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Review

A Critical Review on Charging Technologies of Electric Vehicles

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Abstract: The enormous number of automobiles across the world has caused a significant increase in emissions of greenhouse gases, which pose a grave and mounting threat to modern life by escalating global warming and polluting air quality. These adverse effects of climate change have motivated the automotive sector to reform and have pushed the drive towards the transformation to fully electric. Charging time has been identified as one of the key barriers in large-scale applications of Electric Vehicles (EVs). In addition, various challenges are associated with the formulation of a safe charging scheme, which is concerned with appropriate charging converter architecture, with the aim of ensuring a safe charging protocol within a range of 5–10 min. This paper provides a systematic review of thharging technologies and their impacts on battery systems, including charger converter design and associated limitations. Furthermore, the knowledge gap and research directions are provided with regard to the challenges associated with the charger converter architecture design at the systems level.

Keywords: electric vehicle; fast-charging techniques; fast-charging converter; battery; energy storage

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1. Introduction

Recently, Electric Vehicles (EVs) have gained popularity over traditional fossil fuel-based automobiles, which cause environmental pollution by releasing greenhouse gas emissions (GHG) [1–4]. EVs not only curtail carbon emissions but also reduce the burden of fossil fuel dependency [5]. Key bottlenecks in enabling larger EV adoption include the high cost due to batteries, range anxiety due to reduced battery capacity and speed, high charging time, and lack of sufficient charging infrastructures [6–8]. To meet the challenge of time, it is possible to develop highly efficient, reliable, and compact EVs by enabling game-changing battery charging technologies with the aim of reducing charging time and enhancing battery capacity [9–11]. It is expected that EV penetration by 2030 will be approximately 30% of all vehicles sold that will be either electric-powered or hybrid [12]. China, the US, and Europe are, so far, the biggest EV exporters worldwide, and the sales volume of EVs increased at a rate of 94% between 2011 and 2015. The Li-ion battery itself accounts for 40% of the total production cost of EVs. Prices of Li-ion batteries were reduced from \$600 per kWh in 2012 to \$250 per KWh in 2017 [13]. The recent target is set to push the price drop further to \$100 per KWh by 2024. EVs have become a hot topic of research since 1990, therefore it is important to understand the development trend and technological barriers.

Charging time is the key bottleneck, particularly for Battery Electric Vehicles (BEVs), where it ranges from 2 to 6 h [14]. Three classifications have been made by the U.S.

Department of Energy based on charging EV power capacity. The first includes charging EVs at less than 5 kW [9,15,16], the second covers the fast-charging power range between 5 and 50 kW, and the last one denotes a charging power range greater than 50 kW [17]. The first two are referred to as on-board chargers that are integrated into the vehicle, while the third one is referred to as an off-board charger, which is basically equivalent to a fuel station [18]. The reduction in the size of the off-board charger is the future focus of research. Still, the on-board charger can charge the battery on a domestic load. However, the mileage capacity is restricted to 240–300 Wh/mi [19]. Thus, if the vehicle is needed to make an extra trip urgently outside the daily drive, it would require fast-charging solutions.

EV charging systems can be categorized into three groups based on the power levels, as shown in Table 1. Usually, the chargers with a power level below 3.3 kW (1-phase) are termed slow chargers or Level 1 chargers with 120Vac outlet, which can be integrated in-to the vehicle power train (on-board charger) or can be installed as a convenience outlet at home (wall-charging outlet). The charging time for Level 1 charger is higher which is 4–11 h for 1.4 kW (for PHEV battery of 5–15 kWh capacity) and 11–36 h for 1.9 kW (for EV battery of 16–50 kWh capacity). Level 2 chargers can charge EV batteries with a power of up to 22 kW for both 1-phase and 3-phase with 240Vac (US standard) and 400Vac (EU standard) [20]. Similar to Level 1 chargers, they can either be part of the vehicle or part of the dedicated Electric Vehicle Supply Equipment (EVSE) outside the vehicle. Three types of charging time scenarios are available for Level-2 charger such as 1–4 h for 4 kW with PHEV battery capacity of 5–15 kWh, 2–6 h for 8 kW with EV battery capacity of 16–30 kWh and 2–3 h for 19.2 kW with EV capacity of 3–50 kWh [20]. On the other hand, Level-3 chargers have power levels up to 200 kW and they are always outside the vehicle as a part of EVSE. Level-3 charger has both ac and dc power facilities with voltage outlets of (208–240) Vac and (200–600) Vdc. It is mostly applicable in commercial area analogous to a filling station. It is termed as fast charging prototype due to its less charging time which is 0.4–1 h for 50 kW prototype and 0.2–0.5 h for greater than 90 kW prototype. The battery capacity of the dedicated EVs ranges from 20–50 kWh [20]. All three types of chargers convert AC grid voltage to suitable DC voltage to charge the battery. The power levels determine how fast the battery will be fully charged from a specified state-of-charge (SOC) level [21].

The charging characteristics and required infrastructure of some of the commercially available Plug-in electric vehicles (PEVs) and EVs are shown in Table 1. Most of the vehicles have either a Level 1 or Level 2 charger as a part of their vehicle power train (on-board chargers). However, Level 3 fast charging is the quickest option to charge any EV battery if the required connector is available in the vehicle.

Table 1. Charging characteristics and required infrastructure of some manufactured PHEVs and EVs (data collected from [14–16]).

Vehicle Brand and Model	Battery Type and Energy	All Electric Range	Connector Type	Level 1 Charging		Level 2 Charging		Level 3 Charging	
				Demand	Charge Time	Demand	Charge Time	Demand	Charge Time
Toyota Prius PHEV (2012)	Li-Ion 4.4 kWh	14 miles	SAE J1772	1.4 kW (120 V)	3 h	3.8 kW (240 V)	2.5 h	N/A	N/A
Chevrolet Volt (2012)	Li-Ion 16 kWh	40 miles	SAE J1772	0.96–1.4 kW	5–8 h	3.8 kW	5–8 h	N/A	N/A
Mitsubishi i-MiEV EV	Li-Ion 16 kWh	96 miles	SAE J1772 JARI/TEPCO	1.5 kW	7 h	3 kW	7 h	50 kW	30 min
Nissan Leaf EV	Li-Ion 24 kWh	100 miles	SAE J1772 JARI/TEPCO	1.8 kW	12–16 h	3.3 kW	12–16 h	50+ kW	15–30 min
Tesla Roadster EV	Li-Ion 53 kWh	245 miles	SAE J1772	1.8 kW	30+ h	9.6–16.8 kW	30+ h	N/A	N/A
BYD	$LiFePO_4$ 60.48 kWh	323 miles	IEC60309	1.2 kW	10 h	7 kW	N/A	80 kW	50 min
Hozon NETA	Li-Ion 55 kWh	249 miles	CCS2	N/A	N/A	3.5 kW	8 h	55 kW	30 min

A U.S. Department of Energy report in 2008 [22] pointed out that charging location is critical for building future EV mobility and classified the locations for EV charging into three groups: (i) Residential garage charging (Level 1 and Level 2), (ii) apartment complex charging (Level 1 and Level 2), and (iii) commercial facility charging (Level 2 and Level 3). For both the home and apartment scenarios, it is assumed that a majority of the charging will be performed at night. For commercial facilities, it is assumed that charging is primarily performed during normal business hours.

Several review papers on charging technologies of EVs can be found in the literature based on a number of factors [23,24]. In [25], a comprehensive review of EV charging station infrastructure, standards of charging cables, cords, and connectors, the impact of semiconductors devices used in converters on charger performance and cost, and the integration of a charging system with the microgrid for better energy management systems have been analyzed. The technologies related to EVs, EV charging systems, and optimization strategies to obtain the available output have been represented in another review [26]. An overview of the recent EV market, standards related to charging, grid integration and safety, charging infrastructure, and effects of EV penetration are discussed in [24]. An overview of the diverse kinds of EVs that are commercially available and associated with energy storage systems (ESS), as well as a detailed review of public and residential power outlets, EV charging cords, and charging stands based on various power levels, was discussed in [27]. The negative impact of EV charging on the utility grid and the safety code associated with EV charging systems has also been analyzed. A converter is an integral part of the EV charging system [28]. In [29], a review of converter architectures, international standards, and EV charger manufacturers was analyzed. The architecture of the converter topologies and the reliability associated with these topologies are considered to be important factors to evaluate the effectiveness of these converter topologies, which were not considered in the aforementioned studies.

Different factors have to be considered to design the converter topologies of EV chargers, such as the efficiency, power factor, isolation, harmonic contents, filter, and switching components [30–33], which have been highlighted in this paper for both DC-DC and AC-DC converters. The reliability of electronic components associated with EV converter technology ensures the reliable performance of the entire system [34,35]. Reliability assessment of the power electronics converter from manufacturer, seller, and customer standpoints is crucial to verify the reliable operation of the EVs in all environmental conditions [36,37]. Adaptation of safe and reliable charging methods ensures a long lifetime and better performance of EV batteries by limiting the temperature [38]. The development of the fast-charging converter accelerates the revolution toward sustainable transportation through EVs [39,40]. Therefore, different charging methods and charging strategies are important factors in evaluating the total performance of the EV. EV technologies are facing various challenges such as slow charging, isolation, power loss due to converter structure, power electronic component reliability, and thermal condition of EV batteries [41]. Vehicle to Grid (V2G) is not only a promising solution to cope with a large number of EVs considering all the aspects of charging and discharging EVs but also a possible way to boost economic growth [42,43]. Clearly, the need to develop reliable and fast chargers is not only important to remove the range barrier, but also to improve the robustness of the EV in the energy transfer context. Therefore, the specific goal of this review is to provide a detailed overview of the current development of the charging converter architecture and converter reliability, highlighting the challenges and potential solutions related to EV charging.

The review started by collecting the latest journal papers from major databases such as Scopus and the Web of Science with keywords including EV Charging, EV Charger Converter, EV charger/converter reliability, Thermal challenges in EV charging, and Vehicle to Grid. One hundred and forty papers were selected for this review with particular focus given to the key topics related to EV converter topology and reliability and EV charging. This paper first reviews and presents available converter topologies of both AC-DC and DC-DC converters for charging architectures. An overview of the reliability analysis of

EVs and EV converters with diverse reliability assessment methods to ensure reliable converter performance and future trends related to EV converter topologies have been discussed. Various EV charging methods and strategies are presented, highlighting the charging challenges, thermal challenges of the battery, and V2G as potential solutions. Finally, insights into the fundamental charging protocol and guidelines for new research directions are provided.

2. EV Converter Topology

The EV charger usually creates a non-linear load in the power system, which causes problems such as weak power factor and excessive total harmonic distortion in the network. A well-designed battery charger aims not only to safely charge the battery pack with high efficiency but also to meet international standards such as IEEE 1547 [44]. Therefore, all EV chargers need a power factor correction (PFC) stage, an isolation stage, and filtering components. Several power electronics converter topologies are proposed in the literature to achieve these. The 6.6 kW prototype proposed by Lee et al. [45] used a single-phase PMW rectifier in the first stage and a full bridge resonant converter in the second stage. The rated efficiency in both charging and discharging modes was approximately 93%, but the power density was poor (less than 1 kW/L). The prototype used Silicon (Si) super-junction MOSFETs in the power stage. A three-phase 10 kW prototype based on a three-phase active rectifier and a dual active bridge converter proposed by Zeljkovic et al. [46] (Infineon) showed approximately 91% efficiency for the worst battery charging condition (195 V), with the topology presented in Figure 1. The prototype mostly used Si devices except for the high-voltage section of the dual active bridge (DAB) where Silicon Carbide (SiC) JFETs (Junction Field-Effect Transistors) were used.

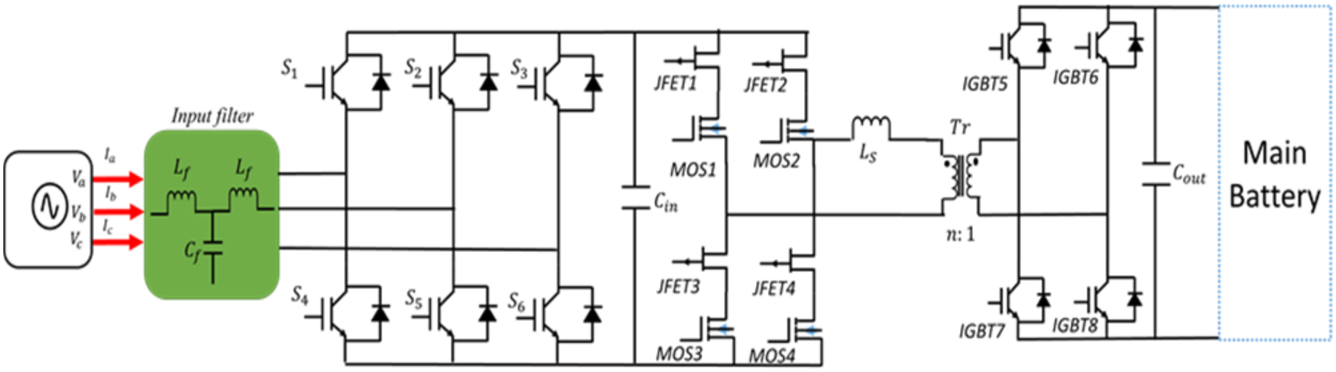


Figure 1. Three-phase on-board charger topology based on active rectifier and single DAB.

2.1. Development Trend of DC-DC Converter

In [28], the DAB topology with the series-resonant converter (SRC) topology and two-stage series-resonant converter topology were compared for the DC-DC stage of the charger. It was found that the two-stage SRC was more efficient compared to the DAB topology. However, the analysis was shown for a 12 V battery charger (auxiliary charger) rather than the main battery charger of the vehicle. SRC and two-stage SRC topologies are shown in Figures 2 and 3, respectively [47].

A modified DAB converter topology for an EV charger was proposed in [48], which uses a turned L-C-L network to improve the efficiency of the converter by reducing the reactive currents in the active bridges. Although the topology reduces the capacitor requirements of traditional DAB topology, the additional L-C-L filter could increase the overall volume of the converter.

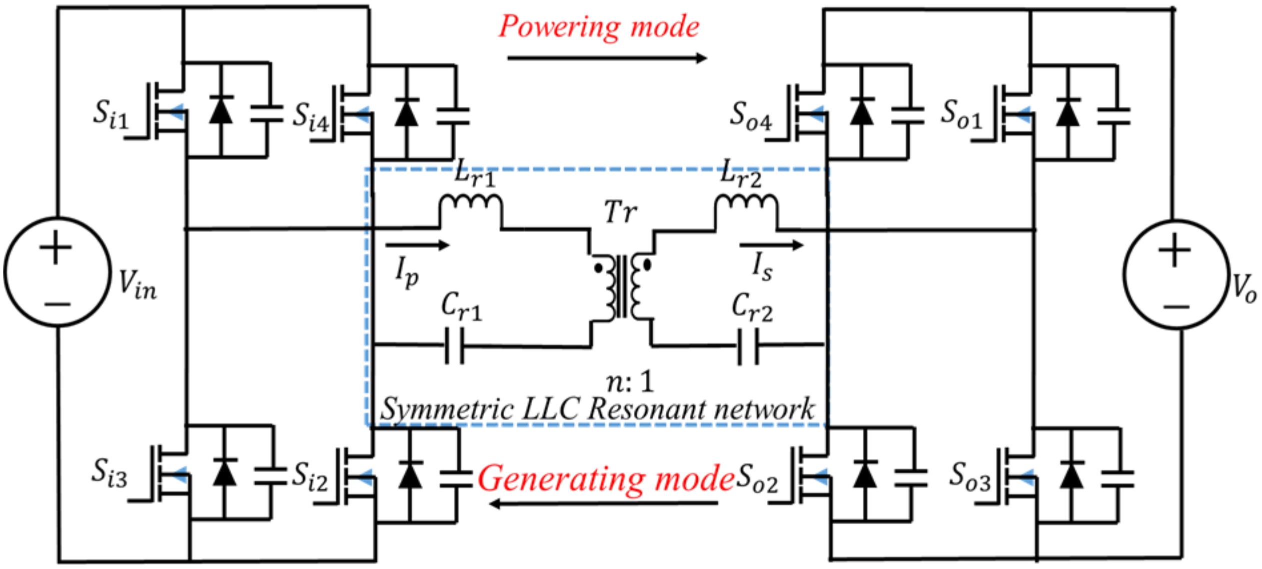


Figure 2. SRC DC-DC converter topology.

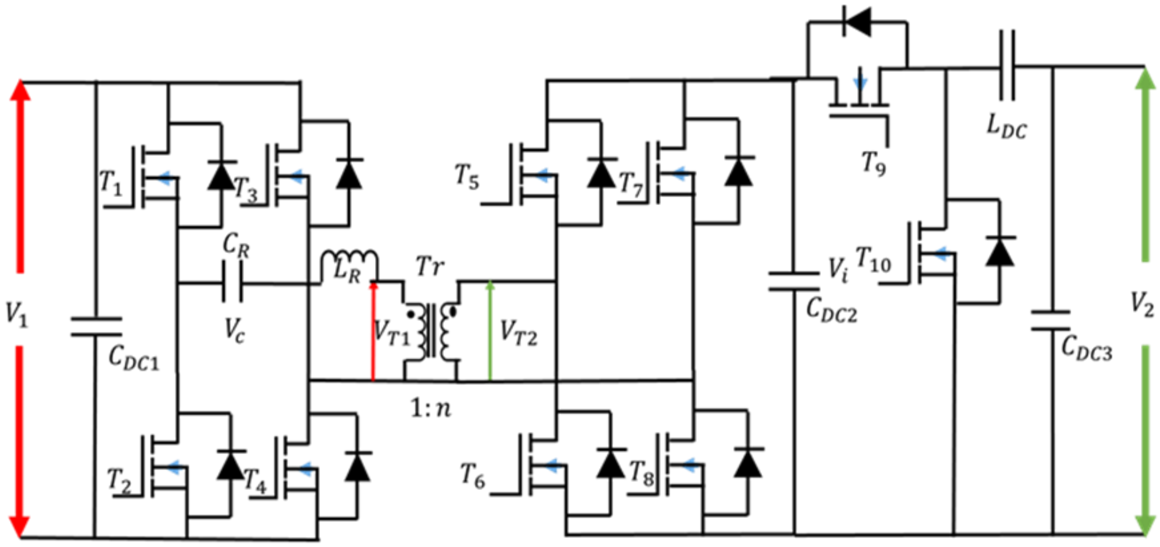


Figure 3. Two-stage SRC topology.

Several advanced modulation strategies have been proposed to reduce the reactive current in the active bridges such as pulse-width modulation (PWM) with phase shift [49–52] and triangular and trapezoidal modulation [53,54]. These advanced modulation schemes also extend the Zero-Voltage Switching (ZVS) range and increase the low-power efficiency of the DAB topology. Reactive currents can also be reduced by combining the phase-shift modulation with equal PWM in corresponding bridge switches [55]. A composite modulation scheme was proposed in [56] for advanced independent PWM control of individual switching devices, as well as phase-shift, which improves the low-power efficiency of the topology significantly. This is due to the reduced root mean square (RMS) current in each switching device. However, the control algorithm is complex and needs to change the modulation strategy at different load conditions.

The authors in [57,58] proposed the CLLC-based SRC topology for EV charging applications. However, it is clear from their research that the CLLC resonant network design in the SRC converter is much more complicated than the DAB converter design. Furthermore, the voltage gain is very sensitive to various parameters, such as the secondary transformer voltage, load condition, inductance of the inductors, and capacitance of the capacitors in the CLLC network. Compared to the DAB topology, the voltage gain equation in CLLC SRC is much more complicated. To design the parameters in CLLC SRC, all the variations in different parameters should be considered. Even for charging mode and discharging mode operations of the EV charger, the topology might require different CLLC parameters to optimize the performance, which significantly complicates the design procedure.

Another critical issue with CLLC SRC is that the control complexity is greatly increased when compared with the DAB topology. Table 2 represents a comparison of various topologies utilized in the DC-DC stage of EV converter topologies for different types of EV chargers.

The dual active half-bridge (DAHB) converter is another promising DC-DC topology for EV fast chargers, which is presented in Figure 4 [59]. Although this topology has a smaller number of semiconductor switches than the DAB topology, maintaining the closed-loop control stability is very challenging in this topology due to the low-frequency resonance issues. The ZVS range with traditional phase-shift modulation is very limited as well. An advanced asymmetrical modulation strategy is needed to resolve the stability issues and extend the ZVS range.

Table 2. Comparisons of various topologies for DC-DC stages.

Ref.	Topology	Power Flow	Number of Switches	Passive Elements	Battery-Side Filter	Output Voltage Range	Rated Power	Switching Frequency	Efficiency
[47]	DAB	Bi-directional	8 MOSFETs with body diode	C_{r1}, C_{r2}, L_{r1}, L_{r2}, C_{DC1}, C_{DC2}	C	220 V to 447 V	2 kW	≥100 kHz	90%
[47]	SRC	Bi-directional	10 MOSFETs with body diode	C_R, L_R, L_{DC}, C_{DC1}, C_{DC2}, C_{DC3}	LC	220 V to 447 V	2 kW	≥100 kHz	88%
[48]	Resonant dual active bridge (RDAB)	Bi-directional	6 IGBTs with free-wheeling diode	C_1, L_1, L_2	None	unknown	2.5 kW	unknown	96%
[48]	DAB	Bi-directional	8 MOSFETs with body diode	C_1, C_2, snubber capacitor across each switch	C	600 V	5 kW	20 kHz	86%
[60]	DAHB	Bi-directional	6 MOSFETs with body diode	L_{in}, C_1, C_2, C_3, C_4, C_o, snubber capacitor across each switch	C	330 V	600 W	100 kHz	unknown
[61]	DAB	Bi-directional	10 MOSFETs with body diode	L_1, C_1, C_2	C	340 V to 380 V	800 W	32 kHz	92.9% & 93.4% with light & heavy load

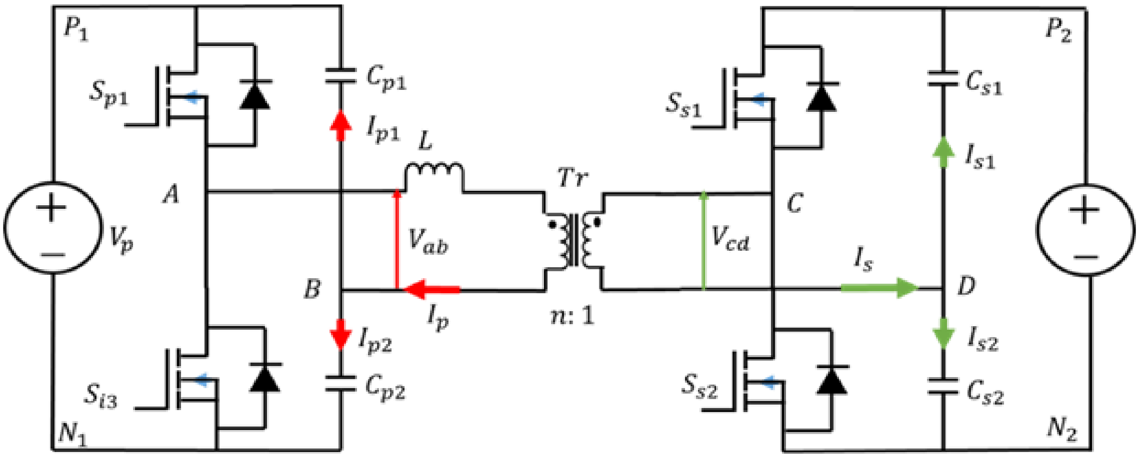


Figure 4. DAHB converter topology.

2.2. Development Trend of AC-DC Converter

Although three-phase diode rectifier [20] (unidirectional topology) and 2-level active PWM rectifier [46] are the two most popular topologies for the AC-DC stage, several other topologies have been found in the literature, which reduces the filtering requirements at the PFC stage of the EV charger. For example, [62,63] proposed a three-level neutral-point clamped (NPC) phase-leg-based AC-DC converter topology, which is presented in Figure 5. Because of the three-level operation and the PWM modulation strategy, the topology can reduce the input filter size. Although the voltage rating of each semiconductor device is reduced, the number of semiconductor devices is doubled compared to the two-level active rectifier, which can reduce the power density of chargers greater than 10 kW.

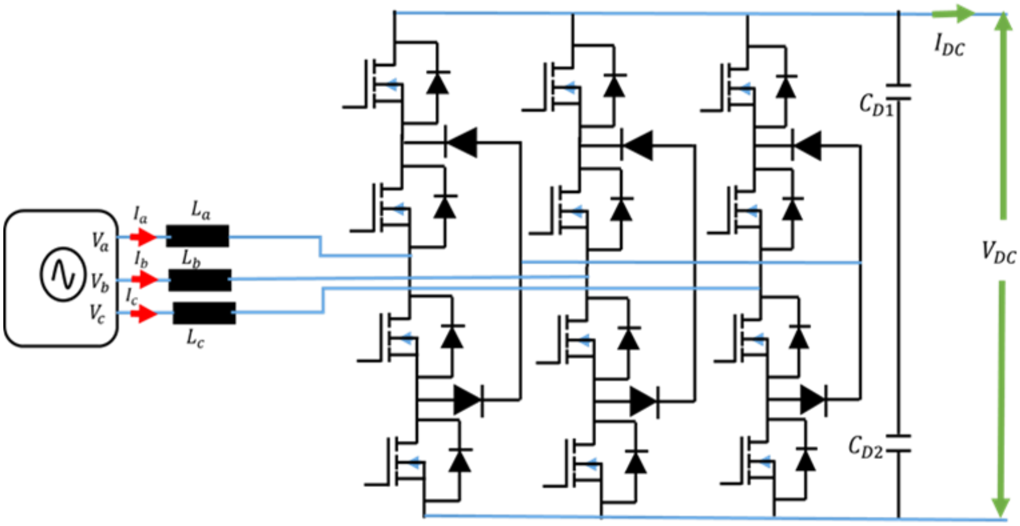


Figure 5. Three-level NPC boost AC-DC converter topology.

A three-level T-NPC PWM boost rectifier-based charger topology was proposed in [64]. The 11 kW charger achieved an impressive 95.6% peak efficiency and 2.5 kW /liter power density by employing a multi-port design approach and a novel phase-shift PEM modulation strategy. Again, the number of semiconductor devices, three times that of the two-level rectifier, is the main issue in this topology.

Krishnamoorthy et al. [65] proposed a matrix converter (AC to AC) for EV fast-charging applications, which does not require the traditional AC/DC/DC structure. The topology is presented in Figure 6. The front-end matrix converter converts the three-phase 50/60 Hz AC voltage to single-phase high-frequency AC voltage. The high-frequency transformer creates the galvanic isolation and the PWM rectifier rectifies the high-frequency AC voltage to DC voltage suitable for the battery. This topology ensures single-stage power conversion and removes the DC link capacitor at the output of the conventional AC-DC stage. Therefore, matrix converters usually achieve higher power density when compared to traditional two-stage solutions [66,67].

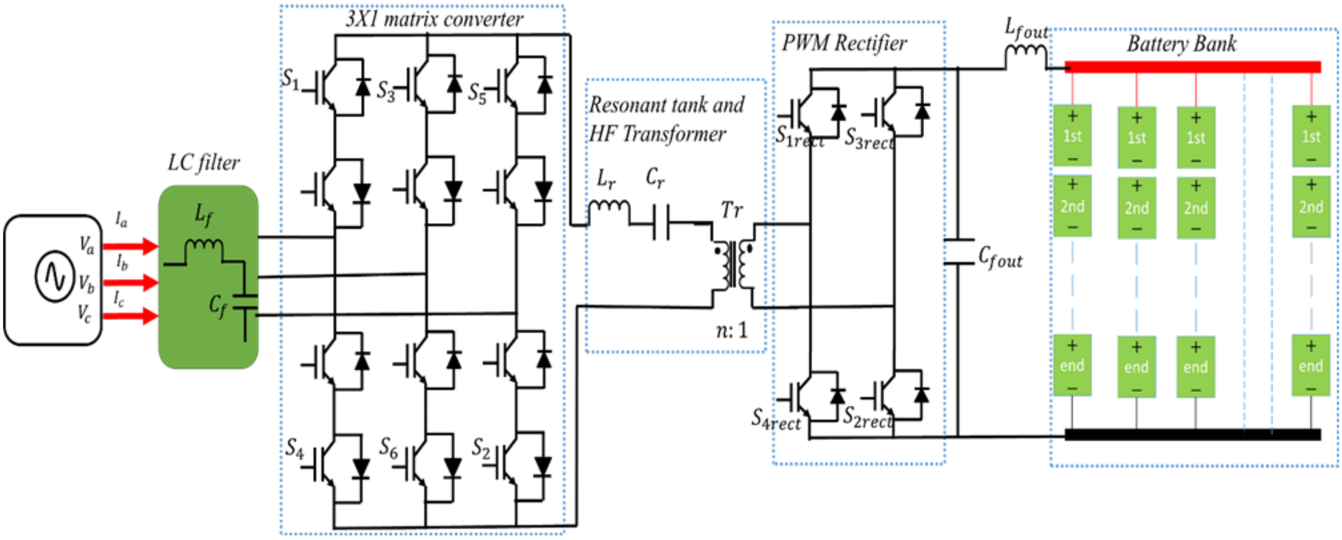


Figure 6. Matrix converter topology with resonant tank and HF transformer for EV charger.

The authors in [68] proposed an advanced modulation strategy to compensate for the reactive power drawn by the input filter, which reduces the input current distortion and ensures very low total harmonic distortion (THD) for the input current. The controller achieves good dynamic performance in both the charging and discharging modes of the EV battery. However, the matrix converter has twice the number of semiconductor devices compared to the two-level PWM rectifier, which could reduce the power density of the charger. Table 3 represents a comparison of various topologies discussed in this paper for the AC-DC stage of EV converter topologies for different types of EV chargers.

Table 3. Comparisons of various topologies for the AC-DC stages.

Ref.	Topology	Number of Switches	Passive Elements	Rated Power	Switching Frequency	THD	Filter	Power Factor
[46]	Full bridge	4 IGBTs with free-wheeling diode	C_{in}, $L_g(L_1, L_2)$ C_{filter}, R_{filter}	10 kW	10 kHz	Unknown	RC on grid-side	Unknown
[64]	Three level	22 MOSFETs with body diode	L_{DC}, C_{ac}, L_f, snubber capacitor across each switch	11 kW	50 kHz–140 kHz	Unknown	LC on output side	Unknown
[65]	Matrix Converter	16 IGBTs with free-wheeling diode	C_{fout}, C_r, L_r, C_f, L_f	50 kW	6 kHz	<5%	LC on grid-side	>0.99
[66]	Full bridge	4 MOSFETs with body diode	L_F, L_B, C_F, R_d, C_{dc}	10 kW	20 kHz	≤5%	LCL on grid-side	>0.90

Table 3. *Cont.*

Ref.	Topology	Number of Switches	Passive Elements	Rated Power	Switching Frequency	THD	Filter	Power Factor
[66]	Matrix Converter	16 MOSFETs with body diode	L_F, C_F, R_d, L_o, C_o	10 kW	20 kHz	≤5%	LC on grid-side, CL on battery side	>0.90
[68]	Matrix Converter	16 MOSFETs with body diode	C_F, L, C_o, L_o	15 kW	Unknown	2.58% in charger mode & 3.44% in inverter mode	C on grid-side	0.94

3. EV Converter Reliability

Every electronic system is developed with individual parts or components. Therefore, if any single part fails then it may affect the entire system. From the manufacturing point of view, it is important to ensure high-quality products are delivered to the customers. They should also ensure that the product will perform consistently under various operating conditions. The key driving factors for reliability issues are the massive adoption of electronic systems and their increasing complexity. In addition, customers are expecting high reliability from their desired product. For example, in modern electric drives, power electronics converters with associated components together work as a power processor mainly for charging the batteries and delivering power to another auxiliary load. Trends of the power converter are shifting toward becoming small in size, compact, efficient, and power dense. They have been popular in EVs due to their ease of control and flexibility in scaling. However, the poor reliability of these devices is an issue, and they fail frequently; therefore, to ensure the reliability of this product, this important issue needs to be considered [69].

The extreme use of fossil fuels in the transport sector has contributed to environmental pollution over the past decades. The automotive industry has introduced a new concept for vehicles by replacing fossil fuels with electricity, as the driving force in electric vehicles (Evs) [70]. Thus, Evs appear to be the best alternative to traditional vehicles. Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Battery Electric Vehicles (BEVs) are the three major Evs that exist in the current market. Automotive manufacturers are conducting research on designing and manufacturing Evs, whereas charging stations are increasing to feed the Evs.

Reliability assessment plays an important role in maintaining the operation of Evs' components, mainly the power electronics converter. Reliability assessment is a critical issue for Evs, and various perspectives of reliability are required to be considered:

I. The customer's standpoint.
II. The manufacturer's standpoint.
III. The seller's standpoint.

3.1. Reliability Evaluation for Evs

Power electronic converters fail for many reasons. For example, an increment in the on-state voltage during power cycling causes power losses that increase the temperature of the entire chip of the converter/inverter, which speeds up the bond wire lift-off via the generated stress through the thermal expansion mismatch between the wire bond and the chip [71]. In view of the developments in the field of Electric Vehicles (Evs), it is vital to assess the lifetime of Evs' electrical components considering reliability in terms of service and maintenance. The significant factors concerning the reliability assessment of Evs that need to be considered are presented in Figure 7 [72–74].

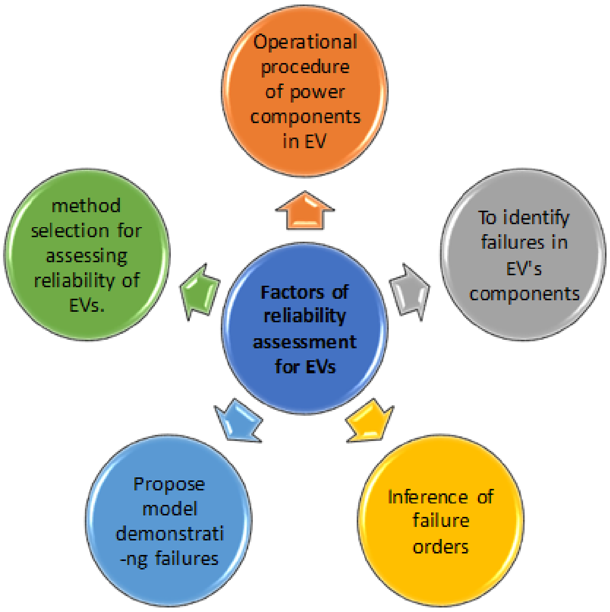


Figure 7. Significant factors concerning the reliability assessment of Evs.

At present, charging is one of the significant concerns observed due to slow battery charging times in Evs. Therefore, fast charging has become popular for consumer convenience, in order to drive an average distance on a daily basis. However, thermal management is critical for fast charging, as a significant amount of heat can be generated during charging, which can immediately increase the temperature inside the battery.

The heat then generates thermal stress and damages associated components within the battery, such as melting the separator, and in the power converter, it can cause the onset of failure in the bond wire or solder fatigue. Therefore, the reliability of converters is an important issue during fast charging in Evs [19].

3.2. Converter Reliability Assessment for Evs

The reliability of electronic components in Evs can be performed based on various perspectives, including the production process, selling time, and lifetime of Evs. Hosting diverse computational techniques of reliability evaluation can improve the lifetime, planning, and maintenance time of Evs. Thermal and electrical management of Evs also plays a great role in evaluating reliability issues through the modification of existing models. A few examples of current research work on reliability assessment methods for Evs are presented in Table 4. It can be observed from the state-of-the-art converter reliability approaches that the Markov model is the dominant approach in terms of estimating and assessing the reliability of the power electronic converters for Evs.

Table 4. State-of-the-art reliability assessment methods for Evs.

Methodology	Purpose
Numerical analysis [75]	Numerical reliability analysis for dc-dc topologies in power electronics converter.
Markov model [76]	Reliability evaluation and comparison of PHEV Chargers.
Markov model [77]	Assessing reliability of power electronic EV charging systems.
Markov model [78]	Reliability enhancement for switching frequency and capacitance
Combined model [79]	The model combines physics of failure and probabilistic modelling techniques
Practical methods [80]	Investigating the building blocks such as a DC/DC and AC/DC on board charger.
Mean Time To Failure estimation [81]	Estimating lifetime of power electronic converter

3.3. Future EV Converter Research Trend

Numerous research studies are being conducted on DC-DC converter topologies, which are currently used in Evs [70,82–84]. Battery packs, power electronic converters, and electric motors are the main components in Evs that require investigation, and the development of solutions for EV fast-charging and reliability issues is outlined below:

I. The design methods of electrical optimization using wide bandgap semiconductor (WBGS)-based topology to exploit their temperature, frequency, and low-loss characteristics [85].
II. A focus on the design phase is required to consider reliability during production.
III. To use mechanical optimization design methods to improve efficiency, power density, modularity, and reliability.
IV. Moving toward high-fidelity, multi-functionality, scalability, and modularity to achieve high efficiency and power density through intelligent control and management techniques [86].
V. To apply various control and optimization techniques such as fuzzy logic, artificial neural networks (ANNs), genetic algorithms, etc., to optimize several parameters of the converter.
VI. To develop a high-fidelity model of the DC-DC converter that can design and validate interfaces for next-generation developers.
VII. Handling the capability of electronic products (i.e., converter) by developing a modular design methodology.
VIII. Advanced converters are required to be developed and optimized to accept fast-charging methods such as pulse-charging EV batteries. Control systems can also be employed for monitoring battery health and optimizing the charging process [19].
IX. A systems-level approach can be developed that can be associated with new fast-charging technologies [19].
X. A complete drain and charge cycle can damage the battery's health. Therefore, further research is required to meet the optimal combination in terms of the dissipation and charging of the battery [19].

4. EV Charging

4.1. Charging Methods

It is somewhat established in the EV research that temperature is the key limiting factor in exploiting Li-ion batteries due to the inevitable heat generation resulting from the high charging current. Since the battery lifetime is highly linked to the battery temperature, we suggest the adoption of a safe and reliable charging protocol that ensures short charging times with a safe battery pack temperature rise below 50 °C [81]. To control the battery pack thermal limit, an efficient charging standard needs to be maintained with the aim of achieving good capacity utilization and maintaining high energy efficiency, while maintaining a long cycle life. Several charging protocols have been proposed in the literature:

- Constant Current (CC) Charge: In this method, the battery reaches the pre-set threshold cell voltage via the constant charging current and then slows down. During the CC mode, the high charging current introduces heat loss and thus pushes the thermal limit and accelerates the aging phenomena [87,88].
- Constant Voltage Charge: In this method, the charging current gradually increases and reaches the steady-state voltage equivalent to the battery voltage. When almost reaching the battery voltage, the current also gradually decreases. The key benefit is a short charging time and easy control. At the same time, the demerit is that the battery cannot be fully charged. The initially high charging current will cause joule heating in the battery and increase the battery temperature, which could lead to battery aging and degradation [88].
- Pulse charge: Using a pulse current, the battery can be charged fast with a drastically shortened charging duration. The demerit is that the quick-charging method can affect the battery's health [88]. Examples of pulse current charging features are given in [89].

More refined research regarding the optimal charging waveform parameters (e.g., frequency, magnitude, and duty ratio of the charging current) is illustrated in [16].

- Boost charging: In this technique, the battery charger can draw a high current for a short time. The 4C rate is implemented in [90].
- Ohmic drop compensation: In this method, in the beginning, it increases the pre-set cell voltage threshold and takes the ohmic drop resistance of the battery into consideration. The highest 6C rate can be achieved [91].
- Linearly decreasing current (LDC) charging: In the LDC, the charging current is decreased linearly depending on the SOC of the battery pack. The initial SOC will be taken into account [92].
- Multistage charging: Three or more charging stages consisting of multistage currents are adopted based on the battery model [92].

4.2. Charging Strategies

In general, fast-charging stations are required to power Evs during trip transit. Topologies for the DC fast charger exist, but the challenge is to make them compact, power-dense, and thermally manageable. The circuit topology shown in Figure 8 can be illustrated as a common EV charger circuit, in which the power level is approximately 1.9 kW. Usually, it has a few components, such as an AC/DC converter stage with a rectifier and a power factor corrector (PFC), and a DC/DC converter stage with an LLC resonant converter [93,94]. For better power factor correction, the circuit topology shown in Figure 9 [95] can be employed and further modified to produce an efficient LLC resonant converter by adding it and using it as a front-end rectifier and boosting the PWM DC/DC converter The boosted DC can be used as an input to the LLC resonant converter [96]. The topologies for the EV fast charger using the current source and voltage source are illustrated in Figures 10 and 11, respectively [97]. Another topology is described in [98], where the converter power is delivered to drive a motor.

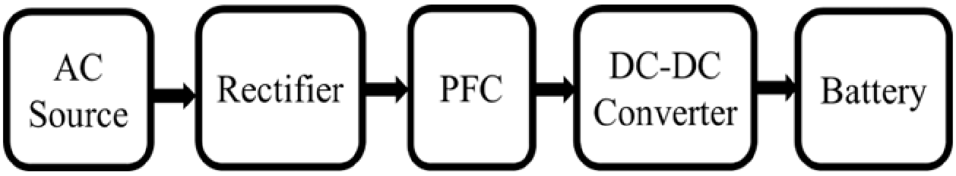


Figure 8. General EV's Charger Circuit.

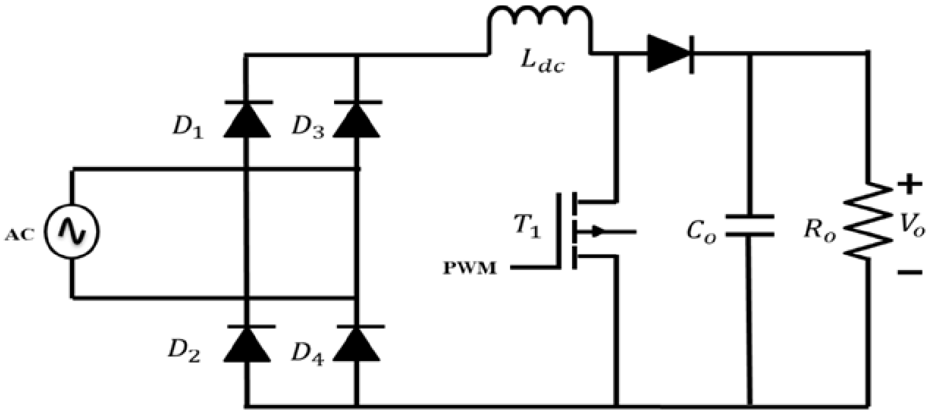


Figure 9. Power factor corrector topology.

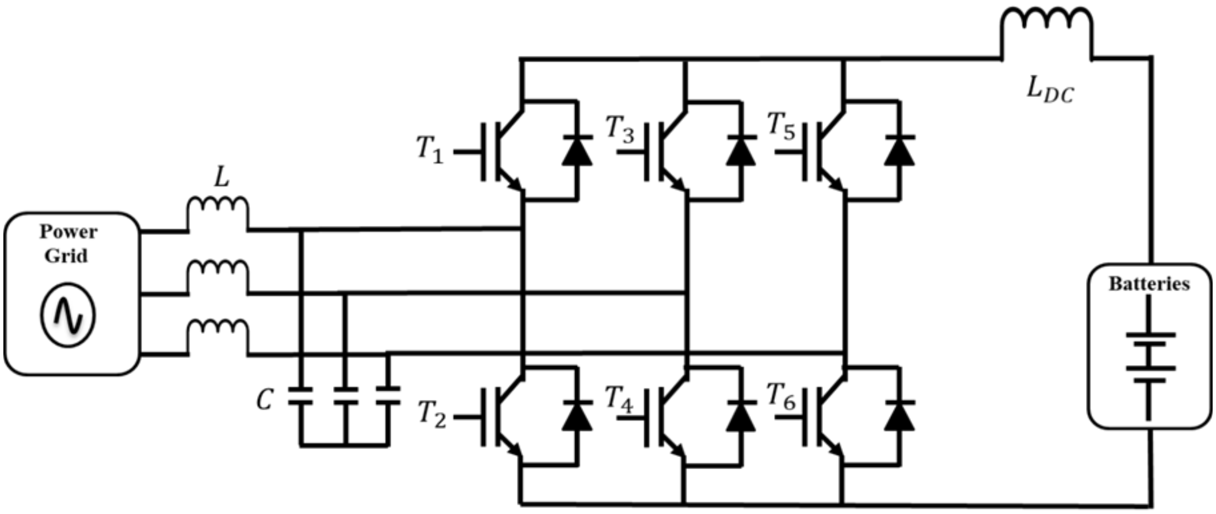


Figure 10. Current source-controlled EV fast charger topology.

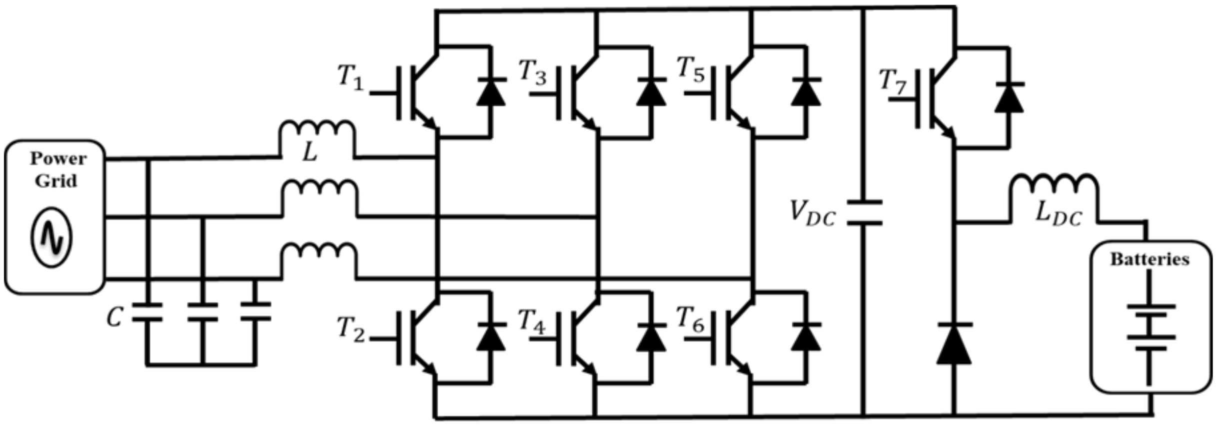
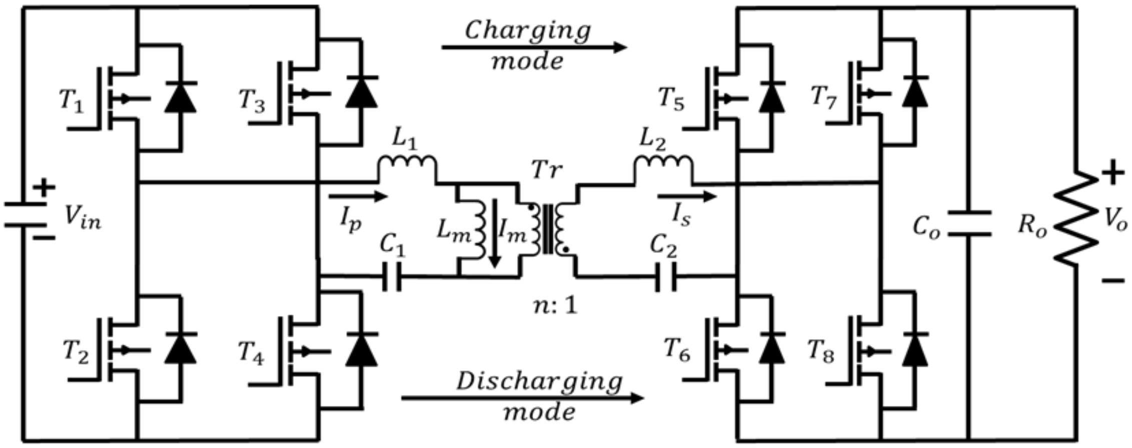


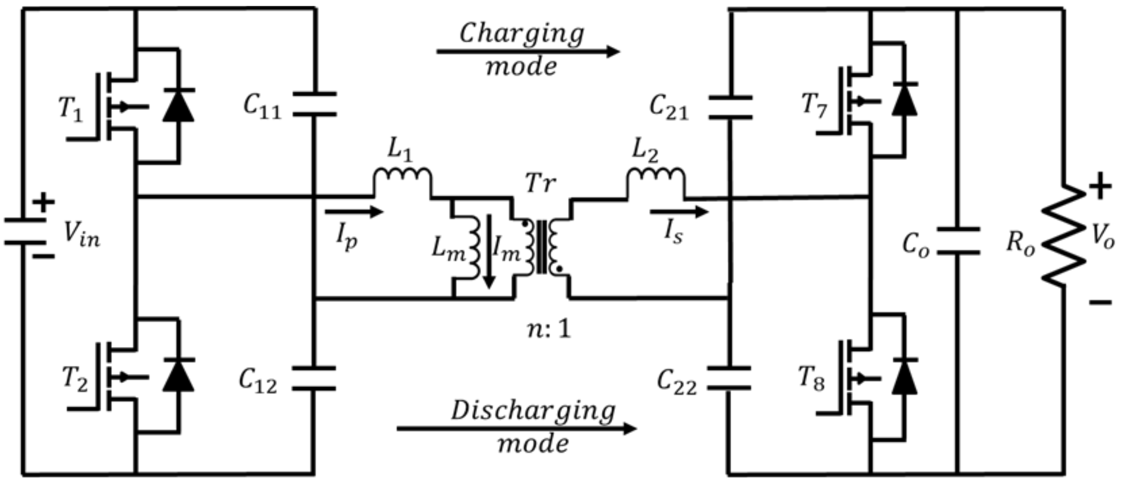
Figure 11. Voltage source-controlled EV fast charger topology.

Both CLLC and DAB can be used as full-bridge and half-bridge configurations to achieve optimal soft-switching features. Bidirectional full-bridge CLLC (FBCLLC) and half-bridge CLLC converters are illustrated in Figure 12 [99].



(**a**)

Figure 12. *Cont.*



(**b**)

Figure 12. Bidirectional (**a**) FBCLLC and (**b**) HBCLLC resonant converter topology.

An initiative was noted in [100] to advance wireless power transfer into EVs using a SiC-based Z-source resonant converter topology as shown in Figure 13. Another converter topology for drive applications is shown in Figure 14.

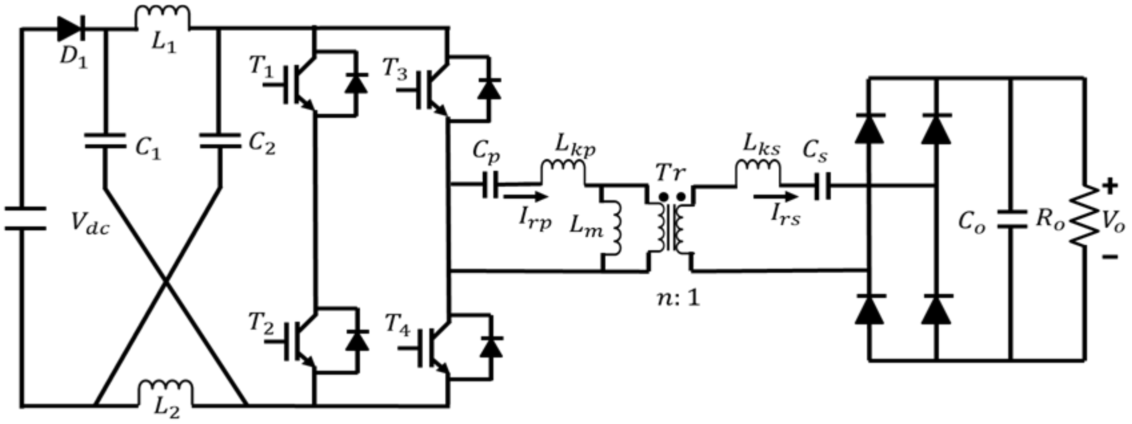


Figure 13. Z-source resonant converter topology.

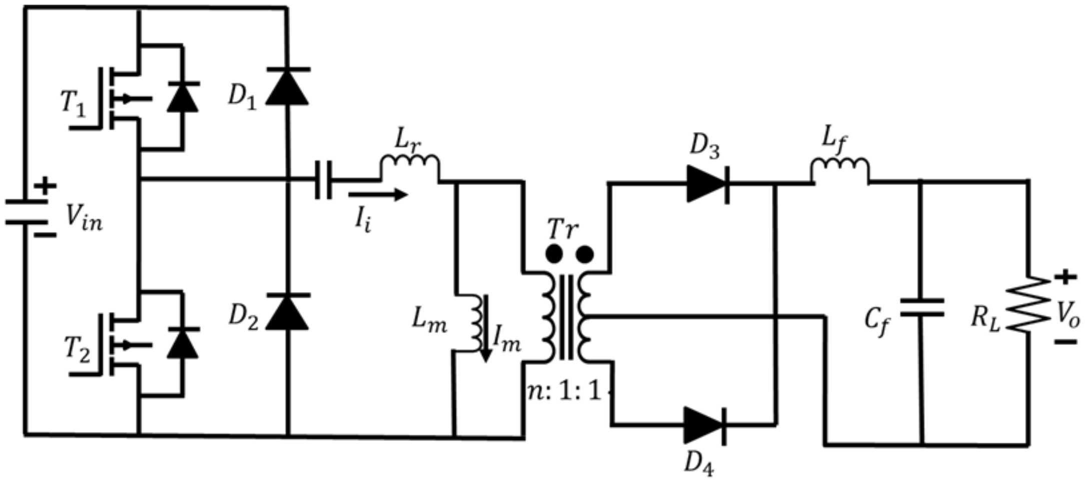


Figure 14. Converter topology for Interior Permanent Magnet Synchronous Motor (IPMSM).

Lately, the popularity of battery charging through a plug connection to a wall socket via an on-board charger (OBC) has increased. Shortening the charging time in single-phase power 6.6 kW OBC is gaining increased interest among EV manufacturers [101]. The Si-based OBC is limited in power density (183–732 kW/m^3) and efficiency range (92–94%) and has a mostly unidirectional power flow [20,94,102–104]. The current state of the art can be enhanced by employing wide-bandgap devices to meet 1526 kW/m^3. Efficiency over 97–99% has been reported by SiC devices [62,105–110]. Despite the LLC converter's well-proven performance and efficiency in ZVS and ZCS [111], the current Si-based LLC converter can operate at a switching frequency of less than 100 kHz. To tap into the potential of wide-bandgap devices, SiC can be exploited to achieve several hundred thousand frequencies to gain a higher power density by shrinking the size of passive components [112]. Table 5 depicts a comparison of the discussed on-board chargers.

A wealth of works exist regarding the application of the LLC converter in battery charging [113,114]. The inherent limitation of this type of LLC converter is that its performance in charging mode cannot be achieved in the same way as in discharging mode due to an asymmetric topology architecture. As a result, it cannot boost the voltage by applying pulse frequency modulation [115]. Most of the OBCs cannot function in regeneration mode. To improve this situation, one additional capacitor is added to achieve a symmetrical architecture [116]. The additional capacitor decreases the voltage gain in charging mode, and the shift from the resonant frequency compared to the LLC converter results in decreased efficiency [117–119].

Table 5. Comparison of on-board chargers for electric vehicles.

Ref.	Stages	Power Flow	Switching Frequency	Efficiency	Power Factor	Power Level	THD	System Volume/Mass	Output Voltage
[119]	First stage is a boost ac–dc converter Second stage is an isolated dc–dc converter	Unidirectional	200 kHz	95%	0.996	6.1 kW	4.2%	1.2 L/1.6 kg	400 V
[94]	First stage is interleaved PFC contains two CCM boost converters in parallel. Second stage is isolated Full-Bridge DC-DC Converter	Unidirectional	70 kHz for PFC & 200 kHzfor DC-DC converter	93.6%	>0.99	3.3 kW	<5%	5.46 L/6.2 kg	200 V to 450 V
[103]	A full-bridge LLC resonant converter A boost PFC converter	Unidirectional	90 kHz for resonant & 45 kHz for PFC converter	92.5% & 88.3% for 220 Vac for 110 Vac input voltage	>0.93	3.3 kW	Unknown	7.1 L/6.8 kg	150 V to 450 V
[120]	A full-bridge AC-DC converter A CLLLC DC-DC converter	Bidirectional	Unknown	94.5%	Unknown	3.3 KW	Unknown	Unknown	250 V to 450 V
[121]	A totem-pole bridgeless PFC rectifier A CLLC resonant converter	Bidirectional	300 kHz for AC-DC & 500 kHz for DC-DC converter	>96%	Unknown	6.6 KW	Unknown	Unknown	250 V to 450 V

4.3. Charging Challenges and Potential Solutions

Bi-directional chargers feed power to the grid while in the resting period. However, there is a limit due to the existence of common-mode noise between EVs and the grid and the non-existence of grounding that can harm the safety of the system. To circumvent the common-mode noise, a transformer can be applied to the converter. The problem with employing a transformer is the increase in the volume and weight of the overall converter.

A transformer-less topology can be applied to reduce the common-mode noise. This will offshoot extra costs to employ a dedicated device to bypass the freewheeling current. EV penetrations will have severe impacts on the distribution of the grid such as overheating of distribution transformers, voltage fluctuations, and harmonic distortion.

EVs are lacking in popularity due to slow charging at the home level in Australia (13A), where the charging time is approximately 7–8 h. The only feasible solution is a fast-charging station, which can charge within half an hour. However, this brings grid distribution issues. The idea is to employ an energy buffer unit to ensure grid stability. There is a new research direction regarding fast-charging technologies. New power converter topologies are required to deliver fast-charging requirements. The main features will be safe charging ability in 5–10 min, isolation for driver safety, ability to employ bidirectional power flow, less power loss based on soft switching, and the achievement of resonance for maximum efficiency. To develop high-power pulse charging, converters need to be designed in a sophisticated way so that BMS can guarantee the safe monitoring of battery health and control the charging process. A high charging current will induce stress on the DC bus and electric grid operation, thus, developing filters and power factor correction topologies will be the new focus. As the EV market will exploit a different range of batteries from various manufacturing companies, the fast-charging system needs to be robust so that it can adjust the required settings for charging accordingly. Adopting wide-bandgap devices is a potential solution to minimizing converter losses and volumes increasing thermal stability. Compared to Si, the wide-bandgap device can be exploited to realize high-voltage and current-rated converters, which need to be efficient, flexible, and robust enough to tune the various parameters and models of EV vehicles.

4.3.1. Thermal Management

Currently, the Li-ion battery is the only power source for EVs. The increase in continuous load due to acceleration, regenerative braking, and heat generation inside the battery pack cannot be neglected. Furthermore, the trend in EVs has shifted towards denser integration of the battery with the connector accessories and peripherals. Thermal challenges come into play due to space constraints. If these thermal issues are left unresolved, the battery performance will be drastically degraded. Heat sources need to be accurately modeled for the accurate estimation of the battery temperature at the cell level. Two types of heat sources are dominant in battery technology. The first is joule heating through the ohmic drop in the internal resistance of the battery and the second is reversible heat loss contribution due to the chemical reaction enthalpy change [122–124]. Pack-level thermal gradients are rather significant as this temperature nonuniformity leads to aging nonuniformity [125–127]. Hence, the accurate estimation of temperature information is required for battery health monitoring and diagnostic systems. Abnormal heating can lead to battery thermal runaway, which is detrimental to the battery and battery pack.

Many thermal management strategies already exist in the literature, including air [128–136], liquid [137–139], heat pipe [140–142], and phase-change materials [143–147], as listed in Table 6.

Table 6. Some studies associated with battery thermal management systems.

Ref.	Thermal Management Strategy	Battery Type	Findings
[128]	Reciprocating air flow	Cylindrical Li-ion	Lower maximum cell temperature and cell temperature difference due to shorter reciprocating period. Cell temperature is decreased with reduced transverse and higher longitudinal spacing. With charge/discharge rate, the maximum cell temperature rises quadratically.

Table 6. *Cont.*

Ref.	Thermal Management Strategy	Battery Type	Findings
[130]	Air and liquid type TMS	Cylindrical Li-ion	For the air TMS, a broad battery module with small cell-to-cell gap is suitable. For a liquid TMS, a narrow battery module with a small gap is appropriate. For high heat load conditions, the power consumption of air TMS is more than liquid TMS.
[134]	Forced air-cooling	Li-ion	Convection and advection of two heat transfer methods are performed to evaluate the cooling performance. Small hydraulic diameter alongside high coolant flow rate enhances the cooling performance but increases fan operating power.
[137]	Forced liquid cooling	Bipolar Li-ion	Higher coolant plate thickness and coolant velocity aid in retaining the temperature non-uniformity, and maximum temperature is closely controlled. Average temperature increases with number of cells among the coolant plates along with growing discharge rates. Increasing the coolant velocity decreases the average temperature.
[143]	Phase change materials (PCM)	Li-ion	Maximum temperature and temperature spread in the cell are decreased with PCM. During transient conditions of cooling system, the PCM on cell temperature is more noticeable. Higher PCM thickness around the cell offers improved cooling in the cell due to higher depth in curvature.
[134]	Air cooling	Prismatic Li-ion	Higher flow rate of the fan and lower gap spacing cause a decline in the maximum temperature growth. Uneven gap spacing influences the temperature circulations but does not affect the maximum temperature growth. Constant gap spacing decreases both the overall temperature uniformity and the maximum temperature growth.
[145]	Phase change materials	Li-ion	Under stressed and normal conditions, it is probable to attain uniform temperatures with passive TMS. The absorption and conduction of heat via the PCM–graphite matrix avoid circulation of thermal runaway.
[141]	Heat pipe cooling	Li-ion	Addition of heat pipe decreased the thermal resistance of a heat sink. Flat heat pipe operates efficiently under diverse grade road conditions. Heat pipe managed instantaneous rises of the heat flux more efficiently than conventional heat sink under high-frequency condition.
[142]	Heat pipe and wet cooling combined TMS	Li-ion	Natural convection cooling system is not suggested for the battery discharged at high rate because of the large temperature gradient and high temperature inside the battery toward the last part of discharge. Heat pipe TMS cooling by water bath is not recommended owing to the buildup of bubbles throughout the discharge.

Table 6. *Cont.*

Ref.	Thermal Management Strategy	Battery Type	Findings
[137]	Liquid-cooling	Li-ion	Growing inlet mass circulation can efficiently constrain the maximum temperature. Temperature is proportional to the inlet temperature and inversely proportional to the width of cooling plate. Width of cooling plate, inlet mass flow rate, and inlet temperature are three factors analyzed for better solutions.

4.3.2. Vehicle to GRID (V2G)

With the advancement of smart grids, the share of EVs is anticipated to grow because of climate concerns, technological advances, rising crude oil prices, and developments in the automatic control of EVs. As EVs always need to be recharged, they require a strategy for the effective utilization of energy, otherwise, a large number of EVs can cause an overload as EVs function as a load during the charging mode. V2G is a promising technology that appeared as a solution for the large number of EVs, where EVs can be utilized as loads as well as energy storage systems (ESSs) to support the power grid [148], as shown in Figure 15. The function of EVs has been advanced in the form of vehicle-to-grid (V2G) technology through the development of the smart grid. V2G permits bidirectional energy transfer between EVs and the electrical grid [149]. The optimal coordination of the V2G framework is required as uncoordinated EV charging/discharging imposes a critical effect on the power system [150].

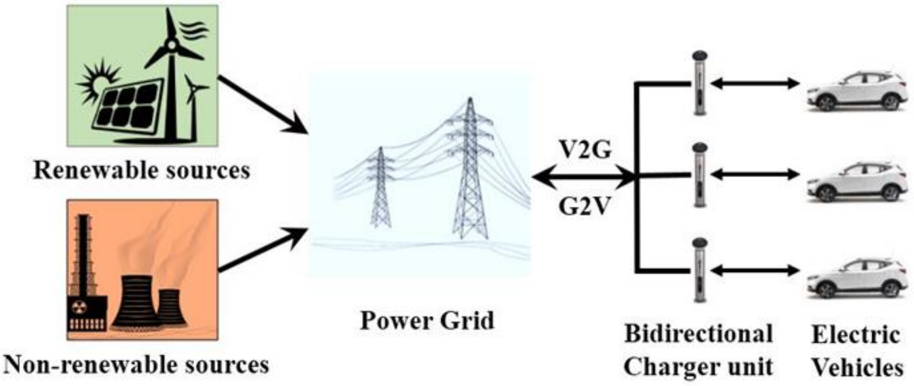


Figure 15. Vehicle-to-grid framework.

Recently, numerous EV charging scheduling structures and pricing approaches have been proposed to minimize charging operation expenses and advance grid reliability. A hybrid strategy for charging and discharging has been suggested, which provides high scalability, distributed operation features to reduce the requirement of a centralized regulated scheme, and a distributed charging tactic for the PEVs [151]. An innovative charging scheme for PHEVs in a smart grid has been proposed where users can adjust the charging rates of PEVs in accordance with their preferences to progress the overall structure efficiency [152]. Strategies for charging/discharging services have been provided to estimate appropriate charging bills and regulate electricity to stabilize the challenging purposes of improving cost-effectiveness, boosting customer fulfilment, and decreasing the influence on the utility grid [153]. In [154], a charging/discharging scheduling crisis was formulated as a Markov Decision Process (MDP) with an unidentified transition possibility from the consumer's viewpoint, where the unpredictability of either the electricity charge or commuting performance was studied. Therefore, to boost the revenue of the EV proprietor and electricity provider, it is essential to estimate the definite charging/discharging behavior of EV batteries so as to employ the optimum electricity charge to increase revenue.

V2G technology is associated with bidirectional energy flow from the EV to the power grid when the stored energy in the EV battery is higher, or from the power grid to the EV if the stored energy in the EV battery is lower. EVs employing the V2G strategy are normally charged when electricity production is higher, or when the expense of electricity is lower, and returning the energy to the power grid at peak load hours with high charges or when there is electricity demand [155]. V2G provides various advantages such as ancillary services, compensation for renewable energy sources, economic aspects, reactive power compensation, active power support, etc. [156]. The capability of EVs to offer ancillary services helps the power system to operate in a more stable way, reducing the protection relay's operation and the influence of contingencies. EVs can be employed as a load or as a power source so as to control the frequency [157,158]. Frequency regulation, peak load shaving, load levelling, and spinning reverse are facilities provided by renewable energy source compensation [159]. The V2G concept is pleasing to EV proprietors due to the revenue from retailing the energy stored in EV batteries. Furthermore, it counterbalances the high purchase and maintenance costs of EVs and decreases the payback time. It provides facilities for the system operator by ensuring probable grid facilities by V2G. This mutual satisfaction from the owner and the service provider provides feasible operation and awareness on the purchaser side, and generates suitable incentives and structures on the supply side [160,161]. The V2G concept provides reactive power compensation without any active power exchange with the aid of the bidirectional battery charger [162]. V2G-oriented EVs can provide active power aid to the distribution framework. The integration of EV charging with V2G maximizes the facilities of EV integration with the distribution system. In [163], two scheduling tactics were executed, considering reactive power dispatch (RPD) and active power dispatch (APD) to diminish losses in the distribution system by employing the V2G scheme. The APD tactic decreases losses through the optimum charging/discharging of EVs, and the RPD tactic diminishes losses by an optimum reactive power addition.

5. Conclusions

The electrification of transport is a tangible solution to equivocate the impact of carbon emissions from IC engine-driven cars on the environment. Shortening the charging time has been the current key focus for EV car-manufacturing companies. Significant research efforts have already been invested to overcome fast-charging issues, yet certain knowledge gaps still exist:

- To date, the impacts of fast charging on battery health and battery aging have not been identified. Battery failure mechanisms due to localized high current density have not yet been elucidated. Appropriate thermal challenges have not been addressed.
- An efficient charging converter is key to achieving the required charging within a 5–10 min range. Various alternative approaches have been identified for fast-charging technologies; however, much remains to be investigated regarding the fast-charging converter, converter reliability, control scheme, and wide-bandgap semiconductor device potentiality in the converter architecture and possible degradation mechanisms in battery and semiconductor switches.
- The behavior of fast-charging technologies in cold climates has still not been investigated, and the approach to charging optimization is not fully clear yet.
- While much attention has already been paid to developing a fast-charging topology, further research is required to investigate the impact of fast charging on battery health and determine how the generated heat load on the battery at the cell and pack levels can be managed. We must also determine how a cooling system can be integrated with EVs, with the constraints of cost and weight.
- Finally, cell-level and pack-level degradations are not well understood. Since the battery's operating window is narrow, it is highly recommended to study the degradation

behavior under different operating conditions. Few modelling works were found, but most are at the cell level. It needs to be extended up to the module and pack levels. Multiscale multiphysics modelling can help researchers to identify those challenges and support EV manufacturers to adopt a safe charging protocol with high reliability.

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References

1. De Santiago, J.; Bernhoff, H.; Ekergård, B.; Eriksson, S.; Ferhatovic, S.; Waters, R.; Leijon, M. Electrical Motor Drivelines in Commercial All-Electric Vehicles: A Review. *IEEE Trans. Veh. Technol.* **2011**, *61*, 475–484. [CrossRef]
2. Bose, B.K. Global Energy Scenario and Impact of Power Electronics in 21st Century. *IEEE Trans. Ind. Electron.* **2012**, *60*, 2638–2651. [CrossRef]
3. Haghbin, S.; Lundmark, S.; Alakula, M.; Carlson, O. Grid-Connected Integrated Battery Chargers in Vehicle Applications: Review and New Solution. *IEEE Trans. Ind. Electron.* **2012**, *60*, 459–473. [CrossRef]
4. Sanguesa, J.; Torres-Sanz, V.; Garrido, P.; Martinez, F.; Marquez-Barja, J. A Review on Electric Vehicles: Technologies and Challenges. *Smart Cities* **2021**, *4*, 372–404. [CrossRef]
5. Zhao, J.; Xi, X.; Na, Q.; Wang, S.; Kadry, S.N.; Kumar, P.M. The technological innovation of hybrid and plug-in electric vehicles for environment carbon pollution control. *Environ. Impact Assess. Rev.* **2020**, *86*, 106506. [CrossRef]
6. Rajashekara, K. Present Status and Future Trends in Electric Vehicle Propulsion Technologies. *IEEE J. Emerg. Sel. Top. Power Electron.* **2013**, *1*, 3–10. [CrossRef]
7. Chen, T.; Zhang, X.-P.; Wang, J.; Li, J.; Wu, C.; Hu, M.; Bian, H. A Review on Electric Vehicle Charging Infrastructure Development in the UK. *J. Mod. Power Syst. Clean Energy* **2020**, *8*, 193–205. [CrossRef]
8. Hemavathi, S.; Shinisha, A. A study on trends and developments in electric vehicle charging technologies. *J. Energy Storage* **2022**, *52*, 105013. [CrossRef]
9. Lee, J.-Y.; Chae, H.-J. 6.6-kW Onboard Charger Design Using DCM PFC Converter With Harmonic Modulation Technique and Two-Stage DC/DC Converter. *IEEE Trans. Ind. Electron.* **2013**, *61*, 1243–1252. [CrossRef]
10. Amjadi, Z.; Williamson, S.S. Power-Electronics-Based Solutions for Plug-in Hybrid Electric Vehicle Energy Storage and Management Systems. *IEEE Trans. Ind. Electron.* **2009**, *57*, 608–616. [CrossRef]
11. Rafi, A.H.; Bauman, J. A Comprehensive Review of DC Fast-Charging Stations with Energy Storage: Architectures, Power Converters, and Analysis. *IEEE Trans. Transp. Electrification* **2020**, *7*, 345–368. [CrossRef]
12. EV Penetration to be 30% by 2030: Study | The Financial Express. Available online: https://www.financialexpress.com/express-mobility/vehicles/electric-vehicles/ev-penetration-to-be-30-by-2030-study/2565092/ (accessed on 13 August 2022).
13. Sreeram, K.; Preetha, P.K.; Poornachandran, P. Electric Vehicle Scenario in India: Roadmap, Challenges and Opportunities. In Proceedings of the 2019 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT), Coimbatore, India, 20–22 February 2019.
14. Berckmans, G.; Messagie, M.; Smekens, J.; Omar, N.; Vanhaverbeke, L.; Van Mierlo, J. Cost Projection of State of the Art Lithium-Ion Batteries for Electric Vehicles Up to 2030. *Energies* **2017**, *10*, 1314. [CrossRef]
15. Lee, J.-H.; Moon, J.-S.; Lee, Y.-S.; Kim, Y.-R.; Won, C.-Y. Fast charging technique for EV battery charger using three-phase AC-DC boost converter. In Proceedings of the IECON 2011—37th Annual Conference of the IEEE Industrial Electronics Society, Melbourne, Australia, 7–10 November 2011; pp. 4577–4582. [CrossRef]
16. Di Yin, M.; Cho, J.; Park, D. Pulse-Based Fast Battery IoT Charger Using Dynamic Frequency and Duty Control Techniques Based on Multi-Sensing of Polarization Curve. *Energies* **2016**, *9*, 209. [CrossRef]
17. Lee, J.H.; Chakraborty, D.; Hardman, S.J.; Tal, G. Exploring electric vehicle charging patterns: Mixed usage of charging infrastructure. *Transp. Res. Part D Transp. Environ.* **2020**, *79*, 102249. [CrossRef]

18. Hardman, S.; Jenn, A.; Tal, G.; Axsen, J.; Beard, G.; Daina, N.; Figenbaum, E.; Jakobsson, N.; Jochem, P.; Kinnear, N.; et al. A review of consumer preferences of and interactions with electric vehicle charging infrastructure. *Transp. Res. Part D: Transp. Environ.* **2018**, *62*, 508–523. [CrossRef]
19. Collin, R.; Miao, Y.; Yokochi, A.; Enjeti, P.; von Jouanne, A. Advanced Electric Vehicle Fast-Charging Technologies. *Energies* **2019**, *12*, 1839. [CrossRef]
20. Yilmaz, M.; Krein, P.T. Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles. *IEEE Trans. Power Electron.* **2013**, *28*, 2151–2169. [CrossRef]
21. Mishra, S.; Verma, S.; Chowdhury, S.; Gaur, A.; Mohapatra, S.; Dwivedi, G.; Verma, P. A Comprehensive Review on Developments in Electric Vehicle Charging Station Infrastructure and Present Scenario of India. *Sustainability* **2021**, *13*, 2396. [CrossRef]
22. Morrow, K.; Karner, D.; Francfort, J. Plug-in Hybrid Electric Vehicle Charging Infrastructure Review Final Report Battelle Energy Alliance Contract No. 58517. 2008. Available online: https://wecanfigurethisout.org/ENERGY/Lecture_notes/Electrification_of_Tranportation_Supporting_Materials%20/INL%20-%20PHEV%20infrastructure%20review.pdf (accessed on 1 July 2022).
23. Hildermeier, J.; Kolokathis, C.; Rosenow, J.; Hogan, M.; Wiese, C.; Jahn, A. Smart EV Charging: A Global Review of Promising Practices. *World Electr. Veh. J.* **2019**, *10*, 80. [CrossRef]
24. Das, H.S.; Rahman, M.M.; Li, S.; Tan, C.W. Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review. *Renew. Sustain. Energy Rev.* **2020**, *120*, 109618. [CrossRef]
25. Abraham, D.S.; Verma, R.; Kanagaraj, L.; Raman, S.G.T.; Rajamanickam, N.; Chokkalingam, B.; Sekar, K.M.; Mihet-Popa, L. Electric Vehicles Charging Stations' Architectures, Criteria, Power Converters, and Control Strategies in Microgrids. *Electronics* **2021**, *10*, 1895. [CrossRef]
26. Arif, S.; Lie, T.; Seet, B.; Ayyadi, S.; Jensen, K. Review of Electric Vehicle Technologies, Charging Methods, Standards and Optimization Techniques. *Electronics* **2021**, *10*, 1910. [CrossRef]
27. Khalid, M.R.; Khan, I.A.; Hameed, S.; Asghar, M.S.J.; Ro, J.-S. A Comprehensive Review on Structural Topologies, Power Levels, Energy Storage Systems, and Standards for Electric Vehicle Charging Stations and Their Impacts on Grid. *IEEE Access* **2021**, *9*, 128069–128094. [CrossRef]
28. Xuan, Y.; Yang, X.; Chen, W.; Liu, T.; Hao, X. A Novel Three-Level *CLLC* Resonant DC–DC Converter for Bidirectional EV Charger in DC Microgrids. *IEEE Trans. Ind. Electron.* **2020**, *68*, 2334–2344. [CrossRef]
29. Rajendran, G.; Vaithilingam, C.A.; Misron, N.; Naidu, K.; Ahmed, R. A comprehensive review on system architecture and international standards for electric vehicle charging stations. *J. Energy Storage* **2021**, *42*, 103099. [CrossRef]
30. Wu, J.; Li, S.; Tan, S.-C.; Hui, S.Y.R. Capacitor-Clamped *LLC* Resonant Converter Operating in Capacitive Region for High-Power-Density EV Charger. *IEEE Trans. Power Electron.* **2021**, *36*, 11456–11468. [CrossRef]
31. Choi, S.-W.; Oh, S.-T.; Kim, M.-W.; Lee, I.-O.; Lee, J.-Y. Interleaved Isolated Single-Phase PFC Converter Module for Three-Phase EV Charger. *IEEE Trans. Veh. Technol.* **2020**, *69*, 4957–4967. [CrossRef]
32. Lara, J.; Masisi, L.; Hernandez, C.; Arjona, M.; Chandra, A. Novel Five-Level ANPC Bidirectional Converter for Power Quality Enhancement during G2V/V2G Operation of Cascaded EV Charger. *Energies* **2021**, *14*, 2650. [CrossRef]
33. Pandey, R.; Singh, B. A Power Factor Corrected Resonant EV Charger Using Reduced Sensor Based Bridgeless Boost PFC Converter. *IEEE Trans. Ind. Appl.* **2021**, *57*, 6465–6474. [CrossRef]
34. Blaabjerg, F.; Wang, H.; Vernica, I.; Liu, B.; Davari, P. Reliability of Power Electronic Systems for EV/HEV Applications. *Proc. IEEE* **2020**, *109*, 1060–1076. [CrossRef]
35. Wen, H.; Li, J.; Shi, H.; Hu, Y.; Yang, Y. Fault Diagnosis and Tolerant Control of Dual-Active-Bridge Converter With Triple-Phase Shift Control for Bidirectional EV Charging Systems. *IEEE Trans. Transp. Electrif.* **2020**, *7*, 287–303. [CrossRef]
36. Samavatian, V.; Fotuhi-Firuzabad, M.; Dehghanian, P.; Blaabjerg, F. Reliability Modeling of Multistate Degraded Power Electronic Converters with Simultaneous Exposure to Dependent Competing Failure Processes. *IEEE Access* **2021**, *9*, 67096–67108. [CrossRef]
37. Chakraborty, S.; Hasan, M.M.; Tran, D.D.; Jaman, S.; Bossche, P.V.D.; El Baghdadi, M.; Hegazy, O. Reliability Assessment of a WBG-based Interleaved Bidirectional HV DC/DC Converter for Electric Vehicle Drivetrains. In Proceedings of the 2020 Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER), Monte-Carlo, Monaco, 10–12 September 2020; pp. 1–8. [CrossRef]
38. Li, Y.; Li, K.; Xie, Y.; Liu, J.; Fu, C.; Liu, B. Optimized charging of lithium-ion battery for electric vehicles: Adaptive multistage constant current–constant voltage charging strategy. *Renew. Energy* **2019**, *146*, 2688–2699. [CrossRef]
39. Garg, A.; Das, M. High Efficiency Three Phase Interleaved Buck Converter for Fast Charging of EV. In Proceedings of the 2021 1st International Conference on Power Electronics and Energy (ICPEE), Bhubaneswar, India, 2–3 January 2021; pp. 1–5. [CrossRef]
40. Rathore, V.; Siddavatam, R.P.R.; Rajashekara, K. An Isolated Multilevel DC-DC Converter Topology with Hybrid Resonant Switching for EV Fast Charging Application. *IEEE Trans. Ind. Appl.* **2022**, *58*, 5546–5557. [CrossRef]
41. Pareek, S.; Sujil, A.; Ratra, S.; Kumar, R. Electric Vehicle Charging Station Challenges and Opportunities: A Future Perspective. In Proceedings of the 2020 International Conference on Emerging Trends in Communication, Control and Computing (ICONC3), Lakshmangarh, India, 21–22 February 2020; pp. 1–6. [CrossRef]
42. Sovacool, B.K.; Kester, J.; Noel, L.; de Rubens, G.Z. Actors, business models, and innovation activity systems for vehicle-to-grid (V2G) technology: A comprehensive review. *Renew. Sustain. Energy Rev.* **2020**, *131*, 109963. [CrossRef]
43. Huda, M.; Koji, T.; Aziz, M. Techno Economic Analysis of Vehicle to Grid (V2G) Integration as Distributed Energy Resources in Indonesia Power System. *Energies* **2020**, *13*, 1162. [CrossRef]

44. Basso, T.S.; DeBlasio, R. IEEE 1547 Series of Standards: Interconnection Issues. *IEEE Trans. Power Electron.* **2004**, *19*, 1159–1162. [CrossRef]
45. Lee, B.-K.; Kim, J.-P.; Kim, S.-G.; Lee, J.-Y. An Isolated/Bidirectional PWM Resonant Converter for V2G(H) EV On-Board Charger. *IEEE Trans. Veh. Technol.* **2017**, *66*, 7741–7750. [CrossRef]
46. Zeljkovic, S.; Vuletic, R.; Miller, A.; Denais, A. A three phase bidirectional V2G interface converter based on SiC JFETs. In Proceedings of the 2015 17th European Conference on Power Electronics and Applications (EPE'15 ECCE-Europe), Geneva, Switzerland, 8–10 September 2015; pp. 1–10. [CrossRef]
47. Krismer, F.; Biela, J.; Kolar, J. A comparative evaluation of isolated bi-directional DC/DC converters with wide input and output voltage range. In Proceedings of the Fourtieth IAS Annual Meeting. Conference Record of the 2005 Industry Applications Conference, Hong Kong, China, 2–6 October 2005; Volume 1, pp. 599–606.
48. Twiname, R.P.; Thrimawithana, D.J.; Madawala, U.K.; Baguley, C.A. A New Resonant Bidirectional DC–DC Converter Topology. *IEEE Trans. Power Electron.* **2013**, *29*, 4733–4740. [CrossRef]
49. Oggier, G.; Leidhold, R.; Garcia, G.; Oliva, A.; Balda, J.; Barlow, F. Extending the ZVS Operating Range of Dual Active Bridge High-Power DC-DC Converters. In Proceedings of the 2006 37th IEEE Power Electronics Specialists Conference, Jeju, Korea, 18–22 June 2006. [CrossRef]
50. Oggier, G.G.; García, G.O.; Oliva, A.R. Switching Control Strategy to Minimize Dual Active Bridge Converter Losses. *IEEE Trans. Power Electron.* **2009**, *24*, 1826–1838. [CrossRef]
51. Zhao, B.; Song, Q.; Liu, W. Efficiency Characterization and Optimization of Isolated Bidirectional DC–DC Converter Based on Dual-Phase-Shift Control for DC Distribution Application. *IEEE Trans. Power Electron.* **2012**, *28*, 1711–1727. [CrossRef]
52. Oggier, G.G.; Garcia, G.O.; Oliva, A.R. Modulation strategy to operate the dual active bridge DC-DC converter under soft switching in the whole operating range. *IEEE Trans. Power Electron.* **2010**, *26*, 1228–1236. [CrossRef]
53. Krismer, F.; Round, S.; Kolar, J.W. Performance Optimization of a High Current Dual Active Bridge with a Wide Operating Voltage Range. In Proceedings of the 2006 37th IEEE Power Electronics Specialists Conference, Jeju, Korea, 18–22 June 2006; pp. 1–7. [CrossRef]
54. Krismer, F.; Kolar, J.W. Efficiency-Optimized High-Current Dual Active Bridge Converter for Automotive Applications. *IEEE Trans. Ind. Electron.* **2011**, *59*, 2745–2760. [CrossRef]
55. Bai, H.; Mi, C. Eliminate Reactive Power and Increase System Efficiency of Isolated Bidirectional Dual-Active-Bridge DC–DC Converters Using Novel Dual-Phase-Shift Control. *IEEE Trans. Power Electron.* **2008**, *23*, 2905–2914. [CrossRef]
56. Jain, A.K.; Ayyanar, R. Pwm control of dual active bridge: Comprehensive analysis and experimental verification. *IEEE Trans. Power Electron.* **2010**, *26*, 1215–1227. [CrossRef]
57. Deng, J.; Li, S.; Hu, S.; Mi, C.C.; Ma, R. Design Methodology of LLC Resonant Converters for Electric Vehicle Battery Chargers. *IEEE Trans. Veh. Technol.* **2013**, *63*, 1581–1592. [CrossRef]
58. He, P.; Khaligh, A. Comprehensive Analyses and Comparison of 1 kW Isolated DC–DC Converters for Bidirectional EV Charging Systems. *IEEE Trans. Transp. Electrif.* **2016**, *3*, 147–156. [CrossRef]
59. Chakraborty, S.; Chattopadhyay, S. Fully ZVS, Minimum RMS Current Operation of the Dual-Active Half-Bridge Converter Using Closed-Loop Three-Degree-of-Freedom Control. *IEEE Trans. Power Electron.* **2018**, *33*, 10188–10199. [CrossRef]
60. Ngo, T.; Won, J.; Nam, K. A single-phase bidirectional dual active half-bridge converter. In Proceedings of the 2012 Twenty-Seventh Annual IEEE Applied Power Electronics Conference and Exposition (APEC), Orlando, FL, USA, 5–9 February 2012; pp. 1127–1133. [CrossRef]
61. Higa, H.; Takuma, S.; Orikawa, K.; Itoh, J.-I. Dual active bridge DC-DC converter using both full and half bridge topologies to achieve high efficiency for wide load. In Proceedings of the 2015 IEEE Energy Conversion Congress and Exposition (ECCE), Montreal, QC, Canada, 20–24 September 2015; pp. 6344–6351. [CrossRef]
62. Singh, B.; Singh, B.N.; Chandra, A.; Al-Haddad, K.; Pandey, A.; Kothari, D.P. A Review of Three-Phase Improved Power Quality AC–DC Converters. *IEEE Trans. Ind. Electron.* **2004**, *51*, 641–660. [CrossRef]
63. Zhang, H.; Yang, L.; Wang, S.; Puukko, J. Common-Mode EMI Noise Modeling and Reduction with Balance Technique for Three-Level Neutral Point Clamped Topology. *IEEE Trans. Ind. Electron.* **2017**, *64*, 7563–7573. [CrossRef]
64. Jauch, F.; Biela, J. Modelling and ZVS control of an isolated three-phase bidirectional AC-DC converter. In Proceedings of the 2013 15th European Conference on Power Electronics and Applications (EPE), Lille, France, 2–6 September 2013; pp. 1–11. [CrossRef]
65. Krishnamoorthy, H.S.; Garg, P.; Enjeti, P.N. A matrix converter-based topology for high power electric vehicle battery charging and V2G application. In Proceedings of the IECON 2012—38th Annual Conference on IEEE Industrial Electronics Society, Montreal, QC, Canada, 25–28 October 2012; pp. 2866–2871. [CrossRef]
66. Varajão, D.; Miranda, L.M.; Araújo, R.E. Towards a new technological solution for community energy storage. In Proceedings of the 2014 16th European Conference on Power Electronics and Applications, Lappeenranta, Finland, 26–28 August 2014; pp. 1–10. [CrossRef]
67. Friedli, T.; Kolar, J.W.; Rodriguez, J.; Wheeler, P.W. Comparative Evaluation of Three-Phase AC–AC Matrix Converter and Voltage DC-Link Back-to-Back Converter Systems. *IEEE Trans. Ind. Electron.* **2011**, *59*, 4487–4510. [CrossRef]
68. Varajao, D.; Araujo, R.E.; Miranda, L.M.; Lopes, J.A.P. Modulation Strategy for a Single-Stage Bidirectional and Isolated AC–DC Matrix Converter for Energy Storage Systems. *IEEE Trans. Ind. Electron.* **2017**, *65*, 3458–3468. [CrossRef]

69. Ahsan, M.; Hon, S.T.; Batunlu, C.; Albarbar, A. Reliability Assessment of IGBT Through Modelling and Experimental Testing. *IEEE Access* **2020**, *8*, 39561–39573. [CrossRef]
70. Gandoman, F.H.; Ahmadi, A.; Bossche, P.V.D.; Van Mierlo, J.; Omar, N.; Nezhad, A.E.; Mavalizadeh, H.; Mayet, C. Status and future perspectives of reliability assessment for electric vehicles. *Reliab. Eng. Syst. Saf.* **2018**, *183*, 1–16. [CrossRef]
71. Li, K.; Tian, G.Y.; Cheng, L.; Yin, A.; Cao, W.; Crichton, S. State Detection of Bond Wires in IGBT Modules Using Eddy Current Pulsed Thermography. *IEEE Trans. Power Electron.* **2013**, *29*, 5000–5009. [CrossRef]
72. Zhang, G. Study on methods of electric vehicle safety test. In Proceedings of the 13th International Conference on Man-Machine-Environment System Engineering, Yantai, China, 21–25 October 2013; pp. 133–142.
73. Baraldi, P.; Galarza, A.; Rigamonti, M.; Rantala, S.; Unanue, I.; Astigarraga, D.; Zio, E.; Maio, D.; Ruddle, A. A Procedure for Practical Prognostics and Health Monitoring of Fully Electric Vehicles for Enhanced Safety and Reliability. In Proceedings of the 5th IET Hybrid and Electric Vehicles Conference (HEVC 2014), London, UK, 5–6 November 2014. [CrossRef]
74. Freschi, F.; Mitolo, M.; Tommasini, R. Electrical safety of electric vehicles. In Proceedings of the 2017 IEEE/IAS 53rd Industrial and Commercial Power Systems Technical Conference (I&CPS), Niagara Falls, ON, Canada, 6–11 May 2017. [CrossRef]
75. Ghavami, M.; Essakiappan, S.; Singh, C. A framework for reliability evaluation of electric vehicle charging stations. In Proceedings of the 2016 IEEE Power and Energy Society General Meeting (PESGM), Boston, MA, USA, 17–21 July 2016; pp. 1–5. [CrossRef]
76. Ghavami, M.; Singh, C. Reliability evaluation of plug-in hybrid electric vehicle chargers. In Proceedings of the 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), Milan, Italy, 6–9 June 2017; pp. 1–6. [CrossRef]
77. Ghavami, M.; Singh, C. Reliability evaluation of electric vehicle charging systems including the impact of repair. In Proceedings of the 2017 IEEE Industry Applications Society Annual Meeting, Cincinnati, OH, USA, 1–5 October 2017; pp. 1–9. [CrossRef]
78. Dhople, S.V.; Davoudi, A.; Domínguez-García, A.D.; Chapman, P.L. A Unified Approach to Reliability Assessment of Multiphase DC–DC Converters in Photovoltaic Energy Conversion Systems. *IEEE Trans. Power Electron.* **2010**, *27*, 739–751. [CrossRef]
79. Zhuang, X.; Yadav, O.P. A new reliability assessment model for power electronic modules. In Proceedings of the 2015 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Singapore, 6–9 December 2015; pp. 1012–1016. [CrossRef]
80. Drobnik, J.; Jain, P. Electric and Hybrid Vehicle Power Electronics Efficiency, Testing and Reliability. *World Electr. Veh. J.* **2013**, *6*, 719–730. [CrossRef]
81. Zeng, B.; Luo, Y.; Zhang, C.; Liu, Y. Assessing the Impact of an EV Battery Swapping Station on the Reliability of Distribution Systems. *Appl. Sci.* **2020**, *10*, 8023. [CrossRef]
82. Reddy, K.J.; Natarajan, S. Energy sources and multi-input DC-DC converters used in hybrid electric vehicle applications—A review. *Int. J. Hydrogen Energy* **2018**, *43*, 17387–17408. [CrossRef]
83. López, I.; Ibarra, E.; Matallana, A.; Andreu, J.; Kortabarria, I. Next generation electric drives for HEV/EV propulsion systems: Technology, trends and challenges. *Renew. Sustain. Energy Rev.* **2019**, *114*, 109336. [CrossRef]
84. Chakraborty, S.; Vu, H.-N.; Hasan, M.M.; Tran, D.-D.; El Baghdadi, M.; Hegazy, O. DC-DC Converter Topologies for Electric Vehicles, Plug-in Hybrid Electric Vehicles and Fast Charging Stations: State of the Art and Future Trends. *Energies* **2019**, *12*, 1569. [CrossRef]
85. Tran, D.; Chakraborty, S.; Lan, Y.; Van Mierlo, J.; Hegazy, O. Optimized Multiport DC/DC Converter for Vehicle Drivetrains: Topology and Design Optimization. *Appl. Sci.* **2018**, *8*, 1351. [CrossRef]
86. Pan, L.; Zhang, C. An Integrated Multifunctional Bidirectional AC/DC and DC/DC Converter for Electric Vehicles Applications. *Energies* **2016**, *9*, 493. [CrossRef]
87. Ikeya, T.; Sawada, N.; Murakami, J.-I.; Kobayashi, K.; Hattori, M.; Murotani, N.; Ujiie, S.; Kajiyama, K.; Nasu, H.; Narisoko, H.; et al. Multi-step constant-current charging method for an electric vehicle nickel/metal hydride battery with high-energy efficiency and long cycle life. *J. Power Sources* **2002**, *105*, 6–12. [CrossRef]
88. Vu, V.-B.; Tran, D.-H.; Choi, W. Implementation of the Constant Current and Constant Voltage Charge of Inductive Power Transfer Systems With the Double-Sided LCC Compensation Topology for Electric Vehicle Battery Charge Applications. *IEEE Trans. Power Electron.* **2017**, *33*, 7398–7410. [CrossRef]
89. Bayati, M.; Abedi, M.; Farahmandrad, M.; Gharehpetian, G.B. Delivering Smooth Power to Pulse-Current Battery Chargers: Electric Vehicles as a Case in Point. *IEEE Trans. Power Electron.* **2020**, *36*, 1295–1302. [CrossRef]
90. Notten, P.; Veld, J.O.H.; van Beek, J. Boostcharging Li-ion batteries: A challenging new charging concept. *J. Power Sources* **2005**, *145*, 89–94. [CrossRef]
91. Fleury, X.; Noh, M.; Geniès, S.; Thivel, P.; Lefrou, C.; Bultel, Y. Fast-charging of Lithium Iron Phosphate battery with ohmic-drop compensation method: Ageing study. *J. Energy Storage* **2018**, *16*, 21–36. [CrossRef]
92. Chen, C.; Shang, F.; Salameh, M.; Krishnamurthy, M. Challenges and Advancements in Fast Charging Solutions for EVs: A Technological Review. In Proceedings of the 2018 IEEE Transportation Electrification Conference and Expo (ITEC), Long Beach, CA, USA, 13–15 June 2018; pp. 695–701. [CrossRef]
93. Petersen, L.; Andersen, M. Two-stage power factor corrected power supplies: The low component-stress approach. In Proceedings of the 2002 APEC, Seventeenth Annual IEEE Applied Power Electronics Conference and Exposition, Dallas, TX, USA, 10–14 March 2002; Volume 2, pp. 1195–1201. [CrossRef]

94. Gautam, D.S.; Musavi, F.; Edington, M.; Eberle, W.; Dunford, W.G. An Automotive Onboard 3.3-kW Battery Charger for PHEV Application. *IEEE Trans. Veh. Technol.* **2012**, *61*, 3466–3474. [CrossRef]
95. Asa, E.; Colak, K.; Czarkowski, D.; de Leon, F.; Sefa, I. PLL control technique of LLC resonant converter for EVs battery charger. In Proceedings of the 4th International Conference on Power Engineering, Energy and Electrical Drives, Istanbul, Turkey, 13–17 May 2013. [CrossRef]
96. Musavi, F.; Craciun, M.; Edington, M.; Eberle, W.; Dunford, W.G. Practical design considerations for a LLC multi-resonant DC-DC converter in battery charging applications. In Proceedings of the 2012 Twenty-Seventh Annual IEEE Applied Power Electronics Conference and Exposition (APEC), Orlando, FL, USA, 5–9 February 2012; pp. 2596–2602. [CrossRef]
97. Monteiro, V.; Pinto, J.G.; Exposto, B.; Afonso, J.L. Comprehensive comparison of a current-source and a voltage-source converter for three-phase EV fast battery chargers. In Proceedings of the 2015 9th International Conference on Compatibility and Power Electronics (CPE), Costa da Caparica, Portugal, 24–26 June 2015; pp. 173–178.
98. Shin, C.-H.; Kim, D.-Y.; Ko, A.-Y.; Won, I.-K.; Kim, Y.-R.; Won, C.-Y. The configuration of electric vehicle system using isolated DC-DC converter for a low-voltage and high-current type battery. In Proceedings of the 2015 9th International Conference on Power Electronics and ECCE Asia (ICPE-ECCE Asia), Seoul, Korea, 1–5 June 2015; pp. 2796–2801. [CrossRef]
99. Park, J.-H.; Lee, K.-B. A two-stage bidirectional DC/DC converter with SiC-MOSFET for vehicle-to-grid (V2G) application. In Proceedings of the 2017 IEEE Conference on Energy Conversion (CENCON), Kuala Lumpur, Malaysia, 30–31 October 2017; pp. 288–293. [CrossRef]
100. Zeng, H.; Peng, F.Z. SiC-Based Z-Source Resonant Converter With Constant Frequency and Load Regulation for EV Wireless Charger. *IEEE Trans. Power Electron.* **2016**, *32*, 8813–8822. [CrossRef]
101. Wang, Y.-F.; Xue, L.-K.; Wang, C.-S.; Wang, P.; Li, W. Interleaved High-Conversion-Ratio Bidirectional DC–DC Converter for Distributed Energy-Storage Systems—Circuit Generation, Analysis, and Design. *IEEE Trans. Power Electron.* **2015**, *31*, 5547–5561. [CrossRef]
102. Zhang, Y.; He, J.; Ionel, D.M. Modeling and Control of a Multiport Converter based EV Charging Station with PV and Battery. In Proceedings of the ITEC 2019—2019 IEEE Transportation Electrification Conference and Expo (ITEC), Novi, MI, USA, 19–21 June 2019. [CrossRef]
103. Chae, H.J.; Kim, W.Y.; Yun, S.Y.; Jeong, Y.S.; Lee, J.Y.; Moon, H.T. 3.3 kW on board charger for electric vehicle. In Proceedings of the 8th International Conference on Power Electronics—ECCE Asia, Jeju, Korea, 30 May–3 June 2011; pp. 2717–2719. [CrossRef]
104. Lam, C.S.; Chung, C.Y.; Wong, M.C. Review of current quality compensators for high power unidirectional electric vehicle battery charger. In Proceedings of the 1st International Future Energy Electronics Conference IFEEC, Tainan, Taiwan, 3–6 November 2013; pp. 259–264. [CrossRef]
105. Zhang, H.; Tolbert, L.M.; Han, J.H.; Chinthavali, M.S.; Barlow, F. 18 kW three phase inverter system using hermetically sealed SiC phase-leg power modules. In Proceedings of the 2010 Twenty-Fifth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), Palm Springs, CA, USA, 21–25 February 2010; pp. 1108–1112. [CrossRef]
106. Chinthavali, M.; Ayers, C.; Campbell, S.; Wiles, R.; Ozpineci, B. A 10-kW SiC inverter with a novel printed metal power module with integrated cooling using additive manufacturing. In Proceedings of the 2014 IEEE Workshop on Wide Bandgap Power Devices and Applications, Knoxville, TN, USA, 13–15 October 2014; pp. 48–54. [CrossRef]
107. Gurpinar, E.; Castellazzi, A. Single-Phase T-Type Inverter Performance Benchmark Using Si IGBTs, SiC MOSFETs and GaN HEMTs. *IEEE Trans. Power Electron.* **2015**, *31*, 7148–7160. [CrossRef]
108. Yamane, A.; Koyanagi, K.; Kozako, M.; Fuji, K.; Hikita, M. Fabrication and evaluation of SiC inverter using SiC-MOSFET. In Proceedings of the 2013 IEEE 10th International Conference on Power Electronics and Drive Systems (PEDS), Kitakyushu, Japan, 22–25 April 2013; pp. 1029–1032. [CrossRef]
109. Yin, S.; Tseng, K.J.; Tong, C.F.; Simanjorang, R.; Gajanayake, C.J.; Gupta, A.K. A 99% efficiency SiC three-phase inverter using synchronous rectification. In Proceedings of the 2016 IEEE Applied Power Electronics Conference and Exposition (APEC), Long Beach, CA, USA, 20–24 March 2016; pp. 2942–2949. [CrossRef]
110. Khaligh, A.; Dusmez, S. Comprehensive Topological Analysis of Conductive and Inductive Charging Solutions for Plug-In Electric Vehicles. *IEEE Trans. Veh. Technol.* **2012**, *61*, 3475–3489. [CrossRef]
111. Upadhyay, P.; Kumar, R. A ZVS-ZCS quadratic boost converter to utilize the energy of PV irrigation system for electric vehicle charging application. *Sol. Energy* **2020**, *206*, 106–119. [CrossRef]
112. Jiang, T.; Zhang, J.; Wu, X.; Sheng, K.; Wang, Y. A Bidirectional LLC Resonant Converter With Automatic Forward and Backward Mode Transition. *IEEE Trans. Power Electron.* **2014**, *30*, 757–770. [CrossRef]
113. Musavi, F.; Craciun, M.; Gautam, D.S.; Eberle, W. Control Strategies for Wide Output Voltage Range LLC Resonant DC–DC Converters in Battery Chargers. *IEEE Trans. Veh. Technol.* **2014**, *63*, 1117–1125. [CrossRef]
114. Li, X. A LLC-Type Dual-Bridge Resonant Converter: Analysis, Design, Simulation, and Experimental Results. *IEEE Trans. Power Electron.* **2013**, *29*, 4313–4321. [CrossRef]
115. Jung, J.H.; Kim, H.S.; Ryu, M.H.; Baek, J.W. Design Methodology of Bidirectional CLLC Resonant Converter for High-Frequency Isolation of DC Distribution Systems. *IEEE Trans. Power Electron.* **2013**, *28*, 1741–1755. [CrossRef]
116. Chen, W.; Rong, P.; Lu, Z. Snubberless Bidirectional DC–DC Converter With New CLLC Resonant Tank Featuring Minimized Switching Loss. *IEEE Trans. Ind. Electron.* **2009**, *57*, 3075–3086. [CrossRef]

117. Zahid, Z.U.; Dalala, Z.M.; Chen, R.; Chen, B.; Lai, J.-S. Design of Bidirectional DC–DC Resonant Converter for Vehicle-to-Grid (V2G) Applications. *IEEE Trans. Transp. Electrification* **2015**, *1*, 232–244. [CrossRef]
118. Li, B.; Lee, F.C.; Li, Q.; Liu, Z. Bi-directional on-board charger architecture and control for achieving ultra-high efficiency with wide battery voltage range. In Proceedings of the 2017 IEEE Applied Power Electronics Conference and Exposition (APEC), Tampa, FL, USA, 26–30 March 2017; pp. 3688–3694. [CrossRef]
119. Whitaker, B.; Barkley, A.; Cole, Z.; Passmore, B.; Martin, D.; McNutt, T.R.; Lostetter, A.B.; Lee, J.S.; Shiozaki, K. A High-Density, High-Efficiency, Isolated On-Board Vehicle Battery Charger Utilizing Silicon Carbide Power Devices. *IEEE Trans. Power Electron.* **2014**, *29*, 2606–2617. [CrossRef]
120. Lai, J.-S.; Zhang, L.; Zahid, Z.; Tseng, N.-H.; Lee, C.-S.; Lin, C.-H. A high-efficiency 3.3-kW bidirectional on-board charger. In Proceedings of the 2015 IEEE 2nd International Future Energy Electronics Conference (IFEEC), Taipei, Taiwan, 1–4 November 2015; pp. 1–5. [CrossRef]
121. Liu, Z.; Li, B.; Lee, F.C.; Li, Q. Design of CRM AC/DC converter for very high-frequency high-density WBG-based 6.6 kW bidirectional on-board battery charger. In Proceedings of the 2016 IEEE Energy Conversion Congress and Exposition (ECCE), Milwaukee, WI, USA, 18–22 September 2016.
122. Newman, J.; Thomas, K.E.; Hafezi, H.; Wheeler, D.R. Modeling of lithium-ion batteries. *J. Power Sources* **2003**, *119–121*, 838–843. [CrossRef]
123. Vertiz, G.; Oyarbide, M.; Macicior, H.; Miguel, O.; Cantero, I.; de Arroiabe, P.F.; Ulacia, I. Thermal characterization of large size lithium-ion pouch cell based on 1d electro-thermal model. *J. Power Sources* **2014**, *272*, 476–484. [CrossRef]
124. Thomas, K.E.; Newman, J. Heats of mixing and of entropy in porous insertion electrodes. *J. Power Sources* **2003**, *119–121*, 844–849. [CrossRef]
125. Forgez, C.; Do, D.V.; Friedrich, G.; Morcrette, M.; Delacourt, C. Thermal modeling of a cylindrical LiFePO4/graphite lithium-ion battery. *J. Power Sources* **2010**, *195*, 2961–2968. [CrossRef]
126. Lee, K.-J.; Smith, K.; Pesaran, A.; Kim, G.-H. Three dimensional thermal-, electrical-, and electrochemical-coupled model for cylindrical wound large format lithium-ion batteries. *J. Power Sources* **2013**, *241*, 20–32. [CrossRef]
127. Kim, G.-H.; Pesaran, A.; Spotnitz, R. A three-dimensional thermal abuse model for lithium-ion cells. *J. Power Sources* **2007**, *170*, 476–489. [CrossRef]
128. Mahamud, R.; Park, C. Reciprocating air flow for Li-ion battery thermal management to improve temperature uniformity. *J. Power Sources* **2011**, *196*, 5685–5696. [CrossRef]
129. Yang, Y.; Hu, X.; Qing, D.; Chen, F. Arrhenius Equation-Based Cell-Health Assessment: Application to Thermal Energy Management Design of a HEV NiMH Battery Pack. *Energies* **2013**, *6*, 2709–2725. [CrossRef]
130. Park, S.; Jung, D. Battery cell arrangement and heat transfer fluid effects on the parasitic power consumption and the cell temperature distribution in a hybrid electric vehicle. *J. Power Sources* **2013**, *227*, 191–198. [CrossRef]
131. Wang, T.; Tseng, K.; Zhao, J.; Wei, Z. Thermal investigation of lithium-ion battery module with different cell arrangement structures and forced air-cooling strategies. *Appl. Energy* **2014**, *134*, 229–238. [CrossRef]
132. Xu, X.; He, R. Research on the heat dissipation performance of battery pack based on forced air cooling. *J. Power Sources* **2013**, *240*, 33–41. [CrossRef]
133. Choi, Y.S.; Kang, D.M. Prediction of thermal behaviors of an air-cooled lithium-ion battery system for hybrid electric vehicles. *J. Power Sources* **2014**, *270*, 273–280. [CrossRef]
134. Park, H. A design of air flow configuration for cooling lithium ion battery in hybrid electric vehicles. *J. Power Sources* **2013**, *239*, 30–36. [CrossRef]
135. Liu, Z.; Wang, Y.; Zhang, J.; Liu, Z. Shortcut computation for the thermal management of a large air-cooled battery pack. *Appl. Therm. Eng.* **2014**, *66*, 445–452. [CrossRef]
136. Fan, L.; Khodadadi, J.; Pesaran, A. A parametric study on thermal management of an air-cooled lithium-ion battery module for plug-in hybrid electric vehicles. *J. Power Sources* **2013**, *238*, 301–312. [CrossRef]
137. Tong, W.; Somasundaram, K.; Birgersson, E.; Mujumdar, A.S.; Yap, C. Numerical investigation of water cooling for a lithium-ion bipolar battery pack. *Int. J. Therm. Sci.* **2015**, *94*, 259–269. [CrossRef]
138. Jarret, A.; Kim, I.Y. Design optimization of electric vehicle battery cooling plates for thermal performance. *J. Power Sources* **2011**, *196*, 10359–10368. [CrossRef]
139. Jarrett, A.; KimI, Y. Influence of operating conditions on the optimum design of electric vehicle battery cooling plates. *J. Power Sources* **2014**, *245*, 644–655. [CrossRef]
140. Zhao, J.; Rao, Z.; Liu, C.; Li, Y. Experimental investigation on thermal performance of phase change material coupled with closed-loop oscillating heat pipe (PCM/CLOHP) used in thermal management. *Appl. Therm. Eng.* **2016**, *93*, 90–100. [CrossRef]
141. Tran, T.-H.; Harmand, S.; Desmet, B.; Filangi, S. Experimental investigation on the feasibility of heat pipe cooling for HEV/EV lithium-ion battery. *Appl. Therm. Eng.* **2014**, *63*, 551–558. [CrossRef]
142. Zhao, R.; Gu, J.; Liu, J. An experimental study of heat pipe thermal management system with wet cooling method for lithium ion batteries. *J. Power Sources* **2015**, *273*, 1089–1097. [CrossRef]
143. Javani, N.; Dincer, I.; Naterer, G.; Yilbas, B. Heat transfer and thermal management with PCMs in a Li-ion battery cell for electric vehicles. *Int. J. Heat Mass Transf.* **2014**, *72*, 690–703. [CrossRef]

144. Khateeb, S.A.; Amiruddin, S.; Farid, M.; Selman, J.R.; Al-Hallaj, S. Thermal management of Li-ion battery with phase change material for electric scooters: Experimental validation. *J. Power Sources* **2005**, *142*, 345–353. [CrossRef]
145. Kizilel, R.; Sabbah, R.; Selman, J.R.; Al-Hallaj, S. An alternative cooling system to enhance the safety of Li-ion battery packs. *J. Power Sources* **2009**, *194*, 1105–1112. [CrossRef]
146. Ling, Z.; Chen, J.; Fang, X.; Zhang, Z.; Xu, T.; Gao, X.; Wang, S. Experimental and numerical investigation of the application of phase change materials in a simulative power batteries thermal management system. *Appl. Energy* **2014**, *121*, 104–113. [CrossRef]
147. Wu, W.; Zhang, G.; Ke, X.; Yang, X.; Wang, Z.; Liu, C. Preparation and thermal conductivity enhancement of composite phase change materials for electronic thermal management. *Energy Convers. Manag.* **2015**, *101*, 278–284. [CrossRef]
148. Ge, S.Y.; Wang, L.; Liu, H.; Feng, L. The impact of discharging electric vehicles on the distribution grid. In Proceedings of the IEEE PES Innovative Smart Grid Technologies, Tianjin, China, 21–24 May 2012; pp. 1–4. [CrossRef]
149. Liao, J.T.; Huang, H.W.; Yang, H.T.; Li, D. Decentralized V2G/G2V Scheduling of EV Charging Stations by Considering the Conversion Efficiency of Bidirectional Chargers. *Energies* **2021**, *14*, 962. [CrossRef]
150. Hu, J.; You, S.; Lind, M.; Ostergaard, J. Coordinated Charging of Electric Vehicles for Congestion Prevention in the Distribution Grid. *IEEE Trans. Smart Grid* **2013**, *5*, 703–711. [CrossRef]
151. Yu, R.; Ding, J.; Zhong, W.; Liu, Y.; Xie, S. PHEV Charging and Discharging Cooperation in V2G Networks: A Coalition Game Approach. *IEEE Internet Things J.* **2014**, *1*, 578–589. [CrossRef]
152. Fan, Z. A Distributed Demand Response Algorithm and Its Application to PHEV Charging in Smart Grids. *IEEE Trans. Smart Grid* **2012**, *3*, 1280–1290. [CrossRef]
153. Luo, C.; Huang, Y.-F.; Gupta, V. Stochastic Dynamic Pricing for EV Charging Stations With Renewable Integration and Energy Storage. *IEEE Trans. Smart Grid* **2017**, *9*, 1494–1505. [CrossRef]
154. Wan, Z.; Li, H.; He, H.L.H.; Prokhorov, D. Model-Free Real-Time EV Charging Scheduling Based on Deep Reinforcement Learning. *IEEE Trans. Smart Grid* **2018**, *10*, 5246–5257. [CrossRef]
155. Vadi, S.; Bayindir, R.; Colak, A.M.; Hossain, E. A Review on Communication Standards and Charging Topologies of V2G and V2H Operation Strategies. *Energies* **2019**, *12*, 3748. [CrossRef]
156. El Chehaly, M.; Saadeh, O.; Martinez, C.; Joos, G. Advantages and applications of vehicle to grid mode of operation in plug-in hybrid electric vehicles. In Proceedings of the 2009 IEEE Electrical Power & Energy Conference (EPEC), Montreal, QC, Canada, 22–23 October 2009; pp. 1–6. [CrossRef]
157. Gao, Y.; Chen, Y.; Wang, C.-Y.; Liu, K.J.R. A contract-based approach for ancillary services in V2G networks: Optimality and learning. In Proceedings of the 2013 Proceedings IEEE INFOCOM, Turin, Italy, 14–19 April 2013; pp. 1151–1159. [CrossRef]
158. Ansari, M.; Al-Awami, A.T.; Sortomme, E.; Abido, M.A. Coordinated bidding of ancillary services for vehicle-to-grid using fuzzy optimization. *IEEE Trans. Smart Grid* **2014**, *6*, 261–270. [CrossRef]
159. Joseph, P.K.; Devaraj, E.; Gopal, A. Overview of wireless charging and vehicle-to-grid integration of electric vehicles using renewable energy for sustainable transportation. *IET Power Electron.* **2019**, *12*, 627–638. [CrossRef]
160. Hosseini, S.S.; Badri, A.; Parvania, M. The plug-in electric vehicles for power system applications: The vehicle to grid (V2G) concept. In Proceedings of the 2012 IEEE International Energy Conference and Exhibition (ENERGYCON), Florence, Italy, 9–12 September 2012; pp. 1101–1106. [CrossRef]
161. Bibak, B.; Tekiner-Moğulkoç, H. A comprehensive analysis of Vehicle to Grid (V2G) systems and scholarly literature on the application of such systems. *Renew. Energy Focus* **2020**, *36*, 1–20. [CrossRef]
162. Buja, G.; Bertoluzzo, M.; Fontana, C. Reactive Power Compensation Capabilities of V2G-Enabled Electric Vehicles. *IEEE Trans. Power Electron.* **2017**, *32*, 9447–9459. [CrossRef]
163. Singh, J.; Tiwari, R. Cost Benefit Analysis for V2G Implementation of Electric Vehicles in Distribution System. *IEEE Trans. Ind. Appl.* **2020**, *56*, 5963–5973. [CrossRef]