

Photovoltaic subpanel converter system With Mppt control

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ABSTRACT

Photovoltaic (PV) power system performance depends on local irradiance conditions. PV systems are sometimes subject to partial shading, which may produce a non ideal characteristic curve, which impacts on electrical energy production. (DMPPT) photovoltaic (PV) system which can compensate the shading effect and the PV module mismatching as well as to increase the overall output electrical power. DMPPT is a very promising technique that allows the increase of efficiency and reliability of such PV systems. MPPT converter that connects to each PV cell string, called a subpanel MPPT converter (SPMC), is discussed in this paper.

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I. INTRODUCTION

Small-scale residential or commercial sized grid-tied photovoltaic (PV) systems have gained greater popularity in recent years, fuelled by new, more flexible module designs and government and utility sponsored incentives favouring solar technologies. It has given rise to the development of electronic power distribution systems (EPDS), such as nanogrid – microgrid – grid structure, utilizing multiple Renewable energy sources (RES) as supplementary energy source to utility grid. DC nanogrid, one kind of EPDS at low power level (10–100 kW), is addressed as a promising EPDS comparing to ac nanogrid from following aspects: higher overall system efficiency, starting with fewer power converters, easier interface of RESs to a dc system, no frequency stability and reactive power issues, no skin effect, and ac losses. RES and appliances are integrated to dc bus by using bidirectional power electronic converters as energy control centers taking charge of interfacing dc bus with utility ac grid [1]–[3].

However, a major drawback of the PV source is its ineffectiveness during the nights or low insulation periods or during partially shaded conditions. etc. [4], the ideal irradiance is practically impossible and the mismatch cases always impact the performance of the PV systems. For the centralized or string level MPPT PV systems, the consequences of the aforementioned mismatch cases are degradations in total power harvest, multiple maxima power points issues on the power-voltage curve and MPPT algorithms can fail [5]–[7]. Moreover, even when the global maximum power point of the shaded PV system is reached with some advanced algorithms [8]–[14], because the shaded part of the PV system would limit the output current of the non shaded part [15], such a power is still lower than the sum of the available maximum powers of the mismatch parts.

The panel level MPPT converter is commonly referred to as “PV optimizer” or “module integrated converters (MIC),” and it is concerned essentially with the current PV system [4], [16]–[25]. In [17] and [26], the authors proposed an improved multi-mode four switch Buck/Boost PV optimizer to increase energy capture in a PV optimizer string. The panel level distributed MPPT solution can, at best, eliminate the mismatch power loss among PV panels. Taking the trend of the “distributed MPPT” concept a step further, this paper focuses on a distributed MPPT structure that connects each PV cell string with a dedicated MPPT converter, called a subpanel MPPT converter (SPMC) module, to address the real-world mismatch issues and given better performance in power recovery comparing with current PV optimizers.

This paper is organized as follows: in the next part, the distributed MPPT concept is introduced, which can be applied to improve the performance of the PV system in real mismatch cases. The performance comparison of the current PV optimizer and the proposed SPMC system is given in Section III. Based on the SPMC concept, a novel unified output MPPT control strategy is proposed accordingly in order to optimize and simplify the distributed MPPT control solution as shown in part IV. In the fifth part, the reliable issue of the SPMC is discussed and in Section VI, simulation and test results are presented to verify that the SPMC PV system can achieve a more effective power harvest performance with the proposed control strategy. Finally, the paper ends with some concluding remarks and future work.

II. ANALYSIS OF DISTRIBUTED MPPT CONVERTER

Fig. 2(a) shows a standard PV panel consisting of PV cell strings connected in series, divided in three parts by corresponding bypass diode. Bypass diodes prevent the appearance of hot spots and protect the PV module from potentially destructive effects. The PV module is connecting with a MPPT converter which always operates the PV module at its maximum power point. So the MPPT converter together with the PV module is operating as a constant power source, the power of which is determined by the peak power of the PV module, at a relatively wide voltage/current range at the output side, making it possible to cascades with other converters in series or parallel. In other words, the distributed MPPT converter changes the MPP of the PV panel from a single voltage/current point into a wide voltage/current range, shown as the green solid curve of Fig. 2(b).

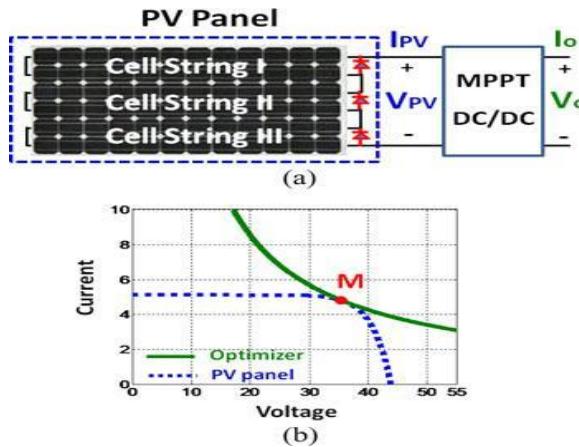


Fig. 2. Concept of distributed MPPT converter.

- (a) PV unit and distributed MPPT converter.
- (b) Output curve of PV unit and optimizer.

In a traditional PV system with centralized MPPT architecture, any disturbance can shift the maximum power point of the module, and results in a significant power decrease unless the module's output voltage is adjusted. However, with distributed MPPT structure, the peak power of the PV module can be achieved over a very wide range of voltages, so even when disturbances occur an adjustment to the output voltage of the distributed MPPT system, it still can maintain peak power. Distributed MPPT converter is usually implemented with a dc/dc power converter. Three possible converter topologies are taken into consideration in this paper because of their simplicity, high efficiency, and the capability of cascade operation as shown in Fig. 3 [23], [24], [27]. The blue I - V and P - V curves indicate the output characteristic curves of an original PV panel, and they are identical in each graph. The point M stands for the MPP of the original PV unit and the N1 and N2 indicate the initial point and ending point of the MPP region, respectively, at the output side of the distributed MPPT converter. The merit and demerit of the three topologies are given as follows: the Boost converter is only suitable for parallel connection, the output current of Boost-type MIMC is inherently limited by the characteristic of original PV panel. For the Buck converter, series connection is a better choice and the inherent voltage limit characteristic is achieved and the Buck/Boost converter enjoys most of the benefits of both Buck and Boost at the expenses of higher cost and more complex control solution.

One important thing to note here is that the second stage central MPPT converter is still required in the distributed MPPT converter-based PV system. However, the enlarged MPP region makes the MPPT of the second converter much easier, faster, more economical, and efficient when facing the mismatch [28].

III. STRUCTURE OF SUBPANEL MPPT CONVERTER

In most mismatch conditions, such as module-to-module difference, different module orientations, and tilts, etc., about 10%–30% of annual performance loss or more can be recovered by using the PV optimizers or PV MICs [28]–[31]. However, frequently, partial PV panel cannot work as expected which result from dust and spot dirtiness such as leaves or bird droppings or damage of PV cells, etc., the PV optimizer's performance is less than satisfactory in such cases. Since the panel is composed of several PV cell strings, taking the trend of "distributed MPPT" concept a step further, papers [31]–[37] propose to divide the standard PV module into several parts and implement distributed MPPT solution into subpanel level. This part discusses a SPMC system with three PV cell-string level dc/dc converter that executes MPPT separately for sections of an individual PV module which provides a better solution in order to address the real-world mismatch impact. For the SPMC system, the output terminals of all the MPPT converters can be connected either in parallel or in series. For the

parallel connection, the control is relatively simple, but the high-voltage gain will increase the cost and reduce the efficiency. And for series connection, lower rating devices and lower voltage gain can be the promising candidate for a low cost and high efficiency distributed solar system [26].

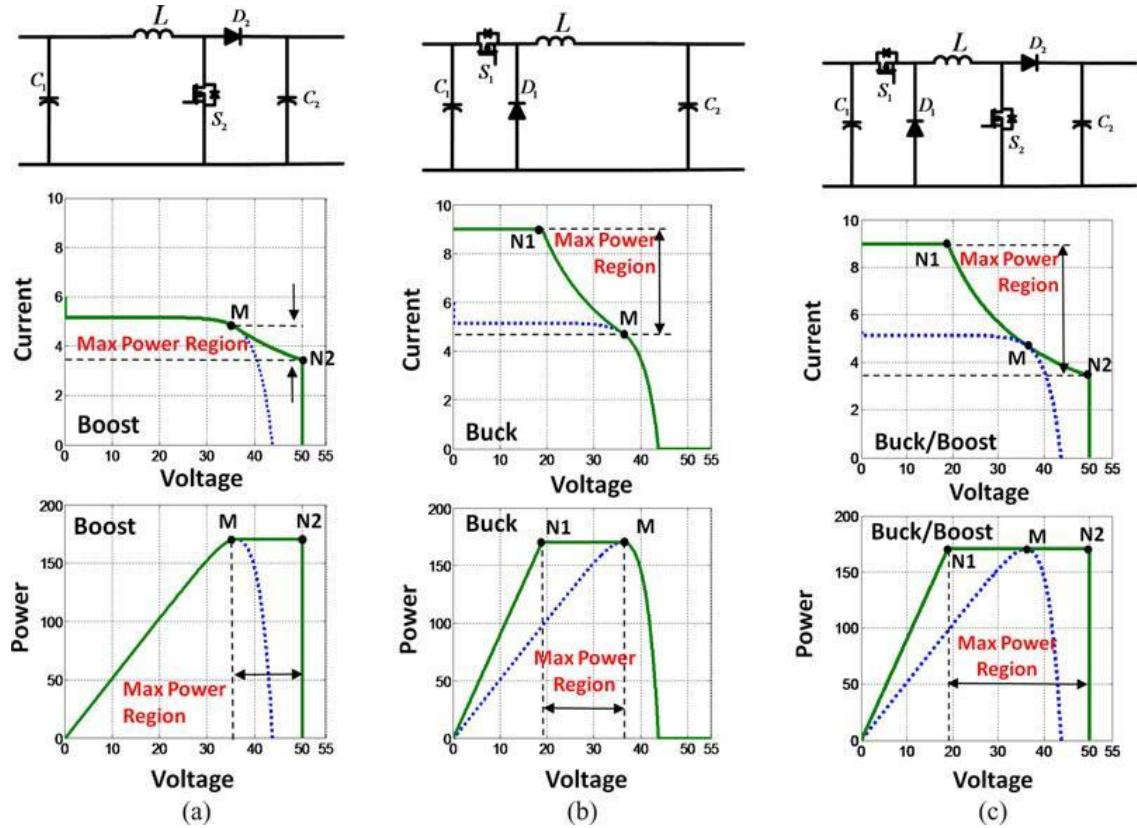


Fig. 3. Output characteristic curve of three topologies.
(a) Boost converter. (b) Buck converter. (c) Buck/Boost converter

Because of simple, high efficiency, and suitability for series connection as aforementioned, the Buck-type converter is chosen as implementation of the SPMC. By employing low-voltage synchronous buck converters connected across each PV cell string, a high-frequency, high-efficiency SPMC power stage can be achieved as shown in Fig. 4. From the input side of each Buck converters, the converters are parallelly connected with each PV cell strings.

From the output side of the MPPT converters, they are connected in series connection. One point should be noted that in this SPMC system, the bypass diodes inside the junction box of a standard PV module should be retained in case of the malfunction of the MPPT converters. For the convenience of theoretical expression of the SPMC, the diodes are not shown here and the detailed information about the reliable issues is given in the fifth part [29], [30]:

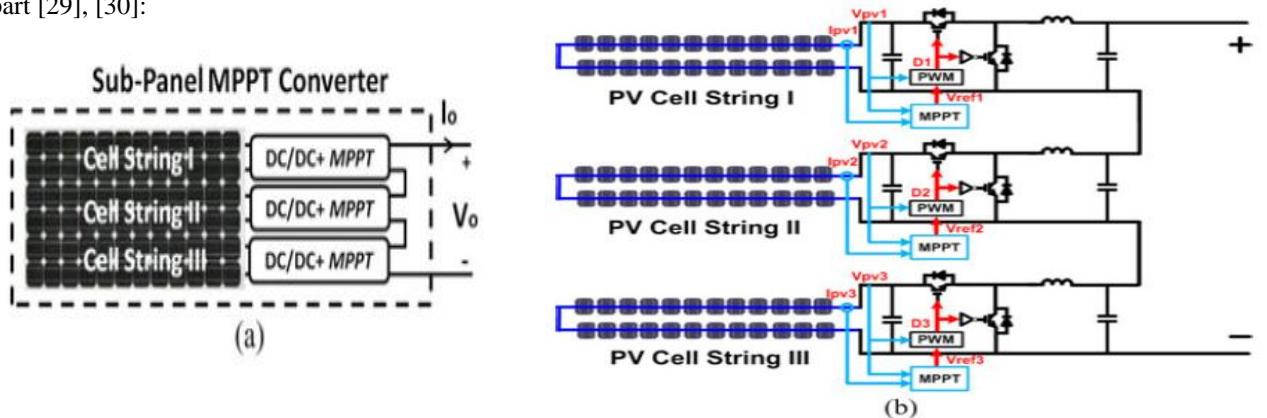


Fig. 4. SPMC diagram.
(a) Distributed MPPT SPMC concept .(b) Implementation of SPMC with Buck converter.

1) In such structure, the series rather than parallel connection of MPPT converter allows the input–output voltage ratio to be close to unity in ideal irradiance case, which leads to the highest switch utilization and is at a performance versus cost disadvantage.

2) Compared to a higher voltage level device used in the MICs, the lower voltage level device used in the SPMC application has better performance in efficiency.

3) Further distributed MPPT solution allows better performance in real-world mismatch cases comparing with PV optimizers, and for series Buck MPPT converters, all the PV cell strings can guarantee always working on its individual MPP regardless of a mismatch case.

The output I - V and P - V curves of the three PV cell groups are shown in Fig. 5(a): blue curve and red curve indicate non-shaded and shaded PV cell string separately. In Fig. 5(b), the solid lines stand for typical output curves of a Buck MPPT converters in non-shading (blue curve) and shading cases (red curve). Adding them up, the output I - V and P - V curves of the SPMC system of a PV panel are shown as black line in Fig. 5(c).

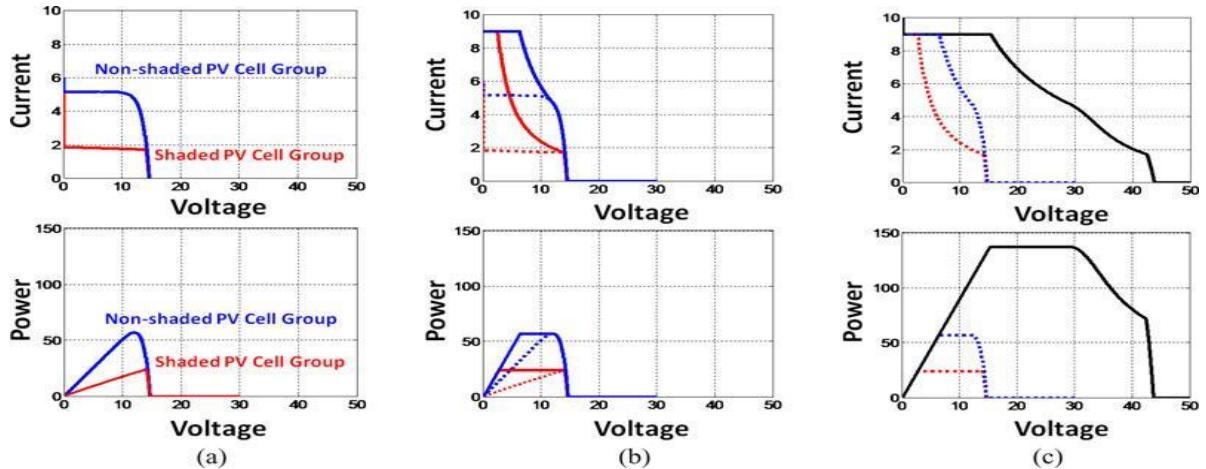


Fig. 5. Output I - V and P - V curve of SPMC system.
(a) Original PV cell strings. (b) Each MPPT converter. (c) SPMC.

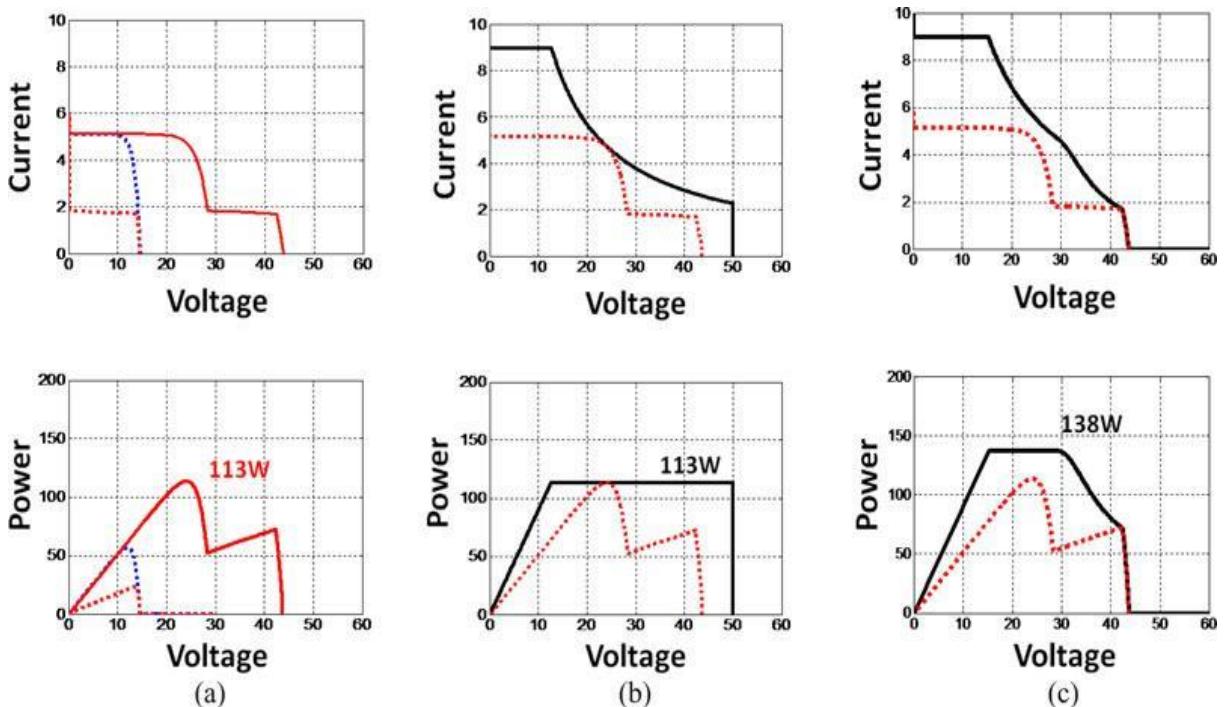


Fig. 6. Output I - V and P - V curve comparison.
(a) Original PV panel. (b) PV optimizer. (c) SPMC.

As we can see, if a few PV cells inside a PV panel are in shading case, the output characteristic of the shaded PV panel suffers multipeak issues and power loss as shown in Fig. 6(a). In such conditions, the PV optimizer can only track the maximum power point of the multipeak curve of the shaded PV panel even adopting some advanced MPPT algorithms as shown in Fig. 6(b), but still lose the power of the shaded PV cell string [24]. However, the SPMC introduces an autonomous MPPT converter for each PV cell string in a standard PV panel. So the capability of performing the independent MPPT function on each PV cell string basis is hereby achieved and it regulates the duty cycle of the power stage separately in order to de-couple a PV cell string from the others inside a PV panel. So a PV panel is divided into three independent parts and the mismatch case in one cell string cannot affect the others, and the power loss resulting from mismatch among PV cell strings, about 22% in this case, is thereby recovered as shown in Fig. 6(c).

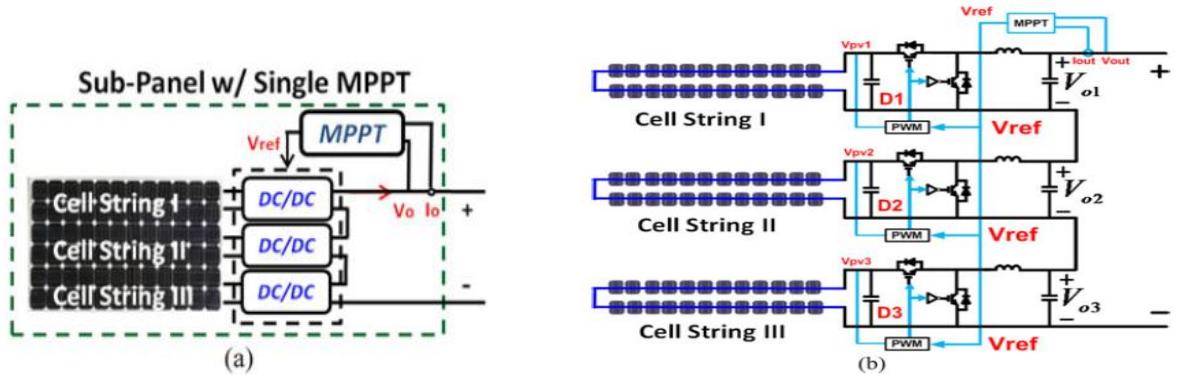


Fig. 7. Unified MPPT control of SPMC diagram

In this part, the SPMC concept is proposed and the working principle is introduced as well. However, although mismatch loss can be recovered through the SPMC with independent MPPT control, the implementation cost of the SPMC system is higher due to the increase in component count. A set of MPPT control IC, current sensor, voltage sensor, and corresponding A/D converters are needed for every PV cell string. In order to address the above issues, an optimal control method for the SPMC solution is proposed in next section.

IV. UNIFIED OUTPUT MPPT CONTROL IN SPMC SYSTEM

In order to reduce the cost and simplify the independent MPPT control in SPMC structure, a unified output voltage control with single MPPT detection strategy is proposed in this part [38], [39], as shown in Fig. 7.

In this structure: 1) a single MPPT unit is sensing the output power of the SPMC system with only one pair of voltage and current sensors; 2) three Buck MPPT converters share a common V_{ref} coming from the single MPPT unit; and 3) each Buck MPPT converter owns an independent control loop. Therefore, the output voltage signal of the MPPT control unit is the common MPPT voltage reference for all the converters in a SPMC module, during the MPPT period. The PWM controller of each Buck converter in the SPMC system compares the sensed output voltage of each PV cell string and the common MPPT voltage reference to control their respective switch. When the common voltage reference is perturbed by the unified output

MPPT controller, the input voltage of each Buck converter is regulated by an independent closed PWM control loop. Hence, the input voltage perturbation can be achieved. Because of their series connection, the Buck converters share a same output current.

Therefore, the output voltage of each Buck converter will vary according to the extracted maximum power from its individual PV cell strings and proportionate to the maximum power. So the total output voltage of the SPMC is the sum of the output voltage of each MPPT converters

$$V_{out} = \sum_{n=1}^3 V_{o_n} \quad (1)$$

Although the PV cell string MPP voltage may change with irradiance case or temperature, it is assumed that such changes can be considered relatively small [32]. For the same V_{ref} signal is given to three independent control loops, so the output voltage of each PV cell string in steady state should be the same and equal to V_{ref}

$$V_{p1} = V_{p2} = V_{p3} = V_{ref} \quad (2)$$

And the duty cycle of each MPPT converter in steady state can also derived

$$\frac{V_{o1}}{V_{pv1}} = D_1, \frac{V_{o2}}{V_{pv2}} = D_2, \frac{V_{o3}}{V_{pv3}} = D_3 \quad (3)$$

If no mismatch happens, the SPMC should be working with high conversion efficiency and all the maximum power points of the three PV cell strings are exactly the same. Therefore, the operating condition of each Buck converter in SPMC system is same as well. If mismatch case happens with part of a PV module, the power coming from the shaded PV cell string is decreased and the duty cycle of the corresponding MPPT converter is also decreased accordingly in order to save the power of shaded PV cell string and adjust the common output current limitation. At this point, the SPMC system is working as a constant power source with different output voltage and current. So we can say that the conversion ratio and duty cycle for each converter can vary over wide range

$$D_2 < D_1 = D_3 \text{ ----- (4)}$$

Fig. 8(a) indicates the output *I-V* and *P-V* curves of shaded (red curve) and non shaded (blue curve) PV cell strings, respectively. Because the voltage reference of the MPP is given by a single MPPT unit, so the constant power curve of the output of each SPMC should start at a same voltage value and ending at current limit of each SPMC as blue and red solid curve shown in Fig. 8(b). The final voltage reference from the MPPT unit is neither the MPP of shaded cell string nor the MPP of the non shaded PV cell strings, it only stands for a trade off state point where the output power of three parallel PV cell strings can reach the maximum in a same voltage value as shown in the enlarged view of the Fig. 8(b), adding the output curve up and the characteristic curve of the whole SPMC system is shown as the black curve in Fig. 8(c).

V. CONCLUSION

For the purpose of improving the performance of PV system in dc nanogrid under common mismatch conditions, this paper explores the benefits of distributed MPPT solution through the use of SPMC structure, which can be seen as the reduced version of the current PV optimizer, connecting each PV cell string with a Buck converter. The approach offers many advantages including better power harvest ability, independent control loop, etc. In order to reduce the cost and simplify the SPMC structure, a unified input voltage control with single output MPPT detection strategy is proposed accordingly. The PV system based on the proposed SPMC unit can recover nearly all of power losses caused by real-world mismatch case. Comparing the distributed MPPT control structure with the SPMC PV system, this simplified control approach offers a number of additional practical implementation advantages such as: saves the number of A/D units, current sensors, and MPPT controllers units on the premise of guaranteeing maximum power statue regardless of the mismatch case.

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