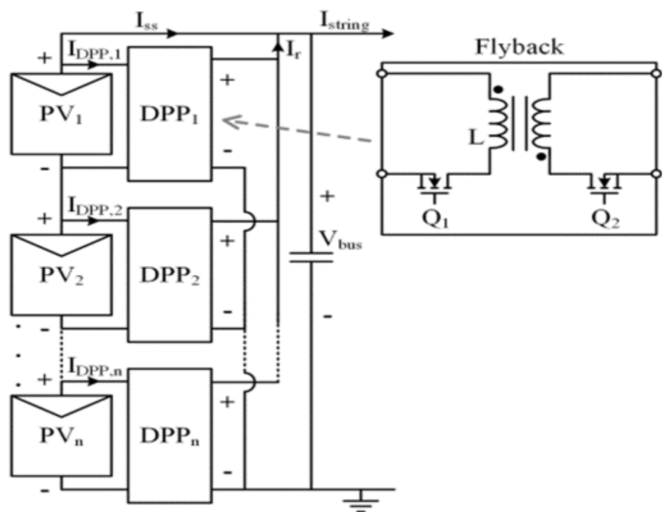

Fig. 6. Flyback DPP converters are used in a series DPP PV-bus design.

If the DPP converter in the PV-bus architecture uses a flyback approach, the input-output voltage ratio can be adjusted using the linked inductor's turns ratio dependent on the PV and bus voltages. To reduce the amount of power going through the converters and maximize output power, bidirectional power flow is required [14].

5.2 PV to PV

As depicted in Fig. 7, in the PV-PV architecture, every two adjacent PV elements have a DPP converter connected. For these converters to enable PV-PV current and power correction, bidirectional power flow is necessary. The voltage stress on the power elements is less than it is for the other two topologies. For n PV elements connected in series, there are frequently (n-1) converters. But instead of a DPP converter, the system's PV string current manages one of the PV elements.

Let the duty ratio of the K^{th} DPP converter be

$$D_K = \frac{V_{PV,K}}{V_{PV,K-1} + V_{PV,K}} \tag{4}$$

The architecture is scalable in relation to the number of PV elements, but this work is challenging because converters need all of the PV elements to interact in power compensation, and as the number of PV elements in series rises, unnecessary extra power conversion becomes a significant factor in the decline of the converter cluster's overall performance [3, 15].

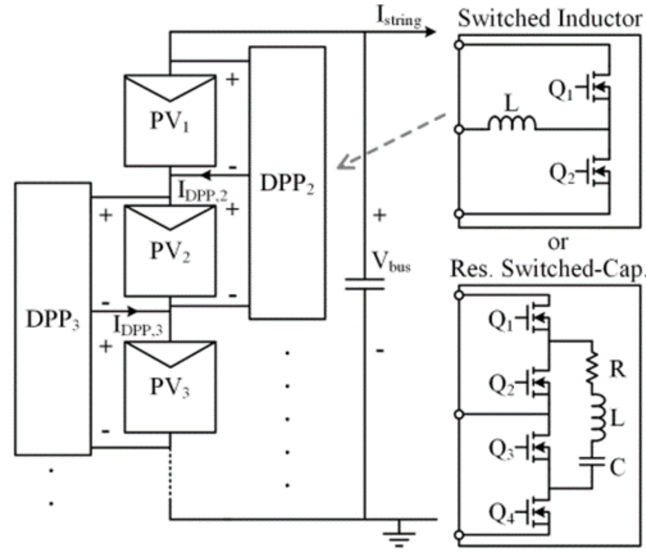

Fig. 7. With switched inductor or resonant switched-capacitor DPP converters, series DPP PV-PV design.

5.3 PV to Isolated port

PV-IP architecture, often known as PV-to virtual bus, is used in the series DPP, Each DPP converter is connected to a separate isolated bus and a PV element, as depicted in Fig. 8. To maximize PV power, Every PV component has a dual-purpose DPP converter that can transmit and receive power to the isolated port. In order for the perfect system to operate, the power going into and coming out of the isolated port must be matched with the following equation

$$\sum_{K=1}^{n} V_{PV,K} I_{DPP,K} = 0 \tag{5}$$

where $I_{DPP.K}$ is as labeled in Fig. 8. Then, the string current is defined as

$$I_{string} = I_{PV,K} + I_{DPP,K} \tag{6}$$

For k = 1, 2, 3…, n.

The DPP converter topology should have a bidirectional isolated topology for proper performance. The benefit of this architecture is that it enables direct power exchange between every PV element and a separate, isolated bus that has a lower voltage than the bus voltage, which lowers component voltage ratings and lowers component costs. However, Power both entering and leaving the bus has to be equal in order to keep a steady voltage on the separated bus, as in (6). This means that a trade-off of choosing this topology is that accurate MPPT may not be possible at whichever specific string current [14].

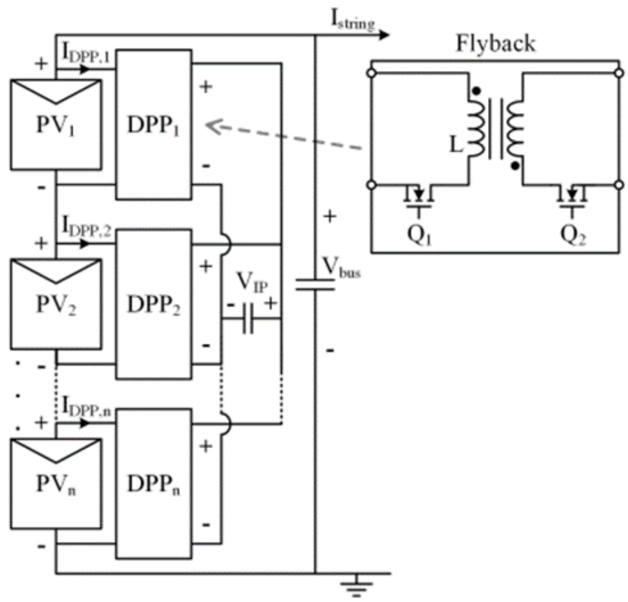

Fig. 8. Flyback DPP converters are used in a series DPP PV-IP design.

The scalability, dependability, and other attributes of each DPP architecture are summarized in Table II [16]

Table II

	PV-PV	PV-bus	PV-IP
Topology	Bidirectional buck-boost	Bidirectional flyback	Bidirectional flyback
Isolation	Not enable	enables	enables
Voltage rating of switches	$2\ x\ V_{PV}$	V_{PV} and V_{Bus}	V_{PV}
The proportional processed power	highest	least	less
ordered power mismatch in the processing	Yes	No	No
Scalability	enable	Not enable	enable
Reliability	less	more	more

6 conclusion

Since the recent introduction of the DPP idea for PV systems, a multitude of work has been researched and posted in a work of literature. In comparison to series string and FPP converters and DCPOs, the benefits of increased delivered energy, cheaper converter expense, and superior system dependability in DPP PV systems have been described. The majority of previous review has concentrated on series DPP designs, which include PV-bus, PV-PV, PV-IP, and various variants

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