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Non-isolated DC–DC converters for residential photovoltaic applications: a review of topologies, MPPT integration, energy storage, and design trade-offs

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ABSTRACT

Non-isolated DC–DC converters are essential components in residential photovoltaic (PV) systems because they regulate voltage, facilitate maximum power extraction, and connect PV modules with batteries, DC loads, and inverter stages. Their compact structure, relatively low cost, and absence of high-frequency isolation transformers make them attractive for household applications. However, conventional converter topologies face limitations involving voltage gain, input-current ripple, semiconductor stress, conversion efficiency, and operating-range flexibility. This review examines non-isolated buck, boost, buck–boost, SEPIC, Cúk, quadratic boost, interleaved, switched-capacitor, coupled-inductor, and bidirectional converter architectures. Their integration with maximum power point tracking (MPPT) and residential battery storage is also evaluated. The comparison considers voltage-conversion capability, component count, current continuity, control complexity, efficiency, and practical implementation constraints. The literature indicates that conventional boost converters remain suitable for relatively simple PV interfaces, whereas high-gain and interleaved structures offer advantages when larger voltage ratios or reduced ripple are required. Bidirectional converters provide additional flexibility for battery charging and discharging. The review identifies priorities in system-level optimization, thermal and reliability assessment, residential safety, and experimental validation under realistic household operating conditions.

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1. INTRODUCTION

Residential photovoltaic (PV) systems have become an important option for reducing household dependence on conventional electricity supplies and improving the utilization of renewable energy. Their practical performance depends not only on the efficiency of photovoltaic modules but also on the quality of the power-conversion stages connecting generation, storage, and household loads. DC–DC converters regulate the electrical operating point of PV modules and adapt their output voltage to the requirements of batteries, DC distribution buses, and inverters. Consequently, converter selection has a direct influence on energy harvesting, system efficiency, installation cost, and operational reliability [1]–[4].

A major challenge in residential PV installations is the variable voltage and power produced by photovoltaic modules. Irradiance, module temperature, partial shading, and changing household demand continuously affect the available electrical operating conditions. Maximum power point tracking (MPPT) therefore requires an adjustable power-conversion interface capable of controlling the effective electrical load seen by the PV array. Non-isolated DC–DC converters are frequently considered because they can provide this function without requiring a high-frequency isolation transformer [1], [4]–[6].

However, conventional converter structures do not satisfy every residential application equally well. A simple boost converter may provide adequate voltage elevation but can experience high semiconductor stress and reduced efficiency at extreme duty ratios. More advanced high-gain structures can overcome some

limitations, although additional inductors, capacitors, switches, and diodes may increase cost and control complexity. This review evaluates these trade-offs and considers how converter topology, MPPT operation, battery integration, and household requirements should be considered together [2], [3], [7].

2. FUNDAMENTAL NON-ISOLATED CONVERTER TOPOLOGIES

Conventional non-isolated DC–DC converters provide the basic voltage-regulation functions required in residential PV systems. Buck converters reduce an input DC voltage, boost converters increase it, and buck–boost converters can perform both functions depending on their configuration. SEPIC and Cúk converters provide additional voltage-regulation flexibility and can maintain a non-inverting output polarity in their conventional implementations. These structures are widely studied for PV interfaces because their operating principles and control methods are well established [1], [4], [5].

The boost converter is particularly attractive when a low-voltage PV source must supply a higher-voltage DC bus. Its continuous input-current characteristic can support PV operation and reduce the input-current discontinuity associated with some other basic topologies. Nevertheless, its voltage gain becomes increasingly difficult to maintain at high duty ratios because conduction losses, switching losses, parasitic resistances, and semiconductor stress become more influential. These limitations have encouraged the development of quadratic, interleaved, and high-gain boost structures [2], [3], [8].

Buck–boost, SEPIC, and Cúk converters are useful when the PV voltage varies over a range that may be either above or below the required DC-bus voltage. Their wider voltage-regulation capability can reduce the risk of losing the MPP when the PV operating voltage changes. However, their component requirements, input-current characteristics, and switching-device stresses differ considerably. Chiang et al. demonstrated the application of a SEPIC converter in a PV charger system, while subsequent studies investigated improved high-gain SEPIC structures for solar-energy applications [5], [9].

3. HIGH-GAIN AND ADVANCED NON-ISOLATED CONVERTER ARCHITECTURES

High-gain converters are relevant when residential PV modules or small PV strings must supply a relatively high DC-link voltage. Their development uses several techniques, including coupled inductors, switched capacitors, voltage-multiplier cells, voltage-lift networks, and cascaded conversion stages. These techniques can increase the voltage-conversion ratio without relying on an extremely high duty cycle. However, the resulting improvement must be evaluated against additional component count, conduction paths, parasitic effects, and implementation complexity [2], [3], [10].

Quadratic boost converters provide higher voltage gain than conventional boost structures through an extended energy-conversion arrangement. Their use in PV systems has been investigated together with hybrid MPPT techniques to improve the extraction of available solar power. Interleaved converters provide another option because parallel switching phases can distribute current and reduce input-current ripple. These characteristics can be useful in residential systems where PV-side current quality and thermal performance are important [11], [12].

Switched-capacitor and coupled-inductor structures can further improve voltage gain and reduce voltage stress on selected semiconductor devices. Farahani et al. proposed a non-isolated high-step-up converter using switched-inductor and switched-capacitor networks for PV applications. Chandra and Gaur investigated a high-gain SEPIC structure that combines continuous input current with voltage elevation without requiring a transformer or coupled inductor. These developments demonstrate the potential of advanced non-isolated architectures, although their suitability for household products still depends on cost, component lifetime, control requirements, and tested efficiency [13], [14].

4. MPPT INTEGRATION AND CONVERTER CONTROL

MPPT is a central control function in residential PV systems because the maximum available PV power changes with environmental conditions. The converter modifies its duty cycle to adjust the operating voltage and current of the PV source toward the maximum power point. Perturb and observe and incremental-conductance algorithms are commonly used because they can be implemented with relatively modest computational resources. However, their tracking accuracy and dynamic response depend on sampling intervals, perturbation size, measurement quality, and converter dynamics [1], [4], [15].

The interaction between the MPPT algorithm and converter topology must be considered during system design. A converter may have sufficient voltage gain but still be unsuitable if its achievable duty-cycle range cannot maintain the PV operating point under the expected load conditions. Conversely, a topology with broad voltage-regulation capability may require additional components and more complex control. Research on PV converter selection therefore emphasizes the need to evaluate the converter and MPPT algorithm as an integrated system rather than as independent design choices [1], [6], [11]. Advanced control methods can

improve the response of converters to changing irradiance, temperature, and household loads. Proportional-integral control, adaptive control, fuzzy logic, and optimization-based techniques have been investigated for voltage regulation and MPPT performance. Nevertheless, sophisticated algorithms should provide measurable benefits that justify their additional computational and implementation requirements. For residential systems, a well-designed conventional controller may be preferable when it provides adequate tracking performance, stable DC-bus regulation, and reliable operation at lower cost [15], [16].

5. BIDIRECTIONAL CONVERSION AND RESIDENTIAL BATTERY STORAGE

Residential PV installations increasingly combine solar generation with battery energy storage to improve self-consumption and provide energy availability outside daylight hours. A bidirectional DC–DC converter manages power transfer between the battery and the DC bus during charging and discharging. Non-isolated bidirectional structures are attractive because they can reduce converter size and component requirements compared with transformer-based alternatives. Their performance depends on voltage-conversion range, current ripple, switching losses, battery voltage variation, and the effectiveness of the charging and discharging controllers [17].

The conventional bidirectional buck–boost converter is a common reference architecture for battery interfaces. Its operation can be extended through interleaving, coupled inductors, switched-capacitor networks, and soft-switching techniques to improve current handling and conversion efficiency. Sutikno et al. reviewed non-isolated bidirectional converters for renewable and sustainable energy systems, highlighting the importance of efficiency, reliability, and energy-storage integration. These findings are relevant to residential PV systems because battery charging and discharging must be coordinated with PV generation and household demand [17], [18].

Multi-input and multiport non-isolated converters can further combine PV generation, batteries, and DC loads within a common power-conversion stage. Such arrangements may reduce the number of separate converters and improve power-routing flexibility. However, their control design becomes more demanding because several energy sources and operating modes must be coordinated. For household installations, the benefits of reduced component count and improved energy management should therefore be assessed against fault handling, protection, and maintenance requirements [18], [19].

6. COMPARATIVE ASSESSMENT AND RESIDENTIAL DESIGN CONSIDERATIONS

Table 1 compares the principal non-isolated converter architectures in terms of their functions, advantages, and limitations in residential PV applications. The comparison emphasizes that voltage gain alone is not sufficient to determine the most appropriate topology. Input-current continuity, component stress, bidirectional capability, control complexity, and cost also influence practical performance. The table provides an application-oriented basis for selecting a converter architecture according to the requirements of a household PV installation.

Table 1. Comparison of non-isolated DC–DC converter topologies for residential PV applications

Converter topology	Main function	Main advantages	Main limitations	Potential residential application
Buck	Step-down conversion	Simple structure and control	Cannot elevate PV voltage	Low-voltage DC loads and charging
Boost	Step-up conversion	Continuous input current and simple control	High duty ratio and switch stress at high gain	PV-to-DC-bus interface
Buck–boost	Step-up and step-down	Wide voltage-regulation range	Conventional form may have inverting output and higher ripple	Variable PV voltage interface
SEPIC	Non-inverting step-up/down	Flexible voltage regulation	Additional passive components	PV chargers and DC loads
Cúk	Step-up/down conversion	Continuous input and output currents	Capacitor stress and component complexity	PV interfaces requiring current continuity
Quadratic boost	High step-up conversion	Higher gain than conventional boost	More demanding design and control	Low-voltage PV to higher DC bus
Interleaved boost	High-current step-up conversion	Reduced input-current ripple and distributed current	Multiple switching phases and control complexity	Higher-power household PV systems
Switched-capacitor / coupled-inductor	High-gain conversion	High voltage gain and potential stress reduction	More components and parasitic effects	Compact high-gain PV interfaces
Bidirectional buck–boost	Battery charge/discharge	Two-way power flow	Control and protection complexity	Residential battery storage

The comparison in Table 1 indicates that conventional boost converters remain attractive for uncomplicated PV interfaces where the required voltage gain is moderate. SEPIC and buck–boost converters offer broader voltage adaptation, which can be beneficial when PV operating voltage changes substantially. High-gain and interleaved structures are more appropriate when voltage elevation or current-ripple reduction is a primary requirement. Bidirectional converters are necessary when the residential system includes battery storage and requires controlled energy exchange [2], [3], [17], [20].

Residential design must also consider safety and reliability beyond the converter's electrical performance. A non-isolated converter does not provide galvanic separation between its input and output, so the overall installation must be designed with appropriate insulation coordination, grounding, overcurrent protection, isolation where required by the system architecture, and safe maintenance procedures. Thermal management is equally important because switching devices, inductors, and capacitors experience temperature-dependent losses and ageing. Therefore, laboratory efficiency measurements should be supplemented by assessments of component temperature, protection behavior, electromagnetic interference, and long-term operating stability [3], [10], [17], [21]–[24]

7. RESEARCH GAPS AND FUTURE DIRECTIONS

Future research should prioritize integrated converter design that considers PV characteristics, MPPT performance, battery operation, and household load profiles simultaneously. Many published studies emphasize voltage gain or peak efficiency under selected laboratory conditions, while fewer provide comprehensive evaluations across changing irradiance, partial shading, variable loads, and battery operating modes. Comparative testing should use consistent power ratings, input-voltage ranges, switching frequencies, and efficiency measurement procedures. Such standardization would make the reported benefits of different converter architectures more meaningful for residential system designers [1], [2], [17].

Reliability and lifecycle performance also require greater attention in advanced non-isolated converters. High component counts may increase the number of possible failure points, while high duty ratios and voltage stress can accelerate semiconductor and passive-component degradation. Future work should evaluate thermal cycling, capacitor ageing, inductor saturation, fault detection, and the effect of switching-frequency selection on long-term efficiency. Cost-oriented optimization should also include component availability, repairability, and the total cost of ownership rather than only the initial converter cost [3], [10], [18].

8. CONCLUSION

Non-isolated DC–DC converters are important elements in residential PV systems because they regulate photovoltaic operating conditions, support MPPT, and connect generation with household loads and battery storage. Conventional buck, boost, buck–boost, SEPIC, and Cúk converters provide established solutions, while quadratic, interleaved, switched-capacitor, and coupled-inductor architectures offer additional voltage-gain and ripple-reduction capabilities. Bidirectional converters extend these functions by enabling controlled battery charging and discharging. However, each topology involves trade-offs involving efficiency, voltage stress, current ripple, component count, control complexity, and safety. The reviewed literature suggests that no single non-isolated converter is optimal for every residential PV configuration. Conventional boost converters are suitable for relatively simple voltage-elevation requirements, while SEPIC and buck–boost structures offer wider operating flexibility. High-gain and interleaved converters are promising for systems requiring greater voltage conversion or improved current quality, whereas bidirectional converters are essential for integrated battery storage. Future development should focus on system-level optimization, realistic experimental validation, lifecycle reliability, and safe integration into household electrical installations.

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, Jan. 2013, doi: 10.1016/j.rser.2012.09.023.

[2] 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, Dec. 2016, doi: 10.1016/j.rser.2016.08.057.

[3] M. Forouzesh, Y. P. Siwakoti, S. A. Gorji, F. Blaabjerg, and B. Lehman, "Step-Up DC-DC converters: A comprehensive review of voltage-boosting techniques, topologies, and applications," *IEEE Transactions on Power Electronics*, vol. 32, no. 12, pp. 9143–9178, Dec. 2017, doi: 10.1109/TPEL.2017.2652318.

[4] 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, Jul. 2012, doi: 10.1016/j.solener.2012.04.005..

[5] S. J. Chiang, H. J. Shieh, and M. C. Chen, "Modeling and control of PV charger system with SEPIC converter," *IEEE Transactions on Industrial Electronics*, vol. 56, no. 11, pp. 4344–4353, Nov. 2009, doi: 10.1109/TIE.2008.2005144.

[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, Dec. 2011, doi: 10.1016/j.renene.2011.02.016.
[7] A. Amir, A. Amir, H. S. Che, A. Elkhateb, and N. A. Rahim, "Comparative analysis of high voltage gain DC-DC converter topologies for photovoltaic systems," *Renewable Energy*, vol. 136, pp. 1147–1163, Jun. 2019, doi: 10.1016/j.renene.2018.09.089.
[8] S. Thangavelu and P. Umapathy, "Design of new high step-up DC-DC converter topology for solar PV applications," *International Journal of Photoenergy*, vol. 1, p. 7833628, Dec. 2021, doi: 10.1155/2021/7833628.
[9] S. Chandra and P. Gaur, "An efficient switched inductor–capacitor-based novel non-isolated high gain SEPIC for solar energy applications," *International Journal of Circuit Theory and Applications*, vol. 51, no. 3, pp. 1286–1312, Mar. 2023, doi: 10.1002/cta.3454.
[10] T. Sutikno, H. S. Purnama, N. S. Widodo, S. Padmanaban, and M. R. Sahid, "A review on non-isolated low-power DC-DC converter topologies with high output gain for solar photovoltaic system applications," *Clean Energy*, vol. 6, no. 4, pp. 557–572, Aug. 2022, doi: 10.1093/ce/zkac037.
[11] Veerabhadra and S. Nagaraja Rao, "Assessment of high-gain quadratic boost converter with hybrid-based maximum power point tracking technique for solar photovoltaic systems," *Clean Energy*, vol. 6, no. 4, pp. 632–645, Aug. 2022, doi: 10.1093/ce/zkac041.
[12] T. Sutikno, A. S. Samosir, R. A. Aprilianto, H. S. Purnama, W. Arsadiando, and S. Padmanaban, "Advanced DC-DC converter topologies for solar energy harvesting applications: A review," *Clean Energy*, vol. 7, no. 3, pp. 555–570, Jun. 2023, doi: 10.1093/ce/zkad003.
[13] H. J. Farahani, M. Rezvanyvardom, and A. Mirzaei, "Non-isolated high step-up DC–DC converter based on switched-inductor switched-capacitor network for photovoltaic application," *IET Generation, Transmission and Distribution*, vol. 17, no. 3, pp. 716–729, Feb. 2023, doi: 10.1049/gtd2.12700.
[14] M. Yavari, A. Salemnia, and H. Javadi, "A new step-up DC-DC converter with high gain for photovoltaic applications," *International Journal of Circuit Theory and Applications*, vol. 51, no. 2, pp. 702–727, Feb. 2023, doi: 10.1002/cta.3447.
[15] D. Taheri, G. Shahgholian, and M. M. Mirtalaei, "Analysis, design and implementation of a high step-up multi-port non-isolated converter with coupled inductor and soft switching for photovoltaic applications," *IET Generation, Transmission and Distribution*, vol. 16, no. 17, pp. 3473–3497, Sep. 2022, doi: 10.1049/gtd2.12537.
[16] H. Javaheri Fard and S. M. Sadeghzadeh, "A high gain DC-DC converter based on coupled inductor and switched-capacitor cell with low-voltage stress," *Journal of Electrical and Computer Engineering*, vol. 1, p. 9323182, May 2022, doi: 10.1155/2022/9323182.
[17] T. Sutikno, R. A. Aprilianto, and H. S. Purnama, "Application of non-isolated bidirectional DC-DC converters for renewable and sustainable energy systems: A review," *Clean Energy*, vol. 7, no. 2, pp. 293–311, Apr. 2023, doi: 10.1093/ce/zkac070.
[18] S. W. Seo, J. H. Ryu, Y. Kim, and H. H. Choi, "Non-isolated high step-up DC/DC converter with coupled inductor and switched capacitor," *IEEE Access*, vol. 8, pp. 217108–217122, 2020, doi: 10.1109/ACCESS.2020.3041738.
[19] M. Muhammad, M. Armstrong, and M. A. Elgendy, "A nonisolated interleaved boost converter for high-voltage gain applications," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 4, no. 2, pp. 352–362, Jun. 2016, doi: 10.1109/JESTPE.2015.2488839.
[20] M. R. S. de Carvalho, R. C. Neto, E. J. Barbosa, L. R. Limongi, F. Bradaschia, and M. C. Cavalcanti, "An overview of voltage boosting techniques and step-up dc-dc converters topologies for pv applications," *Energies*, vol. 14, no. 24, p. 8230, Dec. 2021, doi: 10.3390/en14248230.
[21] S. Saravanan and N. R. Babu, "Non-isolated DC-DC converter for renewable based grid application," *Energy Procedia*, vol. 103, pp. 310–315, Dec. 2016, doi: 10.1016/j.egypro.2016.11.291.
[22] S. W. Seo, J. H. Ryu, H. H. Choi, and J. B. Lee, "Input-parallel output-series high step-up DC/DC converter with coupled inductor and switched capacitor," *IEEE Access*, vol. 11, pp. 89164–89179, 2023, doi: 10.1109/ACCESS.2023.3302350.
[23] F. khan, M. Zaid, A. Tariq, and M. M. A. Khan, "A new non-isolated high-gain DC-DC converter for the PV application," *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, vol. 5, p. 100198, Sep. 2023, doi: 10.1016/j.prime.2023.100198.
[24] R. Hu, J. Zeng, J. Liu, and K. W. Eric Cheng, "A nonisolated bidirectional DC-DC converter with high voltage conversion ratio based on coupled inductor and switched capacitor," *IEEE Transactions on Industrial Electronics*, vol. 68, no. 2, pp. 1155–1165, Feb. 2021, doi: 10.1109/TIE.2020.2967667.