Trends in Engineering and Technology (NCTET-2K17)
International Journal of Advanced Engineering Research and Science (IJAERS) Special Issue-5
https://dx.doi.org/10.22161/ijaers/nctet.2017.eee.22 ISSN: 2349-6495(P) | 2456-1908(O)

Enhancement of Energy Production and Reliability of Photovoltaic Systems using Differential Power Processing Technique

M.PRAMEELA[1], P.VINOD KUMAR[2], A.SUDHAKAR[3]

[1]PG Student, Dept of EEE (PS), S.V.Engineering College for Women, Tirupati, AP, India.
[2]Associate Professor, Dept of EEE, S.V.Engineering College for Women, Tirupati, AP, India.
[3]Associate Professor, Dept of EEE, S.V.Engineering College for Women, Tirupati, A.P, India.

***Abstract*- Increasing energy harvest from PV systems and reducing overall PV system costs are important to the continued adoption of solar energy. In an effort to achieve this, power converters are being integrated into PV modules. These power converters allow for more flexibility in PV system design by enabling each PV module to operate independently. This paper introduces an energy conversion approach that enables each PV element to operate at its maximum power point (MPP) while processing only a small fraction of the total power produced. This is accomplished by providing only the mismatch in the MPP current of a set of series-connected PV elements.**

The physical integration of these power converters creates new possibilities to improve the energy harvest. This paper proposes methods and circuits that leverage this physical integration to further enhance PV module integrated power converters. Different circuit architectures are proposed to enable MPPT for a smaller subsection of PV cells called PV sub modules. By tracking the MPP for PV sub modules, further energy harvest improvements can be made. The proposed circuits include smaller power converters and multiple input converters for full PV sub module power processing as well as differential power processing (DPP) converters to handle the difference in power between PV sub modules.

***Index Terms*— Differential power processing, local control, maximum power point tracking (MPPT), photovoltaic power, renewable energy.**

I. INTRODUCTION

Solar energy, as a promising alternative to the conventional resources such as fossil fuels, has drawn significant attention in recent years. Solar energy technology can be divided into two major categories: concentrated sun power (CSP) and photovoltaic (PV). CSP technology uses concentrated sunlight to produce heat and generate electricity via a thermal process similar to that of a conventional fossil fuel power plant. PV technology, on the other hand, converts solar radiation directly to DC electricity using semiconductors that exhibit the photovoltaic effect. Although both technologies have their own advantages and both are undergoing rapid development recently, CSP technology is often limited to large utility-scale applications while PV technology is more flexible in scale and can be found in residential, commercial and utility-scale applications.

For the purpose of this thesis, the scope of discussion will be limited to PV technology. Photovoltaic solar energy offers a series of benefits such as low pollution and carbon dioxide emission, energy independence and potentially low energy cost, given that sunlight is a free energy resource. However, solar energy historically remains at a cost disadvantage compared to conventional energy resources primarily due to the high manufacturing cost of solar devices and low conversion efficiency from solar radiation to electricity.

The cost of PV energy is typically evaluated in terms of levelized cost of energy (LCOE), i.e.

$$\text{LCOE} = \frac{\text{installation cost} + \text{operation cost} + \text{maintenance cost}}{\text{electricity generated over lifetime}}$$

To reduce PV energy price, measures should be taken on both reducing the manufacturing and maintenance cost and improving energy conversion to generate more electricity within the system lifetime. The work in this thesis addresses these two goals (reducing the cost of the entire PV system and boosting the energy production) through advanced power electronics designs. The work in this thesis is built around an innovative technique known as differential power processing (DPP). DPP allows for significant improvement in terms of power conversion efficiency while reducing power converter size and cost. In this work, and \element-to-element" DPP architecture was developed and bidirectional buck-boost converter is designed and implemented for this architecture.

Local MPP tracking of each PV element is achieved with small converters that provide the differencein MPP current between two adjacent PV elements, as shown in Fig. 1. Earlier research that has employed a similar approach includes a generation control circuit and bypass converters. The technique introduced maintains the series PV configuration while adding external dc–dc converters. The approach does not lead directly to small, local differential converters, as in this paper, relies on a central controller, and requires more

https://dx.doi.org/10.22161/ijaers/nctet.2017.eee.22 ISSN: 2349-6495(P) | 2456-1908(O)

complex (e.g., isolated) gate driving circuits. As the number of PV elements increases, the switch current and voltage ratings increase and MPP tracking slows down.

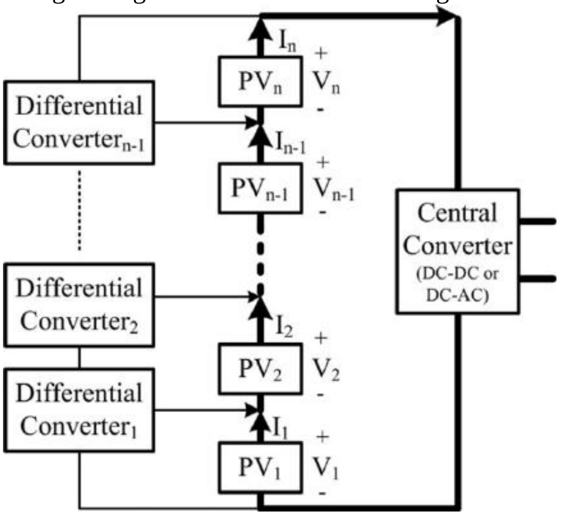

Fig: 1. Conceptual diagram of differential power processing.

The approach may not scale well, but the underlying concept is introduced. In dual half-bridge circuits are explored at the panel level but it is not clear how MPP operation is achieved. Returned energy current converters, introduced utilize a synchronous flyback topology for energy conversion but rely on a central controller which provides the same PWM signal to all converters. Current diverters utilizing a half-bridge topology have been suggested for enabling cascaded dc–dc optimizers to operate at the MPP, but this adds an unnecessary energy conversion step.

More recently, delta converters and other voltage equalization techniques have been proposed using half-bridge, flyback, and switched capacitor circuits. Although this approach has its merits, it does not guarantee MPP operation for each PV element as the MPP voltages may not be equal. The contribution in this study is to optimize and more fully develop the differential power processing method, seeking to minimize conversion loss and cost. This paper quantitatively analyzes and compares several differential power processing architectures for efficient and effective extraction of the maximum available power from PV systems.

An important practical advantage is substantial reduction in PV system cost as the approach facilitates large-scale PV systems. This method can be applied at various scales including multiple panel strings, single panels, and also at the subpanel level as is highlighted in this study. The differential power processing architectures here can track the true MPP of each series PV element while processing only a small fraction of the total energy produced. The series connection of the PV elements is maintained and bulk power is processed only once. The proposed method enables distributed control and improves overall system reliability.

II. PROPOSED METHOD

A number of different DPP architectures are proposed in literature. Three architectures will be explored here: PV-PV, PV-bus, and PV-virtual bus. These DPP architectures along with the dc optimizer architecture are illustrated in Figure 2. Similar DPP architectures, such as switched capacitor architectures and generation control converter architectures exist but will not be explored in this paper.

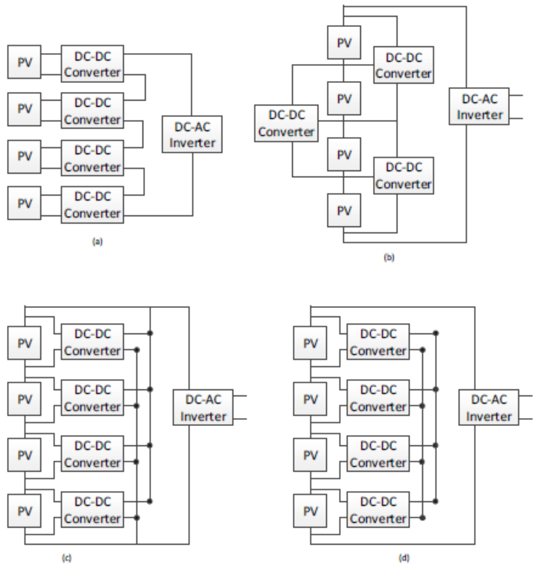

Figure-2 (a) Conventional dc optimizer architecture, (b) PV-PV architecture, (c) PV-bus architecture, and (d) PV-virtual busarchitecture.

When the MPPs of series PV elements match, the energy producedcan be sent directly to an output, such as a grid-connectedinverter, without additional processing. Power is processed justonce by the inverter thereby avoiding local conversion loss. Differentialconverters take advantage of this by only processingpower if there is mismatch in the MPP current of the series PVelements. If MPP currents are matched, differential convertersneed not operate (i.e., have no output current). This is in contrastto cascaded dc–dc converters that must processthe entire PV power over all operating conditions.Differential power processing can be implemented using avariety of architectures and converter topologies. Differentialconverters can be designed to interact with other PV elements,the main bus, an independent energy storage element (e.g., avirtual bus), or even a battery. Isolated or nonisolated converterscan be used for energy conversion, depending on configurationdetails and requirements. Differential power processing appliesat any level: panel by panel, string by string, or even cell bycell. Two differential architectures are described in more detailbelow.

https://dx.doi.org/10.22161/ijaers/nctet.2017.eee.22 ISSN: 2349-6495(P) | 2456-1908(O)

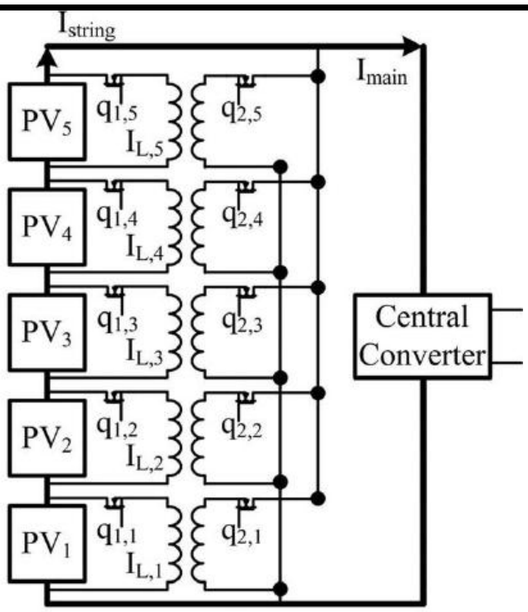

Fig. 3. Differential power converters using a buck–boost topology connected to Flyback differential convertersinterface with the main bus.

- The PV-to-bus architecture can also be implemented with *n* isolated converters, as shown in Fig.3.
- This arrangement tends to reduce the total power processed by the differential converters.
- The overall goal is to minimize power loss due to energy conversion.
- This system is *underdetermined* because there are *n* control objectives (PV MPP operation) and $n + 1$ control actuators (I_{DC}, i, for $i = 1...n$ and I_{string}).
- The extra degree of freedom can be used to minimize power loss.
- One way power loss minimization could be implemented is to adjust I_{string} using the central converter such that power processed by differential converters is minimized.

A variety of maximum power point tracking (MPPT) algorithms can be implemented using local information. Some MPPT algorithms may be less suitable in the context of differential converters. For example, a fractional open-circuit voltage approach may not be desirable since it must open the main circuit path. Simple, low power overhead techniques may be appropriate when power conversion is managed at the sub module level.

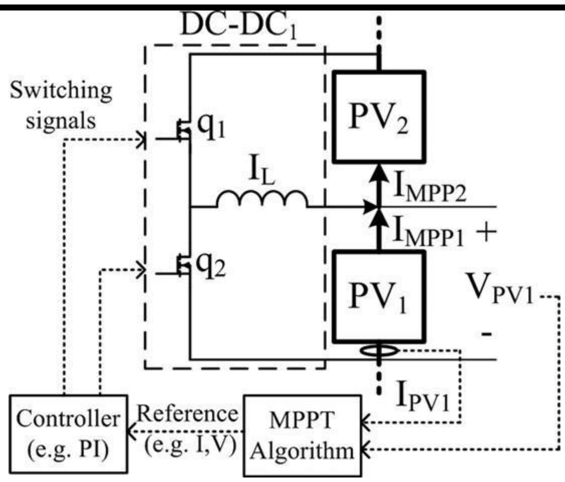

Fig. 4. Maximum power point tracking with local information.

The aim of the local controller is to maximize the powerout of its respective PV element as shown in Fig. 4. In this work, a basic perturb-and-observe (P&O) algorithm is implemented. Periodic voltage and current measurements are madelocally at each PV element. These measurements in form the local controller whether power has increased or decreased from the previous step. The algorithm can generate a reference for acompensator or simply update a duty ratio value. The duty ratio of the switches controls the average voltage of the PV element to operate at the local MPP. If the PV element is operating atits MPP voltage, it must be generating its MPP current sincethe *I–V* curve is a one-to-one mapping function. The differential converter current follows from the need of the system to balancethe flow of charge. A differential converter can be disabled tosave energy if its average current is close to zero.In a system with *n* PV elements and $n - 1$ differential converter, the central converter acts as the *n*th control actuator. Ingeneral, the differential converters would be able to track theirlocal MPPs more quickly than the global MPP tracking capability of the central converter. This time-scale separation aids effective MPP tracking and should limit unwanted interaction.With differential power processing; the true MPP of each PV element can be reached with little conversion loss.

III. SIMULATION RESULTS

To further explore differential power processing, a systemwith three series-connected PV panels and two buck–boost, PV to PV differential converters is modeled and simulated.

https://dx.doi.org/10.22161/ijaers/nctet.2017.eee.22 ISSN: 2349-6495(P) | 2456-1908(O)

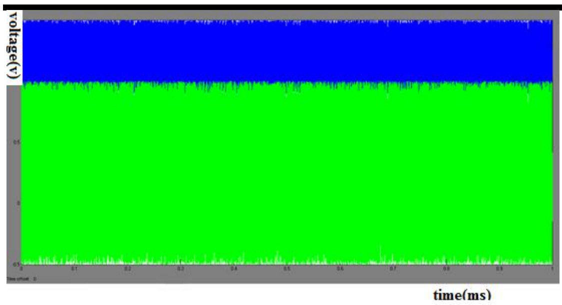

Fig:5(a)

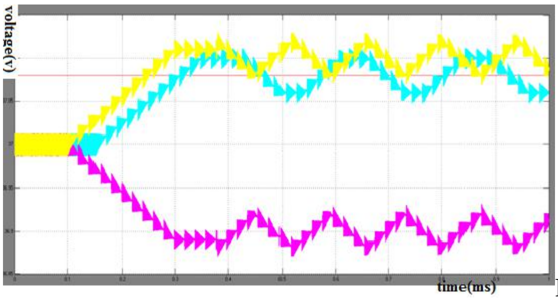

Fig: 5(b)

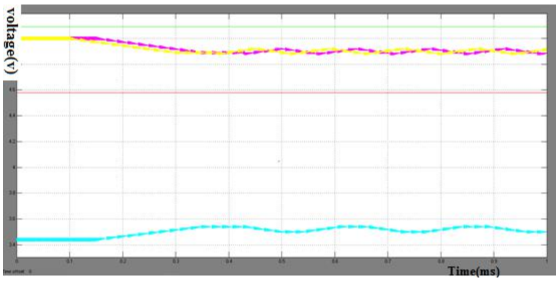

Fig:5(c)

Fig. 5. Tracking the MPP of three series PV panels with local differential converters. (a) differential converters inject current to enable each PV panel to operate at its (b) MPP voltage and (c) MPP current.

MPP operation is achieved while only a fraction of the totalpower is processed in this example with a local 10% mismatch.Differential converters provide a low average current [less than 1 A, shown in Fig. 5(a)] in keeping with theoretical analysis.Note that the differential converters in this configuration do notsimply provide the difference between PV elements MPP currentbecause there is coupling. This means thatthe differential converters process 25 W or less compared to a total system output power of almost 550 W. Each PV panelreaches its local MPP, as shown in Fig. 5(b) and (c). The poweroutput from this system increases by about 16W(a 3%increase)under the given conditions, compared to a direct series connectionwithout the differential converters. A resistor in series withthe inductor was included in the differential converter model torepresent losses.

The use of solar energy is essential for providing solutions to the environmental problems and also energy demand. The vast development to improve the efficiency by the MPPT algorithms encouraged the domestic generation of power using solar panels. The available MPPT techniques based on the number of control variables involved, types of control strategies, circuitry, and applications are possibly useful for selecting an MPPT technique for a particular application for grid tied or standalone mode of operations. This review has included many recent hybrid MPPT techniques along with their benefits for mismatched conditions such as partial shading, no uniformity of PV panel temperatures, and dust effects.It is observed that Perturbation and Observation and Incremental Conductance methods are simple and used by many researches, but they have the slow tracking and low utilization efficiency. To overcome the drawbacks, fuzzy and neural network techniques are used in the present days by which the efficiency is increased. To boost up the voltage various DC-DC converters are used along with battery storage systems in order to store the excessive energy from solar PV panel. The DC link voltage oscillations in the grid connected PV system can be obtained by using Cuk converters, SEPIC converters, and Zeta converters with reducing current ripple injected in the PV array and load. The harmonic content is reduced from the output of DC-DC converters using the filter circuits.

The passive filters as LC, LCL, and LLCC are used for harmonic distortion as well as to improve the power quality. Filter capacitors are used to reduce high frequency current ripple.This DC is again fed to the inverter for converting the DC to AC with various PWM techniques. These PWM inverter techniques yield the better AC outputs which are used to connect the grid interconnections and standalone AC loads. Multilevel inverters with sinusoidal PWM and SVM are used to reduce the harmonics in the load voltage even in low switching frequency. Grid tied inverters with battery backup are preferred in hybrid systems for backup even if the grid goes down for both grid tied and off grid systems.

It also helps in improving the synchronization between output power of solar plant and the ON grid system. As we know that supplying or connecting the output power of solar PV to the ON or commercial grid is the best solution in terms of utilization of energy in the efficient manner, the present researchers are working on designing inverter smarter with improved efficiency, reduced harmonics, soft switching etc. This paper presents the comparison of various types of inverters with their technical advantages, difficulties in handling the issues, capability to work in buck and boost mode with interfacing compatibility also discussed in detail.

International Journal of Advanced Engineering Research and Science (IJAERS) Special Issue-5
https://dx.doi.org/10.22161/ijaers/nctet.2017.eee.22 ISSN: 2349-6495(P) | 2456-1908(O)

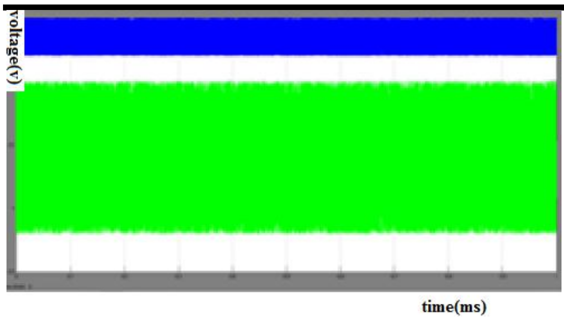

Fig: 6(a)

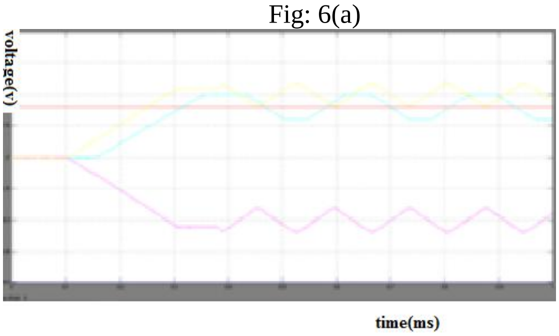

Fig: 6(b)

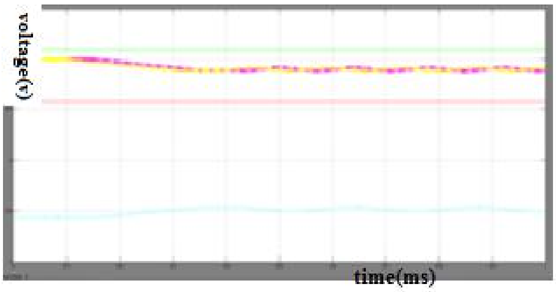

Fig:6(c)

Fig. 6. Tracking the MPP of three series PV panels with local differential converters of LC filters. (a) differential converters inject current to enable each PV panel tooperate at its (b) MPP voltage and (c) MPP current.

IV. CONCLUSION

Differential converters enable a series PV system to truly optimizepower production by reaching the MPP of each seriesPV element. Only a small fraction of the total output power isprocessed when a mismatch among MPP currents exists. Differentialconverters offer several advantages that tend to keepcosts low: 1) differential converter requirements are simple androutine in a power conversion sense, with many possible scalable,local conversion solutions, 2) voltage and current ratingsare modest (and a small fraction of system current), and 3) thereare no special dynamic performance requirements, as MPPTperformance on time scales of a few milliseconds is the state ofthe art.Differential power processing has the potential to substantiallyimprove the LCOE of PV systems.

A comparative analysisof system reliability concludes that the differential powerprocessing architecture results in a longer MTTF than other dcarchitectures. Protection and monitoring capabilities add valueto locally controlled differential converters. Global MPPT in acentral inverter is simplified because local maxima (the kinks inthe *I–V* curve) can be eliminated, and overall energy generationincreases. Because differential converters process little power,there is potential to integrate these systems in small packages oron chip for high-volume, low-cost production.Several differential power processing architectures were presentedand compared. Results show that isolated PV-to-bus differential converters tend to process the least amount of powerand have the ability to minimize the power processed by differentialconverters. Simulation results demonstrate MPP trackingwith local information. Experimental results show differentialconverters generating up to 50% more energy under a 5%partialshading condition for two series PV subpanel modules.

This paper presented the most demanded technique by the Photovoltaic system which needs to be connected to the commercial grid, as the basic requirement of commercial grid is that the standard voltage and frequency in this paper the LC filters with PWM technique has been discussed. As the result shows that this technique improves and gives the better efficiency in terms of reliability, ripples, impedance matching, fast response etc., and it also reduces the switching losses.

V. REFERENCES

[1] T. Esram, P. T. Krein, B. T. Kuhn, R. S. Balog, and P. L. Chapman, “Powerelectronics needs for achieving grid-parity solar energy costs,” in *Proc.IEEE Energy 2030 Conf.*, Nov. 2008.
[2] W. Short, D. J.Packey, and T. Holt, “A manual for the economic evaluationof energy efficiency and renewable energy technologies,” Nat. RenewableEnergy Lab., Golden, CO, Tech. Rep. 462-5173, Mar. 1995.
[3] E.D.Dunlop, D. Halton, andH.A.Ossenbrink, “20 years of life and more:where is the end of life of a PV module?” in *Proc. IEEE Photovoltaic Spec.Conf.*, Jan. 2005, pp. 1593–1596.
[4] N. G. Dhere, “Reliability of PV modules and balance-of-system components,”in *Proc. IEEE Photovoltaic Spec. Conf.*, Jan. 2005, pp. 1570–1576.
[5] P. T. Krein and R. S. Balog, “Cost-effective hundred-year life for singlephaseinverters and rectifiers in solar and LED lighting applications basedon minimum capacitance requirements and a ripple power port,” in *Proc.IEEE Appl. Power Electron. Conf. Expo.*, Feb. 2009, pp. 620–625.
[6] P. T.Krein, R. Balog, andM.Mirjafari, “Minimum energy and capacitancerequirements for single-phase inverters and rectifiers using a ripple port,”*IEEE Trans.*

https://dx.doi.org/10.22161/ijaers/nctet.2017.eee.22 ISSN: 2349-6495(P) | 2456-1908(O)
Power Electron., vol. 27, no. 11, pp. 4690–4698, Nov. 2012.
[7] K. A. Kim and P. T. Krein, "Photovoltaic converter module configurationsfor maximum power point operation," in *Proc. IEEE Power Energy Conf.*,Feb. 2010, pp. 77–82.
[8] D. C. Martins and R. Demonti, "Interconnection of a photovoltaic panelsarray to a single-phase utility line from a static conversion system," in*Proc. IEEE Power Electron. Spec. Conf.*, 2000, pp. 1207–1211.
[9] G. R. Walker and P. C. Sernia, "Cascaded DC-DC converter connectionof photovoltaic modules," *IEEE Trans. Power Electron.*, vol. 19, no. 4,pp. 1130–1139, Jul. 2004.
[10] L. Linares, R. W. Erickson, S. MacAlpine, and M. Brandemuehl, "Improved energy capture in series string photovoltaics via smart distributedpower electronics," in *Proc. IEEE Appl. Power Electron. Conf. Expo.*, Feb.2009, pp. 904–910.