

RESEARCH ARTICLE

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REVIEW OF THE FAULT TOLERANCE OF DC-DC CONVERTER FOR ELECTRIC VEHICLES

Israa Salih Hadi*¹, Ali Hussein Al-Omari²

^{1,2} Electrical Engineering Department, Mustansiriyah University, Baghdad, Iraq.

¹<http://orcid.org/0009-0005-2185-8529>, ²<http://orcid.org/0000-0003-1367-2212>

Email: *israasalih1988@uomustansiriyah.edu.iq, ali.jabbar@uomustansiriyah.edu.iq

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ABSTRACT

DC-DC converters are quietly employed in various applications, especially in electric vehicles. Non-isolated and isolated converters are represented the two primary categories, distinguished by their level of isolation, performance, cost, size, and efficiency. The structural characteristics, operational behaviour, and tolerance to failure associated with each converter are reviewed in the paper. Fault diagnosis, identification, and tolerance in DC-DC converters become essential to ensure a reliable and continuous operation. Rapid interruptions, loss of functionality, or degradation of activity could lead to severe consequences. Advances are reviewed, encompassing TRIAC-assisted interleaving, alternative-branch reconfiguration, LLC Full Bridge-Half Bridge transition and the Triple Phase-Shift based Dual Active Bridge control, emphasising their capacity to sustain continuous power flow during open or short-circuit semiconductor faults or sensor anomalies. Control approaches include stable rendering, dynamic response, and compatibility with fault-tolerant systems. In addition, flow chat is used to describe the process of fault-tolerant operation. The review presents a comparison table that summarises the advantages, limitations, efficiency, and fault tolerance, capabilities of the reviewed topologies, to assist researchers in selecting an appropriate topology ensuring higher efficiency and reliability.



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I. INTRODUCTION

The continuous use of fossil fuels has a direct impact on the environment. According to the International Energy Agency, by 2035, carbon radiations are anticipated to increase to 37.0 gigatons [1]. The transportation system accounts for approximately 20 percent of global carbon emissions. It is anticipated that car ownership will increase by 60 percent by 2070, making it essential to transition to a cleaner energy source. An electric vehicle (EV) is a vital component of an environmentally friendly transportation system, as it produces less pollution and enhances fuel efficiency [2]. These features have been led to increased research on electric vehicles to ensure they operate reliably and perform well, especially in terms of fault tolerance in DC-DC electric vehicles, as shown in Figure 16 in the section key finding. Figure 1 illustrates the structure of electric vehicles.

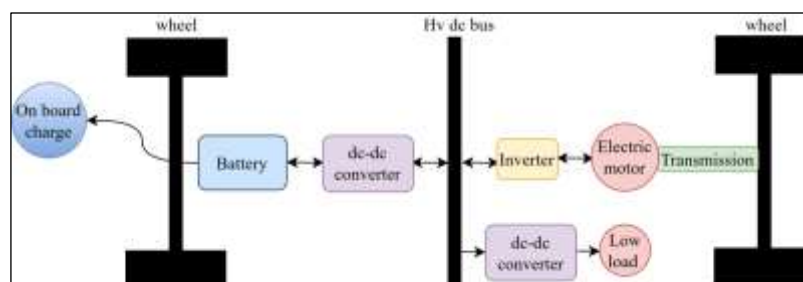


Figure 1: Illustrates the architecture of an electric vehicle.
Source: Authors, (2026).

The DC-DC converters are essential component of electric vehicles, significantly influencing system reliability, efficiency, and current ripple [3], [4]. The transfer power of DC-DC converters can be achieved by two methods: unidirectional, which operates in a single direction, and bidirectional, which operates in both directions. Bidirectional technology is gaining a significant number of applications where power must be capable of bidirectional flow, especially in electric vehicles, as regenerative braking. To enable bidirectional flow, the diode in a DC-DC converter can be replaced with a fully controlled switch, such as a MOSFET or IGBT [5], [6]. At present, DC-DC converters in electric vehicles operate under high electrical and thermal stress, which increases the probability of sudden and progressive faults. Early on, fault detection (FD), fault identification (FI), and fault tolerance (FT) are essential in the healthy operation of electric vehicles. Fault Detection (FD) refers to the identification of the presence of a fault, while Fault Identification (FI) involves determining the exact position of the defect for the following analysis. Fault tolerance is utilized to ensure converter reliability and continuous operation [7]. In general, a DC-DC converter's fault can be occurred into two types: power stage faults, including critical and progressive faults, and control system faults, which include sensor faults. Figure 2 illustrates the classification of faults in the DC-DC converter for EV applications.

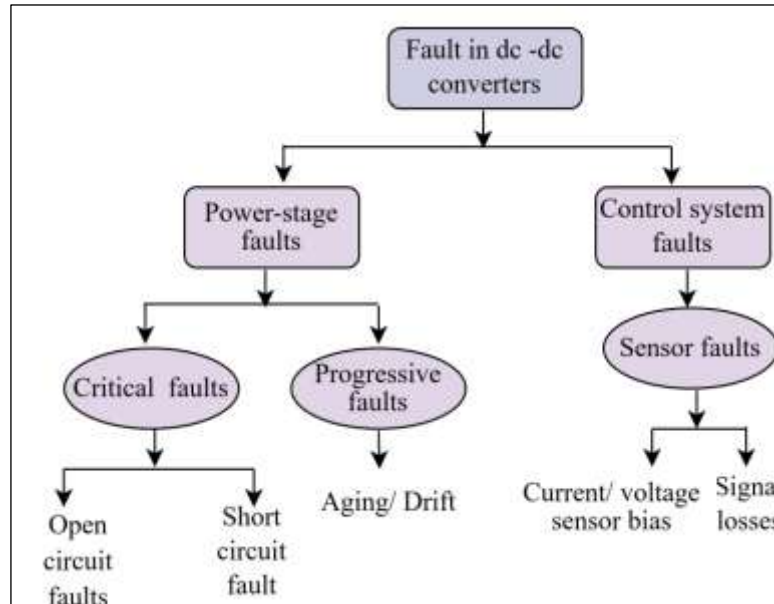


Figure 2: Classification of faults in the DC-DC converter for EV.

Source: Authors, (2026).

Open circuit error in a converter can happen from external disconnections, or the separation of a connection wire due to gate driver failure, connection wire failure, or physical disconnection. The problems lead to input current distortion and pulsating current patterns, while the output voltage falls below the standard level. The remaining component suffers increased electrical stress and reduced power conversion efficiency. The converter can stay in operation; however, unstable output, leading to secondary failure in the capacitor, inductor, and switching device, results in decreased system reliability. However, short circuit fault issues are the most dangerous. A switch or device allows uncontrolled high current to flow quickly, resulting in rapid thermal buildup. Overflowing the current can damage the gate driver or cause the device to break down. This type of problem usually causes the converter to shut down or fail if not isolated [8]. In addition to power switch failures, EV powertrains also require fault-tolerant operation against sensor faults that distort feedback signals and degrade system stability [9].

Flux observers and current observers are used to provide an effective mechanism for fast detection of a sensor fault by comparing measured and estimated values and generating residuals that indicate abnormal behaviour, this strategy enables the transition to a sensorless control mode, which allows for preventing stopping and tolerating failures [10]. A flux observation with third difference operation (TDO) are used to produce a significant amplitude of impulse for every instantaneous variation in the current signal. The absolute value of TDO is input to the associated comparator, which evaluates its output against predetermined threshold value. The high state indicates a malfunctioning condition, while the low position signifies a functional one. No additional sensors are required, and stable operation after fault occurrence therefore, it proves to be very effective in detecting sensor faults within the electric vehicle system [11]. Sensor failure, including noise, drift, gain loss, and interruption, impacts the operation of electric vehicle motors, leading to unhealthy operation [12]. Recent studies demonstrate that wide-band gap semiconductors (WBGs), such as silicon carbide (SiC), are a suitable choice for high-power EV converter design.

There are more advantages than conventional power devices, including ability to manage extensive power ranges, reduce cost, lower weight, high thermal conductivity, and market availability [13]. The reliability and efficiency of the converter are significantly influenced by the total number of switches employed, the voltage stress applied, and the switching strategy used. Topologies characterized by a decreased number of switches and stress typically exhibit greater efficiency and a lower probability of failure, while soft switching solutions and wide-band gap devices contribute to loss reduction, improve thermal response, and extend lifespan [14], [15]. This essay reviews the fault detection and tolerance in DC-DC converters for electric vehicles. Section II introduces the categories of converters, which are divided into isolated and non-isolated types in subsections II.1 and II.2 The comparison of converter topologies for electric vehicles, and their benefits, drawbacks, and fault-tolerant operation, is presented in Section III. Section IV. presents the fault detection and tolerance mechanism. Section V. presents the key finding and highlights the increasing research during the last five-year period. The conclusion of the review is presented in section VI.

II. CLASSIFICATION OF DC TO DC CONVERTER

DC-DC converters are classified into isolated and non-isolated configurations. Selecting an appropriate converter topology for a specified application remains hard. Effective design necessitates the integration of challenges, including the use of transformer, safety and isolation, evaluated voltage gain, enhanced efficiency, reduced switching and conduction losses, compact dimensions, and lower costs [16]. Table 1 presents the comparison analysis of isolated and non-isolated BDC. Summarizing their structural characteristics, performance, and applications [17], [18], [19], [20].

Table 1: Comparison of isolated and non-isolated converters.

Situation	Non-isolated BDC	Isolated BDC
Electrical structure	Absence of a transformer.	contains a transformer.
Voltage gain capability	Limited due to the absence of the transformer, improved use interleaving coupled-inductor techniques.	Highly flexible because the transformer turns ratio allow wide-range voltage.
Efficiency	Higher owing to fewer components.	Lower due to transformer related losses and structure complexity.
Safety and isolation	No galvanic isolation, unsuitable for higher voltage or safety-critical applications.	Provide full isolation and high safety.
Complexity and component count	Simple structure, fewer components, easier assembly, and cooling.	More complex due to include transformer, additional drive circuit, and protection mechanisms.
Conduction and switching losses	Lower losses, improving thermal performance, and efficiency.	Higher losses due to transformer currents and multistage energy transfer paths.
Fault-detection /Fault-tolerant	Clear and direct current or voltage signature enables fast and simple fault detection.	Transformer elements and multiple energy paths make fault discrimination more complex.
Application domain	Low-voltage application, charging of electric vehicle.	EV traction systems, high-power storage.
Size and weight	Smaller and lighter due to absence of transformer.	Larger and heavier due to the transformer presence.
Cost	Lower overall cost.	Higher cost

Source: [17], [18], [19], [20].

From the table above, non-isolated converters are more suitable for low-voltage EV applications because of high efficiency and simple configuration. Alternatively, isolated topologies are more common in medium and high-power systems that demand galvanic isolation and safety. This comparison approach is then used to choose appropriate bidirectional topologies and their applicability for EV. According to previous literature, DC-DC converters can be classified as shown in Figure 3.

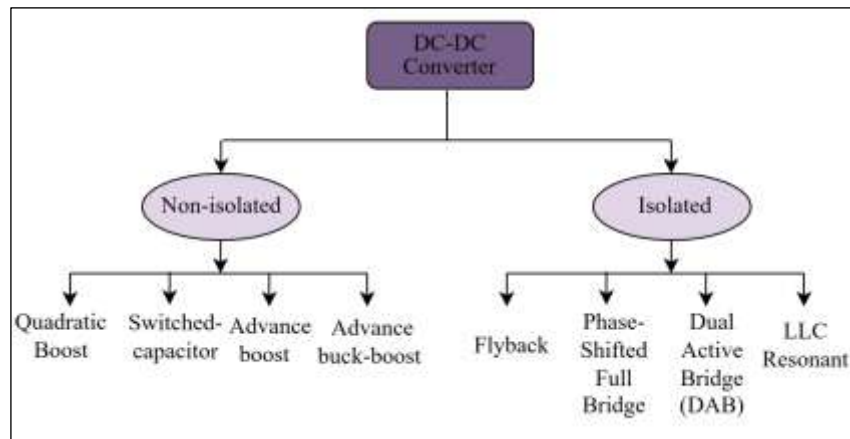


Figure 3: Illustrate the classification of DC-DC converter.

Source: Authors, (2026).

II.1 NON-ISOLATED BIDIRECTIONAL DC-DC CONVERTERS TOPOLOGY

II.1.1 Quadratic Boost Converters

Quadratic boost converter (QBC) has a good step-up ability, which is used in applications for low voltage sources such as a solar cell or a fuel cell. Conversely, the main switch suffers from high voltage stress. To overcome this limitation a high-gain quadratic boost converter combined with the coupled inductor to increase voltage gain, enhance efficiency, lower stress on semiconductor devices, and improve input current [21]. In contrast, a secondary winding is positioned across the inductor to measurement of the voltage inductor and the gate drive signal (GDS). This method enabling the rapid detection and identification of the converter switch and diode in the open circuit or short circuit through utilization of logic gate. This can detect errors during a single switch period. Open circuit fault causes loss of synchronization with the (GDS), while short circuit produces distortion in the measurement of the voltage inductor[22].

II.1.2 Switch-Capacitor Converters

Switch capacitor converters (SCCs) have been increasingly used in industrial power supplies due to their high temperature capability and compact structure, resulting in decreased dimensions and weight compared with magnetic-based converters. No magnet design allows great power density and seamless integration in electric vehicles [5]. Moreover, Zhang et al. (2018) suggested the bidirectional DC-DC converter uses switches and has two sides: low voltage and high voltage. It contains four power semiconductor devices, four capacitors, and one inductor. This topology extends the voltage gain while decreasing the voltage stress on all semiconductor devices to half, due to the switch capacitor sharing the high-side voltage regardless of the operating mode [23]. In addition, using switch-capacitors instead of the heavyweight and expensive conventional inductor. This design results in decrease in weight and size in the overall system, in addition to copper and core losses, which are associated with the inductor, leading to improved efficiency and increased power density. Control strategies used for the space vector pulse width modulation of the switch capacitor (SVPWM-SC), which operates to identify the time for switches to be on to reach the desired voltage. This strategy charges and discharges the capacitor according to the required voltage, which is connected in parallel for charging and in series for discharging to boost voltage [24]. To diagnose faults in capacitor-switched power transformers, one or more internal currents or voltages related to switching elements are measured. When these measurements fall outside a specific range, a fault is detected. Upon detection of a fault, the fault circuit modified the transformer operation. To bypass this fault, a high voltage switch is used to electrically disconnect certain switching elements from one or more of the transformers terminals, or the phase signal timing is altered [25].

II.1.3 Advanced Boost Converters

The interleaved boost converter is derived from a boost converter that is used in electric vehicles. The SAE1772 standard for electric vehicles categorizes power into three tiers. Level 1 is up to 3.7 kW, while level 2 is between (3.7-22 kW), and further categorized as level 3 from (22-43.5 kW). Evaluated currents are required to augment the power rating. This leads to increased ripple in current and evaluated stress in the power switches. A prevalent approach to address this problem is to implement interleaving within the bidirectional boost topologies [26]. A multiphase structure facilitates fault identification, employing harmonic elements built on the frequency switching. When an open circuit fault occurs, imbalance appears and harmonics at the fundamental switching frequency exceed the specified level. This method allows fault position to be identified, and to normal continuity of operation, the phase fault is isolated and the phase shift of the remaining healthy phase is adjusted [22]. Furthermore, when an open circuit fault happened, the current in the faulty phase decreased to zero, while the current in the good phase increased. The healthy current increases the duty cycle to compensate for the output voltage and power.

Peak current control and slope compensation improve dynamic stability under open-switch fault conditions [27]. To handling open circuit faults in interleaved bidirectional DC-DC converters. The method relies on adding a single spare leg containing switches M1 and M2, which is connected to all operating legs through TRIACs. When an open circuit fault happens in any switch as shown in Figure 4. The corresponding TRIAC is activated and the PWM pulses of the faulty switch are redirected to M1 or M2 depending on whether the upper or lower device has failed. This structure enables continuous operation and preserves current sharing after reconfiguration. Balance current distribution and maintaining DC-link voltage stability are restored by switching on the spare leg. The advantage of this method is the ability to tolerate faults in $2n$ switches using only two additional MOSFET and n TRIAC without required additional inductors or current sensors. The diagnosis algorithm detects the faulty leg and switch by monitoring the inductor currents and their dynamic behaviour. Fault detection and hardware reconfiguration are completed within 18ms, maintaining stable current and voltage waveforms [28].

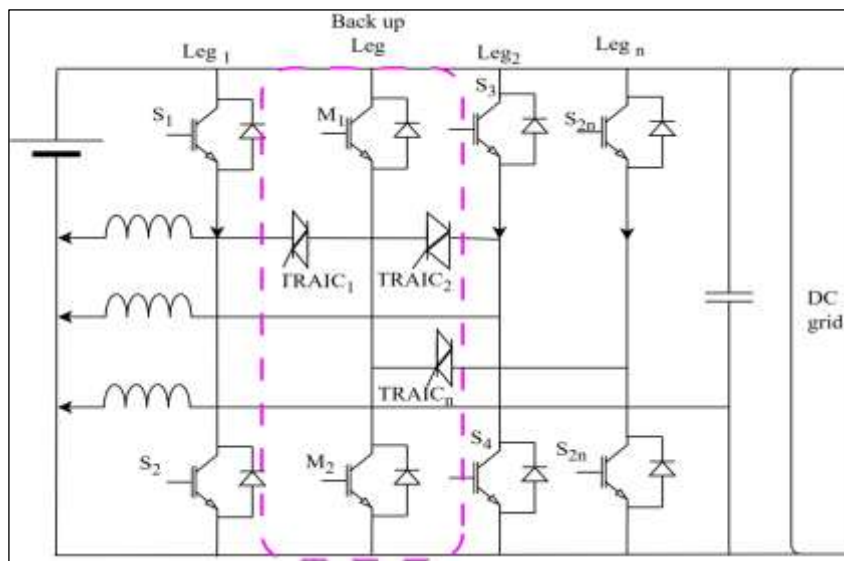


Figure 4: Proposed topology of interleaved bidirectional converters.

Source: [28].

A related TRIAC based fault-tolerant strategy was presented by Selvaraj et al. (2020). Under an open switch in any phase, a TRIAC-based reconfiguration path transfers the PWM pulses from the faulty switch to an auxiliary switch (FT), employing a single backup leg and four TRIACs. A fault detection relies on the park vector angle:

$$\theta_L = \tan^{-1} \frac{iq}{id} \quad (1)$$

When abnormal deviations signal a fault and initiate the TRAIC-based reconfiguration. This integration architecture allows fault-tolerant operation in both step-up conversion stage and the motor driving inverter, ensuring stable performance with minimal supplementary hardware [29]. Another significant advancement is the soft switching in the interleaved boost converter (SS-IIBC) with a resonant auxiliary leg to achieve ZVS turn off and ZCS turn on, which can reduce switching loss dramatically and enable high frequency operation. With interleaved phase balance input current distribution can be achieved and ensures less ripples, fast transient response and less thermal stress on inductor and capacitors. An integrated voltage multiplier stage further improves the gain of the voltage without using a huge duty ratio. Therefore, the SS-IIBC is applicable to high-voltage EV systems [30]. Furthermore, the recent study expanded a standard boost converter into a double boost converter with one capacitor, and combines multiple sources, including (fuel cell, photovoltaic cell, and battery). This method reaches an efficiency of 96% excessive than (85 to 90)%, typically found in the conventional converters [31].

II.1.4 Advanced Buck-Boost Converters

The buck-boost converter has the benefits of simplicity, necessitating just a single magnetic component, and the capability to work as both a step-up/step-down converter. However, it suffers from the current ripple and higher voltage stress on the switches. To overcome these issues, utilize two half-bridges in a cascaded configuration (CHB). The electrical strain on the switches is mitigated, and thermal losses are decreased. In addition, a two-phase interleaved half-bridge(2P-HB) is used to diminish the input current ripple. In contrast, the three-phase interleaved half bridge(3P-HB) with snubber capacitors enables ZVS, suppresses switch losses, and enhances electromagnetic compatibility. Collectively, these types provide the foundation for more advanced high-gain buck-boost architectures [32]. In addition to half-bridge-derived improvements, a more fundamental non-isolated enhancement is achieved through the coupled inductor bidirectional converter (CIBC). Recent converters have notably highlighted the CIBC for its substantial voltage gain and less electrical stress. The CIBC has a single magnetic core, resulting in compact volume, lower iron losses, and decreased inductor current ripples which lead to enhanced efficiency.

Nevertheless, a shortcoming of coupled inductor technology is the emergence of leakage inductance, which induces resonance and voltage spikes. Voltage conversion ratio has been contributed which positions the coupled inductor as the baseline high-gain non-isolated stage [33]. Recent advances in high-gain bidirectional DC-DC conversion have converged toward hybrid architectures that combine the strength of non-isolated interleaved buck-boost structures with high step-up capability of bridge-type converters. In addition, an interleaved coupled-inductor bidirectional converter (ICI-BDC) mechanism through the sharing of low-voltage side switches. This hybrid structure has minimized the input current ripple while achieving a significant voltage conversion ratio (VCR) typically associated with dual active bridge topologies. Moreover, the authors replace the transformer and two filter inductors used in conventional ICBB-DAB cascaded structures with only two coupled inductors as shown in Figure 5. This improves the power density and reduces magnetic losses. The measured bidirectional efficiency reaches 94.5% [34].

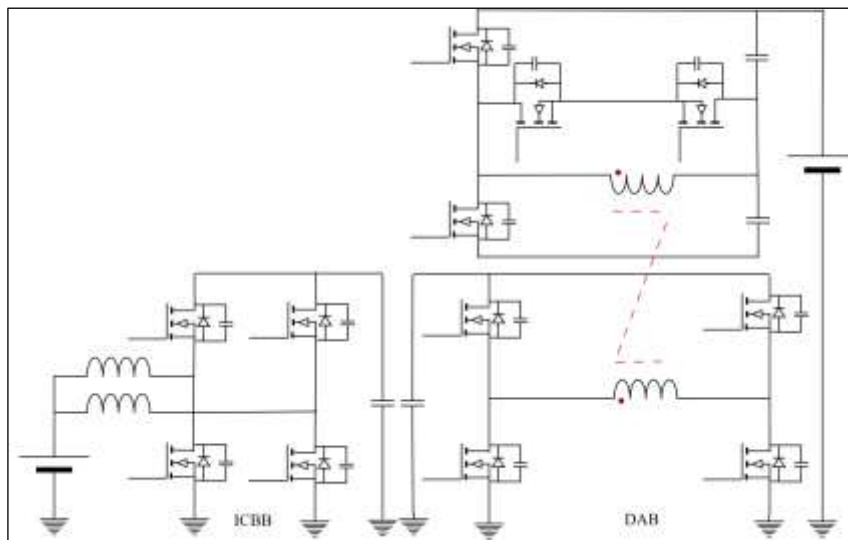


Figure 5: Proposed converter.

Source: [34].

The hybridization concept builds upon earlier work that combining a coupled-inductor buck-boost stage with a dual active half-bridge (DAHB) cell can minimize circulating current, achieve zero voltage switching, and maintain equal to 95% efficiency across wide load conditions, as shown in Figure6. Conventional phase shift modulation is employed to govern bidirectional power flow in DAB-based structures [35].

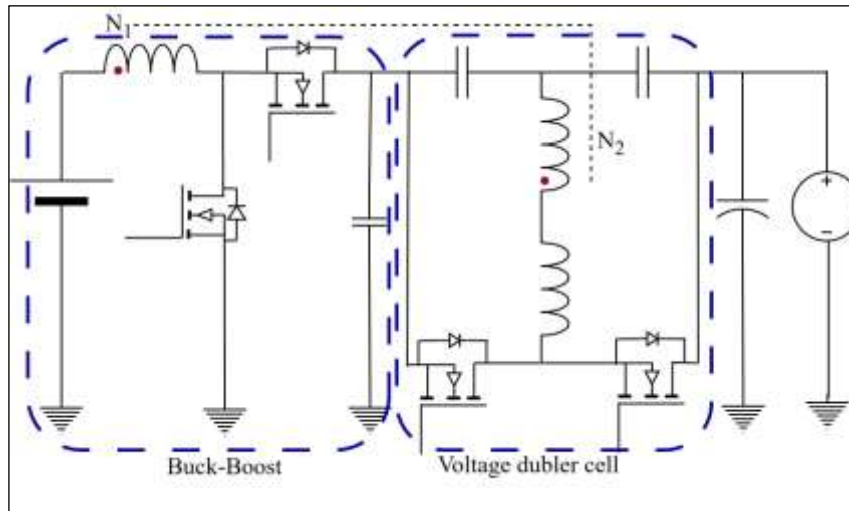


Figure 6: Proposed converter.

Source: [35].

Additionally, the multiphase interleaved coupled-inductor (MIBCI) converter is an advanced extension of the conventional coupled-inductor buck-boost converter (CI-BDC). A multiphase interleaved architecture, typically consisting of four phases, is employed and interconnected through a coupled inductor. The voltage and current ripple, power losses, power element, and magnetic size are reduced in the (MIBCI) converter. The linked inductor simplifies current sharing between legs, simplifying the structure and improving performance. No auxiliary clamp circuit is needed, and it can work across an extensive power and voltage range with better dynamic responsiveness, reduced ripple and good efficiency. Experimental results, reach an efficiency greater than 97% for both buck and boost. All these characteristics enable it to be suitable for high-power electrical vehicles [36]. Moreover, a control system suitable for these advanced topologies, a twofold loop control architecture is used, comprising an inner current loop for input current to ensure near unity power factor and an outer voltage loop for DC-link regulation.

Two loops use PI controllers with the inner loop configured for a larger bandwidth to facilitate rapid current tracking. A passive RC-damping network is implemented across intermediate capacitors to stabilise these dynamics, effectively mitigating the resonance peak and addressing the internal dynamic instability. The authors introduced structure which contains a boost converter followed by a buck converter connected through a capacitor (boost-buck converter) with four switches, as shown in the Figure. This arrangement achieves power factor above 0.98 with total harmonic distortion(THD) of 3.4% in boost mode and 4.7% in buck mode demonstrating that the proposed control strategy ensures high performance across operating modes [37]. Dhananjaya et al. (2024) devised highly dependable non-isolated multi-input buck-boost architecture. The converter employs multiple inputs, triple primary switches (S_1 to S_3) and double redundant switches (S_4 to S_5) capable of operating in buck, boost, or buck-boost modes under standard conditions based on the interaction of input sources as shown in Figure 7.

The structure is the ability to transition into a reconfiguration mode. In the event of an open-circuit failure affecting either of the primary switches, the current path will be repeated using S_4 and S_5 to ensure uninterrupted power transfer. This construction ensures that inductor L_1 and L_2 continuously deliver power to the load even when certain primary switches are open-circuited. Both simulation and experimental findings indicate that all fault scenarios whether involving single switch or multiple switch faults maintain a functional reconfigured path that operates equivalently, thereby sustaining the output voltage at the same level as in the healthy state. The observation of switch currents is relied upon for fault detection. A zero current signature indicates an open circuit fault and indicates automatic reconfiguration. These experimental findings show similar output voltage waveforms under normal, single, multiple fault scenarios, including uninterrupted functioning despite the simultaneous failure of all three primary switches(S_1, S_2, S_3) [38].

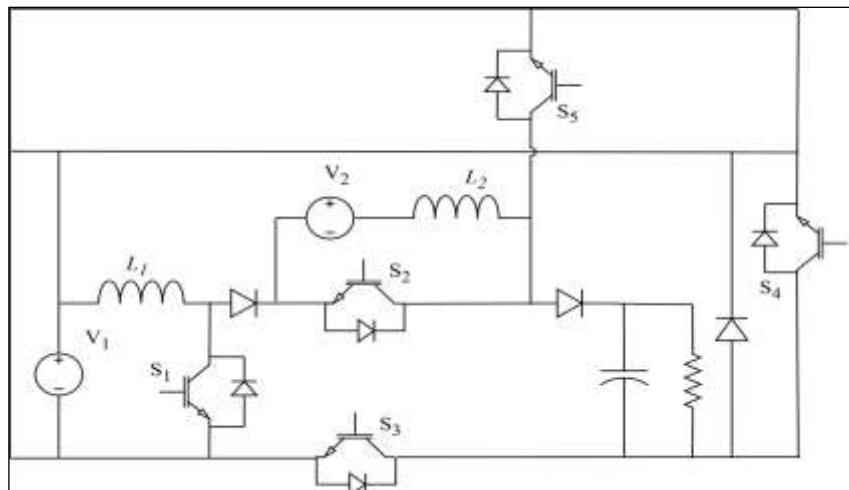


Figure 7: Proposed converter.

Source: [38].

The proposed coupled-inductor-based bidirectional DC-DC converter topology provides simplified high-gain solution suitable for wide voltage conversion ratios ranging from 48V to 380V, while employing only three MOSFETs and two magnetically coupled windings. By exploiting the coupled inductor mechanism, the converter achieves high voltage gain in both buck and boost operating modes and simultaneously reduces input-current ripple without requiring auxiliary clamp circuits or resonant networks. The steady state analytical results demonstrate reduced voltage and current stress on the semiconductor devices and high conversion efficiency. The simulation has achieved efficiency of 95% in boost and 96% in buck mode steady state operation [39]. The Figure presents the evolution of buck-boost from traditional structure to fault tolerance structure.

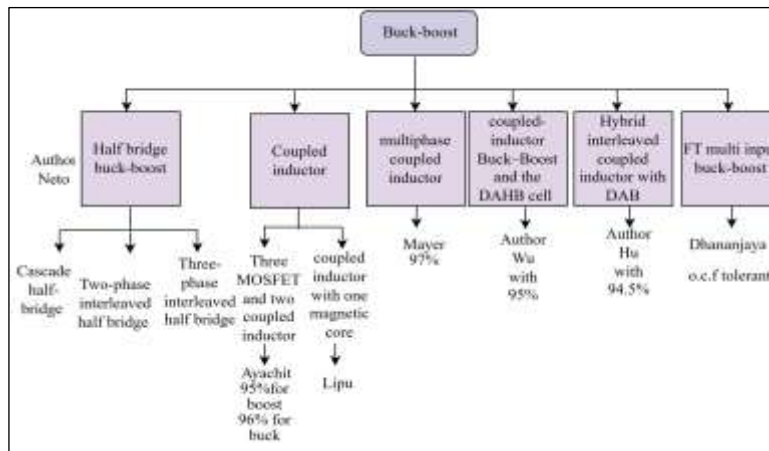


Figure 8: Develop of advance buck boost converter.

Source: Authors, (2026).

II.2 ISOLATED BIDIRECTIONAL DC-DC CONVERTERS TOPOLOGY

II.2.1 Flyback Converters

The flyback converter is a type of AC-DC converter that is beneficial for many DC power applications. It offers the benefits of a straightforward control method and provides isolation due to the transformer employed. Conversely, the traditional AC-DC flyback converter a significant high total harmonic distortion in the grid current and a notably weak power factor, rendering it unsuitable for reliable electrical system. To solve this problem converter replaces the full bridge diode rectifier typically found in conventional converters with half- bridge converter that utilizes IGBT switch and incorporates an inner current feedback loop, and an outer voltage feedback loop. The outer voltage regulates the reactive power sent to the grid, while the inner current loop manages the input grid current [40]. Moreover, using a four parallel flyback stages converter for bidirectional power transfer between the DC link and the battery. This allows us to connect many batteries in parallel. The utilization of sliding mode control provides improved performance, efficiency, and enhanced output current and voltage compared to another controllers, such as fuzzy logic and genetic algorithm-PID [41].

II.2.2 Phase Shifted Full Bridge Converters (PSFB)

The phase shift full-bridge (PSFB) converter is widely used in medium to high-power isolated dc-dc stages due to its ability to achieve zero voltage switching (ZVS) through phase shift control. However, traditional architecture is limited by a restricted ZVS range, increased circulating current, and constrained output-voltage adaptability, particularly under light load and broad range scenarios, hence limiting its use for contemporary EV fast chargers. To reduce these limitations, authors proposed a series /parallel secondary topology and a Centre Tapped Clamp (CDD) network, which recycles leakage energy and extends the zero-voltage switching operating range. Reconfiguration occurs using two SPDT switches (Single Pole Double Throw) as shown in Figure 9. The prototype delivered 10 kW at 900V with 96.69% efficiency [42]. Although these advantages, using mechanical switches limits long-term reliability and reconfiguration speed.

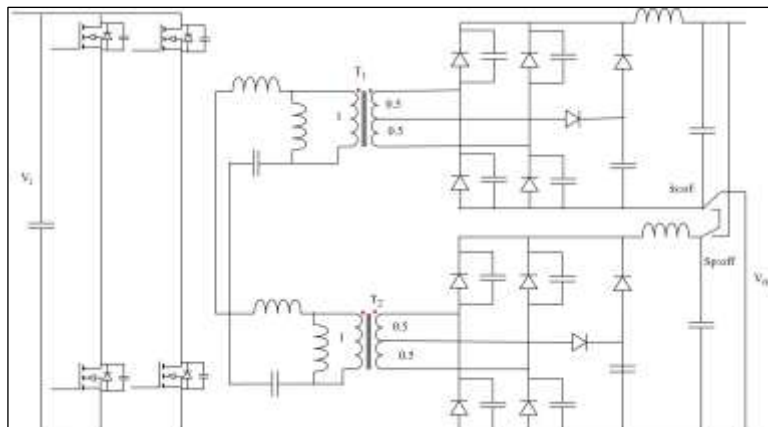


Figure 9: Proposed converter.

Source: [42].

For fault detection in phase shift full bridge converters, simplicity diagnostic method is used to detect open-circuit (OC) switch fault by using the transformer primary side voltage obtained through small accessory winding. The diagnostic variable is compared with an empirical threshold to identify OC status, and once the faulty switch is discovered, the converter is reconfigured into unsymmetrical half-bridge to maintain continuous operation. This technique offer low implementation cost, high diagnostic accuracy, stable voltage stress, and reliable topology reconfiguration [43]. In addition, a half-bridge combined PSFB (HB-PSFB) converter is employ, which couples effectively with improving the soft-switching capability and eliminates circulating current to boost efficiency and reduce volume. The topology involves centre-tapped clamp circuit made with two diodes and one capacitor, which limits the secondary-side voltage and eliminates effectively the voltage oscillations. Therefore, the voltage stress of the rectifier diodes is much lower than that shown in Figure 10 below. Experimental results achieved maximum efficiency of 98.5% with full ZVS, eliminated circulating current, and improved power density making the HB-PSFB a compact and highly efficient isolated topology for EV charger applications [44].

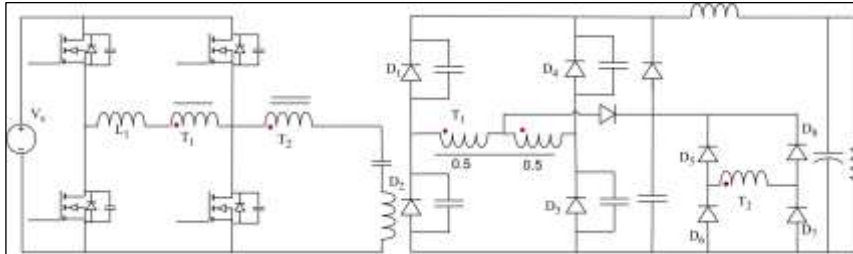


Figure10: Proposed converter.
Source: [44].

II.2.3 LLC Resonant Converters

The LLC resonant converter generates sinusoidal resonant waves through a resonant tank which consists of L_r , C_r , and L_m . It also gets ZVS on the primary switches and ZVS on the secondary rectifiers. These soft switching characteristics reduce switching losses, EMI, and device stress, resulting in high efficiency across a wide range of operating conditions [45]. The LLC topology is more complex to design than other isolated DC-DC converters. This is because of the difficulty of accurately selecting and tuning the resonant components, where even small variations in L_r , L_m , and C_r . This is affected by gain performance and the ability to maintain ZVS/ZCS, which leads need for careful controller design to provide stability under changing loads [46]. Prince and Ayad (2025) introduce the fault-tolerant LLC converter, which has a wide input range of 250-450V and produces a regulated 12V/1.8Kw output. The converter achieves an efficiency of more than 95% in normal working and above 90% under abnormal operations. The proposed solution depends on the fact that when a semiconductor fault occurs in the high-voltage bridge, an automatic reconfiguration mechanism is activated. Under such conditions, the primary stage transitions from full-bridge (FB) to half-bridge (HF) operation. At the same time, the secondary side is reconfigured into a voltage doubler rectifier (VDR) by enabling the auxiliary switch S_f and connecting the midpoint of the capacitors $CO1$ and $CO2$ to one terminal of the transformer secondary winding, as shown in Figure 11. This arrangement maintains the required output voltage even when one switching leg is lost. This eliminates the need for redundant converters or backup batteries. The simulation results demonstrated when fault occurs, the output voltage is restored within a fault-tolerant time interval (FTTI) OF 0.2-0.3 ms [47].

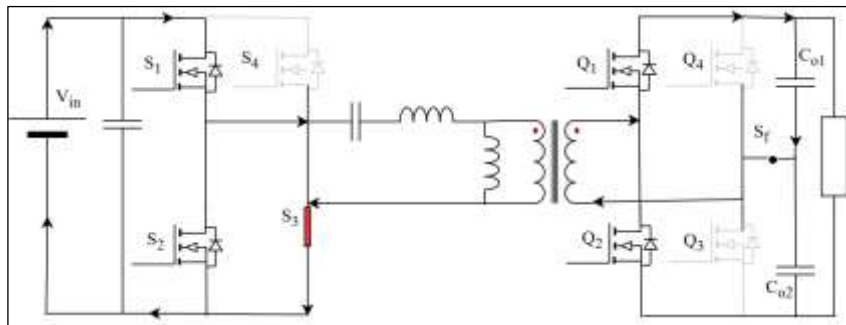


Figure 11: Proposed converter.
Source: [47].

In (2023), the study introduced a topology-reconfiguration architecture that combines a bridgeless interleaved PFC rectifier with an LLC resonant converter, as illustrated in Figure 12. Under regular conditions, the converter operates as a two-stage structure. When an open circuit fault (OCF) is detected in any switch, two bidirectional MOSFETs ($sf, sf2$) connect the midpoints of the bridge legs, automatically reconfiguring the system into a single-stage structure while preserving the same PWM control law:

$$D = 1 - \left| \frac{V_{in}}{V_{dc}} \right| \quad (2)$$

A 1kw SCI-MOSFET hardware prototype of the approach, demonstrating stable input behaviour and maintaining efficiency above 90% in post-fault operation, confirms strong fault-tolerant capability [48].

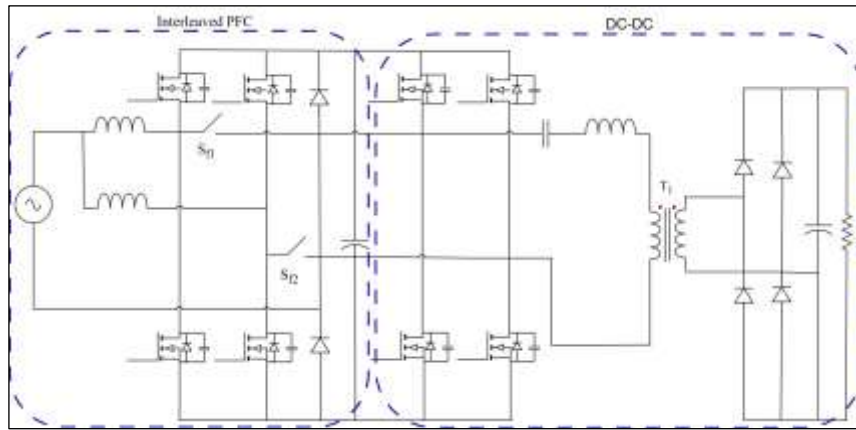


Figure 12: Proposed converter.
Source: [48].

The other authors present a hybrid multi-output dc-dc converter that combines a three-phase LLC resonant converter with a full-bridge converter with a full bridge converter as shown in the Figure below. The main output is controlled by frequency modulation, and the auxiliary outputs are controlled by phase-shift modulation. The outputs are fully independent and free from cross-regulation. The three-phase LLC structure reduces resonant current and lowers output current ripple, thereby improving efficiency and extending capacitor lifetime. The LLC tank ensures ZVS for all primary switches across the whole load range, eliminating the need for auxiliary inductors. A 120° phase shift ensures balanced current sharing between phases. This is providing multi-isolated outputs with high power density and reduced component count. The experimental test shows that load variations in one output do not affect the others and maximum efficiency is reached 95.6% [49].

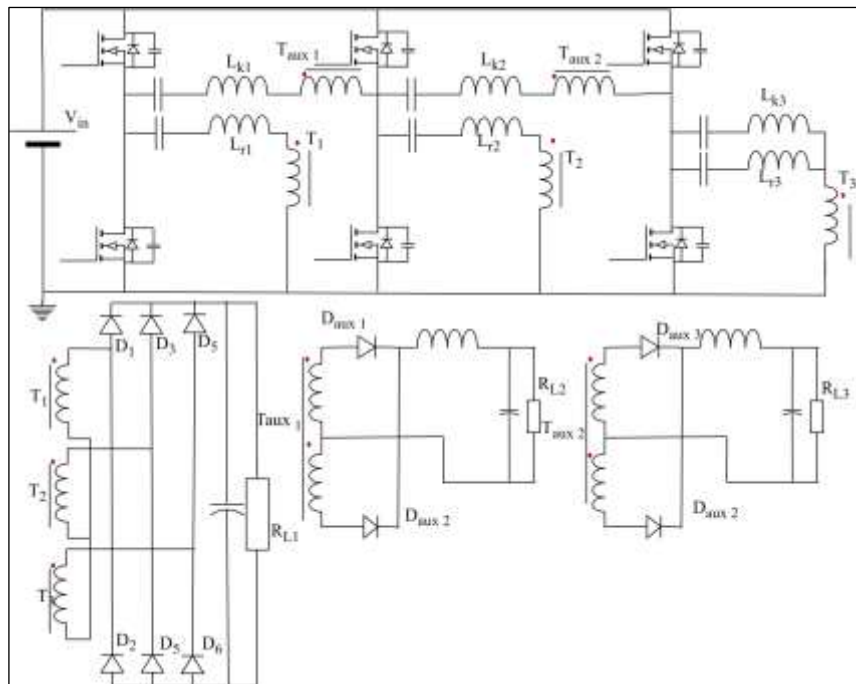


Figure 13: Proposed converter.
Source: [49].

II.2.4 Dual Active Bridge Converters (DAB)

Dual active bridge converter is a widely employed isolated bidirectional DC-DC converter topology in electric vehicle powertrains and onboard charging systems. It comprises two full-bridge circuits linked by a high-frequency transformer, with power transfer regulated by modifying the phase shift between the primary and secondary bridges. The structure provides galvanic isolation, bidirectional energy transfer, a small design, and high-power density. In its conventional two-level form, the DAB operates through a dc-ac-dc conversion stage and achieves soft switching under nominal conditions; however, it still suffers from high circulating currents, limited voltage-conversion ratio and increased conduction losses, particularly under partial load. These drawbacks restrict efficiency, raise thermal stress, and complicate control, especially in multi-phase or modular implementations [50].

Wen et al. (2021) developed the triple phase shift (TPS) control scheme. TPS-based fault diagnosis and tolerant control strategy. This relies on midpoint-voltage distortion to detect OCs and reconfigure the converter into full bridge or half bridge modes. It maintains 75% of rated power. In addition, satisfying the zero-average voltage(ZAV)condition to avoid dc bias in the leakage inductor [51]. Babalou et al. (2024) introduced a method for the fault-tolerant Dual Active Bridge (FT-DAB). This structure employs two transformers, H5 bridge, and blocking capacitors, which are used to prevent transformer saturation and enhanced system reliability under fault conditions as shown in Figure 14.

If one of the power switches causes an (OCF), the other MOSFET will continue to be linked, and the switching method will not change. The occurrence of (SCF) leads to the deactivation of the associated switch. Experimental results demonstrated that the FT-DAB could sustain 1.26 p.u output power under normal operating conditions. When a fault occurs in one bridge, the maximum output power is about 0.82 p.u., while it drops to around 0.3p.u. When both bridges are faulted [52].

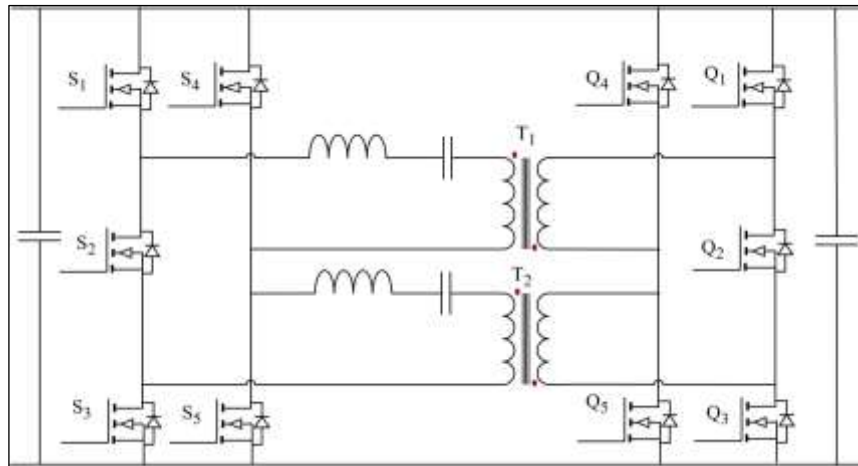


Figure 14: Proposed converter.

Source: [52].

III. COMPARISON OF DC-DC CONVERTER TOPOLOGIES FOR ELECTRIC VEHICLES' POWERTRAINS.

A simplified comparison can offer a clear reference point for understanding different topologies and supports the selection of suitable converters for various EV applications. Therefore, a comparative table is provided to analyse the results presented in the previous sections. The table summarizes the advantages, limitations, efficiency, fault diagnosis, and fault tolerant capabilities of both non-isolated and isolated DC-DC converter topologies.

Table 1: Comparison of DC-DC converter topologies for EV.

Topology type	advantages	Limitation	Fault diagnosis	Fault tolerance and capability	Ref
Quadratic boost converter	Rapid fault detection capabilities.	Needs voltage sensor	Measurement voltage of the inductor.	No mention in the paper	[22]
Switch capacitor converters	Enhance efficiency, and low cost	Complex design, and elevated quiescent current	Monitoring voltage and current	A high switch is used to isolate the fault.	[25]
interleaved boost converters)	Reduce ripple current and decrease stress on switching.	High performance controller, high cost due to increase components.	Inductor current deviation enables rapid detection	Fault is isolated, and the healthy phase is adjusted, peak current control and slope compensation.	[22], [27]
Interleaved boost with TRIAC fault	Fault detection with 18ms, stable performance.	Controller complexity	Monitoring inductor current	Adding TRIAC, spare leg.	[28], [29]
Buck-boost with multi-input.	Ability to transition to reconfiguration if a fault occurs.	Increase size, cost, and number of redundant switch.	Current signature detects fault.	Continued operation even when three main switches fail.	[38]
Flyback with four parallel Flyback.	Simple, galvanic isolation, Improve efficiency.	Low power, difficult to control	No mention in the paper.	No mention in the paper.	[40], [41]
Phase shift converter.	Low cost, no additional component required.	Voltage stress on switch after fault	Measure primary side voltage and compared with the threshold	Half bridge reconfiguration maintains operation.	[43]
LLC resonant converter	High efficiency in normal and post-fault, reduced switching losses, and wide range operation.	Complex design, sensitive to L_r , L_m , L_c , non-linear control.	Monitoring the voltage and current in the primary and secondary sides.	Reconfiguration from FB to HB.	[47], [48]
Dual active bridge (DAB).	Detection fault Fastly, maintain 75% of the power at fault.	Need threshold to avoid false alarm, thermal stress	Mid-point voltage distortion to detects fault.	Reconfiguration to half bridge.	[51]
Dual active bridge with H5 bridge	Maximum output power is 82% when fault in one bridge, stress protection on component.	High cost, increase complexity and weight.	/	Deactivation of the associated fault switch.	[52]

Source: Authors, (2026).

This table highlights the significant evolution of the fault-tolerance topology architecture, which is characterized fault tolerance, high efficiency and reliability. By monitoring the measurement of current and voltage and comparing the readings to the specific threshold to alert if a fault occurs. Allowing the activation of a suitable strategy such as isolation of the phase fault and reconfiguration. This enables the system to change from an abnormal to a fault-tolerant state without interruption and with high power.

IV. FAULT DETECTION AND TOLERANCE MECHANISM (FLOW SUMMARY)

The operation of the fault-tolerant system is illustrated in an operation sequence an operation-sequenced diagram as shown in the Figure. Following the observation of significant parameters such as voltage, current, inductor current slope, and switching actions. Otherwise, if no fault behaviour is detected, the converter continues operating normally. When an abnormal signature is identified, the system transfers to the fault classification stages to determine the fault type, including open-circuit faults, short-circuit faults, sensor failures, or imbalance conditions. If reconfiguration is possible, the fault-tolerant capability is used, and the converter operation is in safe-mode conditions. As a second option, the shutdown is activated to prevent damage to the system.

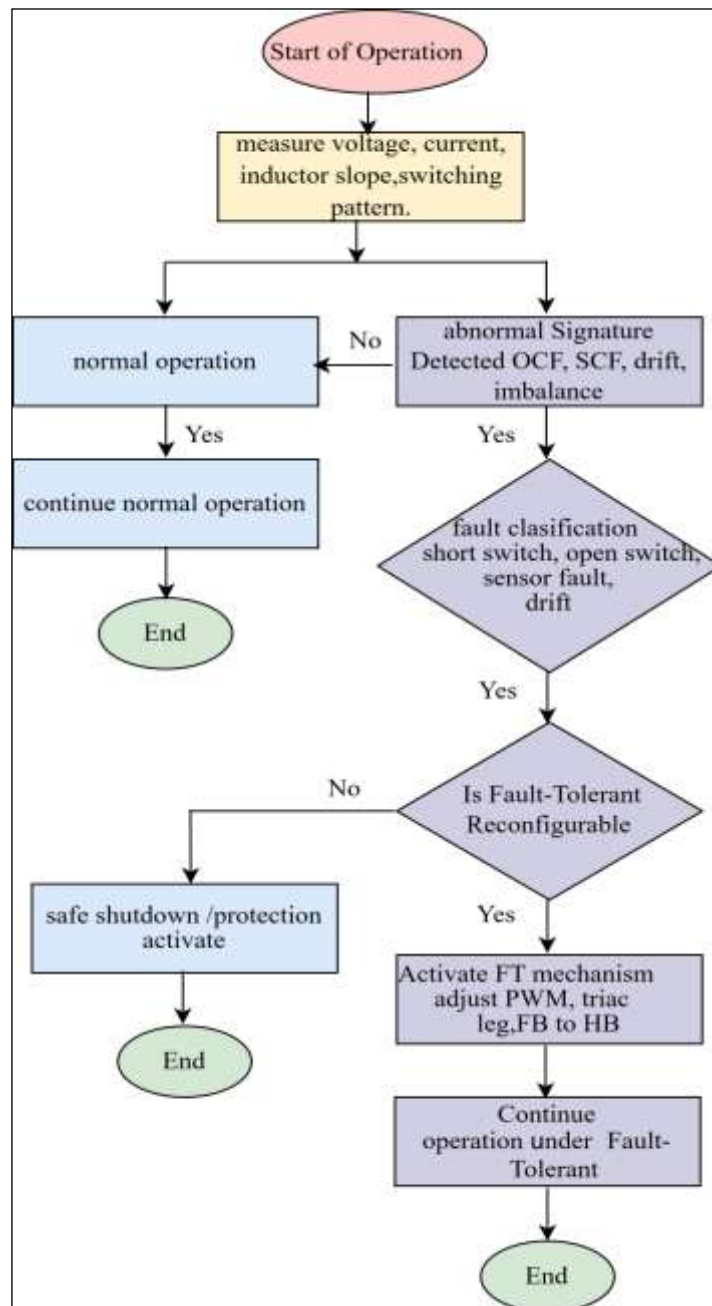


Figure 15: Illustrates a flowchart describing the general process of fault detection and tolerance in EV.

Source: Authors, (2026).

V. KEY FINDING

According to the literature review, the results illustrate a clear and continuous increase in research activity related to DC-DC converters and fault-tolerant techniques for electric vehicle applications during the period from 2019 to 2025, as shown in the Figure below.

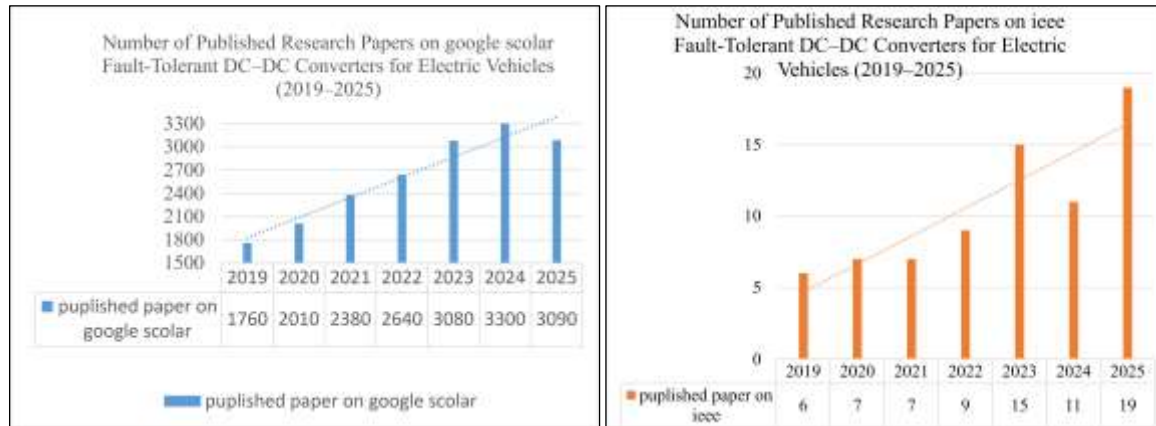


Figure 16: Statical analysis (2019-2025) of publication related to DC-DC converter and fault tolerance of EV.
Source: Authors, (2026).

The increasing demand for highly reliable and efficient power conversion systems. The analysis also shows that recent studies have increased focus on high-gain non-isolated topologies and hybrid structures that combine interleaving, magnetic coupling, and reconfigurable architecture to improve efficiency, reduce current ripple, and enhance fault tolerance. In addition, isolated topologies remain dominant in high-power and safety-critical applications due to their galvanic isolation and robustness. In general, fault tolerance, improved control techniques, and hybrid converter topologies have become an important area of research in modern EV powertrains.

VI. CONCLUSIONS

A review of fault-tolerant DC-DC converters presents a comprehensive analysis and structure of both non-isolated and isolated converters in electric vehicles. It illustrates the characteristics, performance attributes, voltage-gain mechanism, control strategies, and fault behaviours that are associated with each topology. This work provides a clear understanding of development of converter architectures operate under both normal and fault conditions. It is concluded from the analysis that non-isolated converters are generally more efficient for low and moderate power, impose lower stresses on semiconductor devices, and offer more compact designs, whereas isolated converters provide galvanic isolation for enhanced safety and improve robustness in high-voltage environments. Control schemes in both categories are varied among PWM-based methods to resonant and phase-shift techniques, each influencing stability, dynamic response, and fault-tolerant operation. Fault tolerance is addressed by studying component and topology reconfiguration to ensure efficient and high reliable power flow. The review shows that there is no converter design that performs well in all aspects. The ideal choice relies on the voltage levels required for the design, how efficient you want it to be, how much insulation you need, how dynamic you want it to be, and how much it can handle faults. This study provides practical guidance for selecting and designing appropriate converters for Electric vehicle power systems.

VII. AUTHOR'S CONTRIBUTION

Conceptualization: Israa Salih Hadi, Ali Hussein Al-Omari.

Methodology: Israa Salih Hadi and Ali Hussein Al-Omari.

Investigation: Israa Salih Hadi and Ali Hussein Al-Omari.

Discussion of results: Israa Salih Hadi, and Ali Hussein Al-Omari.

Writing – Original Draft: Israa Salih Hadi.

Writing – Review and Editing: Israa Salih Hadi and Ali Hussein Al-Omari.

Resources: Israa Salih Hadi.

Supervision: Ali Hussein Al-Omari.

Approval of the final text: Israa Salih Hadi, and Ali Hussein Al-Omari.

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