IAES Journal of Electrical and Electronics Engineering
Vol. 5, No. 1, June 2018, pp. 6~10
ISSN: 2338-7432, DOI: 10.11591/jeee.v5i1.pp6-10

Designing the power conversion pathway: a review of DC–DC converter topologies for photovoltaic systems

Hendril Satrian Purnama, Watra Arsadiando
Embedded Systems and Power Electronics Research Group, Yogyakarta, Indonesia

Article Info

Article history:

Received Dec 14, 2016
Revised Aug 20, 2017
Accepted Jan 4, 2018

Keywords:

Converter topologies
DC-DC converters
High voltage gain
Maximum power point tracking
Photovoltaic systems
Power conversion efficiency

ABSTRACT

The performance of photovoltaic (PV) energy systems depends not only on solar cell characteristics but also on the effectiveness of the power conversion stage. Direct current-direct current (DC-DC) converters provide the essential interface between PV modules, energy storage devices, and electrical loads or grid-connected inverters. Selecting an appropriate topology is challenging because PV sources exhibit wide operating-voltage variations, nonlinear current–voltage characteristics, and sensitivity to irradiance and temperature. This review examines DC–DC converter topologies for PV applications, emphasizing their operating characteristics, voltage conversion capability, efficiency, and suitability for maximum power point tracking (MPPT). The discussion covers conventional non-isolated converters, isolated high-step-up structures, cascaded and modular architectures, and multiport converters. Relevant studies published up to 2016 are critically compared to identify the principal advantages and limitations of each design family. The analysis indicates that no single topology is optimal for every PV installation, since converter selection depends on voltage gain, power rating, isolation requirements, component stress, and operating conditions. The review concludes by identifying design priorities for developing efficient, reliable, and application-oriented PV power conversion systems.

This is an open access article under the CC BY-SA license.

1. INTRODUCTION

Photovoltaic (PV) technology has become an important component of distributed renewable energy generation, yet extracting the available solar energy efficiently remains a significant engineering challenge. The electrical output of a PV module changes with irradiance, temperature, shading, and load conditions, meaning that its operating point rarely remains at the maximum power point. A direct current-direct current (DC-DC) converter addresses this problem by controlling the electrical operating conditions seen by the PV source while adapting its output to the connected load or subsequent conversion stage. Consequently, converter topology is not merely a matter of voltage regulation, but a fundamental determinant of energy extraction, system efficiency, and operational flexibility [1], [2].

The main research problem concerns the selection of a converter architecture that can accommodate the variable output of PV modules without introducing excessive conduction, switching, or magnetic losses. Conventional buck and boost converters are relatively simple, but their voltage conversion ranges may be insufficient for some grid-connected and low-voltage PV applications. More advanced structures, including coupled-inductor, switched-capacitor, cascaded, and isolated converters, can provide higher voltage gain or improved system integration, although these benefits may require additional components and more complex control [3], [4]. The appropriate design must therefore balance conversion ratio, efficiency, reliability, cost, and maximum power point tracking (MPPT) compatibility rather than optimize a single electrical parameter.

This review critically examines the principal DC–DC converter families used in PV systems and evaluates their suitability for different application requirements. The review is based on peer-reviewed journal and conference publications available up to December 2016, with particular attention to studies that

investigate PV-specific conversion characteristics. The discussion progresses from conventional topologies to high-gain, isolated, modular, and multiport structures before considering comparative design issues and research directions. This organization establishes a connection between the underlying PV interface problem, the available converter solutions, and the practical criteria required for topology selection.

2. CONVENTIONAL NON-ISOLATED CONVERTER TOPOLOGIES

Non-isolated converters are widely used in PV applications because they offer relatively simple circuit structures, compact implementation, and direct control of the PV operating point. The principal configurations include buck, boost, buck–boost, Ćuk, and single-ended primary-inductor converter (SEPIC) converters, each providing different input–output voltage relationships and current characteristics. Taghvaee *et al.* [1] reviewed these structures in the context of PV applications and emphasized that the selected converter affects the operating region and achievable MPPT performance. Bennett *et al.* [5] also demonstrated that the interaction between PV models and converter dynamics should be considered when evaluating MPPT behavior.

The buck converter is suitable when the PV voltage is consistently higher than the required load voltage. Its relatively straightforward structure can provide good efficiency under appropriate operating conditions, although it cannot directly increase the output voltage above the input voltage. The boost converter offers the opposite function and is therefore frequently adopted when a low-voltage PV source must supply a higher-voltage DC link. However, obtaining very high voltage gain from a conventional boost converter requires a high duty ratio, which can increase conduction losses, switch stress, and sensitivity to parasitic effects [2], [6].

Buck–boost, Ćuk, and SEPIC converters provide greater flexibility because they can operate with input and output voltages on either side of the conversion range. Their characteristics can be useful when PV voltage varies substantially or when the connected load requires a regulated output across changing environmental conditions. The Ćuk converter offers continuous input and output current, which can reduce current ripple at the PV interface, although its energy-transfer capacitor and additional passive components increase design complexity. SEPIC provides non-inverting buck–boost operation and can be attractive when output polarity must be preserved, but its component count and conduction path must be considered when evaluating overall efficiency [1], [5].

The choice among these conventional topologies should be based on the complete PV operating range rather than nominal voltage alone. Enrique *et al.* [4] theoretically assessed MPPT efficiency for different converter configurations and showed that converter operating characteristics influence the ability to reach and maintain the maximum power point. Başoğlu and Çakır subsequently compared isolated and non-isolated converters for MPPT applications, highlighting the importance of converter input characteristics and operating constraints [7]. These findings indicate that the converter and MPPT controller should be designed as a coordinated subsystem rather than treated as independent components.

3. HIGH-STEP-UP AND ISOLATED CONVERTER STRUCTURES

High-step-up converters are particularly relevant when low-voltage PV modules must feed a high-voltage DC link or grid-connected inverter. Conventional boost converters can achieve voltage elevation, but their practical performance deteriorates when extreme duty ratios increase semiconductor stress and parasitic losses. Li and He reviewed non-isolated high-step-up converters for PV grid-connected applications and classified several approaches for improving voltage gain while controlling cost and efficiency [2]. Revathi and Prabhakar extended this discussion through a comprehensive review of non-isolated high-gain topologies specifically intended for PV applications [3].

Coupled-inductor converters provide high voltage gain through transformer-like turns ratios without requiring a conventional high-frequency transformer. Their design can reduce the duty ratio required for a given conversion ratio, but leakage inductance may produce voltage spikes and additional losses unless suitable energy-recovery or clamping arrangements are included. Zhao and Lee proposed high-efficiency high-step-up converter structures that address leakage-energy and rectifier reverse-recovery concerns [8]. Evran and Aydemir later presented an isolated high-step-up converter with low voltage stress, demonstrating a topology relevant to renewable sources such as PV modules [9].

Galvanic isolation is an important design consideration when electrical separation between the PV source and the load or grid interface is required. Isolated topologies, including flyback, forward, push–pull, and bridge-derived converters, can provide voltage scaling and safety-related separation, although their transformers and additional switching components affect size, cost, and losses. The choice between isolated and non-isolated designs therefore depends on system voltage, power rating, safety requirements, and the

desired conversion ratio. A high voltage gain alone does not establish the superiority of a topology if the resulting component stress, efficiency, and thermal performance are unacceptable [3], [8], [9].

4. MODULAR, CASCADED, AND MULTIPORT ARCHITECTURES

Modular and cascaded converter architectures address the limitations of conventional centralized PV conversion by distributing power processing across multiple modules or stages. In a cascaded arrangement, individual DC–DC converters can be associated with PV modules or module groups, allowing their operating conditions to be controlled more independently. Vighetti *et al.* [10] investigated the optimization and design of a cascaded DC–DC converter for grid-connected PV systems, demonstrating the relevance of converter architecture to system-level performance. Hu *et al.* [11] also proposed multistage DC–DC converter structures for grid-connected PV applications, emphasizing the need for high step-up capability and flexible conversion.

Distributed conversion can reduce the impact of mismatch between PV modules because each converter can regulate its associated source independently. This approach is particularly useful where partial shading, different module orientations, or non-uniform operating conditions cause individual modules to produce different power levels. However, adding conversion stages increases the number of semiconductor devices, magnetic components, control channels, and potential failure points. The resulting system must therefore justify the additional hardware through improved energy harvesting, maintainability, or system flexibility [10], [11].

Multiport converters extend this concept by integrating PV sources, energy storage, and loads through a shared conversion structure. Zhang *et al.* [12] reviewed three-port DC–DC converter topologies for renewable energy and energy storage integration, highlighting their potential to combine source conversion and storage management within one power-processing stage. Such architectures can reduce the need for separate converter units and support coordinated energy flow between PV generation, batteries, and DC loads. Their practical implementation nevertheless requires careful management of power-flow interactions, control complexity, and the operating constraints of each port.

5. COMPARATIVE ASSESSMENT AND DESIGN CONSIDERATIONS

The converter families discussed above provide different solutions to the central problem of matching variable PV output to application-specific voltage and power requirements. Conventional non-isolated structures offer simplicity, while high-step-up and isolated converters address larger voltage ratios and electrical separation. Modular and multiport architectures provide greater flexibility for distributed generation and energy storage integration. Table 1 summarizes their main characteristics and the design trade-offs that should guide topology selection.

Table 1. Comparison of DC–DC converter topologies for PV applications

Converter topology	Main advantages	Principal limitations	Typical PV application
Buck	Simple structure; potentially high efficiency	Step-down operation only	PV source with voltage above load requirement
Boost	Simple step-up conversion; continuous input current	High duty ratio and switch stress at high gain	Low-voltage PV to DC-link interface
Buck–boost	Step-up and step-down capability	Higher component stress; conventional form has inverted output	Wide PV voltage variation
Ćuk	Continuous input and output currents	Additional passive components and losses	Low-ripple PV interface
SEPIC	Non-inverting step-up and step-down operation	More components and magnetic complexity	PV systems with variable input voltage
Coupled-inductor high-gain	High voltage gain with moderate duty ratio	Leakage-inductance and voltage-spike management	Low-voltage PV grid interfaces
Isolated converter	Galvanic isolation and flexible voltage conversion	Transformer design and additional losses	Applications requiring electrical isolation
Cascaded or multiport	Modular operation and integrated energy management	More complex control and coordination	Distributed PV and PV–storage systems

As indicated in Table 1, the most appropriate topology depends on the interaction between electrical requirements and implementation constraints. For example, a boost converter may be sufficient for a compact low-power system, whereas a high-gain coupled-inductor or isolated structure may be more suitable for a low-voltage PV source connected to a high-voltage DC bus. Modular conversion becomes attractive when

mismatch between PV modules is a dominant concern, while multiport structures are relevant when storage integration is an explicit system requirement. These comparisons are consistent with the broader converter assessments reported by Taghvaee *et al.* [1], Sivakumar *et al.* [3], and Revathi and Prabhakar [13].

Efficiency should be evaluated across the expected operating range rather than at a single rated operating point. Semiconductor conduction losses, switching losses, diode reverse recovery, magnetic losses, and passive-component equivalent resistance all contribute to the final conversion efficiency. High voltage gain may reduce the need for additional conversion stages, but it can also increase voltage stress or circulating energy if the topology is poorly designed. A practical comparison should therefore include efficiency curves, thermal behavior, input-current ripple, output-voltage regulation, component count, and reliability [3], [6], [8].

MPPT compatibility is another essential criterion because the converter determines the electrical conditions through which the PV operating point is controlled. A topology with a suitable conversion ratio may still perform poorly if its dynamic response, input-current behavior, or control range prevents stable tracking. Li *et al.* [5] emphasized the importance of considering PV and converter characteristics together when studying energy extraction, while Bennett *et al.* [6] showed that converter dynamics can influence the behavior of MPPT systems. Therefore, MPPT performance should be evaluated as a property of the combined PV–converter–controller system rather than attributed solely to the tracking algorithm.

6. RESEARCH CHALLENGES AND FUTURE DIRECTIONS

Despite substantial progress in converter design, several challenges remain relevant to the development of efficient PV power conversion systems. High-gain structures must address semiconductor stress, leakage-energy management, reverse-recovery effects, and the practical limits of passive components. Modular and multiport converters introduce additional control and protection requirements because disturbances in one port may affect the operation of other connected sources or loads. These challenges indicate that future designs should prioritize not only high conversion ratios but also predictable dynamic behavior, reliability, and ease of implementation [3], [7], [12].

Further research should strengthen the integration of converter topology, MPPT strategy, and system-level energy management. Experimental comparisons under partial shading, rapid irradiance changes, and variable load conditions are needed to determine whether theoretical advantages translate into measurable energy gains. Standardized evaluation procedures should report efficiency over a broad operating range and include thermal performance, component stress, and long-term reliability. Such investigations can support more objective topology selection and reduce the risk of choosing a converter based on isolated performance indicators.

7. CONCLUSION

DC–DC converter topology plays a central role in determining the efficiency, flexibility, and reliability of PV energy systems. Conventional non-isolated converters remain attractive because of their simplicity, while high-step-up and isolated structures provide solutions for demanding voltage conversion and electrical separation requirements. Cascaded, modular, and multiport architectures extend the available design options by supporting distributed PV operation and integrated energy storage. The literature available up to 2016 demonstrates that no single converter topology is universally optimal, because the preferred design depends on voltage range, power level, MPPT requirements, efficiency, isolation, and system complexity. Future progress will depend on coordinated PV–converter–controller design and comprehensive experimental validation under realistic operating conditions.

REFERENCES

[1] M. H. Taghvaee, M. A. M. Radzi, S. M. Moosavain, H. Hizam, and M. Hamiruce Marhaban, "A current and future study on non-isolated DC-DC converters for photovoltaic applications," *Renewable and Sustainable Energy Reviews*, vol. 17, pp. 216–227, 2013, doi: 10.1016/j.rser.2012.09.023.

[2] W. Li and X. He, "Review of nonisolated high-step-up DC/DC converters in photovoltaic grid-connected applications," *IEEE Transactions on Industrial Electronics*, vol. 58, no. 4, pp. 1239–1250, 2011, doi: 10.1109/TIE.2010.2049715.

[3] B. Sri Revathi and M. Prabhakar, "Non isolated high gain DC-DC converter topologies for PV applications – A comprehensive review," *Renewable and Sustainable Energy Reviews*, vol. 66, pp. 920–933, 2016, doi: 10.1016/j.rser.2016.08.057.

[4] J. M. Enrique, E. Durán, M. Sidrach-de-Cardona, and J. M. Andújar, "Theoretical assessment of the maximum power point tracking efficiency of photovoltaic facilities with different converter topologies," *Solar Energy*, vol. 81, no. 1, pp. 31–38, 2007, doi: 10.1016/j.solener.2006.06.006.

[5] T. Bennett, A. Zilouchian, and R. Messenger, "Photovoltaic model and converter topology considerations for MPPT purposes," *Solar Energy*, vol. 86, no. 7, pp. 2029–2040, 2012, doi: 10.1016/j.solener.2012.04.005.

[6] S. Li, T. A. Haskew, D. Li, and F. Hu, "Integrating photovoltaic and power converter characteristics for energy extraction study of

solar PV systems," *Renewable Energy*, vol. 36, no. 12, pp. 3238–3245, 2011, doi: 10.1016/j.renene.2011.02.016.
[7] M. E. Başoılu and B. Çakir, "Comparisons of MPPT performances of isolated and non-isolated DC-DC converters by using a new approach," *Renewable and Sustainable Energy Reviews*, vol. 60, pp. 1100–1113, 2016, doi: 10.1016/j.rser.2016.01.128.
[8] Q. Zhao and F. C. Lee, "High-efficiency, high step-up dc-dc converters," *IEEE Transactions on Power Electronics*, vol. 18, no. 1 I, pp. 65–73, 2003, doi: 10.1109/TPEL.2002.807188.
[9] F. Evran and M. T. Aydemir, "Isolated high step-Up DC-DC converter with low voltage stress," *IEEE Transactions on Power Electronics*, vol. 29, no. 7, pp. 3591–3603, 2014, doi: 10.1109/TPEL.2013.2282813.
[10] S. Vighetti, J. P. Ferrieux, and Y. Lembeye, "Optimization and design of a cascaded DC/DC converter devoted to grid-connected photovoltaic systems," *IEEE Transactions on Power Electronics*, vol. 27, no. 4, pp. 2018–2027, 2012, doi: 10.1109/TPEL.2011.2167159.
[11] Y. Hu, W. Cao, B. Ji, J. Si, and X. Chen, "New multi-stage DC-DC converters for grid-connected photovoltaic systems," *Renewable Energy*, vol. 74, pp. 247–254, 2015, doi: 10.1016/j.renene.2014.08.009.
[12] N. Zhang, D. Sutanto, and K. M. Muttaqi, "A review of topologies of three-port DC-DC converters for the integration of renewable energy and energy storage system," *Renewable and Sustainable Energy Reviews*, vol. 56, pp. 388–401, 2016, doi: 10.1016/j.rser.2015.11.079.
[13] S. Sivakumar, M. J. Sathik, P. S. Manoj, and G. Sundararajan, "An assessment on performance of DC-DC converters for renewable energy applications," *Renewable and Sustainable Energy Reviews*, vol. 58, pp. 1475–1485, 2016, doi: 10.1016/j.rser.2015.12.057.