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Review on different DC to DC Converters

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Abstract

The use of DC-DC converters is essential in modern power electronics, as they enable the regulation of voltage and transfer energy across a broad spectrum of applications, including renewable energy systems, industrial automation, and food processing equipment. Traditional topologies like buck, boost, and even a simple 'boost-booster' converters still form the basis of conversion principles; however, new demands for higher voltage gain, lower ripple, and better thermal management have increasingly favoured interleaved and multiphase architectures. Why? In high-power, high-efficiency situations, converters like the Interleaved Double Boost (IDB) and Interleaved Dual Embedded (IDB) have proven to be highly efficient. Compared to conventional boost designs, the IDB converter offers greater voltage gain and ripple reduction, while the IDDB topology enhances current sharing through thermal distribution, fault tolerance, and other features. They are especially well-suited for renewable energy integration, DC microgrids, and energy-sensitive food processing technologies. The analysis merges operational rules, design aspects, performance metrics, and comparative analyses of IDB and IDBD converters. It also provides insights into their strengths, weaknesses, techniques, methods, papers, patents & trademarks (CLA), and future research opportunities in sustainable energy and industrial settings.

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1. INTRODUCTION

In today's electrical systems, power electronics are essential because they enable the effective conversion and conditioning of DC energy across a diverse spectrum of applications, from portable electronics to large-scale renewable installations. DC-DC converters are essential in bridge voltage-level mismatches between sources and loads or storage, and their selection has a significant impact on system efficiency, size, and thermal behaviour. Recent comprehensive reviews highlight the importance of topology selection and control strategy in meeting power-density and reliability demands, as well as performance metrics such as efficiency or speed. These metrics demonstrate that applications are likely to benefit from these factors. Additionally, current research supports the idea that more efficient topologies may require refinement before finalization.

By operating multiple converter phases out of phase, interleaving is a popular solution to the problems with single-phase boost stages. This technique reduces input and output ripple, distributes thermal or electrical stress, improves dynamic response for renewable and transport systems where source ripple and reliability are critical [2, 3]. Experimental and modelling studies reveal that interleaved structures (two-phase and multi-phasic) permit smaller passive components for the same ripple specification while also reducing EMI emissions. These advantages encourage the use of high-gain and coupled-inductor designs, which incorporate interleaving and gain-extension cells for PV, fuel-cell, and battery interfaces.

The Interleaved Double Boost family and IDDB are examples of specialized high-step-up interleakable topologies that combine multiple boost stages and charge-transfer or series-stacking cells to achieve significant voltage gains while maintaining low input ripple and balanced stress among devices. Investigations on IDB/IDBD variations reveal higher voltage gain, lower semiconductor voltage stress, and smoother input currents than single-stage high-gain converters. Additionally, various control methods such as sliding-mode and multi-loop schemes have been proven to maintain stability in variable source conditions of PV/fuel-cell systems [6, 7]. These characteristics make IDB/IDBD topologies a promising choice for DC microgrids and renewable-powered industrial loads that prioritize efficiency, reliability, and reduced passive size.

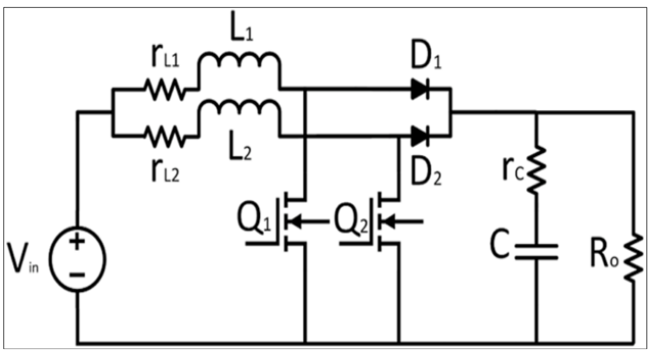

Fig 1: Two-phase interleaved boost converter

Background of DC–DC Converters.

Power electronic circuits known as DC–DC converters convert a DC input voltage into a different DC output voltage level while also controlling voltage and current to satisfy the needs of the load. These converters' steady-state and dynamic behavior is determined by a wide variety of topologies, from basic single-switch topologies (buck, boost, buck-boost) to sophisticated multistage, coupled-inductor, and interleaved designs. The efficiency, electromagnetic interference (EMI), and component stress are all determined by the switching topology, mode of operation (continuous/discontinuous conduction), and control plan [8]. Choosing the topology and creating a dependable converter require a thorough understanding of these basics, including energy transfer methods, duty cycle relationships, and loss sources.

Many thorough evaluations of DC-DC converters have been conducted, comparing performance measures, categorizing topologies, and outlining recent advancements like soft switching, coupled inductors, and others. multiphasic interleaving and switched capacitors to increase power density and reduce ripple [9]. Reviews highlight that contemporary demands (higher power density, wider input ranges from) necessitate modern solutions like multiphasic interleaving and switched capacitors. Hybrid and high-gain topologies are driven by PV/fuel cell sources and smaller passive component sizes, and control strategies such PWM, sliding mode, and multiloop are just as crucial as circuit topology. for attaining stable operation under varying sources and loads.

Importance in Food Processing and Electrical Engineering Applications.

DC-DC converters are the building blocks of power management in electrical engineering, which includes embedded systems, electric vehicles, renewable energy interfaces, and distributed DC microgrids. systems; they facilitate voltage buses with the strict regulation needed by contemporary electronics, bidirectional energy flow for battery systems, and MPPT for photovoltaic arrays, all of which are direct results. They are essential to modern energy system design and optimization because of their capacity to link diverse DC sources and loads, which has an impact on system efficiency, dependability, and lifecycle cost [10].

For applications like high-voltage pulsed power for food sterilization, precision drives, and others, the food processing sector is increasingly dependent on sophisticated power electronic solutions like DC–DC converters. for motors and conveyors, as well as solar-powered cold chain machinery; converters facilitate efficient DC coupling of renewable sources, decrease power distribution losses inside plants, and promote compact electronically regulated processing machinery that enhances product quality and energy efficiency [11]. Practical advantages of case studies and prototype demonstrations (such as PV-powered pulse converters) are shown. customized DC–DC designs for food processing in off-grid or energy-sensitive environments.

OBJECTIVES OF THE STUDY

1. To analyze and summarize the operating concepts, circuit layouts, and control approaches of common DC–DC converters (buck, boost, buck–boost, Ćuk, SEPIC) with a focus on various operational modes, how the selection of topology impacts component stress, voltage gain, and efficiency.
2. To present a thorough comparative examination of Interleaved Double Boost (IDB) and Interleaved Double Dual Boost (IDDB) converters, addressing their specific circuit designs, high gain, and other characteristics. limitations in real-world applications, benefits over single-stage high-gain designs, mechanisms, and steady-state and transient behavior.
3. To use literature-derived data and other methods to assess the performance criteria (efficiency, input/output ripple, thermal stress distribution, electromagnetic interference, and component sizing) for IDB and IDDB topologies. to find the optimum ways to choose and utilize these converters in medium to high-power systems, as well as to

recognize design compromises and best practice recommendations.

4. To investigate application-driven considerations, particularly for food processing systems, DC microgrids, and renewable energy interfaces powered by PV/battery sources, and to provide recommended research directions and practical approaches. Enhancements (control methods, widebandgap devices, and passive reduction techniques) that boost the reliability, power density, and applicability of IDB/IDDB converters for industrial applications.

The Basics of Dc-To-Dc Conversion

Voltage Conversion Principles.

The steady-state relationships of DC–DC converters are governed by basic balance rules, and they work by regularly moving energy between storage components (inductors, capacitors) and switches. capacitor charge (amp second) balance and inductor Volt second balance, which allow the output current and voltage to be related to the duty cycle and input conditions [12]. For instance, volt-second balance on the inductor immediately yields the optimal boost converter connection Vout = Vin/(1-D) (in continuous conduction), and real-world implementations expand upon this. real-world voltages, losses, and component stresses are calculated by incorporating parasitic resistances, switching transitions, and nonideal magnetics into these ideal relationships.

Modern high-gain and multi-stage topologies (coupled inductors, switched-capacitor cells, and series/parallel stacking) use combinations of series stacking and charge transfer to achieve performance that surpasses basic single-stage formulas. Get high step-up ratios without high duty ratios; these methods are examined using the same balance concepts but need longer small ripple approximations and averaged model strategies. for the purpose of designing for stability and control [13].

The Role of Power Electronics in Energy Systems.

The interface layer between energy sources (PV, fuel cells, batteries) and loads or grids is made up of power electronics, which includes DC–DC converters and offers functions such as: including galvanic isolation where necessary, voltage regulation, maximum power point monitoring (MPPT), and bidirectional power flow for storage integration [14]. The efficiency and reliability with which renewable sources can be collected and delivered are determined by converters in distributed and microgrid architectures; they also allow for modular system design where When built properly, DC buses minimize the number of conversion steps and increase the total system efficiency.

The converter's control plan and its capacity for adaptable installation (for example, in EV fast charging, PV-powered cold storage, and DC microgrids for buildings) are crucial in high-availability applications. With high-performance control (multiloop, sliding-mode, model-predictive) enhancing transient response, allowing for tighter regulation under variable source impedance, and lowering bandwidth switching, it has become as crucial as raw topology. the necessity for very large passive components [15].

DC–DC Converter Performance Factors (Efficiency, Ripple, Stability)

Efficiency is frequently the main measure of worth and is influenced by conduction losses (Rds(on), winding resistance), switching losses (transition energy), and passive losses; modern designs Although efficiencies exceeding 95% are attainable in many circumstances, practical systems are often built under the assumption that they range from 80 to 95%, depending on the power level and switching frequency, because the source Actual efficiency is frequently governed by thermal and impedance limitations [16].

Table 1: Typical efficiency and ripple characteristics (illustrative summary from published sources)

Topology	Typical Efficiency Range (%)	Typical Input/Output Ripple Improvement vs single-phase
Buck (well-designed)	90 – 98%	baseline (depends on L/C sizing)
Boost (single-phase)	85 – 95%	baseline
Interleaved boost (2-phase)	90 – 98% (practically achievable)	Input/output ripple can be reduced substantially up to near 100% cancellation for ideal two-phase at 50% duty cycle in theory; typical practical reduction: 40–80% depending on phase shift and component mismatch.

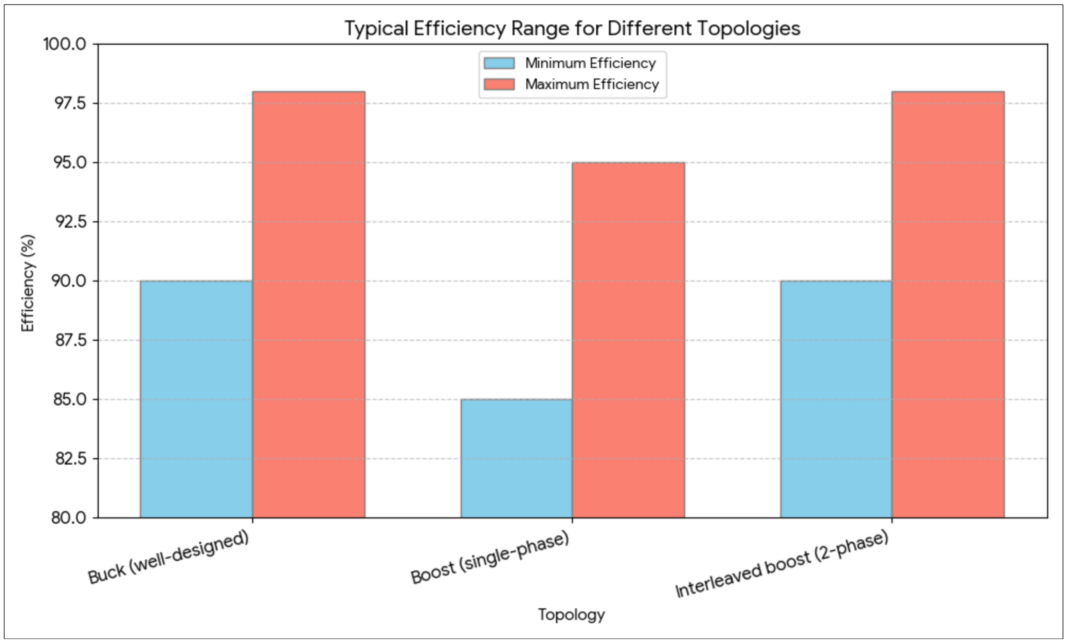

Fig 2: Typical efficiency and ripple characteristics (illustrative summary from published sources)

Important limitations include electromagnetic interference (EMI) and ripple, while interleaving phases (with phase shifts such as 180° for two-phase or 360°/N for N-phase) lowers the net input. In ideal conditions, interleaving can eliminate the main ripple harmonic, but it also generates ripple currents at the output, which necessitates smaller filters and capacitors and simplifies EMI filtering. Real converters experience partial cancellation as a result of component tolerances and nonideal switching [17].

There is a direct trade-off between stability and control bandwidth vs efficiency and component stress: a higher switching frequency reduces passive size but increases switching losses; a wider control bandwidth improves stability. although it may need a tighter thermal design and faster (and perhaps more expensive) equipment, transient regulation is possible. As a result, converter design is a multi-objective optimization process (efficiency vs. size vs. cost vs. EMI/stability), with recent research focusing on integrated methods (widebandgap semiconductors, optimized). magnetics, interleaving, and sophisticated control) to achieve concurrent advancements [18].

DC–DC Converter Categorization.

Converters Not Isolated.

Since they maintain the input and output common reference, non-isolated DC–DC converters offer a straightforward and inexpensive method for increasing or decreasing voltage. They are widely used in they don't need a transformer and usually have better efficiency per cost and per volume than isolated point-of-load controllers, battery management, and local power conversion. comparable units at the same power level [19]. The fundamental operating principle is that a semiconductor device switches to transmit energy between the load and an inductor (or capacitor), with a control loop maintaining control. understanding these fundamental power stages (buck, boost, buck–boost) and their conduction modes (CCM, DCM) is the first step in determining the duty cycle needed to produce the desired output. design phase that specifies EMI reduction, control system, and component sizing.

- **Buck Convertor**
  The most widely used nonisolated topology for controlled lower voltage rails is the buck converter (stepdown), which employs a single switch, an inductor, and an output capacitor. Additionally, properly designed synchronous buck regulators often accomplish very good results in terms of inductor ripple, duty cycle, and output filter size in continuous conduction mode by adhering to well-established design formulas. They are favored for point-of-load supplies in motor drives and embedded electronics due to their high efficiencies (frequently over 90%) in low-voltage, high-current applications [20]. Changing node stress, layout to reduce loop inductance, and making tradeoffs between switching frequency (smaller magnetics) and switching losses (higher losses at higher f) are all examples of realistic design tradeoffs.

- **Increase Converter**
  The most straightforward topology for increasing a DC voltage is the step-up boost converter, which has an ideal duty cycle law. The basis for analysis is the CCM equation $V_{out} = V_{in}/(1-D)$, but real boost converters must account for diode or synchronous switch losses, a wide input range, and a large inductor. The current ripple is high at high gain, which encourages the use of multistage, coupled inductor, or interleaved topologies when high gain and low ripple are

necessary, as in PV interfaces and battery boost rails [19, 21]. When output is greater than input, designers must also handle the high voltage stress on switches and control startup behavior.

- **Boost-and-Buck Converter**
The buck–boost family (which includes inverting and noninverting variations) offers continuous step-up or step-down capabilities and is frequently employed when the input may be above or below. These topologies trade extra complexity and additional stress/power flow path losses for flexibility, and careful selection of synchronous, which is below the desired output (e.g., battery bus interfaces). The use of rectification and control mode decreases losses and enhances transient performance [21]. In order to ensure consistent regulation across a broad range of inputs, appropriate compensation design and average value modelling are necessary.

- **Ćuk Converter**
The Ćuk converter uses coupled components and an energy transfer capacitor to achieve continuous input and output currents with minimal ripple; its inherent polarity inversion and It is appealing in some mixed-rail systems and in PV MPPT front ends because of its capacity to produce low-ripple outputs, but real-world applications may be constrained by its limitations. increased component count compared to simpler topologies [22], the necessity for bipolar switches or sophisticated control. Comparative studies demonstrate that Ćuk can compete with Applications where low ripple and bidirectional operation are given priority: SEPIC/Zeta.

- **Zeta and SEPIC Converters**
The SEPIC and Zeta topologies offer benefits when input ranges cross the desired output and allow for non-inverting step-up/step-down conversion with single-switch control; their decoupled nature. Although they also need to be carefully designed to manage capacitor stress and input/output behaviour, series energy transfer capacitors allow for useful MPPT circuits and battery interfaces. to keep the efficiency comparable to buck/boost stages [23]. Recent modelling research has shed light on the functioning of the DCM and the design of the controller in order to maintain the stability and efficiency of these topologies in changing PV circumstances..

Table 2: Typical non-isolated topology attributes (illustrative, compiled from industry/app-note guidance)

Topology	Typical Power Range	Typical Efficiency Range (%)	Common Application Examples
Buck	mW — kW (point-of-load to downstream rails)	90 – 98	Point-of-load, motor drives
Boost	W — kW (depends on devices)	85 – 95	PV interfaces, sensor biasing
Buck–Boost/SEPIC/Ćuk/Zeta	W — kW	80 – 93	Battery interfaces, MPPT, bidirectional rails

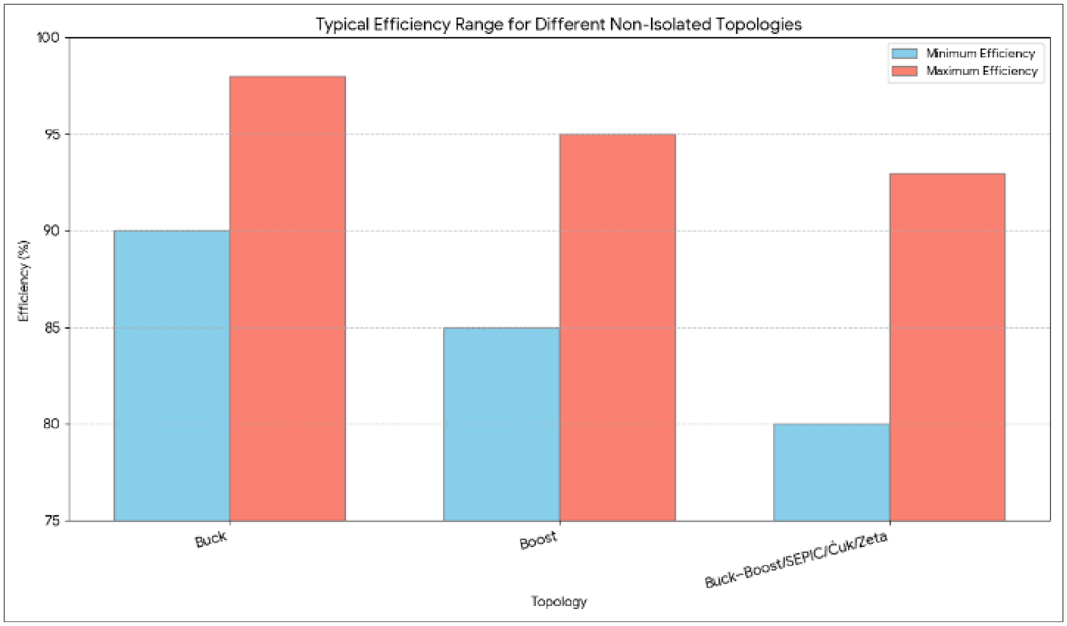

Fig 3: Typical non-isolated topology attributes (illustrative, compiled from industry/app-note guidance)

Discrete Converters

In applications where galvanic isolation, voltage scaling, or high-voltage conversion are necessary (such as telecom, industrial, and medical), isolated converters, which use a transformer to accomplish these tasks, are crucial. The selection of an isolated topology (flyback, forward, push-pull, half-bridge, full-bridge) depends on the power level, cost, and complexity: flyback is affordable at low power, but half-bridge and full-bridge are more complex. Bridge and push-pull topologies scale better to medium and high power because they transmit energy more continuously and minimize transformer stresses [24]. Transformer design (turns ratio, leakage inductance), reset plan, and leakage energy snubbing are all important design considerations.

- **Flyback Converter**
  Flyback converters are able to store energy in the magnetics during the "on" period and release it to the secondary during "off" due to their basic single-switch architecture and capability. They are perfect for numerous outputs in low-power, isolated power supplies, but the energy storage operation can result in increased peak stresses and EMI unless carefully managed. This is why flyback remains. a necessity for inexpensive adapters and little, isolated power sources [25].
- **Forward Converter**
  Forward converters need a reset route for the transformer magnetization and transfer energy directly through the transformer during the switch on-time; when properly designed, they At modest power levels, they provide reduced primary peak currents and increased efficiency compared to flybacks, making them appealing for use in household and industrial products in the tens. ranging up to hundreds of watts [24].

- **Push-Pull Converter**
  By using two switches and a centertapped primary to replicate interleaved energy transmission, the push-pull topology achieves better transformer use and less input ripple than what would be expected from a push-pull converter. It works well for regulated rails above around 100–200 W, but needs a lot of attention to the transformer winding to prevent half-cycle asymmetry and flux imbalance.

- **Half Bridge and Full Bridge Converters**

Halfbridge and fullbridge converters use two and four switches, respectively, to apply bipolar voltages to the transformer primary, allowing for high-power, high-efficiency isolated conversion (telecom rectifiers, etc.). These topologies, along with contemporary widebandgap devices, enable excellent EMI and thermal control, as well as soft switching and synchronous rectification techniques, which optimize efficiency at high power.

Interleaved and advanced multiphase converters

A. The Idea of Interleaving in Power Conversion

The power route of a converter is divided into two or more parallel stages by interleaving, which uses phase-shifted gating to control the fraction of current flowing through each stage. the total current; the main advantages are decreased per-phase current, cancellation of major low-order ripple harmonics at the input/output, less peak device stress, and the ability to to scale current alongside magnetic or silicon components without raising the switching frequency for each phase [26]. To accomplish the theoretical ripple cancellation, interleaving is carried out across boost, buck, and other stages and depends on accurate phase timing and current sharing—control and Although real-world cancellation is constrained by device discrepancies, the technique still allows for significant reductions in filter size and EMI.

Advantages of Multiphase Operation (Lower Ripple, Higher Efficiency)

Multiphase converters enhance thermal distribution and permit the usage of smaller inductors per phase, resulting in less total magnetic volume; in practice, two-phase interleaving can lower input/output. The current ripple is reduced by tens of percent (common practical reductions range from 40% to 80%, depending on the component spread and phase shift accuracy), while multiphase (3–6 phases) provides even more smoothing to the total. renewable interfaces and CPU/GPU power distribution current and eases transient response [27, 28]. Each phase can operate at the same switching frequency but at a lower frequency. By distributing heat across several devices, the perphase current lowers conduction losses and increases reliability.

Table 3: Measured/Reported interleaving benefits (summary from literature)

Metric	Single-phase baseline	Two-phase interleaved (typical)	Multi-phase (3–6 phases)
Input ripple current reduction	0%	40–80%	60–95%
Required filter size reduction	0%	30–70%	50–90%
Per-device RMS current	100%	~50% (per phase)	~100%/N (per phase)

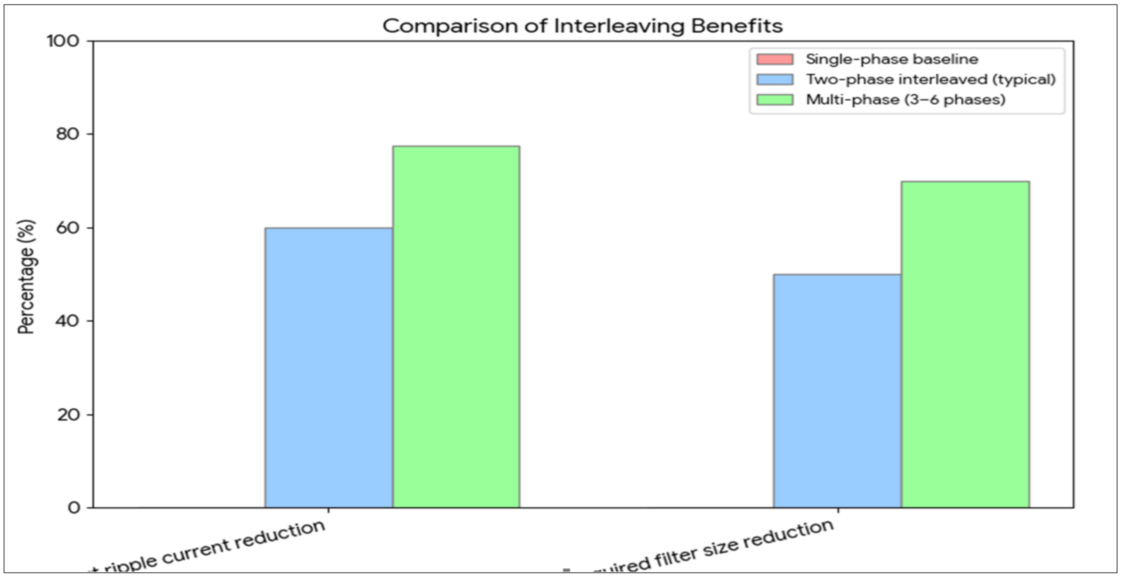

Fig 4: Measured/Reported interleaving benefits (summary from literature)

Use cases for food technology, electric vehicles, and renewable energy

Due to their interleaving and multiphase nature, high-current point-of-load regulators (server CPU/GPU rails), PFC front ends, EV onboard chargers, and PV/battery interfaces are now all standard designs. Interleaving in photovoltaic and battery systems reduces input ripple into the source, which is crucial for extending the life of the system, while also combining high current capacity, enhanced dynamic response, and manageable electromagnetic interference. for mismatch currents in PV arrays and batteries) and enables the utilization of less expensive, smaller passive filters in system-level designs [26, 27]. Interleaved high-gain boost variants (including IDB and) are used in a variety of food technology applications, such as solar-powered cold storage, pulsed high-voltage sterilizing circuits, and mobile food processing units. IDDB families are desirable because they offer high voltage gain with lower input ripple and improved heat distribution, which enhances the dependability and energy efficiency of off-grid processing machinery.

Interleaved Double Boost (Idb) Converter.

Method of Operation.

The Interleaved Double Boost (IDB) converter expands upon the traditional boost topology by employing two (or more) boost sub-stages that are run using phase-shifted gating to manage energy. is transmitted at predetermined intervals; each stage has its own inductor and switch, and the outputs are combined (usually in series or through coupling networks). to attain greater effective voltage gain while the phase shift partially cancels out low-order ripple harmonics at the input and output [29]. By using inductor volt-second balance per phase and adding output contributions, the averaged model of the IDB These Interleaved architectures are frequently employed in medium-to high-current applications (PFC, PV interfaces, may be obtained in continuous conduction mode, which demonstrates that this is the reason why there is a reduction in RMS device stress and the ripple enhancement that is frequently seen. Interleaving lowers the instantaneous phase current while maintaining the same overall delivered power.

Design Factors and Circuit Topology.

Common IDB implementations either series-stack their outputs (voltage adder form) or parallel two boost cells at the input and parallel boost stages. Using coupling techniques, such as sharing diodes, capacitors, or coupled inductors, increases gain and balance. The main design considerations include (a) the phase shift (180° for two phases provides optimum first-harmonic cancellation) and (b) the size of the inductor for an acceptable ripple and boundary between. (c) selection between synchronous and diode rectification to reduce conduction losses, and (d) soft switching/snubber networks if switching losses are significant at the chosen frequency [30, 31]. To make the theoretical advantages a reality in hardware, it is necessary to have a layout that minimizes common source/return loop inductance and precise gate drive timing..

Benefits Over the Standard Boost Converter

When compared to a single-phase boost, an IDB offers several real-world benefits: (1) a lower input and output ripple current since the phase shifted currents somewhat cancel out, which lowers (1) necessary filter size; (2) decreased per-device RMS current, which results in better thermal distribution and lower I2R conduction losses; (3) scalable current management via phase addition (4) superior behaviour in the event of partial mismatch or thermal derating because the load is distributed across phases [32], and (3) avoiding an increase in device size. server rails) because they offer advantages over single-phase designs, which are constrained by thermal and ripple limits.

Table 4: Typical single-phase boost vs two-phase IDB (literature-based ranges)

Metric	Single-phase boost	Two-phase IDB (typical literature ranges)	Source
Typical Efficiency (%)	85 – 95	90 – 98	[31,30]
Input ripple current reduction	baseline	40 – 80% reduction	[31, 32]
Per-device RMS current	100%	≈50% per phase	[31]

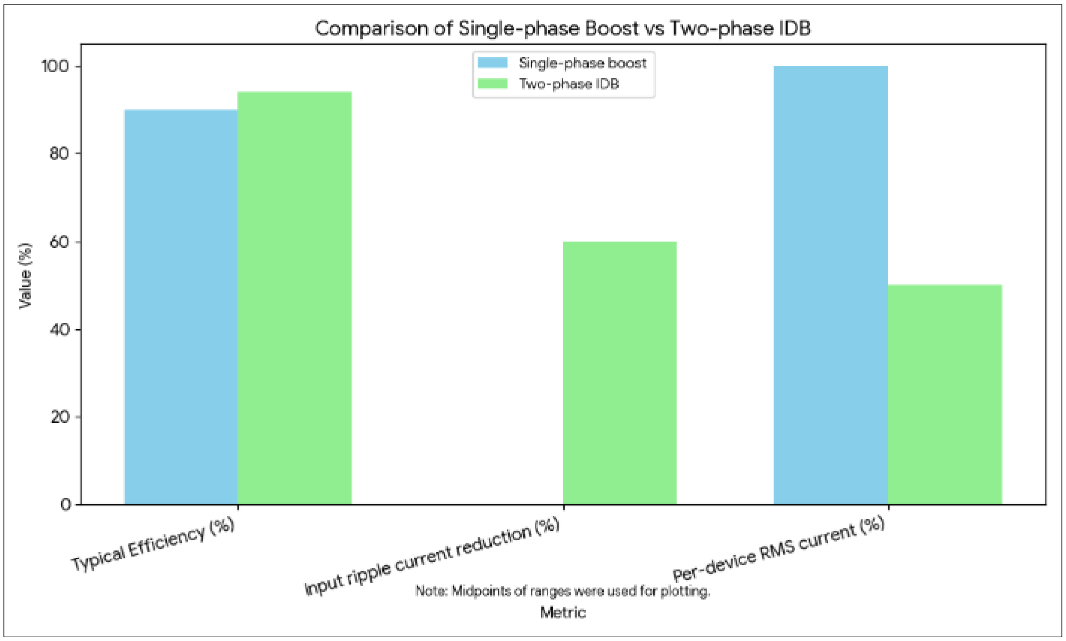

Fig 5: Typical single-phase boost vs two-phase IDB (literature-based ranges)

Evaluation of Performance (Voltage Gain, Ripple Reduction, Efficiency).

The voltage gain in IDB topologies is determined by the manner in which the phases are combined; for instance, a straightforward parallel input/series output configuration might result in an almost additive impact on output voltage (with careful Balancing and timing are important factors, while hybrid designs combine voltage multiplier or switch capacitor cells within an interleaved architecture to increase the effective gain without needing excessive duty cycles. According to analytical averaged model formulas, an IDB with series stacking can attain a greater actual gain for a specific duty cycle DD than a single boost operation. because stacking spreads voltage stress and lowers the limits of the converter duty ratio [33].

Harmonic analysis of the total phase currents provides a quantitative measure of ripple reduction. Ideal two-phase interleaving with perfect symmetry cancels the fundamental switching ripple at the input, which reduces the necessary input capacitance and EMI. The majority of empirical and simulated research shows that compared to single-phase equivalents at the same power level, efficiency is improved by a few percent to several percent, although improvements rely on switching frequency, device Rds(on), and converter topology, they come from reduced conduction and inductor AC losses..

Applications in Food Processing Equipment and High-Power Systems.

IDB converters are appealing in high-power DC–DC applications that need low ripple, high reliability, and a small passive size, such as DC microgrids and PV-to-battery boost stages. power supplies for industrial drives and step-up sections for targeted distribution. IDB capabilities can be used to advantage in certain food processing applications, such as solar-powered cold storage or refrigeration, which need minimal input ripple to safeguard battery life and charge. high step-up ratios with strong thermal behaviour are necessary for pulsed power sterilization and high-voltage heating systems, which can be achieved by interleaving, which helps to spread losses over stages [34, 35]. IDB variations have been shown in prototype demonstrations in renewable and industrial settings to provide dependable service at kW power levels and have superior thermal profiles when compared to single-phase converters..

Interleaved Double Dual Boost (Iddb) Converter

Working Idea

By combining dual boost legs in a doubled (usually four-cell or multi-leg) configuration, the Interleaved Double Dual Boost (IDDB) topology advances the ideas of interleaving and stacking. an IDDB that connects many boost subunits in particular, in order to achieve extremely high step-up ratios while preserving the interleaving advantages for ripple and current sharing. series/parallel networks so the voltage gain is the sum of the effects of each cell, allowing gains that may be many times higher than a single-stage increase without exceptionally high duty ratios [36]. Although the average modelling and small signal design get more complicated (with multistate averaging across more switches and inductors), the fundamental principle remains using volt-second balance to every inductor, taking into account the coupling/series configuration, to determine the overall output voltage.

Circuit Architecture and Control Methodology

Two sets of dual boost cells interleaved in phase are commonly used in IDDB circuit implementations so that each set's switching instant is staggered; control techniques often To ensure current sharing and rapid output, use an advanced sliding-mode / flatness-based technique or a cascaded strategy (inner current loops per phase, outer voltage loop). Despite the increased degrees of freedom, there is regulation [37, 38]. Multiloop and sliding-mode controllers are well-liked because they offer resilience to large disruptions and component mismatches, which are crucial when dealing with complex systems. The interaction of several passive components and switches is common. Practical controller design also takes into account unbalanced parasitic, adaptive current balancing, and occasionally duty cycle modulation between legs to maintain equal stress.

Table 5: Example IDB vs IDDB performance (reported ranges in literature/prototypes)

Metric	IDB (2-phase double-boost)	IDDB (double dual, 4+ phases/legs)	Source
Achievable voltage gain (relative to boost)	1.5–3× (depending on stacking)	3–6× (higher step-up without extreme D)	[33, 36]
Input ripple reduction	40–80%	60–95% (with more phases)	[31,3 6]
Complexity (number of active devices)	Moderate	Higher (more switches/inductors)	[36, 37]

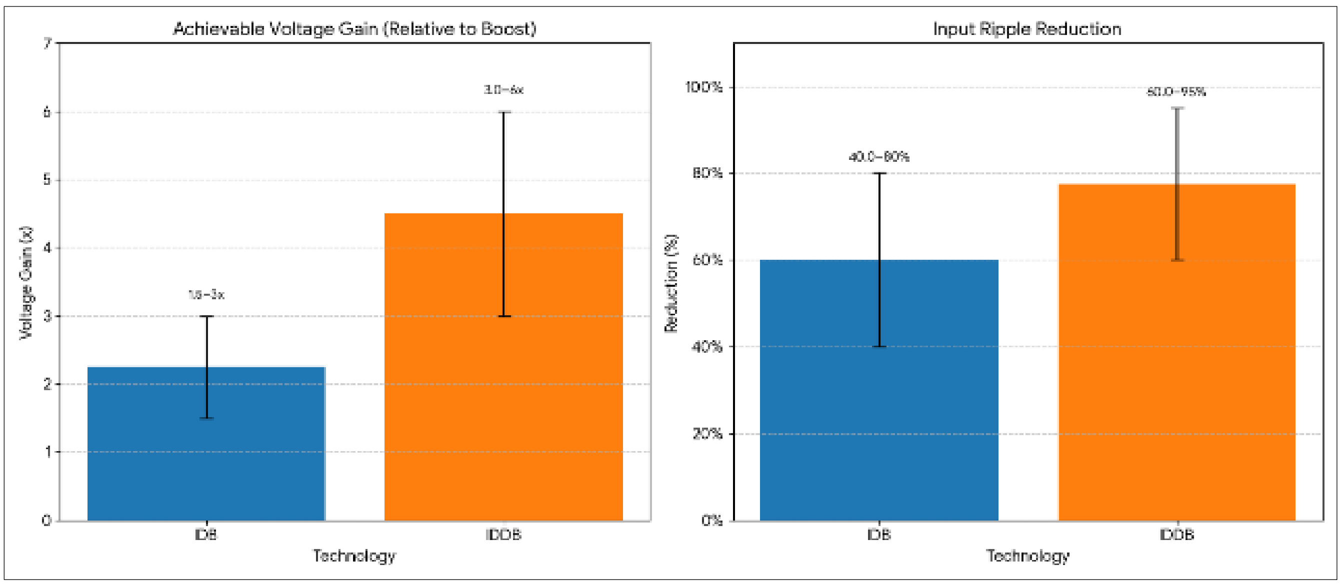

Fig 6: Example IDB vs IDDB performance (reported ranges in literature/prototypes)

Comparison with IDB Converter.

IDDB topologies provide significantly improved voltage gain and input ripple suppression in exchange for increased circuit complexity and control effort; in contrast, an IDB may only provide modest gain. An IDDB may stack more cells (or utilize dual boost legs) to achieve gains appropriate for fuel cell interface voltages and DClink charging, which only increases in two stages. or intermediate stages in medium voltage systems without subjecting any individual switch to severe duty ratios [39]. The penalty is the requirement for strong current sharing and thermal management methods, as well as extra parts such as inductors, switches, and gate drivers, but only for systems where a high IDDB architecture is justifiable if a step-up and low ripple is required, such as in off-grid PV systems that power high-voltage cold chain compressors.

Advantages in Thermal Management and Efficiency

Even though IDDB introduces more semiconductor devices (which increases static conduction pathways), the per-device current and RMS stress decrease, and the AC losses in inductors are lessened. by interleaving and dividing current, which frequently yields net efficiency that is on par with or higher than that of comparable single-stage high-gain converters, particularly when synchronous rectification is used. Additionally, soft switching methods are utilized to reduce switching losses [40]. Thermal management is now more distributed: heat is produced throughout several inductors and devices, making heat sinking simpler and allowing for greater total power before thermal throttling than if the heat were concentrated in one stressed switch. When using modern lowRds(on) MOSFETs or SiC/GaN devices, empirical prototype reports demonstrate that IDDB architectures attain high overall efficiency (mid to high 90%) at kW power levels in optimized designs.

Use in industrial food technology, solar photovoltaics, and DC microgrids

IDDB converters are a good fit for photovoltaic systems and DC microgrids, where the necessary DC bus could be hundreds of volts, while the PV strings are IDDB-enabled, enabling designers to achieve that bus voltage with low source voltages, without using massive transformers or series-stacking power electronics. ripple that protects battery life and PV mismatch behavior [41]. IDDB can facilitate compact, solar-charged high-voltage supplies for cold storage compressors in industrial food technology applications. vacuum-based dehydration pumps or pulsed sterilization circuits, where process dependability and product quality depend on both high gain and low ripple/stable control. Research prototypes. Additionally, tiny field studies have demonstrated that IDDB performs better than single-stage alternatives at maintaining voltage regulation under changing irradiance and load.

IDB and IDDB Converters' Comparative Analysis

A. Comparison of Efficiency

Interleaving reduces the RMS current per device, which is why IDB and IDDB converters frequently outperform single-stage high-gain boost converters in terms of practical efficiency at the same power level. (decreasing I2R loss) and enabling designers to use smaller magnetics with less AC losses; several experimental and modelling investigations have demonstrated efficiency gains in the range of. Although the overall gain depends greatly on the switching frequency, device Rds(on), and whether synchronous rectification or soft switching is used, interleaving can result in a few percentage points of improvement when done correctly.

B. EMI and Ripple Performance

By interleaving phaseshifted currents that cancel out major switching harmonics, interleaving results in a considerable decrease in input/output ripple (typical practical reductions reported: ~40–80% for two-phase and ~60–95% with more). phases or careful coupling), which reduces the necessary filter size and makes EMI filtering easier; but, incomplete current sharing, component tolerances, and phase-shedding techniques under light load may introduce low-frequency circulating currents or EMI peaks that need to be controlled via reactor/interphase impedance selections and controller design. [45, 46].

C. Complexity and Cost

IDDB achieves greater voltage gains and less ripple than IDB, but at the expense of a more complicated design, more inductors, switches, and gate drivers. control (per-phase current loops, active balancing, or sliding-mode/droop systems). The higher cost of materials and development is due to the increased complexity of the hardware and software, which may also introduce failure modes—trade-offs that make IDDB appealing where the extra cost is justified by performance (gain/ripple/thermal), but not so much for inexpensive or highly space-constrained items. [47, 48].

Table 5: Representative comparative metrics (literature-derived ranges)

Metric	IDB (2-phase)	IDDB (4-phase / dual-dual)	Source
Efficiency improvement vs single-phase (%)	+2 – +7	+4 – +10	[44, 48]
Input ripple reduction (%)	40 – 80	60 – 95	[46, 45]
Relative component count (switches/inductors)	baseline ×2	baseline ×3–4	[47]

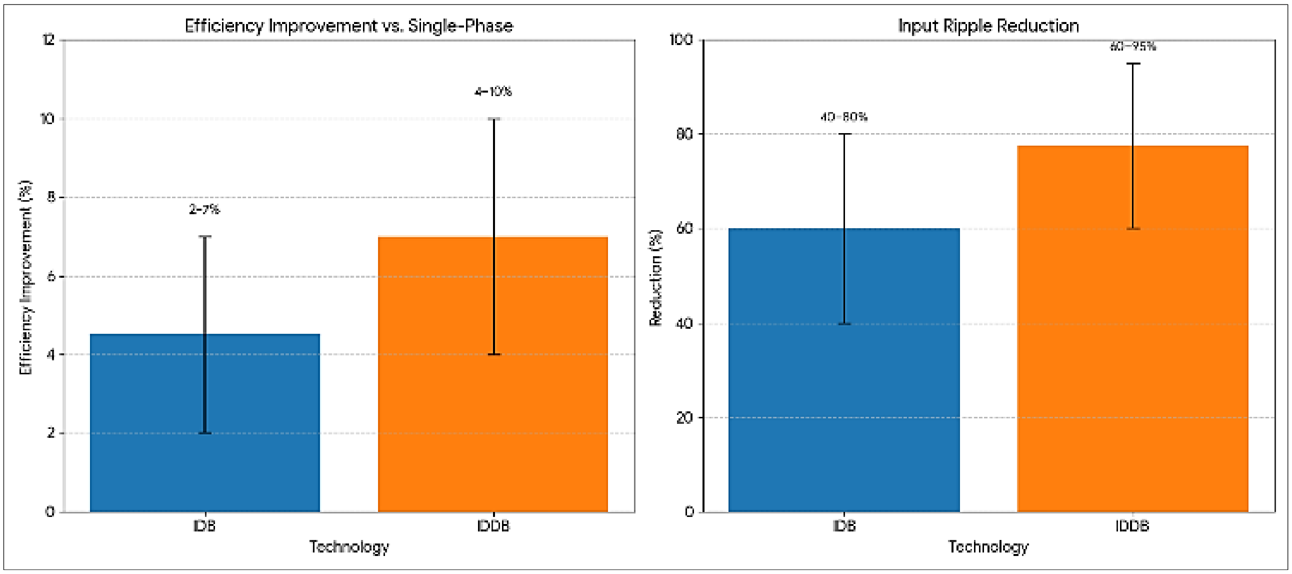

Fig 7: Representative comparative metrics (literature-derived ranges)

Appropriateness for uses in food technology and renewable energy

The low input ripple, distributed thermal loading, and greater achievable step-up without are ideal for renewable interfaces and food technology systems (solar cold storage, pulsed sterilization, off-grid drives). Due to its extreme duty cycles—which safeguard PV/battery sources from high ripple stress and allow for more compact passive designs—IDB/IDDB is a great choice. IDDB is favored when there are very high duty cycles. IDB is frequently the best option when factors such as moderate gain, simplicity, and lower cost are important, but high DC bus voltages with tight ripple limits are necessary [49, 50].

Problems and Restrictions

Challenges with design complexity and control

To prevent circulating currents and imbalance, multiphase stacked topologies need either per-phase current control or sophisticated balancing algorithms. The complexity of the design makes it more difficult to tune the controller (small signal multiloop). The use of sliding mode and model-based multiloop controllers, which require further development and validation, is common but can make digital control implementation and EMI mitigation more difficult [51, 52].

Reliability and Component Stress

In IDDB series/stacking configurations, interleaving can lower RMS current per device, but it can also subject devices and passive components to higher peak voltages or unbalanced stress during transients. To prevent core saturation or uneven flux distribution under mismatch or fault conditions, reliability engineering must address uneven thermal loading, snubbing/soft recovery handling, and meticulous magnetics design [53].

Cost Considerations in Large-Scale Applications

Capital expenses and assembly complexity rise at utility or big industrial scale as a result of the additional components, more complex boards, and extra gatedrivers; hence, the economic choice Rests on lifecycle gains (improved efficiency, extended battery life, reduced filter/thermal costs) rather than upfront increases in BOM and engineering hours—many studies suggest IDB for midrange Only when high gain or tight ripple/EMI restrictions result in quantifiable operational savings should power and IDDB be used [48, 54] .

Future Scope

The use of wide-bandgap (WBG) semiconductors (SiC, GaN) will be a significant facilitator for next-generation IDB/IDDB converters, as WBG devices enable a far higher switching frequency. Interleaved high-gain stages utilized in renewable energy applications provide reduced switching and conduction losses, as well as smaller magnetics, all of which contribute to higher power density and superior thermal performance. industrial food processing machinery and interfaces. Ongoing advancements in devices and packaging (reduced parasitics, improved reliability data for SiC MOSFETs and 600V+ GaN) will enhance the performance of WBG-based IDB/IDDB. At kW–tens of kW scales, the designs are more compact and efficient [55].

Modern digital and control technologies, such as model predictive control (MPC), online optimization, and machine learning-assisted control, are set to enhance dynamic performance, current sharing, and fault tolerance in multileg interleaved topologies. Real-time MPC and learning controllers can handle the multi-input/multi-state dynamics of IDDB converters, such as balancing per-phase currents and adjusting to component variations. allowing for safer installation in foodtech and microgrid systems with rapidly changing sources and loads, while adhering to restrictions (thermal limits, EMI masks) and mitigating drift and circulating currents [56].

Topology innovation will persist: hybrid strategies that combine interleaving with switched-capacitor/voltage-multiplier cells, coupled inductors, soft-switching cells, and resonant components will lower duty-ratio extremes and minimize device stress. while keeping a minimal ripple. From low voltage PV/battery inputs, numerous recent high gain interleaved converter designs and prototypes show viable ways to achieve DC bus voltages of 200–400 V. IDB/IDDB families are fertile ground for study into improved stacking, coupled magnetics, and partial resonant methods because they do not involve extreme duty cycles. These topological advancements will have a direct impact. increase efficiency and decrease passive volume in off-grid food processing machinery [57].

Additional research on DC microgrids, solar cold chain, and mobile food processing devices will be conducted as a result of system-level integration and application studies. Technoeconomic studies and demonstrations will show DC distribution. Additionally, interleaved converters can lessen lifecycle losses and conversion steps in microgrids and buildings; targeted field trials (solarcold storage, PV-powered sterilization, ontruck cold boxes) will For IDB/IDDB implementations, clarify the tradeoffs between actual reliability, maintenance, and overall cost of ownership. The safe adoption of focused standards and interoperability work (controls, protection, and EMI limits) in food technology environments will be accelerated by this [58].

CONCLUSION

Between basic single-stage boost converters and extremely complicated multi-stage systems, IDB and IDDB converters fill a useful, high-value market by integrating interleaving (ripple cancellation, per-device) and other advanced features. They provide high step-up, enhanced thermal distribution, and decreased filter load by combining stacking/dual-leg methods (gain extension without excessive duty) with the current reduction. These features are particularly beneficial. for use in energy-sensitive food processing and renewable energy interfaces. In order to fully realize these advantages in real-world applications, ongoing progress depends on the codesign of topology, magnetics, and control [59].

The immediate plan for researchers and practical engineers is clear: incorporate WBG devices, implement sophisticated digital control (MPC/ML) for per-phase balancing and fault tolerance, and verify designs in application pilots (DC microgrids, solar cold storage, pulsed-power sterilization). Economic feasibility studies and reliability testing (thermal cycling, EMI compliance, long-term device aging) It will be just as critical to turn promising IDB/IDDB converters from prototypes into reliable, affordable goods that reduce energy consumption and enhance the resiliency of food technology. systems and installations of distributed energy [60].

CONFLICT OF INTEREST: Nil

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