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Charging Systems/Techniques of Electric Vehicle: A Comprehensive Review

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ABSTRACT

Recent violent global climate change consequences necessities reducing the consumption of fossil fuel in different sectors. Electric Vehicles (EVs) are growing in popularity as eco-friendly and environmentally compatible solution in transportation industry. This article provides a thoroughly and comprehensive overview of the advancement of topologies and charging techniques for EV. The article is aimed to act as a guide for researchers/engineers in the field of EV and automotive industry.

Charging circuits of EVs have been divided into several categories. Comprehensive comparisons are carried out and revealed in appropriate graphs/charts/tables. Moreover, a sufficient high number of recent and up-dated references are screened. Classifications of electric vehicle charging technologies based on their individual characteristics are provided.

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أنظمة / تقنيات شحن المركبات الكهربائية: مراجعة شاملة

علاء محمود, أمنية البدرى, محمود محمد , هالة الخازندار, ياسر نصار, أحمد حافظ .

ملخص: تقتضي العواقب العنيفة الأخيرة لتغير المناخ العالمي تقليل استهلاك الوقود الأحفوري في مختلف القطاعات. تزداد شعبية المركبات الكهربائية (EVs) كحل صديق للبيئة ومتوافق مع البيئة في صناعة النقل. يوفر هذا المقال نظرة شاملة ومتكاملة حول تقدم الطوبولوجيا وتقنيات الشحن للمركبات الكهربائية. يهدف المقال إلى أن يكون دليلاً للباحثين/المهندسين في مجال المركبات الكهربائية وصناعة السيارات. تم تقسيم دوائر الشحن للمركبات الكهربائية إلى عدة فئات. تم إجراء مقارنات شاملة وكشفها في الرسوم البيانية/الخرائط/الجداول المناسبة. علاوة على ذلك، تم فحص عدد كافٍ من المراجع الحديثة والمحدثة. تم توفير تصنيفات تقنيات شحن المركبات الكهربائية بناءً على خصائصها الفردية.

الكلمات المفتاحية – الطاقة المتجددة، السيارة الكهربائية، محطة الشحن، المحول، الكفاءة.

1. INTRODUCTION

Today, world is exposed to consequences of excessive consumption of fossil fuels such as global warming, climate change and other environmental challenges. Burning of fossil fuels injects tons of pollutants such as carbon monoxide CO and carbon dioxide CO2 [1], The global trend is moving toward the renewable energy sources such as solar, wind, hydraulic and others as promising candidate for fossil fuels. Statistics for 2022 indicate that transport still depends on petroleum products for approximately 91% of its final energy consumption, as it consumed about 106.41 EJ of petroleum derivatives, about 5.25 EJ of NG, about 4.18 EJ of Biofuels, and about 1.65 EJ of electricity. Road travel accounts for three-quarters of transport emissions [2]. Transport emissions grew at an annual average rate of 1.7% from 1990 to 2022, Most of this comes from passenger vehicles – cars and buses – which contribute 45.1%. The transportation industry has a great share in the dilemma of emissions from the combustion of fossil fuels. The fossil fuel engines must be replaced by environmentally compatible ones. The Internal-Combustion-Engines (ICE) are the major contributors of air pollutants. Moreover, they suffer from reduced overall operating efficiency, limited control ability and evaluated maintenance rate [2].

Table 1 Comparison between Electric Vehicles and ICE Vehicles [3]

Vehicle Type	Electric Vehicles	ICE Vehicles
Power Source	Batteries	Products of fossil fuels
Fuel source	Domestic standard electrical outlet/ public charging station.	A gas station.
Emissions & Environmental Impact	Zero emissions, environmentally friendly	Polluting, main source of air pollution and climate change.
Cost of operation	Low	High
Maintenance	Less maintenance requirements	More maintenance requirements
Refueling period	Long	Short
Range	Limited by the capacity of its battery	Limited by the amount of fuel in its tank.
Acceleration	High	Good
Noise	Much quieter	Quiet
Self-driving and Internet Of Things (IOT)	Fully	Partially

EVs could be the answer for the transportation sector. They have a green footprint, as they acquire

their power usually from eco-friendly energy sources such as fuel cells, solar cells, and batteries. Moreover, they provide several advantages over ICE vehicles which are shown in Table 1 [3].
Prototypes for electric vehicles surfaced again in the 1960s as a result of rising fossil fuel costs. Newly designed fuel cells provide an alternative to batteries, and the speed and range have been boosted. Even by the mid-1980s, though, EVs had not yet found a place in the automobile industry. In [4] However, the majority of industrial in-plant lifting and carrying trucks were electrically driven. The late 1990s saw a surge in interest in electric vehicles, in part due to worries about climate change. The Prius, a hybrid vehicle that runs on gasoline and batteries, was unveiled by Toyota. It first appeared in Japan in 1997, and by 2000, it had spread over the globe. Other hybrid cars, such the 1999 Honda Insight and the 2011 Chevrolet Volt, were developed as a result of the Prius's success. In 2008, Tesla unveiled their flagship vehicle, the fully electric luxury sports car known as the Roadster, capable of covering 394 kilometers (245 miles) on a single charge. Some automakers designed their own all-electric cars as a result of the Roadster and other Tesla model's popularity, including the Nissan Leaf (2010) and the Renault ZOE (2012). Many of the major vehicle manufacturers are planning to stop producing ICE in the near future and turns into EVs [5].
EVs are basically isolated electric power system, which could be powered from either battery or fuel cell. EV battery-based power system is usually composed of battery bank, motor(s) and Power Electronic (PE) circuits. PE circuits include the charges that responsible for charging the battery bank with sufficient power. The PE also includes the converters that interface the motor into battery bank. The battery bank, motors and PE circuits are controlled by the vehicle main controller, which has the objectives of reducing the running cost while introducing high levels of comfortability, safety and reliability.
Large charging stations, workplace chargers, public chargers, and private home chargers [6] could all be used to power these EVs. The availability of these charges depends on the local distribution network. The distribution network may be damaged if this new load, which quickly consumes a lot of electric energy from the power system, is not adequately controlled. This will necessitate pricey infrastructure modifications for local grids. It is feasible to use various techniques to increase the range of an EV. Combining energy sources like fuel cells, solar PV, and ultra-capacitors allows for the creation of a Hybrid Energy Storage System (HESS), which outperforms the constituent energy sources [6] by continually charging the battery throughout the trip. With a greater charge/discharge rate and low internal resistance, the usage of Ultra-Capacitors (UC) extends battery life cycles and boosts efficiency. This is realized by managing the power demand under transient conditions. Power transfer efficiency is required for the inclusion of sources. The transport of energy from sources to loads depends on power electronic circuitry. To manage different sources and create stability at the DC bus, the DC-DC converter is crucial.

2. Integrating renewable energy sources to improve the power system of charging/discharging of the EVs.

Reducing carbon emissions and advancing sustainability in the transportation industry can be accomplished through incorporating renewable energy sources into the energy infrastructure used to charge and discharge electric vehicles (EVs). Infrastructure for EV charging can be made more effective and ecologically friendly by utilizing renewable energy sources like solar and wind power. In addition to improving system resilience and dependability, this integration may assist reduce peak demand problems and grid congestion. When EV charging is combined with renewable energy sources, greenhouse gas emissions from traditional fossil fuel-powered automobiles can be greatly reduced. . Compared to internal combustion engine vehicles, studies have demonstrated that electric vehicles powered by renewable energy have a reduced lifetime carbon footprint [7]. Smart charging systems can maximize the usage of renewable energy by planning charging during periods of low demand and high renewable energy generation. Grid stabilization services are made possible by vehicle-to-grid (V2G) technology, which enables EV batteries to store excess renewable energy and release it back into the grid as needed [8]. By minimizing the effects of climate change and lowering reliance on fossil fuels, diversifying the energy sources used for EV charging with renewable energy sources improves energy security and resilience [9]. Since hybrid cars require less fuel and maintenance than conventional cars, integrating renewable energy for EV charging can eventually result in cost savings. Furthermore, V2G service income streams can offer EV owners financial incentives [10].

3. Environmental benefits of using EVs

Throughout their lifetime, electric vehicles (EVs) emit fewer greenhouse gases than traditional internal combustion engine vehicles (ICEVs). Research shows notable reductions in emissions even after accounting for emissions from the production of power [11], [12]. Because they reduce tailpipe emissions of pollutants like nitrogen oxides (NOx), particulate matter (PM), and volatile organic compounds (VOCs) [12], EVs help to enhance the quality of the air. In urban regions with heavy traffic, this reduction in air pollutants is especially advantageous [13]. Compared to conventional cars with internal combustion engines, electric vehicles are quieter to drive, which lessens noise pollution in cities. In highly populated places, this may result in improved livability and lower stress levels [14]. Due to regenerative braking and the effectiveness of the electric drivetrain, EVs often have superior energy efficiency than ICEVs. As battery technologies develop, they become more ecologically friendly and energy-dense, which helps conserve resources. Because EV adoption is compatible with sustainable electricity generation, it encourages the deployment of renewable energy sources. A greater demand for electric vehicles (EVs) may spur infrastructure investment in renewable energy, hence lowering carbon emissions from the production of power.

4. Economic issues from users or owners and for power systems

Compared to conventional internal combustion engine vehicles (ICEVs), electric vehicles (EVs) frequently have a higher initial cost. The upfront outlay may still be a deterrent for some buyers, even though the vehicle's lifetime total cost of ownership may be cheaper due to lower running and maintenance expenses. Compared to ICEVs, there are still fewer options available in terms of vehicle kinds, sizes, and features, despite the fact that the availability of EV models has been constantly growing. Some customers might be discouraged from converting to electric vehicles by this limited selection. Customers may have range anxiety due to worries regarding an EV driving range and the accessibility of charging infrastructure [15]. Because they are afraid of running out of battery power on long excursions, some prospective consumers may be reluctant to transition to electric vehicles, even though the range of EVs is increasing thanks to developments in battery technology. It can be expensive to install charging infrastructure at homes or in public areas, particularly for fast-charging stations. Even with potential government subsidies and incentives to help defray some of these costs, EV owners and operators still have to factor in the cost of installing the necessary charging infrastructure. Factors like quick technology improvements and battery deterioration can impact the resale value of electric vehicles. Consumers' financing choices and purchase selections may be influenced by worries about depreciation and resale value [16], [17]. When EVs are widely used, current electrical grids may be overloaded, especially during times when EV charging is at its highest. Increased grid demand from EV charging could result in voltage fluctuations, reliability problems, and grid congestion if proper infrastructure upgrades and grid management solutions are not implemented. Strategies for load management and demand response are made possible by the integration of EVs into the power grid [18]. Grid operators can better balance the supply and demand of power by offering incentives to EV owners to charge during off-peak hours or to engage in vehicle-to-grid (V2G) programs. This can save infrastructure investments that can be high. The widespread deployment of EVs requires the provision of a suitable and easily accessible infrastructure for charging [19]. To solve range anxiety and enable convenient EV charging for consumers, public and private investment in the deployment and maintenance of charging infrastructure is required. Gas stations and other traditional fuel providers may see changes in their revenue streams as more cars switch from gasoline and diesel to electricity. Utilities may also see changes in their business models as a result of this move. In order to handle the increasing number of EVs on the road, utilities may need to investigate creative pricing systems, invest in smart technology and infrastructure upgrades, and adjust to changing demand patterns. Electric vehicles (EVs) do not contribute to fuel tax earnings, which are normally used to pay for the upkeep and enhancement of transportation infrastructure, because they do not run on gasoline or diesel [20]. Therefore, in order to guarantee stable funding for transportation infrastructure in a future when EVs predominate, policymakers may need to take into account new taxation methods or alternative revenue streams.

There are numerous numbers of research articles on EV charging technology characteristics accessible in the literature, depending on a number of parameters. Therefore, the primary goal of this work is introducing review article regarding the different charging mechanism and methodologies of EV. That article could act as a guide for the researchers and the reader in the areas of EV, charging technology and other related fields.

The contributions of this article are:

- Providing an advanced review of evolving converter topologies and EV charging strategies.
- Outlining theoretical implementations of battery chargers and charging stations specifically for electric vehicles, with potential applications to other power electronic systems.
- Completing contrast between battery replacement and conductive and inductive charging techniques. Regarding projected power levels (kW), charging times, charging efficiency, necessary infrastructure, needed battery sizes, electric shock risk, and range anxiety, among other factors, expected power levels are located.
- Classifying of electric vehicle charging technologies according to their characteristics.

This is the order in which the remaining text is presented. In Section 2, the EV categorization is shown. An overview of EV technology is given in Section 3. In Section 4, an overview of the global EV standards is provided, covering connectors and charging. The classification of EV charging methods is covered in Section 5. In section 6, EV charger converter topologies and configurations are examined. Lastly, the conclusion is provided in Section 7.

5. Classification of Electric Vehicles

Electric vehicles could be classified based on level of electrification, the type of energy storage system, and capacity to use grid power. According to the energy technology employed [21], [22] the four most significant types of EVs may be inferred:

a. Hybrid Electric Vehicle (HEV)

HEV is one that combines an electric propulsion system with a traditional internal combustion engine (ICE) propulsion system. The term "dual-power source vehicle" is also used to describe HEVs [9,10]. Because of regenerative braking allows the battery to be recharged by recapturing the kinetic energy of the vehicle. The fuel tank, the combustion engine, the gearbox, and the gearbox to the wheels make up the mechanical drive. A battery, an electric motor, and power electronics for control make up an electric drive. Ultra capacitors have a lot of promise for use in HEVs. When compared to batteries (Lithium Ion and Nickel Metal Hydride), they have the advantage of being a more durable power source [25], [26], [27].

b. Plug In hybrid Electric Vehicle (PHEV)

In PHEVs, an electric motor is powered by batteries, whereas an internal-combustion-engine (ICE) runs on a different fuel, such gasoline. PHEVs often feature a larger battery pack than a regular HEV [14,15]. Typically, an automobile runs on power up to the battery is nearly depleted, at which point it automatically converts to internal combustion engine power. Three methods are available for charging the battery: internal combustion engine, regenerative braking, and hooking into an electrical power source. Regenerative braking involves capturing and storing kinetic energy that would otherwise be wasted while braking in the battery[30].

c. Battery Electric Vehicle (BEV).

The electric motor that drives this type of vehicle is powered by electricity stored in a battery pack. The only moving components are the wheels, coolant pumps, and an electric motor; there is no internal combustion engine. Occasional wireless charging of the battery is possible, however other power sources can also be used to charge the battery [14,15]. BEVs are far more effective than equivalent conventional cars at turning energy into motion. Long charging times and a lack of public charging infrastructure provide the biggest obstacles for BEVs. Some suggested solutions will be presented in this article[31].

d. Fuel Cell Electric Vehicle (FCEV).

FCEVs are driven by an electric motor, just like BEVs. Fuel cells and hydrogen fuel are used in place of batteries. When compressed hydrogen from the vehicle mounted tank is combined with atmospheric air. DC energy is generated to power the electric motor, and water is produced as a byproduct, which is released through the exhaust pipe [14,15]. The FCEV is an environmentally friendly vehicle because there is no carbon in the fuel and therefore no CO2 output. Additionally, during the conversion process, there is no combustion and no usage of high temperatures. [32]

6. EV Charging Stations

It is necessary to have a properly dispersed recharging infrastructure with safe and trustworthy recharging choices to satisfy user needs and advance the adoption of electric transportation. This is because the market for electric vehicles (including electric and plug-in hybrids) is expanding quickly and because the battery capacity of these vehicles is rising. Electric vehicle charging technologies could thus be divided into three basic categories: Inductive Charging (IC), Conductive Charging (CC), and Battery Swap (BS) as shown in Table 2.

Table 2 Comparison between the conductive charging, inductive charging, and battery swapping methods [33].

EV Charging Stations Technologies	Power Levels & Location	Expected Power Level (KW)	Charging duration	Charging efficiency	Infrastructure required	Required battery size	Risk of electric shock	Range anxiety
AC	Slow Charge (Level I) On-board	Single phase 3.6 kW	6 - 8 hours	High	Depending on charging power levels but relatively low	High	Possible	Depending on the state of charge of the batter
	Semi-fast Charge (Level II) On-board	Three phase up to 22 kW	1 - 3 hours					
	Fast Charge (Level III) Off-board	Three phase up to 43 kW	15 - 30 min					

DC	Fast Charge (Level III) Off-board	1000 W up to 400 kW	15 - 20 min					
Static	Slow Charge (Level I)	3 kW	4 - 8 hours	Lower than CC and BS	High	High	Safer than CC and BS	
	Fast Charge (Level III)	50 kW	15 - 30 min					
Dynamic	Charging along the way	Lower than CC and BS						
	Very high	Lower than the other methods	Safer than CC and BS	Lower than the other methods due to charging in motion				
BS			5 min	High	Very high	High	Possible	Depending on the state of charge of the battery

6.1. Conductive Charger (CC)

The process of physically connecting an electric vehicle (EV) to the electrical grid and charging it is known as "conductive charging." EVs could be charged via conductive charging using both on- and off-board chargers. Using the on-board charger that is built into the car, an EV can be charged by plugging it into an electrical outlet. To connect to the grid, this doesn't need any more gear. Because of the charger's restricted power transfer capacity, charging an EV using this way takes longer[33]. Because off-board chargers offer a larger power output, they can charge EVs faster. On the other hand, these chargers are more costly, complicated, and occasionally unavailable [10].

6.2. Inductive Chargers (IC)

When employing the inductive charging technique, an actual physical connection between the electric vehicle and the power grid is not required. Another name for it is wireless charging. Rather, an electromagnetic field is used to transport electricity. One advantage of inductive charging is a lower danger of electric shocks and related damages because of the power transmission through the air gap; nevertheless, the charging efficiency is negatively impacted in this scenario because of the relatively large air gap and the non-compliance of the windings [18,19]. In general, there are two types of uses for inductive charging: static and dynamic. The EV charges in static mode while it is stationary, as shown in Table 1. However, The dynamic charging option allows the EV to be charged while it is in motion [36] [37]. Dynamic inductive charging has the potential to reduce battery capacity, which will assist users in overcoming a number of challenges, including a restricted driving range, long charging times, and higher EV prices in comparison to traditional internal combustion engine vehicles.

6.3. Battery Swapping (BS)

Switching out the batteries in an EV is one of the quickest ways to get the battery fully charged. By using this strategy, the EV's owner can replace the depleted battery with a newly charged one by going to a battery swapping station. By handling charges, discharging, and battery switching, this technique helps the BS station and considerably saves the charging time [22,23]. Moreover, proper management of the charge and discharge of the batteries at the battery switching station could improve grid performance generally and operations [40]. This method could reduce the gap between peak and valley needs and facilitate the grid's integration of more renewable energy sources. However, there are certain drawbacks to this approach: the battery must be designed in such a way that it can be quickly removed from the electric vehicle and replaced with a brand-new battery due to the exclusive nature of the battery, unique compatibility, and difficulty in finding a similar battery.

7. International Standards for EV charging connectors

The SAE J1772 plug, often known as a "J plug," is the most widely used port and connector for Level 1&2 charging systems. Any Level or Level 2 charging station can be used by vehicles equipped with this equipment. Except for Tesla, the majority of EVs in North America come with this plug as standard. However, when a Tesla vehicle is purchased, an adapter is included. The DCFC stations don't all adhere to the same standard. While most EV manufacturers utilize the CHAdeMO or the Combined Charging System (CCS) for fast charging, Tesla has its own connected network. A vehicle with a CHAdeMO port cannot charge using a CCS connection since these connectors are not compatible. Table 3 contrasts various EV charging connector types.

Table 3 International specifications for connections for electric vehicle charging [41].

Standard	Charging Type	Compatibility	Connector	Standards
Port J1772	Level 2	100% of EVs (Tesla requires an adaptor)		SAE j1772 IEC 62196
CHAdeMO	DCFC	Dependent on EV manufacturer (e.g., Nissan & Mitsubishi). Tesla requires an adapter.		IEC 61851-23, -24 IEC 62196-3 IEEE2030.1.1TM-2015
SAE Combo CCS	DCFC	Dependent on EV manufacturer (e.g., General Motors & Vokswagen). Not Tesla compatible.		IEC 62196 1/2/3 IEC 61851-1/22 IEC 61851-1/23 ISO/IEC 15118 DIN SPEC 70121 SAE J2847/2
Tesla Connector	Level 2 & DCFC	Tesla only		IEC 62196

8. EV Charging Technique Classification

EV battery chargers come in a broad variety. They are typically categorized based on factors including location, type, galvanic isolation, and power flow direction [42].

a. On-board Chargers (On-BC)

On-BCs are the kind of chargers that is built into the car and have a converter, an inverter, and a controller. The power of these chargers On-BC is constrained by their size and weight. They often work with Level 1&2 chargers as a result. The onboard charger, which is well-liked in the automotive industry, enables electric vehicles to be charged directly from the AC grid. The range of the electric vehicle is directly proportional to its battery capacity [26,27]. Figure 1 depicts the configurations of the onboard EV charger.

b. Off- Board Chargers (Off-BC)

Off-BCs, the charger is located outside the car. It is not constrained by the size and weight issues present in lower levels and are compatible with Level III chargers. Typically, the Off-BC mechanism has two stages: Battery-side DC/DC converters are used to support charging electric vehicle batteries, followed by grid-side AC/DC converters [45]–[47]. The EV battery receives DC power from an external, separated power converter via the cable. Up to 50 kW more power is available for an Off-BC than from an on-board one. The topologies for the DC/DC converters can be either one directional (G2V) or two directional (G2V and V2G). Electric vehicle charging at the DC level is shown in Figure 1 (EVSE contains an Off-BC) [48].

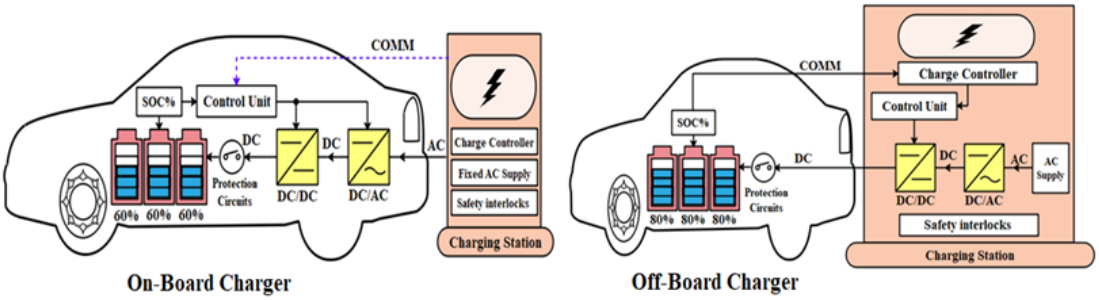

Figure 1. The structure of conventional on-board and off-board EV chargers [31].

9. Electric vehicle charging topology

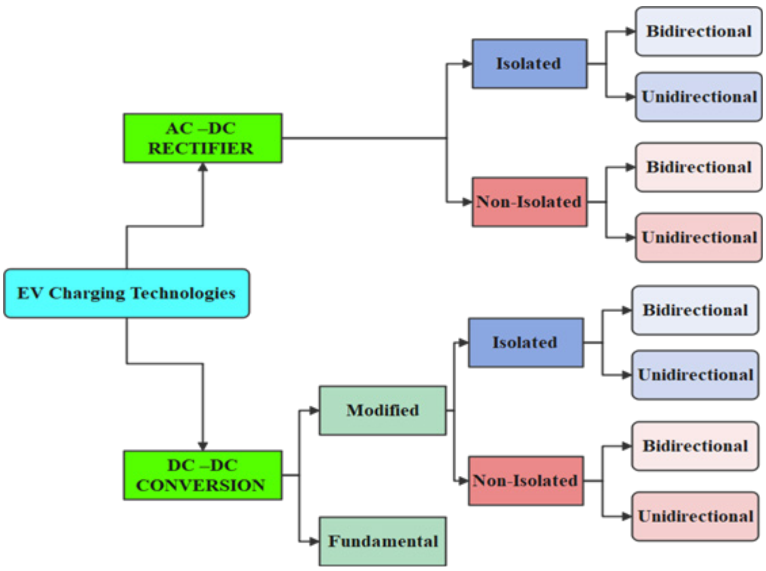

Figure 2. Classification of electric vehicle charging topology[49].

An EV battery charger usually has two conversion steps. The first is the AC-DC conversion step, which ensures unity power factor by rectifying incoming AC power from the grid into the necessary DC power. The second is DC-DC conversion, which involves stepping up or down DC voltage to accommodate different battery requirements. This voltage fluctuates according to the battery pack's state of charge (SoC). Therefor, the charging circuits for electric vehicles are classified into two primary types: AC-DC converter and DC-DC converter. Fig. 2 shows the many topological classifications of these circuits. Modified and fundamental converter topologies are the two categories under which DC-DC converters are classified. Isolated and non-isolated modified converter topologies are also separated.

9.1. Topologies for AC–DC Conversion Stage

As an intermediary between the DC connection and the power grid, the AC-DC converter offers superior power quality on both the DC and AC sides of the charging system. Either single-phase H-bridge inverters or three-phase, three-leg inverters with controlled or uncontrolled legs are frequently used in their creation [50]. Initially, the EV charging system consists of an AC-DC converter that controls reactive power consumption and grid-side current harmonics [51]. The PF correction technology in the AC-DC converter ensures efficient and secure power output for consumers, associated devices, and the grid.

Table 4 illustrates the phase topology of the AC-DC converter. The table is an extensive comparison based on the operating frequency, power rating, and efficiency. However, the table shows, reference, component count, efficiency, output voltage of the circuit and the charging voltage level.

Table 4 Classification of AC/DC converter circuits.

REF	Freq. (KHz)	Power rating (W)	Component count S	L	D	C	Efficiency	Vout. (V)	Charging level (V)
[50]	50 / 90	2.8k	2	3	6	6	NR	340 / 520	380
[51]	72	10k	6	3	6	3	97.3%	700	300
[51]	250	10k	6	2	6	3	96.7%	700	400
[52]	36	7.5k	8	2	8	4	98.5%	230	400
[52]	18	2.5k	10	4	19	1	97.52%	200	230
[53]	60	NR	6	2	6	4	98.1%	400	200 / 240
[54]	200	1.5k	6	5	8	6	98.2%	400	380
[54]	200	1k	6	5	7	5	NR	200	220
[55]	50	5k	12	6	4	4	NR	380	400 / 480
[56]	27	8k	8	5	10	4	99.3%	230	400
[57]	90	10k	10	6	10	12	95%	400	380
[58]	36	7.5k	16	5	0	4	96.8%	400	230
[59]	50	1.8k	6	3	6	2	98.84%	700	440
[60]	70	15k	12	6	0	5	>98%	800	400
[61]	20	3k	6	3	0	2	NR	400	120
[62]	100	6k	6	3	0	0	98.3%	650	230
[63]	48	22k/3-ph 19k/1-ph	6	19	2	13	NR	400 / 32A 240 / 80A	240
[64]	10	NR	8	1	0	3	95.46%,	3ph/100 / 1ph/120	230
[65]	120	2k	28	4	0	1	96%	400	311
[66]	30	175	8	2	4	2	92.5%	200	127
[67]	10	3.3k	6	2	0	1	99.2%	300 / 600	85 / 265
[68]	100k	6.6k	8	3	2	1	98.86%	400-600v	240
[69]	4k-30k	10k	8	0	0	2	99%	650v	325

Table 4 shows that some circuits could produce significant high efficiency, particularly for high power ratings.

9.2. Techniques for DC_DC Conversion Stage

Both the on/off board chargers have both a unidirectional and a bidirectional DC-DC converter. The fundamental topologies and modified topologies, which are variations of the fundamental topologies, are the two primary categories of unidirectional charger converter topologies, as shown in fig. 2.

9.2.1. Fundamental Converter Topology

According to whether the current is flowing in a unidirectional or bidirectional manner, Table 5 illustrates the most relevant fundamental topologies for use in electric vehicle charging topologies.

A new low-loss ZVT circuit is suggested in [70] for a boost-based PFC circuit used in an electric vehicle's battery charging application.
In [49] a group of diode-assisted DC. DC converters compared to a conventional DC-DC converter in situations involving renewable energy is demonstrated. A buck converter-based high PF rectifier that operates in dis-continuous capacitor voltage method is proposed in [71]. A study investigation of a bi-directional DC. DC converter prototype for small-size electric vehicles driven by axial-flux PM motor drives is presented in [72]. A 30kW standalone fast battery charging system for EVs was made available in[73].
The proposed system consists of a non-isolated bidirectional DC-DC converter with coupled inductors and an active front-end rectifier.
It can operate with both lithium-polymer and lithium-ion batteries. In [74], a modified bidirectional SEPIC/Zeta converter for storage systems for renewable energy is shown.

Table 5 Classification of Fundamental DC-DC converter circuits.

Power Flow	Ref.	On/Off Board	Freq. KHz	Power rating	Component Count S	L	D	C	Efficiency	Vout. (V)	Charging level (V)
Unidirectional	[70]	On/Off	500	3.3kw	1	2	1	2	NR	400	240
	[49]	On/Off	10	3.3/6.6kW	1	1	1	1	94.13%	600	90-265
	[71]	On/Off	100	100W	1	2	1	2	80%	48	255
Bidirectional	[72]	On/Off	15	NR	2	1	0	1	<95%	450	60
	[73]	On/Off	10	30 kW	4	2	0	2	NR	50-450	342-506
	[74]	On/Off	50	200w	2	2	0	2	92%	24	200

9.2.2. Modified Converter Topologies

The on-board charger and off board charger contains unidirectional and bidirectional DC-DC converter.

9.2.2.1 Unidirectional DC-DC Converter.

Unidirectional battery chargers meet the demand for a secure, dependable, and cost-effective EV charging solution by offering an easy-to-use and manageable way to manage an EV fleet. Nevertheless, as unidirectional EV chargers cannot fully secure main grid management (frequency and voltage regulation), EVs are anticipated to play a major role as they grow more common in the transportation industry. Therefore, in order for EVs to serve as distributed energy storage on the power grid, bidirectional power flow topologies are needed[75].

9.2.2.2 Bidirectional DC-DC Converter

One sort of DC converter that permits power flow inversion is the bi-directional DC. DC converter. They permit the transfer of DC voltage between two levels in both directions. [76]. One of the two voltages is larger than the other in magnitude.
In a V-to-G connectivity subsystem, a bidirectional DC-DC type converter carries out the two separate tasks mentioned below: while the battery is in the G2V mode, also referred to as the charging mode, its voltage is adjusted to the proper level of charging voltage; while it is in the V2G mode, its voltage is changed to DC side voltage. Table 6 lists the features of both bidirectional and unidirectional converters.

Table 6 Unidirectional /bidirectional energy flow characteristics of EVs.

FEATURES	UNIDIRECTIONAL CHARGING (G2V)	BIDIRECTIONAL CHARGING (V2G)
Power flow	G2V	Bi-direction
Type of switches	Diode bridge and Unidirectional powerconverters	High-powergate thyristor and Low and medium power transistors
Control system	☐ Charging current is actively controlled ☐ The system is straightforward and easy to use ☐ Energy pricing strategies are employed to regulate basic control	☐ Additional drive circuit with a complex control system. ☐ Safety precautions control ☐ Effective communication system
Services	☐ Frequency regulation, ☐ Load levelling, ☐ Load profile management and ancillary services	☐ Regulation of frequency and voltage ☐ Assistance with backup power during peak times. ☐ Support for active and reactive power. ☐ Aids in integrating RESs into the grid.
Safety	non-isolated /Isolated	Isolated and non-isolated, with strong safety precautions and anti-islanding protection
Merits	☐ Reduced operational costs, power losses, emissions, overloading, and connectivity concerns ☐ Provide voltage and frequency controls. ☐ Support reactive power of regulating the current phase angle.	☐ Improve load leveling, active and reactive power support, voltage profile, and power quality ☐ Control of frequency, voltage, and peak load reduction. ☐ Reducing grid power losses and emissions ☐ An improved load factor and higher profit ☐ Make RES and grid integration possible
Demerits	☐ A power connection was necessary for the limited services.	☐ Two-way power converters and communication are necessary. ☐ High complexity, capital expense, energy waste, and device stress. ☐ Smart sensors and meters are required. ☐ Quick battery deterioration

9.2.2.3 Non isolated DC-DC Converter

Non isolated converters are favored for moderate and elevated power applications in EVs because of their straightforward construction, high power density, and attainable control schemes [77]. Non-isolated methodologies have the advantages of using fewer switches and passive components, being less expensive, and having a smaller physical footprint than isolated methodologies because the high-frequency isolation converters is not present [78].

In reference [79], an enhanced interleaved phase-shifted semi-bridgeless boost converter is suggested for EV battery charging applications. This converter employs an interleaved network to produce an equal current injection. In [80] suggested a simplified bridgeless topology for input harmonic distortion and conduction loss reduction in electric vehicle battery chargers. The converter is developed with built-in PF correction ability at the man's side. For use in the application of on-board EV charging, [81] provided a single phase (SPH) switched mode bridgeless AC/DC buck/boost converter. The suggested converter is more dependable, affordable, and resilient than traditional continuous current conduction mode converters because it operates in DCM mode, which achieves natural PFC for fluctuating AC input. Two new Ferdowsi rectifiers, or PF correcting rectifiers with buck/boost capabilities, are presented in this ref. [82].

In [83] presented a two-switch topological 1-phase non isolated on board circuit for electric vehicles. The one switch bridgeless PFC one-ended primary-inductor converter structure that is suggested in [84] has modifications to address the shortcomings of the current design. The improved structure is intended to function in DCM mode to obtain nearly a unity PF. In [85] suggested a new EV charging based on a bridgeless Cuk converter with enhanced power quality features. For electric bikes using battery, [86] presented a PF correction converter based on a one stage switching inductor Cuk converter. In [87], a cheap, small charger for light-electric vehicles (LEVs) based on a bridgeless switching inductor converter was described. By utilizing a one-stage step down DC voltage gain, the charger increases low voltage reliability while reducing the cost and size of its magnetic components. The EV charger illustrated in [88] is built around a bridgeless isolated Zeta-L converter with supply side power factor reregulation capabilities.

A new AC/DC bridgeless buck converter that has high PF correction performance and naturally low dead-zones for PF correction applications presented in [89]. To get around all of the restrictions for conventional design, [90] introduced a multi-port SIMO DC-DC converter. The proposed topology operates independently of the other loads, producing separate outputs during operation with no limitations on duty ratio or inductor current charging. In [91] examined the effectiveness of a large step-up S-Z-source DC/DC converter model for applications involving 3-ph H-bridge inverters that are grid-connected. In [92] suggested that a DC converter with a novel topology be used in automotive applications to control an EV electrical storage system. a new voltage-doubler-based topological Q-Z-source elevated step-up DC converter for the P-V system suggested in [93]. In comparison to a conventional Q-Z-source DC converter, the converter offers a number of benefits, such as fewer stresses on circuit components, a common ground switch, and decreased voltage ripple at the output.

An innovative architecture for electric car off-board quick battery charging is found in [94]. The suggested architecture is founded on a converter with two stages and acts as an interleaved converter to minimize the footprint of passive filters and minimize grid current harmonic distortion. In [95] a DC rapid battery charger for EV is presented. The objective is to generate output-current-ripple while minimizing input-voltage-ripple. A modular 3-ph interleaved converter serves as the basis of the charger. The new bridgeless buck PF-Correction converter proposed by [96] decreases dead angles in the current in order to increase input-current-harmonics and PF. To improve the efficiency of the present battery chargers utilized in electric vehicles, [97] suggested a modified bridgeless Luo converter. By removing the input diode bridge from the typical power factor correction converter, the converter provides a high-power density at a reasonable cost.

The Modified bridgeless Positive-Output-Luo converter is created in [98] with the goal of improving power quality and maintaining DC voltage at the output side. The design and carrying out of a novel PF pre-regulator based EV battery charger utilizing an interleaved-L converter are described in [99]. The suggested charger maintains consistent battery voltage utilizing a flyback converter while charging the battery at a high-power level with dependability and efficiency. It also lowers switch conduction loss. According to component number, power-factor, charging level, output voltage, switching frequency, efficiency at rated power, and total harmonic distortion, Table 7 analyzes several non-isolate unidirectional DC-DC converters employing varied topologies. The comparison enables us to select an eco-friendly EV on/off board charger converter topology that is less complicated and more efficient.

Table 7 Classification of Non-isolate modified Unidirectional DC-DC converter circuits.

REF	On /Off Board	Freq. kHz	Power rating	Component Count S	L	D	C	Efficiency	Vout (V)	Charging level (V)
[50]	On	110	50W-750W	2	2	4	1	96 % - 99 %.	400	Level1&2
[79]	On	NR	20W-600W	2	4	10	1	93%-96%	388	85 / 265
[80]	On	20	100W-850W	2	2	4	1	45%-82%.	48v	Level1
[81]	On	1	250W-1kW	2	1	2	1	90%-96%	400v	Level1
[61]	On	NR	6 kW	4	2	2	1	96 % - 98 %.	NR	NR
[82]	On	60	60W-300W	2	3	2	3	89%-93%	48 v	Level1
[82]	On	60	60W-300W	2	3	2	3	89%-94%	48 v	Level1
[83]	On	30	300W-1kW	2	2	2	2	91%-96%	150V-450V	Level1&2
[84]	On	50	160W	1	3	3	3	NR	48v	Level1
[85]	On	50	150W-850W	2	3	2	4	87%-90%	300v	Level1& 2
[85]	On	50	150W-850W	2	4	4	3	88%-92%	300v	Level1&l2
[86]	On	25	300W-500W	1	3	2	2	78%-84% at	48v	Level1&2
[87]	On	20	130W-850W	2	2	4	2	79%-89%	45v-65v	Level1&2
[88]	On	30	150W	2	4	4	3	87%-95%	60v	Level1
[89]	On	20	40-120	2	2	3	1	85%-90%	85	Level1
[90]	On/Off	10	100W	2	2	2	2	NR	NR	48v
[91]	On/Off	3	NR	2	3	2	3	83.6%	160v	Level1
[92]	On/Off	400	30kW	3	2	0	2	95%	400v	48:
[93]	On/Off	NR	40W	1	2	3	4	94.9 %.	114v-286v	40v
[94]	On/Off	50	40k	4	2	0	3	98%	200-500v	400v
[95]	On/Off	16	150k	6	3	0	1	98.5%	600-800	NR
.[96]	On	50	35-100	1	3	5	3	NR	130	Level1&2
[96]	On	300	30-300	2	2	2	1	NR	80	Level1

[110]	On/Off	50	200W	4	1	0	3	94.8%	24	200
[111]	On/Off	10	285W	3	5	7	5	NR	380-400	40-50
[112]	On/Off	10	270W	3	3	3	3	NR	63.5	36-70
[113]	on	NR	NR	4	2	0	4	97.25%	430v	48V, 96
[114]	On/Off	50	500W	5	2	0	2	96.37% - 93.08%	200	24
[115]	On/Off	50	500W	7	2	0	4	95.3%, 93.8%	200	24
[116]	On/Off	20	100	2	2	4	3	90.21%	350	200
[117]	On/Off	50	160W	3	2	3	3	93.2%	400	20
[118]	On/Off	25	150W	1	5	3	3	95.2%	150	20

9.2.2.4 Isolated Modified DC-DC Converter

In autos, isolated DC/DC converters are commonly used for low-medium-power applications. The most often used architecture for DC/DC converters in EV charging applications is full-bridge isolated. It is important to have isolation for high power fast charging stations, which are usually placed between the EV battery and the grid. Examples of these stations include a line-frequency transformer linked in front of the AC/DC converter or a high-frequency transformer attached to the DC/DC converter. Nevertheless, high voltage DC/DC converters have certain disadvantages, such as low efficiency due to hard switching, challenges in establishing high bandwidth control loops, challenges in achieving high power density, and challenges in providing flat voltage with moderate switching gate signals. Table 9 compares the characteristics of isolated and non-isolated DC/DC converters. The comparison is based on merits and demerits OF converters.

Table 9 Comparison of isolated and non-isolated DC-DC converters.

	Merits	Demerits
Isolated Converter	▪ High efficacy of PF; ▪ Low output ripple; ▪ Advanced output regulation capabilities	▪ **Complicated design and control,** ▪ **Requires extra components,** ▪ **Expensive and rising in weight and space,** ▪ **Inefficient operation at light load**
Non-Isolated Converter	▪ **Easy design and control approach,** ▪ **Affordable and lightweight, Small input/output filter,** ▪ **High power and energy density**	▪ **The stress caused by high voltage on switching devices,** ▪ **High line frequency and current ripples,** ▪ **Input current that is not constant**

In [119] interleaved L-L-C converter for charging highly depleted plug-in electric vehicle batteries that has cascaded voltage-doubler circuits. When used in simultaneous mode with easy frequency control. An LLC resonant converter for an on board lithium battery charger of a PHEV is presented in this research along with a step-by-step design technique [120]. Additionally, it analyzes the worst-case situations for primary-side zero-voltage switching operation and suggests a design focal point to guarantee soft-switching function globally. In [121] a modulation method for a FB, 3-level LLC converter for EV battery chargers. A high-switching-frequency TC-mode, high-performance, two directional-interleaved buck converter in [122] was suggested to charge batteries with digital control. For two-active-bridge DC/DC converters utilized in two-directional, two-stage EV on-board battery chargers, it provides a transformer saturation prevention algorithm in [123]. In [124] provided a technique for expanding the ZVS range in dual-active-bridge based two-directional chargers for electric vehicles for both temporary and transient operations. A 3-level dual-active-bridge converter for a two-directional EV charger that includes blocking capacitors in [125]. The converter can adjust to the wide voltage range of EVs, and an algorithm for operating mode selection has been devised to reduce the converter's transformer RMS current.

[112] offered 4-stage, very precise, ripple-free DC converter for an electronic power conditioner. The galvanic isolated 4-stage technique has four cascade connections: a buck circuit, a push-pull circuit, a power converter, and a voltage regulator. The output-side rectifier's push-pull switches and the diodes work in ZVS and ZCS modes at both switch-off/on, which aids in improving efficiency. In order to charge and discharge batteries in an ES system, a new, high-efficiency, bidirectional isolated DC converter is presented in [126]. A linked inductance and switched-capacitor voltage doubler may be incorporated into the suggested converter to provide for both isolation and in two directions power flow. Additionally, the suggested topology may recover the energy from leakage inductance to increase conversion efficiency. ZVS is present in the main switches, which lowers switching losses. In [127] presented a novel one-stage ac/dc rectifier that allows for bidirectional power flow, high-frequency isolation, and the connection of dc grids to ac grids. For obtaining high efficiency and high-power density, a SiC two directional LLC charger architecture proposed in [128].

Table 10 Classification of Isolated Modified (Bidirectional/ Unidirectional) DC Converter circuits.

Power Flow	Ref.	On/Off Board	Freq. (kHz)	Power rating (W)	Component Count S	L	D	C	Efficiency	Vout.	Charging level
Unidirectional	[104]	on	20	100 / 750	2	4	2	3	60%-90%	300v	Level1&2
	[119]	off	70.96 / 472	1.5 k	4	4	4	7	95.65%	50-420V	Level3
	[120]	off	75 / 300	3.2 k	4	4	4	3	98.5%	250-400V	Level3
	[131]	off	83.33 / 220	3.3 k	4	3	4	2	98.2%	250-450V	Level3
Bidirectional	[122]	On/Off	350k-1MHz	1k	4	2	0	2	97.52%	35-50V	Level1 66V
	[123]	off	125	6.6	8	3	0	1	96.8%	320-450	Level3
	[124]	off	100	20	8	1	0	2	96%	200-450	Level3
	[125]	off	50	3.5	16	1	8	10	97.5%	200-700	Level3
	[132]	off	100	130	5	4	3	1	94.5%.	7000v	Level3
	[126]	off	40	500	5	5	0	4	97.59% & 96.5%	48-400v	Level3
	[127]	on	NR	22k	12	1	0	2	97%	200-450V	80V to 260V
	[128]	on	300	6.6k	8	2	0	3	96%	240-420V	Level3
	[129]	off	100	1	8	2	0	3	97.7%	250	Level3
	[130]	off	500	12.5k	18	6	18	9	97%	400	Level3 800
	[133]	off	40	8k	24	6	0	3	96.6%	150v	Level3
	[134]	off	20	17k	6	2	0	2	98.3%	500v	Level3
	[135].	off	100	10k	8	1	8	14	98.2%	380-500	700-800 Level3
	[136]	NR	100	3.3k	8	3	0	12	NR	250-430	390-410

A modulation strategy is suggested for a dual-active-bridge series-resonant converter to lessen conduction and switching losses presented in [129]. To provide zero-reactive-power, a minimum tank current, and full soft-switching operation, the suggested technique uses switching frequency and, internal-external phase shifts, as modulation parameters. [130] provided a revolutionary

six-layer only PCB winding transformer for a three-phase CLLC resonant converter that incorporates all of the resonant inductors within the transformer and considerably shrinks the size of the magnetic component. Based on component count, charging level, output voltage, switching frequency, efficiency, and power, Table 10 analyzes several discrete unidirectional and bidirectional DC-DC converters. The comparison enables us to select an eco-friendly EV on and off board charger converter topology that is less complicated and more efficient.
According to their operating characteristics, EV charging technologies are summarized in Table 11 as follows: on-board, off-board, isolated, non-isolated, bidirectional, unidirectional, one stage, two stage, single/three phase, V-to-G, and V-to-V.

Table 11 Categorization of EV charging technologies according to their features [137].

Reference	On-Board	Off-Board	Isolated	Non-isolated	Bidirectional	Unidirectional	One Stage	Two Stage	Single Phase	Three Phase	V2V	V2G	Reference	On-Board	Off-Board	Isolated	Non-isolated	Bidirectional	Unidirectional	One Stage	Two Stage	Single Phase	Three Phase	V2V	V2G
[50]	√			√		√		√	√		√	√	[105]	√			√		√		√	√		√	
[70], [71]	√			√		√	√		√		√		[106]	√	√		√		√	√		√		√	
[72], [74]	√	√		√	√			√				√	[107]–[113]	√	√		√	√			√	√		√	√
[80]–[82]	√			√		√		√	√		√	√	[114]–[118]	√	√		√	√		√		√		√	√
[83]	√			√		√	√		√		√	√	[119]		√	√			√	√		√		√	
[84], [85]	√			√		√		√	√		√	√	[120], [121]		√	√			√			√		√	
[86]	√			√		√	√		√		√	√	[122]	√	√		√	√		√		√		√	√
[87]–[89]	√			√		√		√	√		√	√	[123], [124]		√	√		√		√		√		√	√
[90]–[92]	√	√		√		√		√	√		√		[125]		√	√		√		√			√	√	√
[93], [94]	√	√		√		√	√		√		√		[126], [132]		√	√		√			√	√		√	√
[95]	√	√		√		√	√			√	√		[127]	√		√		√			√	√		√	√
[96]	√			√		√		√	√		√		[128], [129]		√	√		√		√		√		√	√
[96]	√			√		√	√		√		√		[130]		√	√		√		√			√	√	√
[97]–[100]	√			√		√		√	√		√	√	[131]		√	√			√		√	√		√	
[104]	√			√		√		√	√		√		[133]		√	√		√		√		√		√	√
[102], [103]	√	√		√		√	√		√		√		[134]		√	√		√			√	√		√	√
[104]	√			√		√		√	√		√														

Table 11 provides a comprehensive overview of EV charging circuit technology by discussing a wide range of references. Regarding the state of the charging circuit On-Board or Off-Board status, whether it comes from isolated or non-isolated circuits, whether it is unidirectional or bidirectional, whether it operates in one or two phases, whether it is 1-phase or 3-phase, whether it can be powered from a vehicle Others, and whether they can be linked to a grid.

10. Conclusion

This paper provides an overview of the various EV types. Moreover, several types of charging techniques/topologies: on board, off board, one directional and two directional power flow circuits are thoroughly analyzed. The following conclusions could be extracted:

- Battery based EV is currently the core of EV industry. However, the limitations of the battery and charging system could represent as obstacle for EV. More research effort is required in these areas.
- The on-board chargers are limited owing to weight, space, and cost considerations.

- By properly constructing off-board chargers, difficulties with size and weight are avoided and higher charging power levels can be obtained.
- Hardware limitations and fewer connecting problems are provided by unidirectional charging.
- The core component of V-to-G technology is two directional charging.
- The potential benefits of V-to-G technology for the economy, the environment, and the power network make it an exciting area for research.

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REFERENCES

[1] G. Town, S. Taghizadeh, and S. Deilami, "Review of Fast Charging for Electrified Transport: Demand, Technology, Systems, and Planning," Energies, vol. 15, no. 4, 2022, doi: 10.3390/en15041276.

[2] P. Makeen, S. Memon, M. A. Elkasrawy, S. O. Abdullatif, and H. A. Ghali, "Smart green charging scheme of centralized electric vehicle stations," Int. J. Green Energy, vol. 19, no. 5, pp. 490–498, 2022, doi: 10.1080/15435075.2021.1947822.

[3] Y. Amry, E. Elbouchikhi, F. Le Gall, M. Ghogho, and S. El Hani, "Electric Vehicle Traction Drives and Charging Station Power Electronics: Current Status and Challenges," Energies, vol. 15, no. 16, pp. 1–30, 2022, doi: 10.3390/en15166037.

[4] Y. Ota, H. Taniguchi, J. Baba, and A. Yokoyama, "Implementation of autonomous distributed V2G to electric vehicle and DC charging system," Electr. Power Syst. Res., vol. 120, no. July, pp. 177–183, 2015, doi: 10.1016/j.epsr.2014.05.016.

[5] A. Mahesh, B. Chokkalingam, and L. Mihet-Popa, "Inductive Wireless Power Transfer Charging for Electric Vehicles-A Review," IEEE Access, vol. 9, pp. 137667–137713, 2021, doi: 10.1109/ACCESS.2021.3116678.

[6] S. Panchanathan et al., "A Comprehensive Review of the Bidirectional Converter Topologies for the Vehicle-to-Grid System," Energies, vol. 16, no. 5, 2023, doi: 10.3390/en16052503.

[7] M. Shafique and X. Luo, "Environmental life cycle assessment of battery electric vehicles from the current and future energy mix perspective," J. Environ. Manage., vol. 303, p. 114050, 2022.

[8] A. Alsharif, C. W. Tan, R. Ayop, A. Dobi, and K. Y. Lau, "A comprehensive review of energy management strategy in Vehicle-to-Grid technology integrated with renewable energy sources," Sustain. Energy Technol. Assessments, vol. 47, p. 101439, 2021.

[9] Y. Xue, L. Cheng, K. Wang, J. An, and H. Guan, "System dynamics analysis of the relationship between transit metropolis construction and sustainable development of urban transportation—case study of Nanchang City, China," Sustainability, vol. 12, no. 7, p. 3028, 2020.

[10] H. S. Das, M. M. Rahman, S. Li, and C. W. Tan, "Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review," Renew. Sustain. Energy Rev.,

vol. 120, no. February, 2020, doi: 10.1016/j.rser.2019.109618.

[11] X. Xia and P. Li, "A review of the life cycle assessment of electric vehicles: Considering the influence of batteries," Sci. Total Environ., vol. 814, p. 152870, 2022.

[12] S. Verma, G. Dwivedi, and P. Verma, "Life cycle assessment of electric vehicles in comparison to combustion engine vehicles: A review," Mater. Today Proc., vol. 49, pp. 217–222, 2022.

[13] M. S. Hossain, L. Kumar, M. M. Islam, and J. Selvaraj, "A comprehensive review on the integration of electric vehicles for sustainable development," J. Adv. Transp., vol. 2022, pp. 1–26, 2022.

[14] N. M. Manousakis, P. S. Karagiannopoulos, G. J. Tsekouras, and F. D. Kanellos, "Integration of Renewable Energy and Electric Vehicles in Power Systems: A Review," Processes, vol. 11, no. 5, pp. 1–27, 2023, doi: 10.3390/pr11051544.

[15] S. Sachan, S. Deb, and S. N. Singh, "Different charging infrastructures along with smart charging strategies for electric vehicles," Sustain. Cities Soc., vol. 60, p. 102238, 2020.

[16] J. Ebrahimi, M. Abedini, M. M. Rezaei, and M. Nasri, "Optimum design of a multi-form energy in the presence of electric vehicle charging station and renewable resources considering uncertainty," Sustain. Energy, Grids Networks, vol. 23, p. 100375, 2020.

[17] A. Ghasemi-Marzbali, "Fast-charging station for electric vehicles, challenges and issues: A comprehensive review," J. Energy Storage, vol. 49, p. 104136, 2022.

[18] F. Pardo-Bosch, P. Pujadas, C. Morton, and C. Cervera, "Sustainable deployment of an electric vehicle public charging infrastructure network from a city business model perspective," Sustain. Cities Soc., vol. 71, p. 102957, 2021.

[19] G. Sree Lakshmi, R. Olena, G. Divya, and I. Hunko, "Electric vehicles integration with renewable energy sources and smart grids," in Advances in Smart Grid Technology: Select Proceedings of PECCON 2019—Volume I, Springer, 2020, pp. 397–411.

[20] P. Barman et al., "Renewable energy integration with electric vehicle technology: A review of the existing smart charging approaches," Renew. Sustain. Energy Rev., vol. 183, p. 113518, 2023.

[21] S. Fan, J. Wen, J. Duan, Z. Song, and T. Liu, "A Full Load Range ZVS Isolated Three-Level DC/DC Converter with Active Commutation Auxiliary Circuit Suitable for Electric Vehicle Charging Application," Appl. Sci., vol. 12, no. 16, 2022, doi: 10.3390/app12168325.

[22] S. Bozhkov, "Structure of the Model of Hybrid Electric Vehicle Energy Efficiency," Int. Sci. J. "TRANS MOTAUTO WORLD, vol. 79, no. 3, pp. 76–79, 2021.

[23] W. Van Harselaar, T. Hofman, and M. Brouwer, "Automated Dynamic Modeling of Arbitrary Hybrid and Electric Drivetrain Topologies," IEEE Trans. Veh. Technol., vol. 67, no. 8, pp. 6921–6934, 2018, doi: 10.1109/TVT.2018.2834537.

[24] B. Kabalan, E. Vinot, C. Yuan, R. Trigui, C. Dumand, and T. El Hajji, "Efficiency Improvement of a Series-Parallel Hybrid Electric Powertrain by Topology Modification," IEEE Trans. Veh. Technol., vol. 68, no. 12, pp. 11523–11531, 2019, doi: 10.1109/TVT.2019.2952190.

[25] M. Khodaparastan, A. A. Mohamed, and W. Brandauer, "Recuperation of regenerative braking energy in electric rail transit systems," IEEE Trans. Intell. Transp. Syst., vol. 20, no. 8, pp. 2831–2847, 2019, doi: 10.1109/TITS.2018.2886809.

[26] W. Xu, H. Chen, H. Zhao, and B. Ren, "Torque optimization control for electric vehicles with four in-wheel motors equipped with regenerative braking system," Mechatronics, vol. 57, no. January 2018, pp. 95–108, 2019, doi: 10.1016/j.mechatronics.2018.11.006.

[27] S. K. V K Guruprasad Rao Editors, Lecture Notes in Electrical Engineering 750 Smart Sensors

Measurements and Instrumentation Select Proceedings of CISCON 2020. 2020. [Online]. Available: http://www.springer.com/series/7818

[28] C. Gschwendtner, S. R. Sinsel, and A. Stephan, "Vehicle-to-X (V2X) implementation: An overview of predominate trial configurations and technical, social and regulatory challenges," Renew. Sustain. Energy Rev., vol. 145, p. 110977, 2021, doi: 10.1016/j.rser.2021.110977.

[29] Y. F. Zhou, L. J. Huang, X. X. Sun, L. H. Li, and J. Lian, "A Long-term Energy Management Strategy for Fuel Cell Electric Vehicles Using Reinforcement Learning," Fuel Cells, vol. 20, no. 6, pp. 753–761, 2020, doi: 10.1002/fuce.202000095.

[30] C. Energy, "Plug-In Hybrid Electric Vehicles Plug-In Hybrid Electric Vehicles," Power Electr. Veh. Green Energy Technol. https//doi.org/10.1007/978-981-15-9251-5_3, no. October 2014, 2007, doi: 10.1007/978-981-15-9251-5.

[31] A. Faraz, A. Ambikapathy, S. Thangavel, K. Logavani, and G. Arun Prasad, "Battery Electric Vehicles (BEVs)," Green Energy Technol., no. January 2021, pp. 137–160, 2021, doi: 10.1007/978-981-15-9251-5_8.

[32] U. Mitra, A. Arya, S. Gupta, and A. K. Gupta, "A Brief Overview on Fuel Cell Electric Vehicles," 2022 Int. Conf. Emerg. Trends Eng. Med. Sci. ICETEMS 2022, no. April, pp. 124–129, 2022, doi: 10.1109/ICETEMS56252.2022.10093428.

[33] G. Rajendran, C. A. Vaithilingam, N. Misron, K. Naidu, and M. R. Ahmed, "A comprehensive review on system architecture and international standards for electric vehicle charging stations," J. Energy Storage, vol. 42, no. August, p. 103099, 2021, doi: 10.1016/j.est.2021.103099.

[34] R. Bosshard and J. W. Kolar, "Inductive Power Transfer for Electric Vehicle Charging: Technical challenges and tradeoffs," IEEE Power Electron. Mag., vol. 3, no. 3, pp. 22–30, 2016, doi: 10.1109/MPEL.2016.2583839.

[35] S. Niu, H. Xu, Z. Sun, Z. Y. Shao, and L. Jian, "The state-of-the-arts of wireless electric vehicle charging via magnetic resonance: principles, standards and core technologies," Renew. Sustain. Energy Rev., vol. 114, no. June, p. 109302, 2019, doi: 10.1016/j.rser.2019.109302.

[36] L. Sun, D. Ma, and H. Tang, "A review of recent trends in wireless power transfer technology and its applications in electric vehicle wireless charging," Renew. Sustain. Energy Rev., vol. 91, no. December 2016, pp. 490–503, 2018, doi: 10.1016/j.rser.2018.04.016.

[37] P. Lazzeroni, V. Cirimele, and A. Canova, "Economic and environmental sustainability of Dynamic Wireless Power Transfer for electric vehicles supporting reduction of local air pollutant emissions," Renew. Sustain. Energy Rev., vol. 138, no. October, p. 110537, 2021, doi: 10.1016/j.rser.2020.110537.

[38] V. B. Vu, J. M. Gonzalez-Gonzalez, V. Pickert, M. Dahidah, and A. Trivino, "A Hybrid Charger of Conductive and Inductive Modes for Electric Vehicles," IEEE Trans. Ind. Electron., vol. 68, no. 12, pp. 12021–12033, 2021, doi: 10.1109/TIE.2020.3042162.

[39] H. Wu, "A Survey of Battery Swapping Stations for Electric Vehicles: Operation Modes and Decision Scenarios," IEEE Trans. Intell. Transp. Syst., vol. 23, no. 8, pp. 10163–10185, 2022, doi: 10.1109/TITS.2021.3125861.

[40] F. Ahmad, M. S. Alam, I. S. Alsaidan, and S. M. Shariff, "Battery swapping station for electric vehicles: Opportunities and challenges," IET Smart Grid, vol. 3, no. 3, pp. 280–286, 2020, doi: 10.1049/iet-stg.2019.0059.

[41] A. Ahmed, A. Alsharif, M. Khaleel, N. Fathi, A. Obelaid, M. Bajaj, A. Bhatt, S. Choudhury, Integrating Renewable Energy Sources with Electric Vehicle Infrastructure for Enhanced Renewability, 3ed EAI International Conference on Intelligent Systems and Machine Learning (ICISML-2023), 5th-6th January 2024, Pune – India.

[42] D. Ronanki, A. Kelkar, and S. S. Williamson, "Extreme fast charging technology—prospects to enhance sustainable electric transportation," Energies, vol. 12, no. 19, pp. 1–17, 2019, doi: 10.3390/en12193721.

[43] J. R. Szymanski, M. Zurek-Mortka, and D. Acharjee, "Unidirectional voltage converter for battery electric vehicle ultrafast charger," Microsyst. Technol., vol. 27, no. 8, pp. 2865–2872, 2021, doi: 10.1007/s00542-020-05038-7.

[44] M. Quraan, M. Abu-Khaizaran, J. Sa'ed, W. Hashlamoun, and P. Tricoli, "Design and control of battery charger for electric vehicles using modular multilevel converters," IET Power Electron., vol. 14, no. 1, pp. 140–157, 2021, doi: 10.1049/pel2.12018.

[45] M. Brenna, F. Foiadelli, C. Leone, and M. Longo, "Electric Vehicles Charging Technology Review and Optimal Size Estimation," J. Electr. Eng. Technol., vol. 15, no. 6, pp. 2539–2552, 2020, doi: 10.1007/s42835-020-00547-x.

[46] S. Alatai, M. Salem, I. Alhamrouni, D. Ishak, A. Bughneda, and M. Kamarol, "Design Methodology and Analysis of Five-Level LLC Resonant Converter for Battery Chargers," Sustain. Artic., 2022, doi: . https://doi.org/10.3390/su14148255.

[47] A. Rajabi, F. M. Shahir, and R. Sedaghati, "New unidirectional step-up DC-DC converter for fuel-cell vehicle: Design and implementation," Electr. Power Syst. Res., vol. 212, no. October, p. 108653, 2022, doi: 10.1016/j.epsr.2022.108653.

[48] E. Sustainable and E. Transportation, "Extreme Fast Charging Technology—Prospects to Enhance Sustainable Electric Transportation," energies Rev., vol. 1, no. 120 V, pp. 1–17, 2019, doi: 10.3390/en12193721.

[49] Y. Zhang, C. Zhang, J. Liu, and Y. Cheng, "Comparison of conventional dc-dc converter and a family of diode-assisted dc-dc converter," Conf. Proc. - 2012 IEEE 7th Int. Power Electron. Motion Control Conf. - ECCE Asia, IPEMC 2012, vol. 3, pp. 1718–1723, 2012, doi: 10.1109/IPEMC.2012.6259095.

[50] Y. Jang and M. M. Jovanović, "The TAIPEI rectifier-A new three-phase two-switch ZVS PFC DCM boost rectifier," IEEE Trans. Power Electron., vol. 28, no. 2, pp. 686–694, 2013, doi: 10.1109/TPEL.2012.2205271.

[51] J. W. Kolar and T. Friedli, "The essence of three-phase PFC rectifier systemspart i," IEEE Trans. Power Electron., vol. 28, no. 1, pp. 176–198, 2013, doi: 10.1109/TPEL.2012.2197867.

[52] M. C. Ancuti, C. Sorandaru, S. Musuroi, and V. N. Olarescu, "High efficiency three-phase interleaved buck-Type PFC rectifier concepts," IECON 2015 - 41st Annu. Conf. IEEE Ind. Electron. Soc., pp. 4990–4995, 2015, doi: 10.1109/IECON.2015.7392883.

[53] J. Lei, S. Feng, J. Zhao, W. Chen, P. Wheeler, and M. Shi, "An Improved Three-Phase Buck Rectifier Topology with Reduced Voltage Stress on Transistors," IEEE Trans. Power Electron., vol. 35, no. 3, pp. 2458–2466, 2020, doi: 10.1109/TPEL.2019.2931803.

[54] Q. Chen, J. Xu, F. Zeng, R. Huang, and L. Wang, "An Improved Three-Phase Buck Rectifier with Low Voltage Stress on Switching Devices," IEEE Trans. Power Electron., vol. 36, no. 6, pp. 6168–6174, 2021, doi: 10.1109/TPEL.2020.3035030.

[55] J. Afsharian, D. Xu, B. Wu, B. Gong, and Z. Yang, "A New PWM and Commutation Scheme for One Phase Loss Operation of Three-Phase Isolated Buck Matrix-Type Rectifier," IEEE Trans. Power Electron., vol. 33, no. 11, pp. 9854–9865, 2018, doi: 10.1109/TPEL.2018.2789905.

[56] L. Schrittwieser, M. Leibl, M. Haider, F. Thony, J. W. Kolar, and T. B. Soeiro, "99.3% Efficient Three-Phase Buck-Type All-SiC SWISS Rectifier for DC Distribution Systems," IEEE Trans. Power Electron., vol. 34, no. 1, pp. 126–140, 2018, doi: 10.1109/TPEL.2018.2817074.

[57] B. Zhang, S. Xie, X. Wang, and J. Xu, "Modulation Method and Control Strategy for Full-Bridge-Based Swiss Rectifier to Achieve ZVS Operation and Suppress Low-Order Harmonics of Injected Current," IEEE Trans. Power Electron., vol. 35, no. 6, pp. 6512–6522, 2020, doi: 10.1109/TPEL.2019.2951795.

[58] L. Schrittwieser, J. W. Kolar, and T. B. Soeiro, "Novel SWISS Rectifier Modulation Scheme Preventing Input Current Distortions at Sector Boundaries," IEEE Trans. Power Electron., vol. 32, no. 7, pp. 5771–5785, 2017, doi: 10.1109/TPEL.2016.2609935.

[59] G. Rajendran, C. A. Vaithilingam, N. Misron, K. Naidu, and M. R. Ahmed, "Voltage oriented controller based vienna rectifier for electric vehicle charging stations," IEEE Access, vol. 9, pp. 50798–50809, 2021, doi: 10.1109/ACCESS.2021.3068653.

[60] H. R. I. Skdvh et al., "design of three phase vienna PFC Circuit with integral improved PI controller," IEEE Int. Power Electron. Appl. Conf. Expo. 2018, doi: 10.1109/PEAC.2018.8590648.

[61] L. Huber, M. Kumar, and M. M. Jovanovic, "Performance Comparison of Three-Step and Six-Step PWM in Average-Current-Controlled Three-Phase Six-Switch Boost PFC Rectifier," IEEE Trans. Power Electron., vol. 31, no. 10, pp. 7264–7272, 2016, doi: 10.1109/TPEL.2015.2506554.

[62] A. Mallik, W. Ding, C. Shi, and A. Khaligh, "Input Voltage Sensorless Duty Compensation Control for a Three-Phase Boost PFC Converter," IEEE Trans. Ind. Appl., vol. 53, no. 2, pp. 1527–1537, 2017, doi: 10.1109/TIA.2016.2626247.

[63] P. Papamanolis, D. Bortis, F. Krismer, D. Menzi, and J. W. Kolar, "New EV battery charger PFC rectifier front-end allowing full power delivery in 3-phase and 1-phase operation," Electron., vol. 10, no. 17, pp. 1–33, 2021, doi: 10.3390/electronics10172069.

[64] I. Using et al., "A V2G Enabled Bidirectional Single / Three-Phase EV Charging," Electron. 2022, 11, 1891. https//doi.org/10.3390/ Electron., 2022.

[65] E. Couderc, "Single-Stage Isolated and Bidirectional Three-Phase Series-Resonant AC–DC Converter: Modulation for Active and Reactive Power Control," Nat. Energy . Energies 2022, 15, 8070. https//doi.org/ 10.3390/en15218070, vol. 2, no. 10, p. 764, 2017, doi: 10.1038/s41560-017-0020-0.

[66] P. Guzmán, N. Vázquez, M. Liserre, R. Orosco, J. Vaquero, and C. Hernández, "AC-DC DAB Converter with Power Factor Correction," Energies, vol. 16, no. 1, 2023, doi: 10.3390/en16010320.

[67] Y. Tang, W. Ding, and A. Khaligh, "A bridgeless totem-pole interleaved PFC converter for plug-in electric vehicles," Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC, vol. 2016-May, pp. 440–445, 2016, doi: 10.1109/APEC.2016.7467909.

[68] X. Gong, G. Wang, and M. Bhardwaj, "6.6kW three-phase interleaved totem pole PFC design with 98.9% peak efficiency for HEV/EV onboard charger," Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC, vol. 2019-March, pp. 2029–2034, 2019, doi: 10.1109/APEC.2019.8722110.

[69] M. Schweizer and J. W. Kolar, "Design and implementation of a highly efficient three-level T-type converter for low-voltage applications," IEEE Trans. Power Electron., vol. 28, no. 2, pp. 899–907, 2013, doi: 10.1109/TPEL.2012.2203151.

[70] S. Kulasekaran and R. Ayyanar, "A 500-kHz, 3.3-kW Power Factor Correction Circuit with Low-Loss Auxiliary ZVT Circuit," IEEE Trans. Power Electron., vol. 33, no. 6, pp. 4783–4795, 2018, doi: 10.1109/TPEL.2017.2737660.

[71] V. Grigore and J. Kyyrä, "High power factor rectifier based on buck converter operating in discontinuous capacitor voltage mode," IEEE Trans. Power Electron., vol. 15, no. 6, pp. 1241–1249, 2000, doi: 10.1109/63.892839.

[72] F. Caricchi, F. Crescimbini, G. Noia, and D. Pirolo, "Experimental study of a bidirectional dc-dc converter for the dc link voltage control and the regenerative braking in PM motor drives devoted to

electrical vehicles," Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC, vol. 1, pp. 381–386, 1994, doi: 10.1109/apec.1994.316373.

[73] T. Kang, C. Kim, Y. Suh, H. Park, B. Kang, and D. Kim, "A design and control of bi-directional non-isolated DC-DC converter for rapid electric vehicle charging system," Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC, pp. 14–21, 2012, doi: 10.1109/APEC.2012.6165792.

[74] C. Dimna Denny and M. Shahin, "Analysis of bidirectional SEPIC/Zeta converter with coupled inductor," Proc. IEEE Int. Conf. Technol. Adv. Power Energy, TAP Energy 2015, pp. 103–108, 2015, doi: 10.1109/TAPENERGY.2015.7229600.

[75] F. Yi and F. Wang, "and Applications," 2023.

[76] V. Monteiro and J. A. Afonso, "Bidirectional Power Converters for EV Battery Chargers," Energies 2023, 16, 1694. https// doi.org/10.3390/en16041694, pp. 2–5, 2023.

[77] F. Mumtaz, N. Zaihar, S. Tanzim, B. Singh, and R. Kannan, "Review on non-isolated DC-DC converters and their control techniques for renewable energy applications," Ain Shams Eng. J., 2021, doi: 10.1016/j.asej.2021.03.022.

[78] X. Cheng, C. Liu, D. Wang, and Y. Zhang, "State-of-The-Art Review on Soft-Switching Technologies for Non-Isolated DC-DC Converters," IEEE Access, vol. PP, p. 1, 2021, doi: 10.1109/ACCESS.2021.3107861.

[79] K. Kadirvel, R. Kannadasan, M. H. Alsharif, and Z. W. Geem, "Design and Modeling of Modified Interleaved Phase-Shifted Semi-Bridgeless Boost Converter for EV Battery Charging Applications," Sustain., vol. 15, no. 3, 2023, doi: 10.3390/su15032712.

[80] R. Kushwaha and B. Singh, "An improved battery charger for electric vehicle with high power factor," 2018 IEEE Ind. Appl. Soc. Annu. Meet. IAS 2018, pp. 1–8, 2018, doi: 10.1109/IAS.2018.8544585.

[81] A. Dixit, K. Pande, S. Gangavarapu, and A. K. Rathore, "DCM-Based Bridgeless PFC Converter for EV Charging Application," IEEE J. Emerg. Sel. Top. Ind. Electron., vol. 1, no. 1, pp. 57–66, 2020, doi: 10.1109/jestie.2020.2999595.

[82] S. Sharifi, M. Monfared, and M. Babaei, "Ferdowsi Rectifiers - Single-Phase Buck-Boost Bridgeless PFC Rectifiers with Low Semiconductor Count," IEEE Trans. Ind. Electron., vol. 67, no. 11, pp. 9206–9214, 2020, doi: 10.1109/TIE.2019.2955430.

[83] A. V. J. S. Praneeth and S. S. Williamson, "Modeling, Design, Analysis, and Control of a Nonisolated Universal On-Board Battery Charger for Electric Transportation," IEEE Trans. Transp. Electrif., vol. 5, no. 4, pp. 912–924, 2019, doi: 10.1109/TTE.2019.2919197.

[84] M. K. R. Noor et al., "Modified single-switch bridgeless PFC SEPIC structure by eliminating circulating current and power quality improvement," IET Power Electron., vol. 12, no. 14, pp. 3792–3801, 2019, doi: 10.1049/iet-pel.2018.6076.

[85] R. Kushwaha and B. Singh, "A Modified Bridgeless Cuk Converter based EV Charger with Improved Power Quality," ITEC 2019 - 2019 IEEE Transp. Electrif. Conf. Expo, no. 1, p. 1, 2019, doi: 10.1109/ITEC.2019.8790509.

[86] B. R. Ananthapadmanabha, R. Maurya, and S. R. Arya, "Improved Power Quality Switched Inductor Cuk Converter for Battery Charging Applications," IEEE Trans. Power Electron., vol. 33, no. 11, pp. 9412–9423, 2018, doi: 10.1109/TPEL.2018.2797005.

[87] J. Gupta, R. Kushwaha, and B. Singh, "Improved Power Quality Transformerless Single-Stage Bridgeless Converter Based Charger for Light Electric Vehicles," IEEE Trans. Power Electron., vol. 36, no. 7, pp. 7716–7724, 2021, doi: 10.1109/TPEL.2020.3048790.

[88] R. Kushwaha and B. Singh, "Bridgeless Isolated Zeta – Luo Converter-Based EV," IEEE Trans.

Ind. Appl., vol. 57, no. 1, pp. 628–636, 2021.

[89] X. Lin and F. Wang, "AC-DC bridgeless buck converter with high PFC performance by inherently reduced dead zones," IET Power Electron., vol. 11, no. 9, pp. 1575–1581, 2018, doi: 10.1049/iet-pel.2016.0962.

[90] M. Dhananjaya, D. Potnuru, P. Manoharan, and H. H. Alhelou, "Design and Implementation of Single-Input-Multi-Output DC-DC Converter Topology for Auxiliary Power Modules of Electric Vehicle," IEEE Access, vol. 10, no. July, pp. 76975–76989, 2022, doi: 10.1109/ACCESS.2022.3192738.

[91] H. D. C. G. Inverters et al., "An Efficient Design of High Step-Up Switched Z-Source (HS-SZSC) DC-DC Converter for Grid-Connected Inverters," . Electron. 2022, 11, 2440. https//doi.org/10.3390/electronics11152440 Acad., 2022.

[92] F. Pellitteri, V. Di Dio, C. Puccio, and R. Miceli, "A Model of DC-DC Converter with Switched-Capacitor Structure for Electric Vehicle Applications," Energies, vol. 15, no. 3, 2022, doi: 10.3390/en15031224.

[93] T. Sai, Y. Moon, and Y. Sugimoto, "Improved Quasi-Z-Source High Step-Up DC-DC Converter Based on Voltage-Doubler Topology," Sensors (Basel)., vol. 22, no. 24, 2022, doi: 10.3390/s22249893.

[94] V. Monteiro, J. C. Ferreira, A. A. Nogueiras Melendez, C. Couto, and J. L. Afonso, "Experimental Validation of a Novel Architecture Based on a Dual-Stage Converter for Off-Board Fast Battery Chargers of Electric Vehicles," IEEE Trans. Veh. Technol., vol. 67, no. 2, pp. 1000–1011, 2018, doi: 10.1109/TVT.2017.2755545.

[95] M. Hammami, A. Viatkin, M. Ricco, and G. Grandi, "A DC/DC Fast Charger for Electric Vehicles with Minimum Input/Output Ripple Based on Multiphase Interleaved Converters," ICCEP 2019 - 7th Int. Conf. Clean Electr. Power Renew. Energy Resour. Impact, pp. 187–192, 2019, doi: 10.1109/ICCEP.2019.8890200.

[96] X. Lin and F. Wang, "New Bridgeless Buck PFC Converter with Improved Input Current and Power Factor," IEEE Trans. Ind. Electron., vol. 65, no. 10, pp. 7730–7740, 2018, doi: 10.1109/TIE.2018.2801782.

[97] R. Kushwaha and B. Singh, "Design and Development of Modified BL Luo Converter for PQ Improvement in EV Charger," IEEE Trans. Ind. Appl., vol. 56, no. 4, pp. 3976–3984, 2020, doi: 10.1109/TIA.2020.2988197.

[98] J. Gnanavadivel, P. Yogalakshmi, N. S. Kumar, and K. S. K. Veni, "Design and development of single phase AC- DC discontinuous conduction mode modified bridgeless positive output Luo converter for power quality improvement," IET Power Electron., vol. 12, no. 11, pp. 2722–2730, 2019, doi: 10.1049/iet-pel.2018.6059.

[99] Y. C. Liu, T. F. Pan, P. L. Tseng, C. C. Huang, Y. K. La, and H. J. Chiu, "Study and implementation of a two-phase interleaved bridgeless buck power factor corrector," 1st Int. Futur. Energy Electron. Conf. IFEEC 2013, pp. 42–47, 2013, doi: 10.1109/ifeec.2013.6687476.

[100] B. Lu, W. Hall, R. Brown, M. Soldano, and E. Segundo, "Bridgele ss PFC Implementation Using One Cycle Control Technique," IEEE Access, 2005, doi: 10.1109/APEC.2005.1453073.

[101] N. N. Do et al., "Design and implementation of a control method for gan-based totem-pole boost-type pfc rectifier in energy storage systems," Energies, vol. 13, no. 23, 2020, doi: 10.3390/en13236297.

[102] G. Anjinappa, D. B. Prabhakar, and W.-C. Lai, "Bidirectional Converter for Plug-In Hybrid Electric Vehicle On-Board Battery Chargers with Hybrid Technique," World Electr. Veh. J., vol. 13, no. 11, p. 196, 2022, doi: 10.3390/wevj13110196.

[103] J. H. Kim, I. O. Lee, and G. W. Moon, "Analysis and Design of a Hybrid-Type Converter for Optimal Conversion Efficiency in Electric Vehicle Chargers," IEEE Trans. Ind. Electron., vol. 64, no. 4, pp. 2789–2800, 2017, doi: 10.1109/TIE.2016.2623261.

[104] R. Kushwaha and B. Singh, "A Modified Luo Converter-Based Electric Vehicle Battery Charger with Power Quality Improvement," IEEE Trans. Transp. Electrif., vol. 5, no. 4, pp. 1087–1096, 2019, doi: 10.1109/TTE.2019.2952089.

[105] B. Singh and R. Kushwaha, "Power Factor Preregulation in Interleaved Luo Converter-Fed Electric Vehicle Battery Charger," IEEE Trans. Ind. Appl., vol. 57, no. 3, pp. 2870–2882, 2021, doi: 10.1109/TIA.2021.3061964.

[106] D. Raveendhra et al., "A High-Gain Multiphase Interleaved Differential Capacitor Clamped Boost Converter," Electron., vol. 11, no. 2, 2022, doi: 10.3390/electronics11020264.

[107] M. R. Mohammadi and H. Farzanehfard, "Family of Soft-Switching Bidirectional Converters with Extended ZVS Range," IEEE Trans. Ind. Electron., vol. 64, no. 9, pp. 7000–7008, 2017, doi: 10.1109/TIE.2017.2686308.

[108] S. H. Kim, H. J. Byun, J. Yi, and C. Y. Won, "A Bi-Directional Dual-Input Dual-Output Converter for Voltage Balancer in Bipolar DC Microgrid," Energies, vol. 15, no. 14, 2022, doi: 10.3390/en15145043.

[109] Y. R. Ong et al., "A Dual-Buck-Boost DC–DC/AC Universal Converter," Electron., vol. 11, no. 13, pp. 1–12, 2022, doi: 10.3390/electronics11131973.

[110] C. C. Lin, L. S. Yang, and G. W. Wu, "Study of a non-isolated bidirectional DC-DC converter," IET Power Electron., vol. 6, no. 1, pp. 30–37, 2013, doi: 10.1049/iet-pel.2012.0338.

[111] A. Hussain, R. Akhtar, B. Ali, S. E. Awan, and S. Iqbal, "A novel bidirectional DC–DC converter with low stress and low magnitude ripples for stand-alone photovoltaic power systems," Energies, vol. 12, no. 15, 2019, doi: 10.3390/en12152884.

[112] S. Usha, C. Subramani, B. Dinesh Naidu, and M. S. R. Vishnu Venkatesh, "Analysis of non-isolated bidirectional active clamped DC-DC converter for PV and battery integrated systems," Indian J. Sci. Technol., vol. 9, no. 22, pp. 1–7, 2016, doi: 10.17485/ijst/2016/v9i22/93191.

[113] K. Venkata Govardhan Rao, M. K. Kumar, B. S. Goud, M. Bajaj, M. Abou Houran, and S. Kamel, "Design of a bidirectional DC/DC converter for a hybrid electric drive system with dual-battery storing energy," Front. Energy Res., vol. 10, no. November, pp. 1–19, 2022, doi: 10.3389/fenrg.2022.972089.

[114] B. Z. Chen, H. Liao, L. Chen, and J. F. Chen, "Design and Implementation of the Bidirectional DC-DC Converter with Rapid Energy Conversion," Energies, vol. 15, no. 3, 2022, doi: 10.3390/en15030898.

[115] H. Liao, Y. Chen, and L. Chen, "Development of a Bidirectional DC–DC Converter with Rapid Energy Bidirectional Transition Technology," Energies 2022, 15, 4583. https//doi.org/10.3390/en15134583 Acad., 2022.

[116] G. G. Ramanathan and N. Urasaki, "Non-Isolated Interleaved Hybrid Boost Converter for Renewable Energy Applications," Energies, vol. 15, no. 2, pp. 1–14, 2022, doi: 10.3390/en15020610.

[117] F. Mumtaz, N. Z. Yahaya, S. T. Meraj, N. Singh, and S. Singh, "A Novel Non-Isolated High-Gain Non-Inverting Interleaved DC – DC Converter," Micromachines 2023, 14, 585. https//doi.org/10.3390/mi14030585 Acad., pp. 1–17, 2023.

[118] M. L. Alghaythi, "A Non-Isolated High Voltage Gain DC–DC Converter Suitable for Sustainable Energy Systems," Sustainability, vol. 15, no. 15, p. 12058, Aug. 2023, doi: 10.3390/su151512058.

[119] M. I. Shahzad, S. Iqbal, and S. Taib, "Interleaved LLC Converter with Cascaded Voltage-Doubler Rectifiers for Deeply Depleted PEV Battery Charging," IEEE Trans. Transp. Electrif., vol. 4, no. 1, pp. 89–98, 2017, doi: 10.1109/TTE.2017.2753407.

[120] L. Zhao, Y. Pei, X. Liu, W. Fan, and Y. Du, "Design Methodology of CLLC Resonant Converters for Electric Vehicle Battery Chargers," Zhongguo Dianji Gongcheng Xuebao/Proceedings Chinese Soc. Electr. Eng., vol. 40, no. 15, pp. 4965–4976, 2020, doi: 10.13334/j.0258-8013.pcsee.191289.

[121] H. Haga and F. Kurokawa, "Modulation method of a full-bridge three-level LLC resonant converter for battery charger of electrical vehicles," IEEE Trans. Power Electron., vol. 32, no. 4, pp. 2498–2507, 2017, doi: 10.1109/TPEL.2016.2570800.

[122] Y. C. Liu, Y. L. Syu, N. A. Dung, C. Chen, K. De Chen, and K. A. Kim, "High-Switching-Frequency TCM Digital Control for Bidirectional-Interleaved Buck Converters Without Phase Error for Battery Charging," IEEE J. Emerg. Sel. Top. Power Electron., vol. 8, no. 3, pp. 2111–2123, 2020, doi: 10.1109/JESTPE.2019.2954602.

[123] S. A. Assadi, H. Matsumoto, M. Moshirvaziri, M. Nasr, M. S. Zaman, and O. Trescases, "Active Saturation Mitigation in High-Density Dual-Active-Bridge DC-DC Converter for On-Board EV Charger Applications," IEEE Trans. Power Electron., vol. 35, no. 4, pp. 4376–4387, 2020, doi: 10.1109/TPEL.2019.2939301.

[124] Y. Yan, H. Bai, A. Foote, and W. Wang, "Securing Full-Power-Range Zero-Voltage Switching in Both Steady-State and Transient Operations for a Dual-Active-Bridge-Based Bidirectional Electric Vehicle Charger," IEEE Trans. Power Electron., vol. 35, no. 7, pp. 7506–7519, 2020, doi: 10.1109/TPEL.2019.2955896.

[125] Y. Xuan, X. Yang, W. Chen, T. Liu, and X. Hao, "A Three-Level Dual-Active-Bridge Converter with Blocking Capacitors for Bidirectional Electric Vehicle Charger," IEEE Access, vol. 7, pp. 173838–173847, 2019, doi: 10.1109/ACCESS.2019.2957022.

[126] Y. Wu and K. Chen, "High Efficiency and High Voltage Conversion Ratio Bidirectional Isolated DC–DC Converter for Energy Storage Systems," Process. 2022, 10, 2711. https//doi.org/ 10.3390/pr10122711 Acad., 2022.

[127] B. R. De Almeida, J. W. M. De Araújo, P. P. Praça, and D. D. S. Oliveira, "A Single-Stage Three-Phase Bidirectional AC/DC Converter With High-Frequency Isolation and PFC," IEEE Trans. Power Electron., vol. 33, no. 10, pp. 8298–8307, 2018, doi: 10.1109/TPEL.2017.2775522.

[128] H. Li, Z. Zhang, S. Wang, J. Tang, X. Ren, and Q. Chen, "A 300-kHz 6.6-kW SiC Bidirectional LLC Onboard Charger," IEEE Trans. Ind. Electron., vol. 67, no. 2, pp. 1435–1445, 2020, doi: 10.1109/TIE.2019.2910048.

[129] M. Yaqoob, K. H. Loo, and Y. M. Lai, "A Four-Degrees-of-Freedom Modulation Strategy for Dual-Active-Bridge Series-Resonant Converter Designed for Total Loss Minimization," IEEE Trans. Power Electron., vol. 34, no. 2, pp. 1065–1081, 2019, doi: 10.1109/TPEL.2018.2865969.

[130] B. Li, Q. Li, and F. C. Lee, "A WBG based three phase 12.5 kW 500 kHz CLLC resonant converter with integrated PCB winding transformer," Conf. Proc. - IEEE Appl. Power Electron. Conf. Expo. - APEC, vol. 2018-March, pp. 469–475, 2018, doi: 10.1109/APEC.2018.8341053.

[131] S. Habib, "Assessment of electric vehicles concerning impacts , charging infrastructure with unidirectional and bidirectional chargers , and power flow comparisons," WILY ENERGY Res., no. June 2018, 2017, doi: 10.1002/er.4033.

[132] W. Zheng, C. Hu, B. Zhao, X. Su, G. Wang, and X. Hou, "Design for a Four-Stage DC/DC High-Voltage Converter with High Precision and a Small Ripple," Energies, vol. 16, no. 1, 2023, doi: 10.3390/en16010389.

[133] S. J. Park, J. W. Park, K. H. Kim, and F. S. Kang, "Battery Energy Storage System with Interleaving Structure of Dual-Active-Bridge Converter and Non-Isolated DC-to-DC Converter with Wide Input and Output Voltage," IEEE Access, vol. 10, no. November, pp. 127205–127224, 2022, doi: 10.1109/ACCESS.2022.3226779.

[134] H. A. Gabbar and A. Elshora, "Modular Multi-Input DC/DC Converter for EV Fast Charging," Technologies, vol. 10, no. 6, p. 113, 2022, doi: 10.3390/technologies10060113.

[135] D. Folder, P. Folder, P. Folder, P. Folder, P. Folder, and P. Folder, "Bidirectional, Dual Active Bridge Reference Design for Level 3 Electric Vehicle Charging Stations," Texas Instruments, Can. Automob. Assoc., no. July, pp. 1–86, 2022.

[136] N. Z. Jin, Y. Feng, Z. Y. Chen, and X. G. Wu, "Bidirectional CLLLC Resonant Converter Based on Frequency-Conversion and Phase-Shift Hybrid Control," Electron., vol. 12, no. 7, 2023, doi: 10.3390/electronics12071605.

[137] A. Alsharif et al., "Impact of Electric Vehicle on Residential Power Distribution Considering Energy Management Strategy and Stochastic Monte Carlo Algorithm," Energies, vol. 16, no. 3, pp. 1–22, 2023, doi: 10.3390/en16031358.