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Review

State-of-the-Art and Advancement of Charging Infrastructure in Electric Mobility: An Integrated Review

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Abstract: Electric mobility is attracting significant attention in the current era due to its environmental benefits, sustainable transportation options, and the absence of carbon emissions. However, challenges such as the high price of batteries, inefficient charging techniques, and compatibility linking the charging station with electric vehicles (EVs) must be addressed. This article reviews advancements and identifies challenges in charging infrastructure for electric mobility. This study incorporates and analyzes an integrated review of approximately 223 research articles. Current research trends and states of charging infrastructure are prepared as per the Web of Science (WoS) database from 2013 to 2023. In light of recent extensions in wireless power transfer technology, including capacitive, inductive, and magnetic gear topology, are presented to advance the charging infrastructure. Different charging tactics based on power source, such as level-1 AC, level-2 AC, level-3 DC fast, and level-3 DC ultra-rapid charging, related to charging infrastructure are addressed. The vehicle-to-grid (V2G) integration methodology is addressed to construct a smart city by presenting the transfer of power and related data through linkage and moving systems. The exploration of artificial intelligence, global connectivity of electric vehicles (EVs), sun-to-vehicle (S2V), and vehicle-to-everything (V2X) techniques with EVs is conducted to enhance and progress the charging infrastructure. Key barriers associated with charging infrastructure are identified.

Keywords: electric vehicle; battery technology; vehicle-to-grid (V2G); charging infrastructure; sun-to-vehicle (S2V)

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1. Introduction

Environmental degradation, inferior air quality, and the rapid exhaustion of fossil fuels have recently drawn attention to more environmentally friendly resources around the world [1,2]. Internal combustion engines (ICEs) are by far the most common form of transportation and a major contributor to ecological issues and global warming [3,4]. Furthermore, India's transport industry consumes 18% of the country's total energy supply, which is mostly provided by crude oil imports [5]. Around 142 million tons of CO_2 are emitted annually by India's transport sector [5]. By 2030, India would be required to reduce its emissions concentration by 33–35% from 2005 levels at the COP21 Summit in Paris [5]. Therefore, it is necessary to implement alternative modes of transportation to handle India's rapid economic growth and urbanization. In an effort to stop the growing decline of the environment, designers of electric vehicles (EVs) have garnered a lot of attention from academics and inventors worldwide [6–9]. Patil et al. [10] emphasized that the European Union's pledge to achieve a zero-carbon economy by 2050, as detailed in the European Green Deal, encompasses a compulsory phaseout of new ICE vehicles by 2035. This charter has expedited the allocation of resources toward the production of electric vehicles and the development of related infrastructure within the member states. Additionally, EVs are regarded as the future's automobiles for the following reasons: (i) long-term sustainability, (ii) reduced reliance on gasoline, (iii) reduced carbon emanations, (iv) green transportation, (v) opportunity to address the effects of climatic change, and (vi) increased computerization in the self-propelled division.

Figure 1 depicts global sales of EVs, involving BEVs (battery-electric vehicles) and PHEVs (plug-in hybrid electric cars), according to a report by the International Energy Agency (IEA) [11,12]. According to this report, there is an increment in sales of EVs by a factor of 25% in the financial year 2023 compared to 2022.

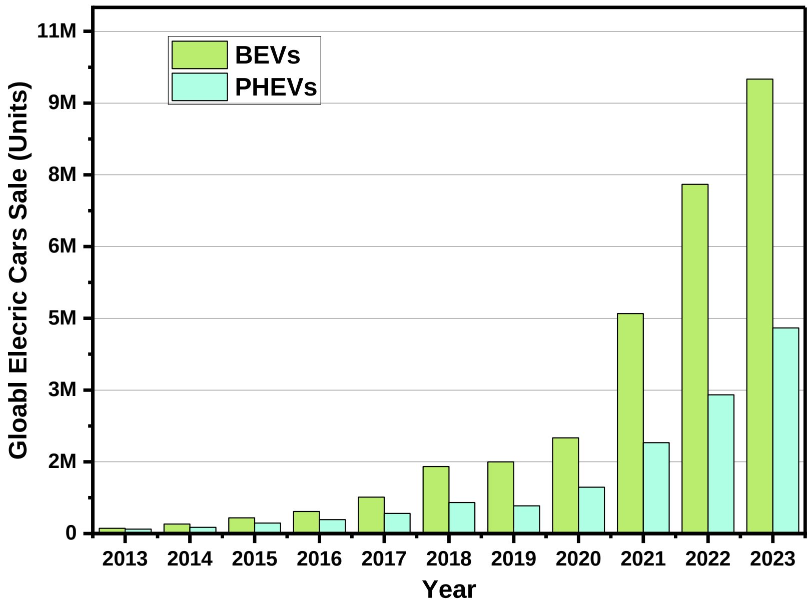

Figure 1. Global electric car sales as per the EIA report.

Figure 2 shows the sales situation of EVs, including the 2W, 3W, and 4W, in India from the fiscal years 2017–18 to 2022–23 according to the Society of Manufacturers of Electric Vehicles (SMEV) [13]. Due to the COVID epidemic, EV sales for the fiscal year 2022–23 increased by 60% from the prior year as per Figure 2 [13].

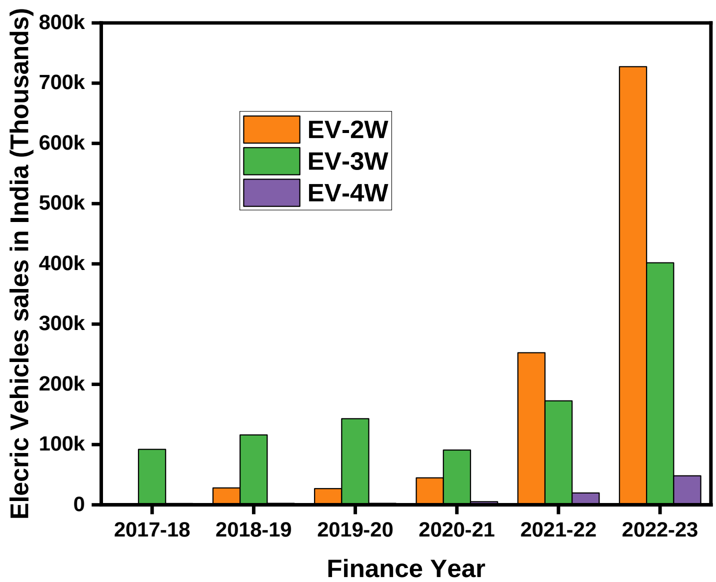

Figure 2. EV market status and sales in India as per the SIAM database.

The main issue with electric vehicles (EVs) for consumer happiness and dependability is their ability to store energy in their battery cells [14,15]. Energy storage systems (ESS) for EVs come in a variety of forms, including chemical batteries, hydrogen, ultra-capacitors, and flywheels. High specific power, substantial storage capacity, high specific energy, quicker response times, longer life cycles, high operating efficiency, and low maintenance costs are desirable characteristics for an ESS [14,16]. LIBs (lithium-ion batteries) are becoming increasingly prominent among battery technologies as an energy storage alternative in EVs [17–19].

Numerous problems need to be rectified before EVs can be inexpensive in the emporium, together with battery costs, efficient charging techniques, and integration of EVs with the grid [14,20,21]. Additionally, the expansion of EVs during the ensuing ten years will depend on the creation of global norms and protocols, common arrangements, ancillary devices, and operator-intelligible packages [22,23]. The car industry faces a difficult issue in trying to make EVs more popular due to a lack of charging infrastructure. To lessen EVs' reliance on their batteries, wireless energy transport, commonly recognized as the passage-and-charge system, is applicable to driving lanes [24–26]. However, battery-swapping techniques are also proposed to refill electric vehicles [27]. Several research studies give outlines of EV charging infrastructure [28,29], the integration of EVs with the grid [30,31], and the effect of the V2G (vehicle-to-grid) technology [32–36]. Sensor-on-chip technology allows EVs to exchange information and energy [37,38].

1.1. Current Research Trends in Charging Infrastructure

Figure 3 depicts the current trends of charging infrastructure in EVs, based on publications published in the Web of Science (WoS) database from 2013 to 2023. The current trends include several EV technologies such as battery electric vehicles (BEVs), EV charging stations, vehicle-to-grid (V2G), and wireless charging technology. Figure 3 underlines that the overall current research trends conform to EV technologies, but now, BEV is the dominant research subject. Around fifteen thousand BEV-related papers were published until 2023. The second most popular topic is HEVs, with 9740 relevant articles already published by 2023. EV charging stations have taken third place, with around 2934 research articles published by 2023. However, because of recent breakthroughs in V2G and wireless technologies, EV charging technology has made more significant development than any other study subject from 2013 to the present.

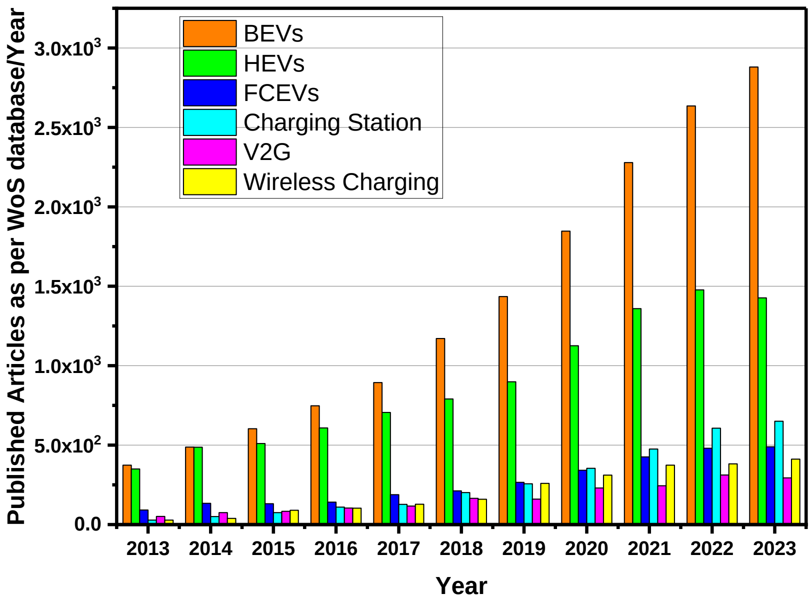

Figure 3. Research articles published linked to BEVs, HEVs, FCEVs, charging stations, vehicle-to-grid (V2G), and wireless charging as per the Web of Science (WoS) database.

The current status of international charging infrastructure standards for China, the UK, India, and the United States (US) is displayed in Table 1. There were 25,521 charging places and 44,408 electric car charging points spread around the UK as of the end of June 2023 [39]. Since June 2022, there have been a total of 36 percent more charging devices. More than 8600 new charge points—a 30 percent increase—were added to the UK network during the previous year, between the ends of 2021 and 2022. The network of charge points increased fourfold between the end of 2016 and 2022, from 6500 to more than 37,261 devices [39]. Slow charging, which typically has a 3 kW rating, is primarily carried out overnight at home or work. The entire charging process takes 8–10 h. Fast charging is usually observed in parking lots, shops, and sports facilities. It is rated at either 7 kW or 22 kW and allows charging to be completed in 3 to 4 h. In supermarkets, gas stations, and service areas around highways, the rapid charge technology is offered (rated from 43 kW) to complete the charge in 30 to 60 min [40–42].

Table 1. Specifications for existing charging infrastructure across the globe.

Country	Charger's Type	Connector's Type and Power Rating	Voltage Level/Current Level	Total Connectors Rifles	Usage in EVs	Reference
India	DC Slow/Moderate	Bharat DC-001, 15 kW Bharat DC-001, 15 kW Bharat DC 001, 15 kW	48 V 72–200 V 230 V	1 CG 1 CG 3 CG	2, 3, 4W vehicles 2, 3, 4W vehicles 2, 3, 4W vehicles	[43,44]
	DC Fast	CCS (Min. 50 kW) CHAdeMO (Min. 50 kW) Type 2 AC (Min. 22 kW)	200–1000 V 200–1000 V 380–480 V	1 CG 1 CG 1 CG	4W vehicles 4W vehicles 2, 3, 4W vehicles	[44]
UK	Slow	UK (3–7 kW), AC 1~Phase	48 V	3-pin	2, 3, 4W vehicles	[40,42]
	Fast	UK 11–22 kW AC, 1~Phase/3~Phase	72–230 V	J1772	2, 3, 4W vehicles	[40,42]
	Rapid	CHAdeMO 25–50 kW DC, Three Phase	500 V	CHAdeMO plug	4W vehicles	[40]
	Ultra-rapid	CCS, 50–350 kW DC	500–750 V	CCS-2	2, 3, 4W vehicles	[40,42]
North America	Level-1	1~ph AC, (1.4~1.9 kW)	120 V	J1772 (Type 1)	2, 3, 4W vehicles	[45,46]
	Level-2	1~ph AC, (2.5~9.2 kW)	208–240 V	J1772 (Type-2)	4W vehicles	[45,47]
	Level-3	DC, (max. 240 kW)	208–600 V	CCS-1	2, 3, 4W vehicles	[47]
	Tesla DC	250 kW	410 V	Tesla	4W	[47,48]
China	GB/T-AC	1/3~ph, 22 kW	380–480 V	7 Pin GB-20234	2, 3, 4W vehicles	[49]
	GB/T-DC	DC (up to 237 kW)	Up to 950 V	7 Pin GB-20234	2, 3, 4W vehicles	[48,49]

Kitter et al. [50] examined the European Union (EU) funds allocated from the Recovery and Resilience Facility (RRF) to improve charging accessibility through the installation of public electric vehicle (EV) chargers, aiming to establish one million charging points by the year 2025. The focus of these projects is on ensuring comprehensive coverage in both urban and rural regions to facilitate a large-scale transition. Additionally, the EU, via initiatives such as Horizon Europe, facilitates research in cutting-edge electric vehicle technologies, encompassing wireless and bidirectional charging, aimed at improving the efficiency and integration of electric vehicles into the grid as per Azerine et al. [51]. These initiatives facilitate cooperation between universities, industry, and governments to address technical and infrastructural challenges. As of March 2021, India had 16,200 electric vehicles and 1800 charging outlets, as per SMEV [52]. The government has been researching several charging strategies in India to accelerate the proliferation of EVs there. As a foundational standard for EV charging, the BIS released IS: 17017 [53]. In terms of EV standards for India, the BIS suggests CCS Type-2 and CHAdeMO [43,44]. In India, there are primarily two categories of chargers that differ in terms of charging speed. The first category is slow chargers. Single-phase 5–15 A plugs are used with these chargers, which range in power from 1.2 kW to 3 kW. These chargers are compatible with both residential and community charging locations. The battery of an EV has to be fully charged in 5 to 6 h. They provide the onboard charger in the car with alternating current electricity, which transforms into direct current before it can start charging the battery. The second category is chargers that are quickly accessible at public charging locations; these chargers may produce 15 to 50 kW of power. By providing the EV's battery with direct current (DC), the battery can be fully charged in 30 to 90 min [44,52].

1.2. Review Goals and Strategy

A search technique was employed to locate pertinent research for this organized assessment. Search phrases used to access the Web of Science (WoS) databases included: "electric mobility", "charging infrastructure", "wireless charging", and "key challenges in charging infrastructure". The current research study's flowchart is shown in Figure 4. This article's prime objective is to invigorate: (i) current states of charging infrastructure, (ii) advancement of charging infrastructure in electric vehicles, (iii) integration of electric vehicles with grid technology, (iv) key barriers to charging infrastructure, (v) current research trends in charging infrastructure, and (vi) outlines and future suggestions.

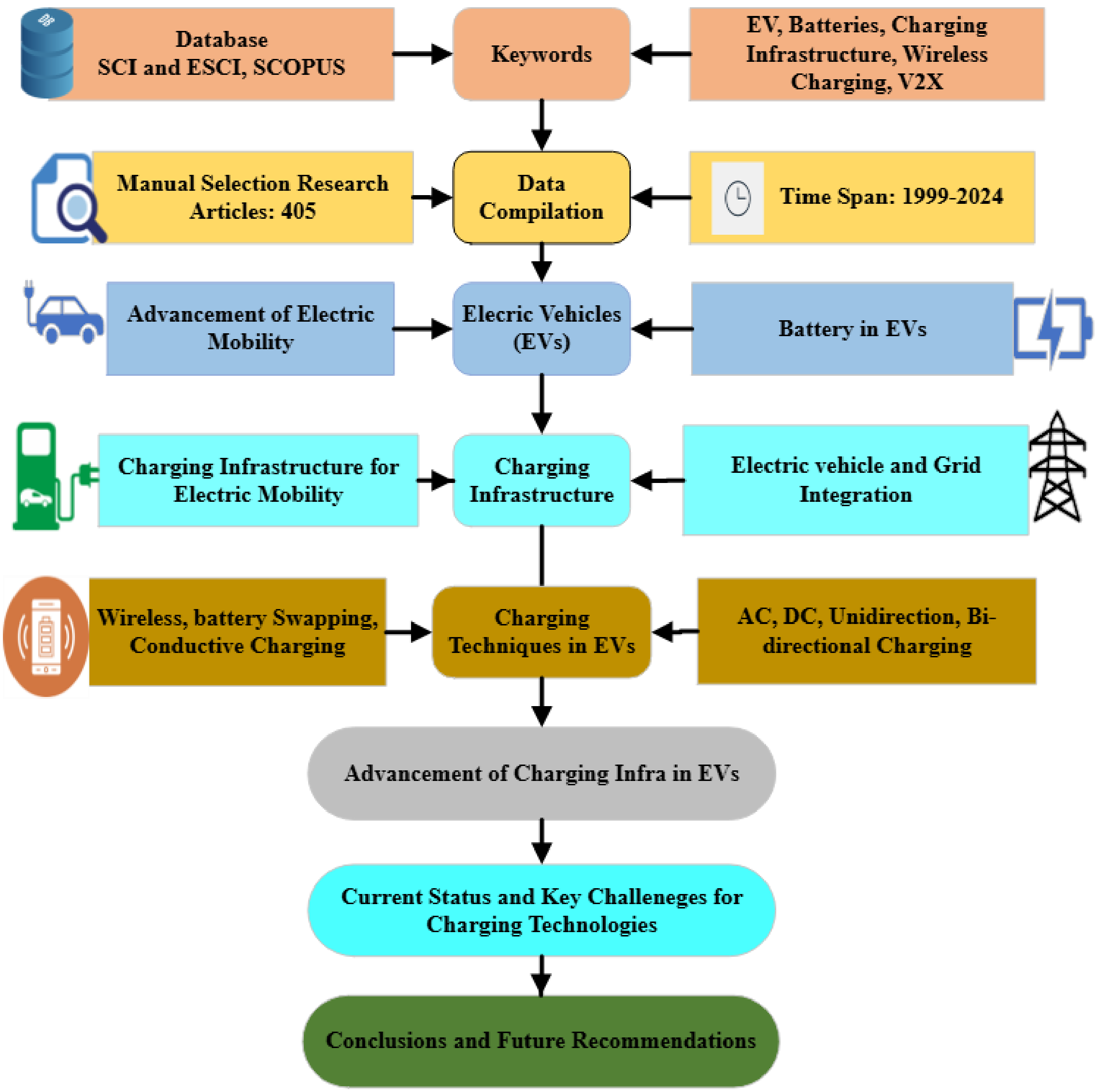

Figure 4. Materials and Methods.

Comparative research is conducted to develop electric mobility in terms of power drives, specifications, and charging times. It explains and analyzes how different charging infrastructure classifications can be made based on physical touch, power consumption, and power flow. The benefits and drawbacks of charging schemes, involving wireless charging, battery swapping, and conductive charging, are analyzed. A comparison of EV charging levels under IEC 61851, IEC 62196, and SAE J1772 is conducted. The progression of the setup for incriminating EVs is discussed, along with changes to charging procedures, global EV connectivity with artificial intelligence (AI), and the integration of vehicles-to-grid (V2G), vehicles-to-sun (V2S), and vehicles-to-infrastructure (V2I). To encourage electric mobility, how charging infrastructure is set up right now and its main obstacles are reviewed. Modifications to charging procedures, smart charging, and the incorporation of renewable energy sources with EV technologies will all be used to meet future energy demands and support electric mobility.

The configuration of this article is illustrated as follows: Section 1 provides the current research trends and states of charging infrastructure as per the Web of Science (WoS) database. Section 2 outlines the advancement in electric mobility. Description of various types of charging infrastructure for EVs is addressed in Section 3. Section 4 delivers the description of the EV-grid integration network, its effects, and agents. Modernizing the charging infrastructure through the use of cutting-edge technologies and electric mobility is included inside Section 5. Section 6 provides the key action for promoting electric transportation. The overall evaluation and recommendations for future improvements to the infrastructure for charging electric vehicles are provided in Section 7.

2. Advancements in Electric Mobility

An EV is a moving vehicle that runs totally or primarily on an electric traction system. Several nations have contributed to EV expansion, although the USA, UK, Germany, and China account for the majority of the worldwide EV market [54,55]. The first functional EVs were created in the 1880s, and EVs have emerged as a popular substitute for combustion-fueled automobiles in the beginning of the 20th century. However, the utilization of electric vehicles dropped as a result of innovation, increasing ICE development, and the mass manufacture of less expensive gasoline-powered automobiles [56,57]. Innovative EV machinery is still relatively new, but EVs are becoming again more and more popular because of their many benefits, including zero emissions, independence from fossil fuels, efficiency, relative quietness, and so on. In order to extend the range and efficiency of EVs, lower their cost, and build effective charging systems, research has been concentrated on these issues [58,59].

All-electric vehicles (AEVs) and hybrid electric vehicles are dual elementary categories into which EVs can be categorized [60,61]. The prime electrically driven component of EVs is electric traction systems. The two subcategories of EVs are battery-powered vehicles (BEVs) and fuel-cell-powered vehicles (FCEVs) [62,63]. An FCEV is based on fuel-cell storage technology and does not need a battery charging setup because energy is stored in the form of hydrogen. A BEV, however, can only recharge its storage unit using external electricity. Plug-in hybrid electric vehicles recharge their batteries through the grid [60,64]. This research uses the word "EVs" to refer to both BEVs and PHEVs.

Figure 5 depicts various categories of EVs and explains how energy is transferred from the energy source to the wheels. The technical details of EVs that are currently available on the market, released by various manufacturers, are shown in Table 2. Table 2 also provides an estimate of the charging interval needed to use multiple charging standards to bring the car's charge from 0% to at least 80%. In this case, level 1 is equivalent to a charging voltage between 110 and 120 V, level 2 to that of 220–240 V, and level 3 to that of 200–800 V, proven as DC fast charging (DCFC). It is clear that most electric cars (EVs) have a battery-based range of roughly 100 km, with some models having ranges between 200 and 400 km.

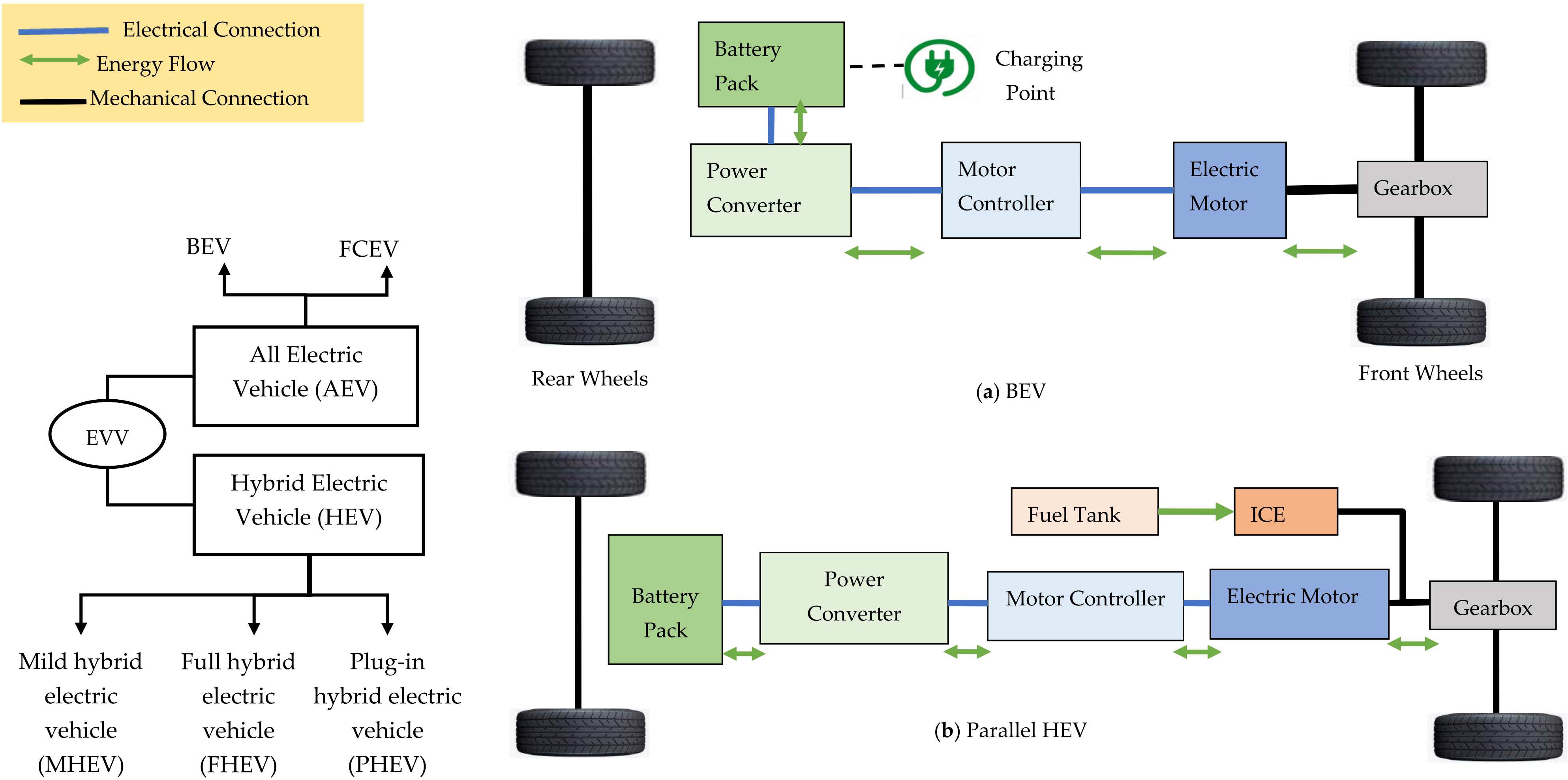

Figure 5. Classifications of electric vehicles and their power flow arrangements.

Table 2. Specifications of different EVs and their charging times as per automotive manufacturing firm standards.

Assembly	EV Model	Year/Type	Range (km)	Power (kWh)	Time for Charging (0–80%)			Ref.
					Level 1	Level 2	DCFC	
Honda	Fit	2014/BEV	132	20	15 h	3 h	--	[65]
	Spark	2016/BEV	132	19	--	7 h	45 min	
	Clarity	2018/PHEV	75 batteries	25.5	12 h	2.5 h	--	
Tesla	Model 3	2017/BEV	354	50	--	12 h	52–60 h	[66]
	Models S and X	2018/BEV	506 & 465	100	97.7 and 89 h	10.7 and 9.5 h	1.33 h	[67]
Chevrolet	EUV	2018/BEV	19	20	--	7 h	30 min	[68]
	Bolt	2019/BEV	383	60	--	9.3 h	1.33 h	
	Volt	2018/PHEV	85 batteries	18.4	13 h	4.5 h	20 min	
Renault	Zoe	2017/BEV	400	41	16 h	4.5 h	2.67 h	[69]
	Twizy	2017/BEV	100	61	--	3 h	--	[70]
Mitsubishi	i-MEV	2017/BEV	180	16	25 h	6 h	30 min	[71]
Volkswagen	e-golf	2017/BEV	201	35.8	--	6 h	1 h	[72]
Ford	Focus	2016/BEV	161	23	15 h	3 h	--	[73]
Nissan	Leaf	2018/BEV	243	40	35 h	7.5 h	30 min	[74]
Kia	Kia Soul	2018/BEV	177	41	24 h	4.8 h	45 min	[75]
Toyota	Prius Prime	2018/PHEV	40 batteries	8.8	5.5 h	2.1 h	--	[76]
BMW	i3	2018/PHEV	183	33	13–16 h	5 h	30 min	[77]
Fiat	Fiat 500e	2020/BEV	185	24	7–8 h	4 h	45 min	[78]

Hybrid electric vehicles can be classified into Mild Hybrid Electric Vehicles (MHEVs) and Full Hybrid Electric Vehicles (FHEVs). A MHEV operates via an integrated powertrain that combines an internal combustion engine with a small electric motor, typically employing a 48 V battery system for energy supply [79]. This configuration aims to enhance engine performance during acceleration and facilitate smoother gearbox transitions, all while minimizing fuel usage and emissions. The battery delivers brief intervals of electric power during start-stop functions and acceleration, enhancing fuel efficiency while eliminating the requirement for a high-voltage charging system. The motor in MHEVs operates as both a generator and a starter and is often referred to as the Belt Starter Generator (BSG) [80]. This system harnesses kinetic energy generated during braking and transforms it into electrical energy for battery recharging. In scenarios where increased power is necessary, like during acceleration, the motor assists the internal combustion engine. MHEVs provide an integrated combination of thermal and electric technologies, enhancing power delivery and fuel efficiency while maintaining versatility for both automotive configurations. In contrast to MHEVs, FHEVs can also drive on battery power alone for a certain range and at low speed. This leads to notable fuel savings and a significant reduction in emissions during stop-and-go driving scenarios [79].

The drivetrain configuration in HEVs differs according to the model and its intended application, with prevalent setups comprising parallel, series, and series-parallel systems. A parallel drivetrain configuration allows both the internal combustion engine and the electric motor to directly power the wheels, which is advantageous for meeting high-power demands and optimizing efficiency during highway travel [81,82]. In contrast, series drivetrains employ the internal combustion engine exclusively to produce electrical energy for the motor, which is responsible for propelling the wheels. This configuration is particularly well-suited for urban driving, as per Srivastava et al. [83]. The series-parallel drivetrain integrates both configurations, enabling the FHEV to alternate between pure electric, ICE, and combined power modes, thereby optimizing flexibility and fuel efficiency. The adaptable drivetrain architecture plays a crucial role in the performance of FHEVs, ensuring an optimal balance of power, range, and fuel economy in various driving conditions.

3. Charging Infrastructure for Electric Mobility

Infrastructure for EV charging consists of power, control, and communication systems. A circuit or mechanism for transferring electricity linking EVs and the grid is provided by power infrastructure. According to Figure 6, electric vehicle charging infrastructure may be split into different classes depending on charging speed, charger standardization, ownership, charging technique, power flow direction, and connector type. It would be simpler to accept electric vehicles if there were a sufficient infrastructure that allowed users to recharge their vehicles [84].

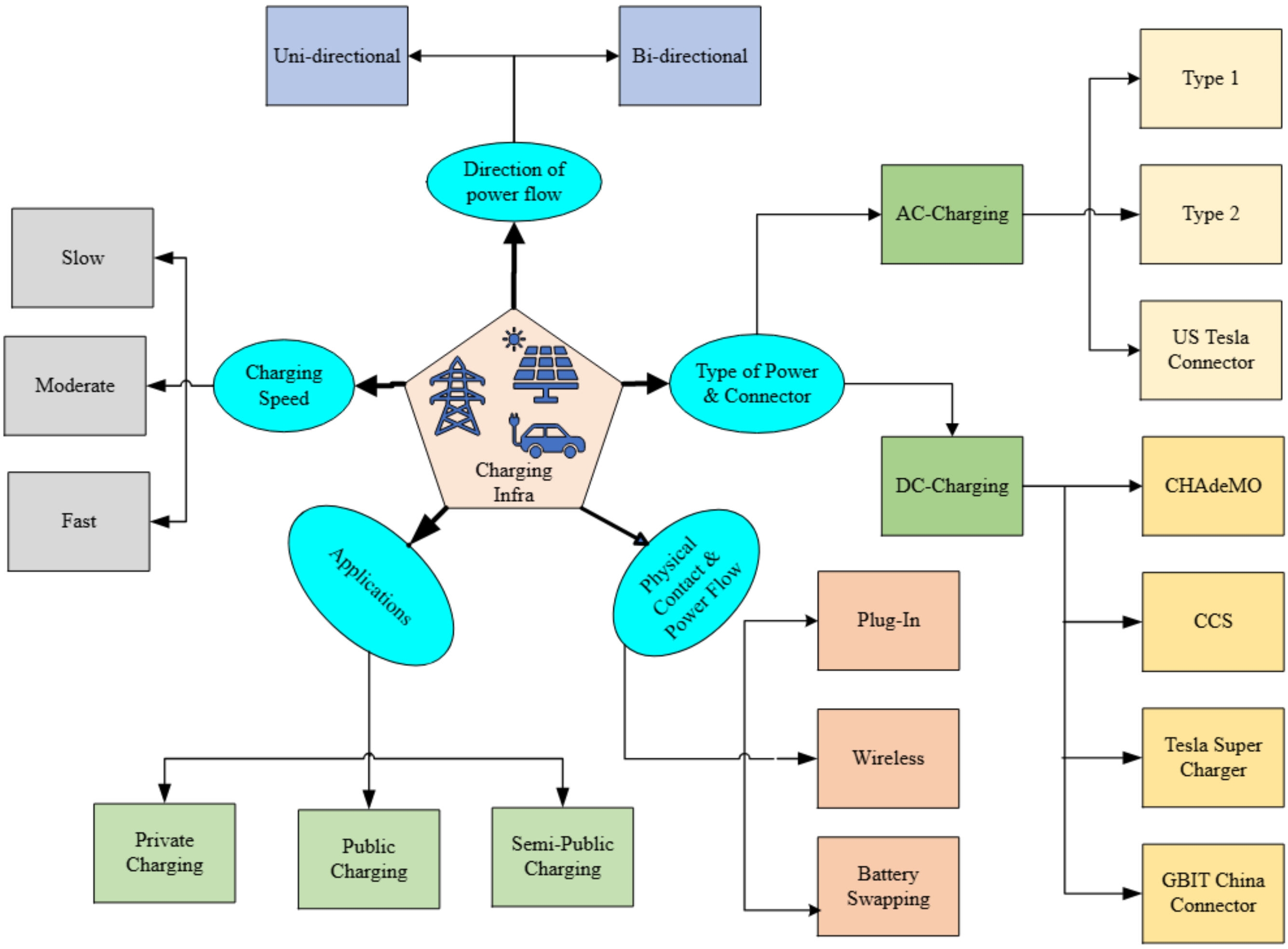

Figure 6. Different classifications of charging infrastructure for electric mobility.

Two subcategories of connection-type charging infrastructure are AC and DC charging, with AC charging further broken down into Type 1, Type 2, and US Tesla connectors and DC charging into CHAdeMO, CCS, Tesla Supercharger, and GB/T China connectors. The three different power flow charging methods fall under the categories of plug-in, wireless, and battery switching. Depending on the charging pace, infrared charging might be slow, moderate, or quick. According to the technique, there are two infra-charging methods: unidirectional and bidirectional. Infrastructures for charging might be private, public, or semi-public depending on applications [85]. In most cases, only one person or a family has use of a private charging network, which can be built in a garage or house. Nevertheless, everyone can use the infrastructure for public charging. In the case of semi-public infrastructures, only a select group of persons have access to semi-public charging, such as employees or members of a sports team.

There were more than 190,000 communal charging locations installed worldwide by the end of 2015 [86]. Total EV charging stations in Europe rose from 2379 in 2011 to 50,000 in 2015 to 165,000 in 2019 [87]. In contrast to Europe, with more EV charging stations than anywhere else in the world, China has twice as many as Europe (330,000 as of January 2019). India currently has 1640 public charging stations for electric vehicles.

3.1. Charging Infrastructure for Electric Mobility Based on Physical Contact

A battery can be charged using different techniques, and its current can be managed by a battery management system (BMS). Rectifiers are used in electric vehicles to transform AC into DC to be compatible with batteries.

Charge can be transferred via a number of methods, such as battery switching, conductive charging, and inductive charging, depending on how the user makes physical contact with the circuit. In the conductive charging method, the onboard battery and power source are linked by a wire. On the other hand, inductive charging technology allows electricity to be delivered without any physical touch. Figure 7 illustrates the different charging methods based on physical touch for electric mobility.

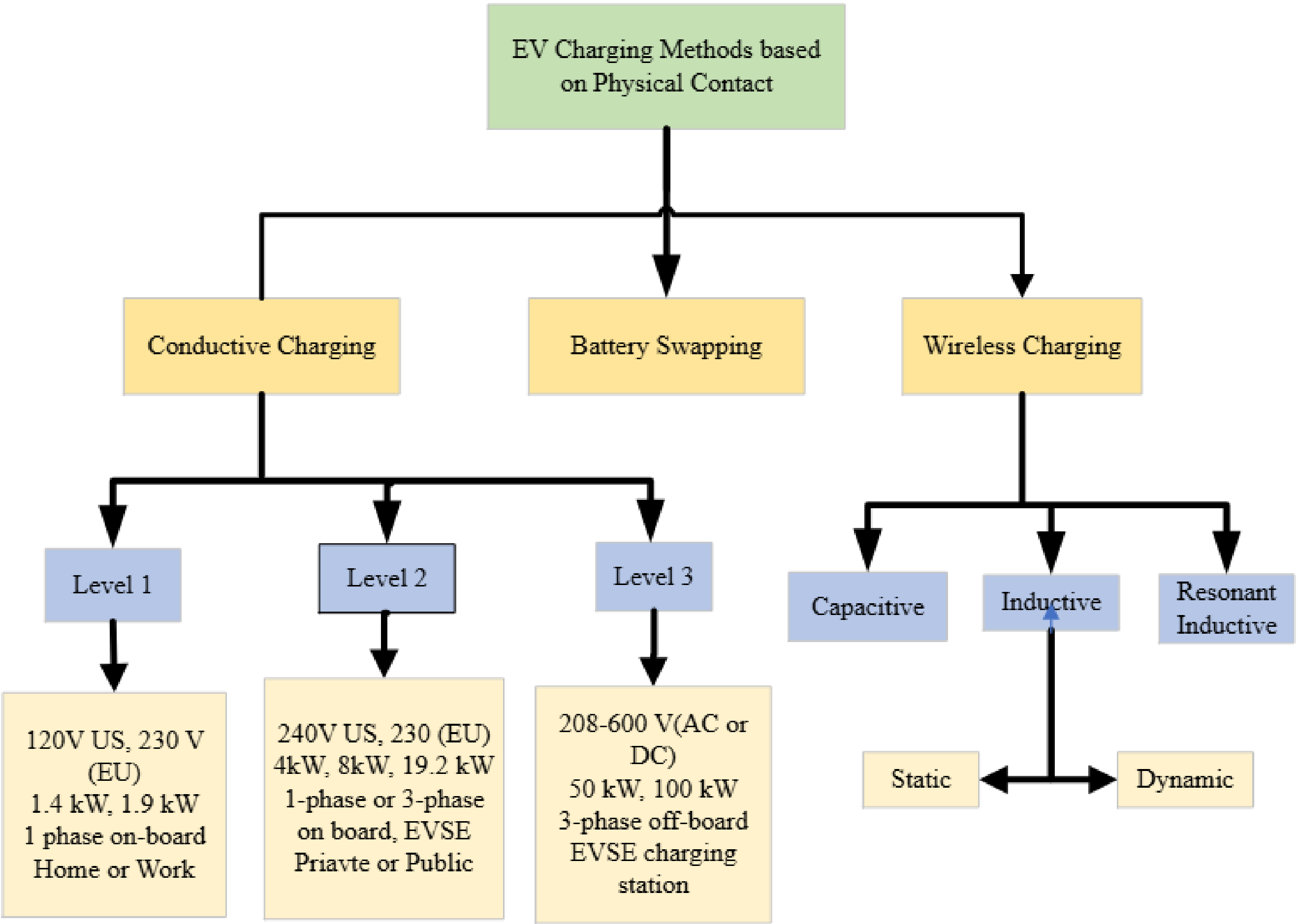

Figure 7. Different charging methods for EVs based on physical contact.

3.1.1. Conductive Charging

Direct metal-to-metal contact between the electric vehicle and the utility grid is necessary for conductive charging. The efficiency and dependability of this charging technique are demonstrated in Figure 8 [88]. Conduction-based charging has several advantages, including its high efficiency, economic feasibility, quick charging speed, and ease of use.

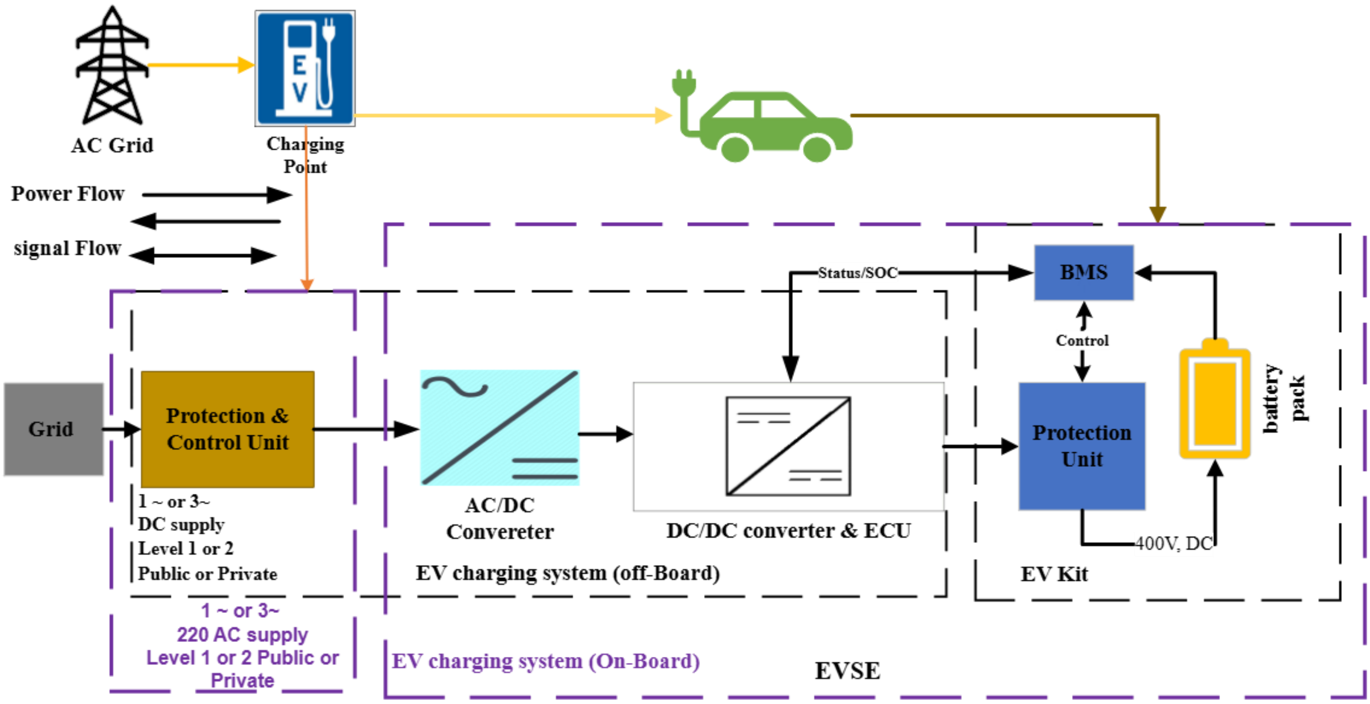

Figure 8. Electric vehicle On-board and off-board charging structure.

System categories for conductive charging have been added to those for onboard and offboard charging [89]. Chargers built into electric cars, like AC-DC converters, are typically slow chargers that fill the car's interior with electricity. The charging speed offered by offboard chargers is quick. Another way to extend EV range is to use offboard chargers to lighten the car [90]. In contrast to onboard chargers, which face limitations due to the vehicle's weight, spatial restrictions, and thermal management, offboard charging systems enable the placement of high-powered charging equipment, such as direct current (DC) fast chargers, in external locations. These systems can deliver significantly higher power levels, often reaching 350 kW or more, compared to standard onboard chargers. This capability greatly decreases the time needed to fully recharge an electric vehicle battery as per Srivastava et al. [83]. Furthermore, maintaining high-power components outside the vehicle allows offboard systems to decrease vehicle weight and create additional space that can be utilized for other functions, including battery storage or passenger accommodations. Levels 1 and 2 of conductive charging correspond to moderate charging, whereas level 3 corresponds to fast charging (level 3 or DCFC) [91].

In order for it to be the best option on the market, problems with charging times [92], accessibility to the general public [93], integration of renewable energy sources, and other issues must be resolved. The general concept for conductive EV charging is shown in Figure 8.

3.1.2. Battery Swapping

Through a process called "Battery Exchange", the batteries are replaced from the side of the vehicle or discharged from the battery swapping station (BSS). Using this method, the battery can be changed rapidly without requiring the operator to exit the vehicle. Then, batteries are charged by the BSS owner with a slow charging process that prolongs battery life [94], possibly adopting solar and wind energy, and it can be included in vehicle-to-grid (V2G) programs as an additional benefit [95,96]. To switch batteries, there are two techniques: (i) employing a chassis, which involves loading and unloading the battery from the bottom of the vehicle to replace the battery, and (ii) battery packs can be switched out from the side or back of the vehicle.

It is easy and quick to swap out batteries in small electric vehicles like two- or three-wheelers, while the battery packs of electric four-wheelers (4W) must be replaced using specialized equipment because they are situated at the bottom of the chassis and are quite heavy [97]. For example, the battery of a model from the 1990s might be changed using a technology introduced by Tesla in 2013 [98].

Another disadvantage of this strategy is that the battery is difficult to replace since the battery pack is tightly fastened with multiple screws and nuts due to its placement on the chassis' underbelly [99]. Since the BSS owner leases the EV batteries rather than purchasing them, it costs more to run an ICE engine on gasoline than it does to charge EVs at this station. Because of the lack of a standard in battery size and specifications, this method necessitates the purchase of numerous batteries and an extensive storage provision, both of which could be pricey in a location with heavy traffic [100,101]. It is also feasible for the station to use one set of standards for the vehicles while using different battery models [102].

3.1.3. Wireless Charging

The use of near-field electromagnetic coupling allows for wireless charging. Inductive and capacitive are the two different forms of wireless charging. As opposed to inductive wireless power transfer (WPT), which connects conducting coils with an electromagnetic field, conducting plates are connected to an electric field by capacitive WPT [103]. In a standard WPT setup, the power supply is linked to the transmitter, and the receiver is linked to the load. Wireless charging stations consist of two main parts: the ground assembly and the vehicle assembly. These parts work together to charge the car either while it is moving or at a fixed location [104]. These two parts of the wireless charging system typically communicate with one another to exchange data. The system's overall design is depicted in Figure 9. The following are descriptions of wireless power transfer mechanisms involving capacitive, inductive, and magnetic gear.

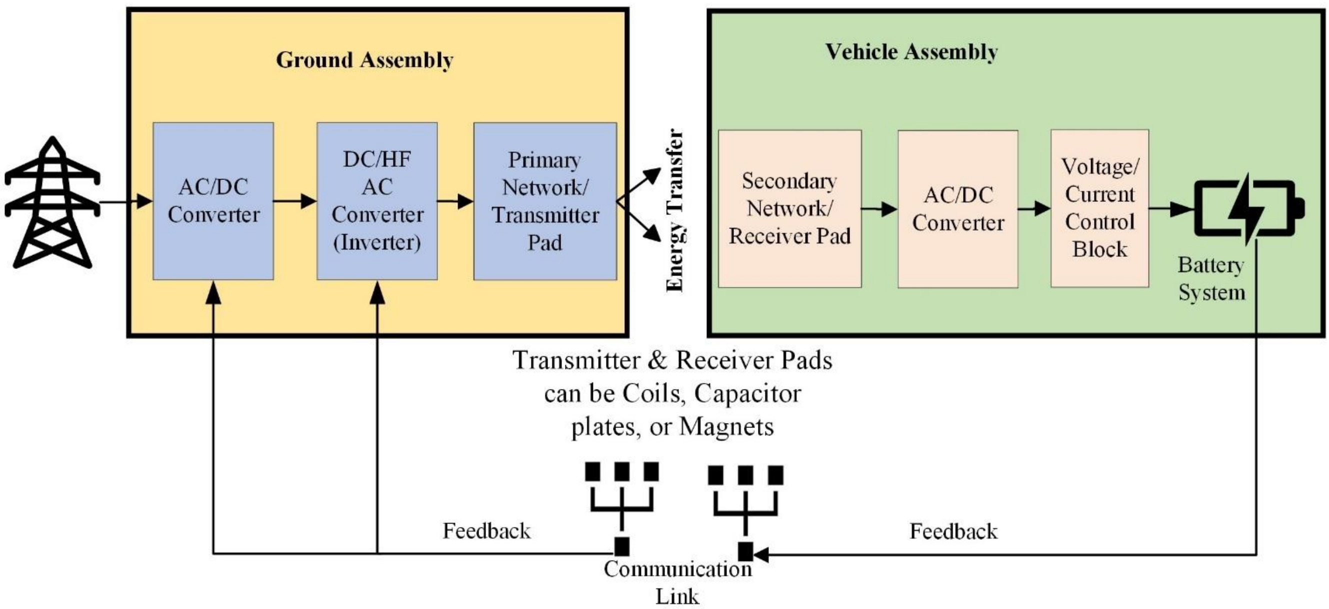

Figure 9. Workflow diagram for a WPT system.

(a) Inductive wireless charging: This electromagnetic induction-based technique makes use of a two-coil setup. After the setup is finished, the collecting coil is put inside the car, and the charging coil is set up on the ground. In light of recent extensions in WPT technology, EV applications have become more popular because it is now possible to recharge a car securely and conveniently. The charger lacks the need for a traditional connector but does require a standard connection in order to function, and it can be used while driving [105]. Inductive power transmission is still not a particularly effective technology. Twenty to one hundred centimeters should separate the transmitter and receiver coils [106]. If the transmitter coil is not deactivated in the WPT, eddy current loss may also pose a challenge. While real-time information transmission between the EV and transmitter should be possible, there might be a small amount of communication lag [107,108]. Because of its high cost and limited power transmission density from the huge coils and cumbersome design, inductive wireless charging is not commercially viable. A 97 percent efficient inductive charger with an output of 8.3 kW and a considerable air gap has been created [109]. Whilst the vehicle is immobile, a static wireless charger charges it [110]. Because alignment is better with static wireless charging, power transfer efficiency is increased [111]. With dynamic wireless charging, the majority of EV problems, such as range concerns, battery capacity, and cost, are solved [112].

(b) Capacitive wireless charging: Because of the directional form of the electric field, capacitive wireless power transfer is significantly more advantageous than inductive WPT in that electromagnetic shielding is not necessary. Because ferrite is absent, high frequency can be used, resulting in a smaller, more affordable device. Assuring electromagnetic safety while retaining elevated power transport intensity and acceptable efficiency is the fundamental challenge with capacitive WPT [113]. The advantages and disadvantages of various charging schemes are depicted in Table 3.

Table 3. Pros and cons of different charging schemes based on physical contact.

Charging Method	Pros	Cons	Reference
Conductive Charging	• Supplying different charge levels. • Assure high performance. • Coordination exists at the V2G facility. • Keeping the voltage constant while minimizing grid losses. • It is possible to avoid overloading the grid.	• Limitations on the electrical grid. • Structures that are incredibly complicated. • Fast charging contributes to distribution system voltage instability. • It is necessary to use a common connector and charge level. • When using V2G, battery life is decreased.	[114] [115] [116] [117] [118]
Battery Swapping	• You can rapidly swap out a battery that is fully charged. • BSS assists with V2G; utilities may balance demand and load. • A simple method of integrating the locally produced RESs.	• The cost is higher than ICE automobiles because the BSS pays rent each month. • An enormous expenditure is needed for equipment and batteries. • Numerous locations require the installation of batteries, and the battery specifications for various EVs vary.	[119] [120] [121] [122]
Wireless charging	• Without a conventional connector, the EV can be charged safely and easily. • No normal plugs are needed for vehicles to recharge while they are moving.	• Power is typically weakly conveyed; the 20 to 100 cm range is optimal for effective power transmission. • It is essential to have an EV with quick communication and a real-time transmitter.	[123] [107]

(c) Magnetic Gear WPT or MGWPT: There are some key differences between MGWPT and capacitive and inductive wireless charging technologies. Wireless power transfer between two parallel permanent magnets (PM) is the basis of MGWPT systems. Previous wireless charging systems used a coaxial design, while this one uses a different setup. Whenever the main winding receives current, it generates mechanical torque on the primary PM. Following this, the first PM will rotate, which will create torque on the secondary PM. Under this configuration, the secondary PM acts as a generator, feeding electricity into the battery via a power converter. When it comes to wireless electric vehicle charging, MGWPT devices have not seen widespread use. Typically, MGWPT systems are used for applications that require modest power, typically within the 1.5–3 kW range. According to [37], a 150 mm-long laboratory prototype could transmit 1.6 kW of power. The pros and cons of different charging methods based on physical contact are demonstrated in Table 3.

Table 4 presents a compilation of prototypes that incorporate wireless charging technology.

Table 4. Prototype implementation in wireless charging technology.

Prototype/Demonstration	Applications	Capacity	Ref.
Design of charging lanes utilizing machine learning techniques	Wireless charging systems for vehicles in urban environments	3.3 kW	[124]
Primary side hybrid compensation utilizing constant voltage control	Wireless EV charging with stable current/voltage	3.3 kW	[125]
Guided wireless charging utilizing a magnetic field	Accuracy in positioning for electric vehicle charging	—	[126]
High-density capacitive wireless power transfer with reduced fringing fields	Improved safety and efficiency in EV charging	13.56 MHz	[127]
Eco Charge Framework	Sustainable EV charger mapping	—	[128]
Solution for misalignment in dynamic wireless charging	Correction of misalignment in dynamic charging systems	—	[129]

3.2. AC vs. DC Power Sources

Both AC and DC power sources are used for EV charging. Depending on the nation's electrical infrastructure in question, AC charging has varying voltage and frequency levels. Level 3 charging provides the maximum charging voltage when it comes to voltage levels for AC charging, which are classified into levels 1, 2, and 3. While stations for charging at levels 1 and 2 can be installed in a private area., level 3 charging stations, which call for independent cabling and a converter and are typically erected at community charging places, need approval from utility providers to be set up. When compared to AC charging, DC charging is speedier and frequently more powerful [130]. With the most recent DC fast charging (DCFC) technology, an EV can be fully charged in as little as 20 min [131,132].

The NEMA 5-15R, a type of common single-phase grounded outlet with a rating of 120 V/15 A, is an example of a charging outlet used for slow charging at level 1 [133] connecting to the AC port of the EV with a standard J1772 connector. The on-board chargers typically allow level 1 charging with a 120 V single-phase AC supply up to 1.9 kW of power, with a legal charging current range of 15–20 A. Depending on the ESS type, level 1 charging can charge an EV to 100% in 3 to 20 h. Because ordinary power outlets are readily available and overnight charging frequently takes place in residences or parking lots, level 1 is the best option [134].

In both communal and remote services, level 2 charging dominates the charging landscape. The charging ranges offered by the current level 2 chargers are 208 V or 240 V (max 80 A, 19.2 kW). EVs like the Tesla Model S only need an outlet because they feature on-board chargers. The installation and handling of them require specific treatment at the home and business levels nevertheless. In American households, a 240 V supply is frequently accessible, yet a level 2 charger needs an entire night to charge an EV to 100%. Due to their quick charging periods and widespread charger-to-vehicle interfaces, level 2 chargers are preferred by EV owners. Between USD 1000 and USD 3000 is required to install a level 2 charger [135,136].

ESS, which offers speedy charging for businesses, and level 3 technologies have the ability to lessen EV range concern. The different specifications, harbors, and connections for 1/3 Phase AC charging, DC rapid charging, and the SAE AC/DC Combo J1772 connection, which pushes the EV in less than an hour. For fast charging, the Japanese CHAdeMO standard has gained adoption on a global scale. Between USD 30 k and USD 60 k may be the price range for level 3 chargers [137,138].

According to SAE J1772, level 1 and level 2 EVSE must be installed on-board; however, level 3 EVSE must be installed off-board. Different degrees of EV charging are described by IEC 61851 and SAE J1772 and are shown in Table 5. The numerous standards' functions include defining, assessing, and protecting low-voltage electrical installations as well as providing fundamental principles. The standards' many sections outline requirements for safeguards against electrical shocks and thermal effects. Additionally, it offers safety requirements for the electrical system, switching, control, and isolation.

Table 5. Comparative analysis of EV charging levels according to IEC 61851, IEC 62196, and SAE J1772.

Parameters	**120 V Level 1 AC (US)**	**230 V Level 1 AC (EU)**	**240 V Level 2 AC (US)**	**400 V Level 2 AC (EU)**	**Level 3 DC Fast Charging 300–600 V**	**DC Level Ultra-Rapid Charging**
phase/charger type	On-board Phase 1	On-board Phase 1	On-board Phase 1	On-board Phase 1	Off-board Three-Phase	Off-board Three-Phase
Installation site	Domestic	Household	Offices, shopping centers, and public parking lots.	Public parking lots, businesses, shopping centers, etc.	Adjacent to the gas station in terms of business	Charging in an area open to the public, such as a petrol station
Levels of power and current	1.5 kW, 12 A	1.9 kW, 20 A	5 kW, 17 A	8–19.4 kW, 32–80 A	50–350 kW, 400 A	>400 kW, >400 A
Charge duration	5–12 h	11–36 h	2–4 h	3–6 h	30–60 min	roughly 10 min
Applications	PHEVs	EVs	PHEVs	EVs	EVs	EVs
Reference	[139]	[139,140]	[139]	[139,141]	[139]	[139,142]

3.3. Unidirectional vs. Bidirectional Power Flow

For charging control, a unidirectional DC-DC converter and a semiconductor diode rectifier are used in an EV charger using unidirectional topography. Figure 10 illustrates how EV chargers are classified into unidirectional and bidirectional groups by the direction of power transfer [143]. Due to its simplicity, the unidirectional charger is straightforward to operate. When compared to bidirectional varieties, it lowers battery depreciation and has fewer connecting concerns. As opposed to that, the majority of grid subordinate facilities cannot be provided by unidirectional charging [144].

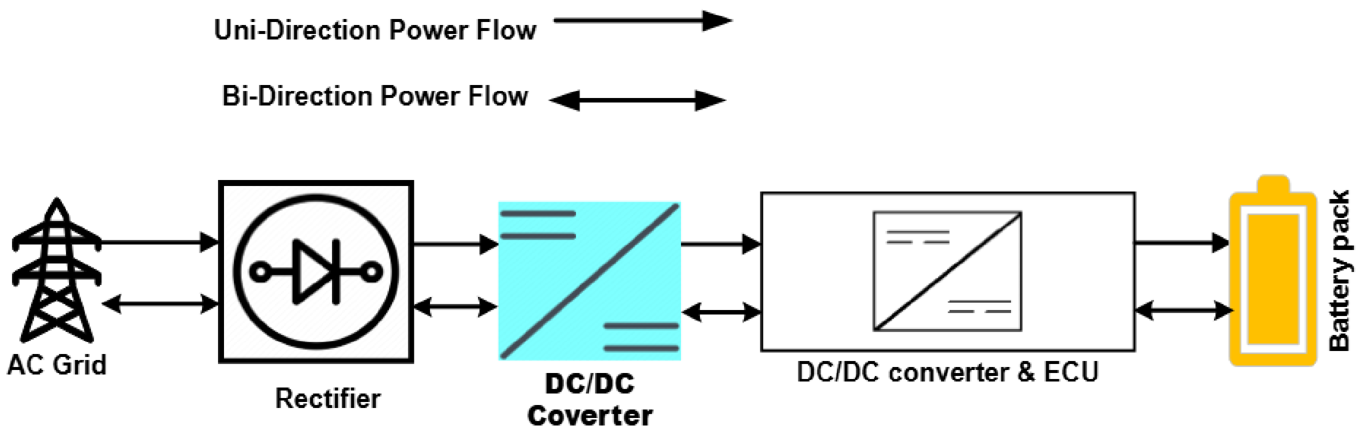

Figure 10. Uni-directional and bi-directional charging topology.

Mastoi et al. [145] explained that the operational mechanism of bidirectional power flow in charging systems relies on the capacity to charge a battery (transferring power from the grid to the vehicle) and to discharge the battery to provide energy back to the grid or to another load (power). This application, commonly known as vehicle-to-grid (V2G) or vehicle-to-home (V2H), utilizes sophisticated electronics to control the direction and flow of energy between the vehicle and associated systems. A bidirectional converter facilitates the reversal of power flow direction. While charging, it transforms AC power from the grid into DC to replenish the EV's battery. During the discharging process, the system converts the direct current (DC) power from the battery back to alternating current (AC) to ensure compatibility with the grid as per Kern et al. [146]. Bidirectional charging systems are commonly connected to the grid to manage load demands effectively. Electric vehicles have the capability to release power during periods of high demand, contributing to grid stability, and subsequently recharge when demand decreases, thereby enhancing energy efficiency as per Schwenk et al. [147].

A grid-linked bidirectional AC-DC converter plus a bidirectional DC-DC converter make up a bidirectional EV charger [148]. The grid can benefit from a number of supplementary services provided by EVs because of this type of charger's ability to function in both charge and discharge approaches. However, repeated trips back and forth to the grid to discharge power can shorten the lifespan of an EV battery. The process is complicated further due to metering and network constancy difficulties, which imply purchasing and marketing power from services [149].

4. Electric Vehicle–Grid Integration (EVGI)

Due to the rise in load demand, high EV amalgamation into the delivery grid at various levels can produce several difficulties with the electrical grid's operation [150,151]. In the past, integrating an electric car's grid has been the most important step in charging the batteries of an electric vehicle. In a setting of intelligent energy management, it might be conceivable for EVs to contribute significantly to the grid's ability to receive electricity and to provide services like spontaneous power supply, peak necessity flake, etc. To achieve these objectives, EV-grid integration (EVGI) needs to have strong technological and operational capabilities. To incorporate EVs on a broader scale into the grid, a regulatory organization with expertise in EV aggregation is required [152]. In order to maximize the business potential within the electricity sector, EV aggregators typically organize EVs according to owner preferences. The industry's contribution from EVs alone is negligible and ineffective, but if EVs and EV aggregators collaborate, the contribution can be increased [153].

Figure 11 summarizes the positive and negative effects of EVGI effects, while Tables 6 and 7 show an explanation of the detrimental and beneficial consequences of EV-Grid integration, respectively.

Table 6. Description of the adverse effects of EV-grid integration.

Effects	Explanation	Reference
Voltage Stability	• Nonlinear EV loads use a great deal of power quickly over a period of time, which contributes to the instability of the power grid. • EVs make power system interruptions more likely and prolong the time it takes for things to get back to normal. • The reliability of the grid can be increased with an EVGI system that is properly controlled.	[154–156]
Power Quality	• The main way to gauge how an electric grid will affect a V2G network is to look at the type of power supply. • The grid is susceptible to harmonics because of high-frequency converters used to charge EVs by transforming AC energy into DC energy. This leads to poor-quality power.	[157,158]
Enhance load demand	• Additional loads totalling 1000 TWh may be added (a 25 percent rise from the present level). • Uninhibited EV charging increases peak-time fees, placing a heavy burden on utilities.	[159,160]
Overloading of components	• A need for more load is generated or transmitted by the exceptionally large amount of EVGI. • Due to overloading and decreased transformer existences, some components of the current control logic were not intended to handle the higher loads.	[161,162]

Table 6. *Cont.*

Stability power grid	• The stability of tiny signals in the electrical network is examined. An electric car is considered to be an impedance and constant load. • An EV, represented as a continuous power load, was proven to be unstable; hence, an EV modeled as persistent resistance consignment is controlled by the intelligent control method.	[158,162]
Power supply and demand	• The main way to gauge how an electric grid will affect a V2G network is to look at the type of power supply. • The unpredictability of charging electric vehicles causes a number of issues, including grid overvoltage, declining power quality, and greater line loss. • The grid is vulnerable to harmonics as a result of high-frequency converters used to charge EVs through the conversion of AC power to DC electricity, which leads to poor-quality power.	[163,164]

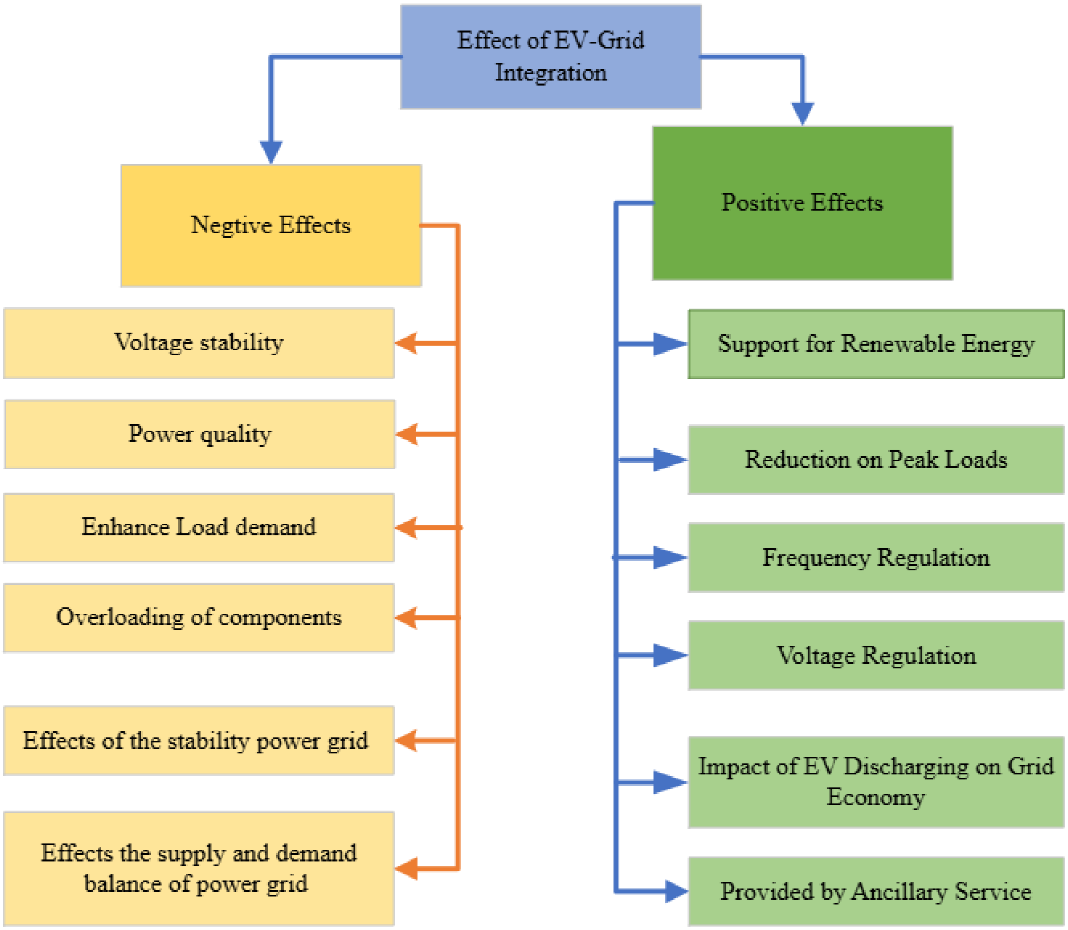

Figure 11. The advantages and disadvantages of EV-Grid integration.

Table 7. Explanation of the positive impacts of EV-grid integration.

Effects	Explanation	Reference
Renewable energy support	• Renewable energy's unpredictability can be decreased by using EVs as energy storage. • Reducing pollutants and saving money are two benefits of using EVs as a buffer for renewable energy.	[165–167]

Table 7. *Cont.*

Effects	Explanation	Reference
Peak load reduction	• Without increasing the amount of generating capacity, the grid becomes more energy-efficient when time-of-use (TOU) rates and coordinated charging schemes are used. • Negative effects are experienced with regard to EV grid penetration. • Practical measures can cut the peak demand on the electricity grid by 96%. In the end, this might result in more efficient utilization of the electricity system.	[168–170]
Frequency and voltage regulations	• In order to regulate frequency, grid frequency deviation must be corrected. • Due to their role as an obstacle to renewable energy, EVs can reduce greenhouse gas emissions while saving money. • Using reactive power to either produce or consume voltage. • Electricity flow equilibrium is attained by storing excess power. • Electric networks in rural areas are seemingly more dependable due to an increase in power inclusion.	[157,171,172]
Discharging and grid economy	• Utilizing planned charging and discharging enables improved power management. • In order to meet peak load demand, scheduling is necessary. The busiest times for discharge.	[171,173,174]
Ancillary service	• The provision of auxiliary services for the generation of electricity guarantees grid stability, demand, and reliability. • The stability of the electrical grid can be increased by offering auxiliary services utilizing V2G technology.	[172,175]

Framework and Agents for Electric Vehicle–Grid Integration

According to the institution, the main function of the EV-grid Integration (EVGI) is to charge an EV's batteries. However, in a smart grid context, whether it is now or in the future, EVs may serve a second purpose, which is to offer an electricity backbone to the network and subsidiary amenities like sympathetic justification, a volatile power source, top control splinter, and so forth [176]. The practical and sell function domains are the two key components of the full EVGI framework that is needed to accomplish these objectives. Contrarily, numerous agents are involved in market activity, including power consumers, EV owners, communication organization workers, allocation technique workers, capacity allocation units, supply agents, and producer corporations (GENCO) [177,178]. A new organization termed an "EV aggregator" is required to incorporate many EVs into the grid. For the purpose of profiting from economic prospects in the power market, EV owners choose to group their EVs into groups via EV aggregators. The marketplace provision of a single EV would be small and defective; this can be changed by clustering EVs and using EV aggregators. Figure 12 depicts the entire EVGI architecture, which can manage its own activities based on its observations of the operational circumstances and how the market is acting.

An agent is free-standing computer software that has the ability to direct its actions in accordance with observations of its surroundings. Electric authority mediators should be autonomous, intelligent, rational, and able to learn and assimilate new information [179]. Some are governed agents, including transmission system operators (TSOs) and distribution system operators (DSOs). Despite operating under real domination, structured agents are governed by encouragement-based supervision. Electric energy coordination agents should possess the following qualities: autonomy, intelligence, rationality, and the capacity for learning and absorbing new information [180,181]. The term "non-regulated agents" refers to some agents, such as generation corporations (GENCOs) and load-serving entities (LSEs), who operate on the wholesale and retail energy markets, respectively. The others are referred to as regulated agents, including TSOs and DSOs. Nevertheless, enticement-constructed organizing is used to control the set agents, who operate under true dominations. In addition to these agents, EVGI may also need EV vendors, EV dealercollectors (EVDC), and charging station administrators (CPM) [182,183]. Table 8 lists the functions and descriptions of several agents.

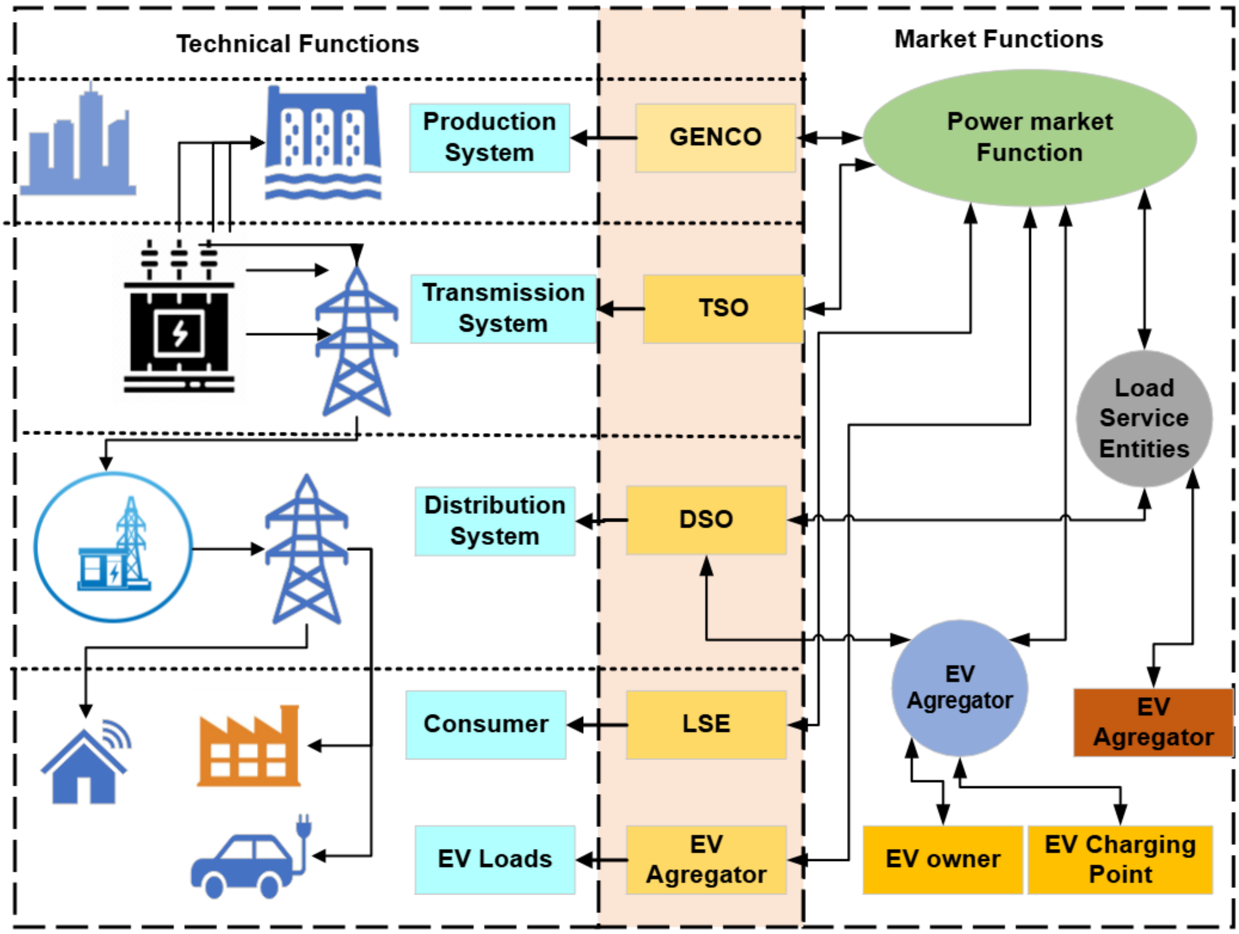

Figure 12. Network of EV and Grid Integration.

Table 8. Role of different agents in EVGI with descriptions.

Agents	Description	Reference
GENCO	• In charge of setting pricing in the electrical market. • Ensures efficient electricity production and market sales.	[180]
TSO	• Oversees the transmission system's functioning and security. • Regulates frequency and operating reserves, among other regularity provision buying.	[182,184]
DSO	• The allocation grid is looked after. • Ensures that the allocation link is protected and dependable. • Gives firmness and optimization maintenance for the entire system. • Guarantees an equitable and efficient allocation network • Enhances the competitiveness of the energy market.	[185]
LSE	• Charged with exporting energy to the final consumers. • End consumers are provided with power by a supplier or retailer agent, who also reimburses the DSO for deregulation and further provision charges.	[186]
EV Aggregator/EV	• Charging point directors, who serve as ultimate consumers, are in charge of managing EV charging and discharging stations. • Gives plug-in vehicle owners access to energy • Aggregators behave in a manner that is comparable to other extensive mediators.	[187]
EV Owner	• What supplementary provisions EVs can offer among V2G is determined by the EV load requirement, and the EVs plan the electricity needed to replenish batteries.	[188]

5. Advancements in Charging Infrastructure

The growth of commercial and community charging infrastructure has been very different around the world [189]. Although charging at households is a possibility, doing so requires consumers to pay a higher electricity bill and requires a parking space that is appropriate for charging EVs. Regarding infrastructure for car technologies, there are not enough specialized services and goods available. As per the above-mentioned key factors, it is advised that the subsequent requirement be mandatory in order to properly implement the integrated EV setup in the future.

5.1. Amendments in Charging Approaches

Despite the fact that there are now numerous benefits for the economy, the environment, and the smart grid, the customer's concerns about cost, range anxiety, dependability, and charging times remain prominent [190,191]. Utilizing sophisticated technology is one way to deal with some of these problems:

i. Among the most crucial features of electric cars is charging more quickly and effectively to increase range [14].
ii. Currently, there are different types of common connectors available for quick charges; these conventional connectors include superchargers, since the CCS and CHAdeMO were introduced to J1772, IEC 62196, and the GB/T, respectively [192,193].

5.2. Global Connectivity of EVs with Artificial Intelligence

The EV industry is currently heavily influenced by AI, which has applications in areas like real-time traffic monitoring and intellectual routing systems [194]. As mentioned in the point that follows, it can be utilized for a variety of safety purposes, including monitoring driver behavior, predicting equipment maintenance, and enhancing transportation security.

i. By lowering costs or making greater use of the electrical infrastructure, artificial algorithms employed to optimize charges have the potential to reform the charging method [14].
ii. The study assumes that a lot of questions remain unanswered and that there will be several prospects for future research, including the use of telecommunications among vehicles and their authority substructure and the adoption of AI-based technologies (like deep learning or optimization strategies) [195,196].
iii. It will be possible to connect automobiles to communiqué logics that qualify as vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) as a result of wireless communication networks [197]. The application of an AI-based set of rules will create a varied scale of innovative prospects by giving cars some intelligence and eventually greatly improving transport [14].
iv. Many EV-related concerns have AI-based solutions, such as energy-efficient guiding, improved and additional intelligent charging, as well as temperature control for batteries [198,199].
v. To improve the system and consume less energy, artificial neural networks (ANNs) can be adopted for managing battery temperature. The usage of communications and artificial intelligence will encourage the development of novel solutions [200,201].

5.3. Integration of Renewable Energy with EVs

The transmission system operator (TSO) has numerous obstacles when integrating renewable energy sources (RESs) into the grid because RESs cannot be dispatched; the maintenance of supply and demand is challenging. The energy that is produced over what is needed can simply be utilized to charge storage during periods of high generation or low demand. In G2V, an electric vehicle receives power from the grid, while in V2G, a vehicle sends power back to the grid. In the conventional system, it is feasible to control the dual communication of electric power linking automobiles and the power grid. As indicated in Figure 12 [202], V2G attempts to execute the mutually beneficial interactions required to construct a smart city by presenting the transfer of power and related data through linkage and moving systems [203]. The following are discussions on V2G, S2G, and V2X technologies for improving charging infrastructure and electric mobility:

(a) Vehicle-to-grid (V2G): EV and power grid demand response (DR) services are provided by V2G to enable network operations with intelligence. In this context, "V2G" implies the diffusion of power and related data among linkage and transference schemes, implementing the collaboration linking the two that is required to create an intelligent city [204]. A V2G structure's potential block diagram is depicted in Figure 12 [205].

(b) Sun-to-vehicle (S2V): Like the fueling stations required for fuel-based vehicles, EVs now in use around the world need charging stations. S2V or EV-PV refers to the process of using a photovoltaic-powered charging station to store solar energy [206,207]. The smart grid idea put into practice by S2V is seen in Figure 12. Despite the fact that the idea and practice of solar machines are relatively old, Birnie primarily refers to them as S2Vs in his work [208]. He advises installing PV boards at parking sites to provide daytime charging for people who often drive electric vehicles. By serving as EV charging stations, these solar systems can help stabilize the current, lessen dependence upon remnant fuels, and cut carbon radiation.

(c) V2X infrastructure: Through this technological innovation, the idea of using the energy contained in EV batteries for new purposes was developed (V2G). V2G plans to implement intelligent EV charging in order to manage the two-way energy stream involving EVs and the grid [209]. The notion is broadened by V2X to include a number of EV power utilization scenarios and locations, such as V2H, V2B, V2F, V2L, and vehicle-to-infrastructure (V2I) [210,211]. Figure 13 illustrates V2I, one of the contemporary advancements in communications and vehicle tools. V2I allows for information sharing between cars by connecting them to the road system. Through this technology, varying vehicle speeds frequently result in energetic performance. V2I technology assists in addressing two important issues—road safety and the increase in workload—while having a less detrimental effect on the environment [211].

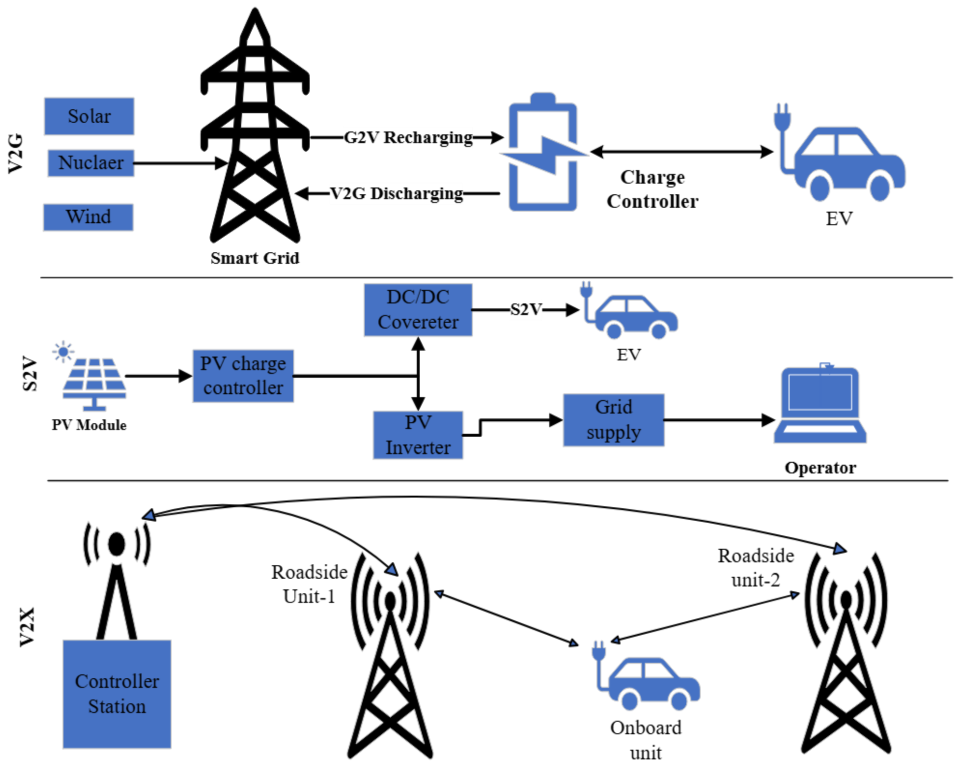

Figure 13. Charging infrastructure of V2G, S2V, and V2X.

(d) Technical and environmental challenges associated with implementing S2V and V2X technologies

V2X and S2V technologies represent significant advancements in transportation systems, facilitating connectivity among vehicles, businesses, and various entities. Significant challenges related to the technical and environmental aspects of these technologies are presented below:

Technical challenges

(i) Network communication: V2X utilizes sophisticated communication protocols, including Cellular-V2X (C-V2X) and dedicated short-range communications (DSRC). Ensuring dependable, uninterrupted, and safe communication in ever-changing environments presents a significant challenge.
(ii) Scalability: With the rise in connected devices, the complexity of managing data exchange and mitigating congestion in communication networks escalates significantly. Incorporating S2V into urban planning necessitates addressing challenges related to network scalability and implementing resilient edge computing technologies to manage data traffic effectively.
(iii) Interoperability: Achieving compatibility across diverse V2X standards, protocols, and devices produced by various manufacturers continues to pose a significant challenge.
(iv) Cybersecurity risk: The incorporation of vehicles into digital frameworks introduces potential weaknesses to cyber threats, particularly in the realm of identifying misconduct in autonomous systems. Recognizing and addressing cybersecurity threats in V2X systems is crucial, with an emphasis on multi-layered detection mechanisms.
(v) Data processing and storage: Managing large volumes of real-time data produced by V2X systems requires strong edge computing capabilities and effective storage strategies.

Environmental challenges

(i) Energy consumption: The integration of V2X and S2V devices, particularly through the synergy of 5G and edge computing, has the potential to elevate energy consumption, which stands in opposition to sustainability objectives.
(ii) Infrastructure cost: Creating and sustaining sustainable infrastructure to facilitate V2X systems while minimizing ecological disruption presents a considerable challenge.
(iii) Electromagnetic interference: The widespread use of communication devices may lead to heightened electromagnetic interference, which could impact other essential systems.

6. Key Barriers for Charging Infrastructure

In the future, electric vehicles will be a more appealing tool if batteries can meet all of the demands for energy while being affordable, safe, and dependable [212]. Driving range, ease of refueling, and price are all important aspects that affect how popular EVs are. India faces a number of difficulties, including the high cost of electric vehicles, particularly four-wheelers; the capacity to produce batteries; the consumption of power; the compatibility of chargers; the site of inappropriate charging; and a lack of a robust electric charging setups [213]. When it comes to development, the infrastructure for charging electric vehicles confronts many obstacles. The infrastructure for EV charging is mostly responsible for these elements. The difficulties and recommendations for EV charging are listed below.

6.1. High Initial Expenditure

It costs a lot of money for an EV charging setup to be installed. There are a number of prerequisites to developing the EV charging infrastructure. Certain requirements must be fulfilled, including a suitable site, retailer, grid power reliability, various charger categories, cords, and supplementary auxiliary equipment. Installation costs for public EV charging stations can be significant, with level 2 chargers costing as little as $25,000 and DC fast chargers costing as much as $36,000 [214]. Installation and "soft costs", like securing permits and establishing utility connections, are not included [215]. Among the most crucial elements of EVs is the battery and using poor materials for battery equipment is an additional important concern because the battery will account for roughly 30% of the total price of an EV [216].

6.2. Different Charging Connector Types

A single charging station should be equipped with connectors like CCS (Combined Charging System), CHAdeMO, Bharat DC-001, and AC-001, in order to give clients the option of quick or slow charging based on their requirements and time considerations. The EV needs to possess the capacity for either excessive voltage or current. This means that the optimum solution for EVs might be a blend of slow and quick charges. It is advisable to employ superchargers to cut down on waiting time [217].

6.3. EV Charging Station Installation Location

When installing an EV charging station, the location poses a serious challenge. A charging station's location or design should make it easy to see, accessible, and quick to use, hence reducing waiting times. In order for customers to take advantage of the best time to charge their EVs, the location should be thought of as a premier location with qualities like plenty of parking space, accessibility, ability to set up, a suitable waiting area, etc. [218].

6.4. Technical Safety at EV Charging Stations

Technical safety is required for the installation of the EV charging infrastructure. Voltage changes, overcurrent, frequency inconsistencies, and ground faults are significant difficulties. Sensors for stabilizing, detecting proximity, and controlling the pilot must be integrated to monitor voltage variations in order to overcome them. By carefully designing some hardware components, a number of issues can be overcome, such as those with power, heat dissipation, grounding, and voltage measurement [219].

6.5. High Charging Time and Driving Range

Among the major stumbling obstacles to EV acceptance is the length of the recharge process. Battery charging takes a long time, even taking up consumer time that could be spent working [216]. When it comes to energy and potential intensity, battery life degrades over time, which reduces driving range, lengthens recharging times, and reduces efficiency [220]. Further affecting EV owners is the replacement of outdated batteries with fresh batteries. New batteries can be added to EVs to expand their driving range, but doing so adds weight and necessitates a more potent electric motor to move the car [221,222]. These variables collectively raise the price for EV buyers.

6.6. Software-Related Challenges

One of the most crucial responsibilities is determining whether a charging slot is available. Such software is quite beneficial in this regard because it makes life simpler and saves time. Consider Fortum India, one of the leading businesses in the EV charging position industry. For EV drivers and companies, it provides safe, reliable, and user-friendly charging solutions. It is a prominent contributor of EV charging services [223,224].

6.7. Suggestions and Strategic Policy in the Development of Charging Infrastructure

The present study examines and provides multiple policy suggestions aimed at improving the development of charging infrastructure. Below are discussions on recommendations, policies, and strategies for effective planning in the development of charging infrastructure:

(a) Infrastructure planning and integration
   - (i) Grid modernization: Allocation of resources for grid enhancements to accommodate the rising electricity requirements stemming from the extensive adoption of electric vehicles. Implementing vehicle-to-grid (V2G) systems to efficiently manage peak loads.
   - (ii) Targeted deployment: It is essential to focus on the installation of fast chargers in strategic locations such as highways, urban centers, and areas with high traffic flow. Concentrating on overlooked areas like rural regions to guarantee fair access.

(iii) Urban integration: Integrating charging stations within public transit hubs, workplaces, and community centers.

(b) Financial incentives and economic strategies

(i) Subsidies and grants: It is possible for governments to provide subsidies for the installation of charging stations in order to alleviate the significant capital and operational expenses involved. Examples include direct financial support for rural and underserved areas to close the accessibility gap.

(ii) Public–private partnership (PPP): Fostering partnerships among the private sector, utilities, and governmental bodies to jointly finance and enhance infrastructure development.

(iii) Tax credit and rebates: Providing tax incentives for enterprises and residences that implement private charging stations.

(c) Technological innovation

(i) R&D support: Supporting investigations into cutting-edge charging technologies, such as ultra-fast charging and wireless systems.

(ii) Real-time data sharing: Creating systems that provide immediate information on the availability and operational status of charging stations.

(iii) Standardization initiatives: Advocating for international benchmarks in hardware and software to guarantee a consistent user experience.

6.8. Key Standards and Protocols for Global EV Charging Integration

The effective incorporation of electric vehicles (EVs) into the worldwide charging infrastructure relies significantly on the establishment of strong standards and protocols. These facilitate interoperability among various manufacturers, guarantee safe functioning, and accommodate advancing technologies such as vehicle-to-grid (V2G) systems. The establishment of international standards focuses on enhancing interoperability, improving charging efficiency, and ensuring data security, all while fostering user-friendly and economically viable charging solutions. Table 9 provides a summary of the key standards, protocols, and their applications for the integration of electric vehicles into the global charging network:

Table 9. Key standards, protocols, and their applications for the seamless integration of EVs into the global charging network.

Category	Standard/Protocol	Key Features	Applications
Connector and plug standards	CHAdeMO	Rapid charging solutions for vehicles that meet compatibility standards.	DC fast charging, with a focus on Japan
	Combined charging system (CCS)	Integrates both AC and DC within a single connector, providing extensive compatibility.	Universal AC/DC charging across various regions
	Type 1 and Type 2 Plugs	Facilitates adherence to localized AC charging standards.	AC charging in North America (Type 1) and Europe (Type 2)
Communication protocols	Open charge point protocol (OCPP)	Interoperability that is not tied to any specific vendor; includes functionalities such as diagnostics and dynamic pricing.	Communication protocols between electric vehicle chargers and management systems
	ISO 15118	Enables seamless authentication and bidirectional energy flow.	Plug-and-charge, vehicle-to-grid (V2G) communication
	Open charge point interface (OCPI)	Ensures uniformity in access and billing across various networks.	Roaming between charging networks

Table 9. *Cont.*

Category	Standard/Protocol	Key Features	Applications
Grid integration standards	IEC 61851	Defines safety features and modes of charging.	Conductive charging systems
	IEC 62196	Ensures safe and standardized physical connections.	Connectors and interface configurations
	IEEE 2030.5	Supports smart grid integration and V2G functionalities	Distributed energy resource management
Security standards	Public key infrastructure (PKI)	Safeguards against unauthorized access and cyber threats.	Ensuring safe communication for interactions between electric vehicles and the grid
Wireless charging	SAE J2954	Establishes standards for inductive charging, enhancing user convenience	Wireless power transmission for electric vehicles
Data management standards	Energy management systems (EMS)	Enhances energy distribution and ensures effective load balancing.	Data integration from EVs, chargers, and grids.

7. Conclusions and Future Recommendations

To perform an exhaustive and in-depth investigation, we have carefully provided an integrated review of 223 research articles related to charging infrastructure technologies for electric transportation. The key elements, advantages and disadvantages, recent technological advancements, challenges, and potential outcomes for growing electrification have all been thoroughly examined. The significant contributions are outlined below:

i. Current research trends and states of charging infrastructure are provided in terms of the number of charging stations in different leading countries for electric mobility as per the WoS database from 2013 to 2024.
ii. Official and governmental websites such as IEA, SIAM, BEEINDIAN, and SMEV are referenced to obtain and examine reliable data related to electric vehicles and charging infrastructure.
iii. There is a detailed examination of the different types of charging infrastructures, from unidirectional to bidirectional, and how they differ. Along with battery swapping, wireless charging, and conductive charging, it is explained how forecasting the charge levels in relation to the charging infrastructure can be performed.
iv. The pros and cons of static and dynamic wireless power transfer methods for the purpose of recharging electric vehicles, including magnetic gear WPT, inductive charging, and capacitive charging, are presented.
v. A collection of prototypes utilizing wireless charging technology is examined and investigated, focusing on their advantages and disadvantages.
vi. To support sustainable electric mobility, a network of electric vehicles with grid integration, together with its effects and the role of various agents, is analyzed and described.
vii. To advance the charging infrastructure, artificial intelligence (AI), vehicle-to-grid (V2G), sun-to-vehicle (S2V), and vehicle-to-infrastructure (V2I) technologies are described.
viii. Different key barriers and current research trends related to charging infrastructure and electric mobility are presented.
ix. Recommendations, policies, and strategies for effective planning in the development of charging infrastructure are examined.
x. Key standards, protocols, and their applications for the smooth integration of electric vehicles into the worldwide charging network are outlined.

After reviewing the research that is now available regarding the condition of charging infrastructure, it is believed that the following innovative solutions may be useful to overcome difficulties:

- Conventional charging connections need to be made more user-friendly to attract customer interest and reliability in electric mobility.
- Not all EV models currently on the market are compatible with all charging levels, and not every charging outlet in public offers all power levels of charging. EV consumers struggle to locate accessible charging outlets as a result.
- To strengthen the use of EVs, it is necessary to create readily available charging stations that utilize vehicle-to-grid (V2G), solar-to-vehicle (S2V), and vehicle-to-infrastructure technologies.
- The construction of personal quick-charging infrastructure, for instance in homes, is still a problem and typically calls for EV owners to acquire approval from neighborhood utility companies and authorities. Due to the inconvenience of this prolonged activity, EV owners are less motivated to build their own privileged fast-charging stations.
- It is crucial to plan the areas where EV charging stations are located on roads and in cities. Since most motorways have not yet been incorporated into the strategy, the sites of EV charging stations are now planned primarily in urban areas, which worries EV owners.
- In the future, data and energy could be shared between electric vehicles (EVs) and other vehicles using AIEI (automobile information and energy internet) and sensor-on-chip technologies.

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Nomenclature

Acronyms

2W	Two-wheeled
3W	Three-wheeled
4W	Four-wheeled
AC	Alternating current
AEV	All-electric vehicle
AI	Artificial intelligence
ANN	Artificial Neural Network
BEVs	Battery electric vehicles
BIS	Bureau of Indian Standards
BMS	Battery management system
BSS	Battery swap station
CCS	Combined Charging System
CHAdeMO	Charge for moving” in Japanese
CSA	Charging Station Administrator
DC	Direct Current
DCFC	Direct-current fast charging
DSO	Distribution system operator
ECU	Electronic control unit
EES	Energy storage system
ES	Energy storage

EVDC	Electric vehicle dealer collector
EVGI	Electric vehicle–grid integration
EVs	Electric vehicles
EVSE	Electric vehicle supply energy
FCEVs	Fuel-cell electric vehicles
G2V	Grid-to-vehicle
GENCO	Generation Corporation
GHG	Greenhouse gas
HEVs	Hybrid electric vehicles
ICEs	Internal combustion engines
IEA	International Energy Agency
IEC	International Electrotechnical Commission
LCO	Lithium cobalt oxide
LFP	Lithium iron phosphate
LIBs	Lithium-ion batteries
Li-ion	Lithium-ion
LMO	Lithium manganese oxide
LNO	Lithium-nickel-oxide
LSE	Load-Serving Entity
NCA	Lithium nickel cobalt aluminum oxide
Ni-Cd	Nickel-cadmium
Ni-MH	Nickel-metal hydride
NMC	Nickel manganese cobalt
PHEVs	Plug-in hybrid electric vehicles
S2V	Sun-to-vehicle
SAE	Society of Automotive Engineers
SMEV	Society of Manufacturers of Electric Vehicles
SoC	State of charge
TSO	Transmission system operator
V2B	Vehicle-to-Building
V2F	Vehicle-to-farm
V2G	Vehicle-to-grid
V2H	Vehicle-to-home
V2I	Vehicle-to-infrastructure
V2L	Vehicle-to-load
V2S	Vehicle-to-sun
V2X	Vehicle-to-everything
WPT	Wireless power transfer
ZEBRA	Zero Emissions Batteries Research Activity

References

1. Gwalwanshi, M.; Kumar, R.; Chauhan, M.K. A review on butanol properties, production and its application in internal combustion engines. *Mater. Today Proc.* **2022**, *62*, 6573–6577. [CrossRef]
2. Tian, Z.; Wang, Y.; Zhen, X.; Liu, Z. The effect of methanol production and application in internal combustion engines on emissions in the context of carbon neutrality: A review. *Fuel* **2022**, *320*, 123902. [CrossRef]
3. Falfari, S.; Cazzoli, G.; Mariani, V.; Bianchi, G.M. Hydrogen Application as a Fuel in Internal Combustion Engines. *Energies* **2023**, *16*, 2545. [CrossRef]
4. Noura, N.; Boulon, L.; Jemeï, S. A review of battery state of health estimation methods: Hybrid electric vehicle challenges. *World Electr. Veh. J.* **2020**, *11*, 66. [CrossRef]
5. GOI, Electric Mobility | BUREAU OF ENERGY EFFICIENCY, Government of India, Ministry of Power, EV, GOI. 2023. Available online: https://beeindia.gov.in/en/programmesenergy-efficiency-in-transport-sector/electric-mobility (accessed on 7 July 2023).
6. 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]
7. Cao, J.; Chen, X.; Qiu, R.; Hou, S. Electric vehicle industry sustainable development with a stakeholder engagement system. *Technol. Soc.* **2021**, *67*, 101771. [CrossRef]
8. Mololoth, V.K.; Saguna, S.; Åhlund, C. Blockchain and Machine Learning for Future Smart Grids: A Review. *Energies* **2023**, *16*, 528. [CrossRef]

9. Qureshi, K.N.; Alhudhaif, A.; Jeon, G. Electric-vehicle energy management and charging scheduling system in sustainable cities and society. *Sustain. Cities Soc.* **2021**, *71*, 102990. [CrossRef]
10. Patil, G.; Pode, G.; Diouf, B.; Pode, R. Sustainable Decarbonization of Road Transport: Policies, Current Status, and Challenges of Electric Vehicles. *Sustainability* **2024**, *16*, 8058. [CrossRef]
11. Waseem, M.; Waseem, M.; Ahmad, M.; Parveen, A. Study and Assessment of Propulsion Systems of Three-Wheeled Electric Powered Rickshaw in India. *Int. J. Emerg. Trends Eng. Res.* **2021**, *9*, 1111–1117. [CrossRef]
12. IEA. Global EV Data Explorer—Data Tools—IEA. 2023. Available online: https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer (accessed on 14 November 2022).
13. SMEV. SMEV EV Industry. 2023. Available online: https://www.smev.in/statistics (accessed on 7 July 2023).
14. Waseem, M.; Ahmad, M.; Parveen, A.; Suhaib, M. Battery technologies and functionality of battery management system for EVs: Current status, key challenges, and future prospectives. *J. Power Sources* **2023**, *580*, 233349. [CrossRef]
15. Wang, K.; Wang, W.; Wang, L.; Li, L. An improved SOC control strategy for electric vehicle hybrid energy storage systems. *Energies* **2020**, *13*, 5297. [CrossRef]
16. Waseem, M.; Suhaib, M.; Sherwani, A.F. Modelling and analysis of gradient effect on the dynamic performance of three-wheeled vehicle system using Simscape. *SN Appl. Sci.* **2019**, *1*, 225. [CrossRef]
17. El Kharbachi, A.; Zavorotynska, O.; Latroche, M.; Cuevas, F.; Yartys, V.; Fichtner, M. Exploits, advances and challenges benefiting beyond Li-ion battery technologies. *J. Alloys Compd.* **2020**, *817*, 153261. [CrossRef]
18. Amjadi, Z.; Williamson, S.S. Prototype design and controller implementation for a battery-ultracapacitor hybrid electric vehicle energy storage system. *IEEE Trans. Smart Grid* **2011**, *3*, 332–340. [CrossRef]
19. Liu, F.; Wang, C.; Luo, Y. Parameter matching method of a battery-supercapacitor hybrid energy storage system for electric vehicles. *World Electr. Veh. J.* **2021**, *12*, 253. [CrossRef]
20. Samadi, M.; Afshar, A.K. Optimal Planning of Charging and Power Delivering from/to the Network for Electric Vehicles Considering Types of Trip. *Int. J. Eng. Technol.* **2017**, *9*, 749–758. [CrossRef]
21. Ramesh, P.; Gouda, P.K.; Lakshmikhandan, K.; Ramanathan, G.; Bharatiraja, C. A three port bidirectional DC-DC converter for PV—Battery—DC microgrid application using fuzzy logic control. *Mater. Today Proc.* **2022**, *68*, 1898–1905. [CrossRef]
22. Arancibia, A.; Strunz, K. Modeling of an electric vehicle charging station for fast DC charging. In Proceedings of the 2012 IEEE International Electric Vehicle Conference, IEVC, Greenville, SC, USA, 4–8 March 2012. [CrossRef]
23. Zhou, K.; Wu, Y.; Wu, X.; Sun, Y.; Teng, D.; Liu, Y. Research and Development Review of Power Converter Topologies and Control Technology for Electric Vehicle Fast-Charging Systems. *Electronics* **2023**, *12*, 1581. [CrossRef]
24. Subudhi, P.S.; Krithiga, S. Wireless Power Transfer Topologies used for Static and Dynamic Charging of EV Battery: A Review. *Int. J. Emerg. Electr. Power Syst.* **2020**, *21*, 20190151. [CrossRef]
25. Esteban, B.; Sid-Ahmed, M.; Kar, N.C. A Comparative Study of Power Supply Architectures in Wireless EV Charging Systems. *IEEE Trans. Power Electron.* **2015**, *30*, 6408–6422. [CrossRef]
26. Jang, Y.J. Survey of the operation and system study on wireless charging electric vehicle systems. *Transp. Res. Part C Emerg. Technol.* **2018**, *95*, 844–866. [CrossRef]
27. Zhang, M.; Li, W.; Yu, S.S.; Wen, K.; Zhou, C.; Shi, P. A unified configurational optimization framework for battery swapping and charging stations considering electric vehicle uncertainty. *Energy* **2020**, *218*, 119536. [CrossRef]
28. Ahmad, A.; Khan, Z.A.; Saad Alam, M.; Khateeb, S. A Review of the Electric Vehicle Charging Techniques, Standards, Progression and Evolution of EV Technologies in Germany. *Smart Sci.* **2018**, *6*, 36–53. [CrossRef]
29. Tan, K.M.; Ramachandaramurthy, V.K.; Yong, J.Y. Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques. *Renew. Sustain. Energy Rev.* **2016**, *53*, 720–732. [CrossRef]
30. Zheng, Y.; Niu, S.; Shang, Y.; Shao, Z.; Jian, L. Integrating plug-in electric vehicles into power grids: A comprehensive review on power interaction mode, scheduling methodology and mathematical foundation. *Renew. Sustain. Energy Rev.* **2019**, *112*, 424–439. [CrossRef]
31. Han, S. *Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) Technologies*; MDPI: Basel, Switzerland, 2021. [CrossRef]
32. Sharma, A.; Sharma, S. Review of power electronics in vehicle-to-grid systems. *J. Energy Storage* **2019**, *21*, 337–361. [CrossRef]
33. Afonso, J.L.; Cardoso, L.A.L.; Pedrosa, D.; Sousa, T.J.C.; Machado, L.; Tanta, M.; Monteiro, V. A review on power electronics technologies for electric mobility. *Energies* **2020**, *13*, 6343. [CrossRef]
34. Habib, S.; Kamran, M. A novel vehicle-to-grid technology with constraint analysis—A review. In Proceedings of the 2014 International Conference on Emerging Technologies (ICET), Islamabad, Pakistan, 8–9 December 2014. [CrossRef]
35. Aljanad, A.; Mohamed, A. Impact of plug-in hybrid electric vehicle on power distribution system considering vehicle to grid technology: A review. *Res. J. Appl. Sci. Eng. Technol.* **2015**, *10*, 1404–1413. [CrossRef]
36. Richardson, D.B. Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration. *Renew. Sustain. Energy Rev.* **2013**, *19*, 247–254. [CrossRef]
37. Zhang, Y.; Xiong, R.; He, H.; Pecht, M.G. Lithium-Ion Battery Remaining Useful Life Prediction with Box–Cox Transformation and Monte Carlo Simulation. *IEEE Trans. Ind. Electron.* **2019**, *66*, 1585–1597. [CrossRef]
38. Liu, C.; Chau, K.T.; Wu, D.; Gao, S. Opportunities and Challenges of Vehicle-to-Home, Vehicle-to-Vehicle, and Vehicle-to-Grid Technologies. *Proc. IEEE* **2013**, *101*, 2409–2427. [CrossRef]
39. GoI, H. *Taking Charge: The Electric Vehicle Infrastructure Strategy*; HM Government: London, UK, 2023.

40. EDF. Electric Car (EV) Charging Points UK—A Complete Guide | EDF. 2023. Available online: https://www.edfenergy.com/electric-cars/charging-points (accessed on 22 July 2023).
41. ZApmap. How Many EV Charging Points Are There in the UK—Zapmap. 2023. Available online: https://www.zap-map.com/ev-stats/how-many-charging-points (accessed on 22 July 2023).
42. Chamberlain, K.; Al-Majeed, S. Standardisation of UK electric vehicle charging protocol, payment and charge point connection. *World Electr. Veh. J.* **2021**, *12*, 63. [CrossRef]
43. MoP, BEE | Ministry of Power (MoP). 2023. Available online: https://evyatra.beeindia.gov.in/central-govt-initiative-details/amendment-in-revised-consolidated-guidelines/ (accessed on 4 July 2023).
44. MoP, Electric Vehicle | Government of India | Ministry of Power, POM. 2023. Available online: https://powermin.gov.in/en/content/electric-vehicle (accessed on 4 July 2023).
45. EV Europe, Electric Vehicle Charging Levels, Modes and Types Explained | North America vs. Europe Charging Cables and Plug Types | LinkedIn. 2023. Available online: https://www.linkedin.com/pulse/electric-vehicle-charging-levels-modes-types-explained-kris-wang/ (accessed on 22 July 2023).
46. PDI. Slow, Fast and Super: EV Chargers Conundrum | by Parag Diwan | Medium. 2023. Available online: https://pdiwan.medium.com/slow-fast-and-super-ev-chargers-conundrum-d35ea0da5a87 (accessed on 22 July 2023).
47. Enelxway. EV Charging Connector Types | Enel X Way. 2023. Available online: https://www.enelxway.com/us/en/resources/blog/ev-charging-connector-types (accessed on 22 July 2023).
48. Fleely. EV Charging Stations—Different Types of Connector Guns—Fleely, Fleely. 2023. Available online: https://fleely.com/different-types-of-connector-guns-cgs/ (accessed on 22 July 2023).
49. China's Electric Car Fast Charging (GB/T 20234) to Become World Standard?—The Long Tail Pipe. 2023. Available online: https://longtailpipe.com/2014/02/13/chinas-electric-car-fast-charging-gb/ (accessed on 22 July 2023).
50. Kittner, N.; Jolly, S.; Basu, S. An analytical framework to examine power in sustainable energy decision-making in cities. *Front. Sustain. Energy Policy* **2024**, *3*, 1440594. [CrossRef]
51. Azerine, A.; Oulamara, A.; Basset, M.; Idoumghar, L. Improved Methods for Solving the Electric Vehicle Charging Scheduling Problem to Maximize the Delive. In Proceedings of the 2024 IEEE Congress on Evolutionary Computation (CEC), Yokohama, Japan, 30 June–5 July 2024. [CrossRef]
52. Chhikara, R.; Garg, R.; Chhabra, S.; Karnatak, U.; Agrawal, G. Factors affecting adoption of electric vehicles in India: An exploratory study. *Transp. Res. D Transp. Environ.* **2021**, *100*, 103084. [CrossRef]
53. *IS 17017:Part 1:2018*; Electric Vehicle Conductive Charging System Part 1 General Requirements. Bureau of Indian Standards (BIS): New Delhi, India, 2018.
54. Ahmad, F.; Khalid, M.; Panigrahi, B.K. Development in energy storage system for electric transportation: A comprehensive review. *J. Energy Storage* **2021**, *43*, 103153. [CrossRef]
55. Purwadi, A.; Dozeno, J.; Heryana, N. Simulation and Testing of a Typical On-board Charger for ITB Electric Vehicle Prototype Application. *Procedia Technol.* **2013**, *11*, 974–979. [CrossRef]
56. Xie, R.; Wei, W.; Wu, Q.; Ding, T.; Mei, S. Optimal Service Pricing and Charging Scheduling of an Electric Vehicle Sharing System. *IEEE Trans. Veh. Technol.* **2020**, *69*, 78–89. [CrossRef]
57. Waseem, M.; Sherwani, A.F.; Suhaib, M. Application of Renewable Solar Energy with Autonomous Vehicles: A Review. In *Smart Cities—Opportunities and Challenges*; Springer: Singapore, 2020; pp. 135–142. [CrossRef]
58. Guo, G.; Kang, M. Rebalancing and Charging Scheduling with Price Incentives for Car Sharing Systems. *IEEE Trans. Intell. Transp. Syst.* **2022**, *23*, 18592–18602. [CrossRef]
59. Veldman, E.; Verzijlbergh, R.A. Distribution grid impacts of smart electric vehicle charging from different perspectives. *IEEE Trans. Smart Grid* **2015**, *6*, 333–342. [CrossRef]
60. Waseem, M.; Sherwani, A.F.; Suhaib, M. Driving Pattern-based Optimization and Design of Electric Propulsion System for Three-Wheeler Battery Vehicle. *Int. J. Perform. Eng.* **2020**, *16*, 342–353. [CrossRef]
61. Knutsen, D.; Willén, O. A Study of Electric Vehicle Charging Patterns and Range Anxiety. 2013. Available online: https://www.diva-portal.org/smash/get/diva2:626048/FULLTEXT01.pdf (accessed on 30 November 2024).
62. Aggarwal, S.; Singh, A.K. Electric vehicles the future of transportation sector: A review. *Energy Sources Part A Recover. Util. Environ. Eff.* **2021**, 1–21. [CrossRef]
63. Waseem, M.; Sherwani, A.F.; Suhaib, M. Simscape Modelling and Analysis of Photovoltaic Modules with Boost Converter for Solar Electric Vehicles. In *Applications of Computing, Automation and Wireless Systems in Electrical Engineering*; Springer: Singapore, 2019. [CrossRef]
64. Waseem, M.; Sherwani, A.F.; Suhaib, M. Highway Gradient Effects on Hybrid Electric Vehicle Performance. In *Smart Cities—Opportunities and Challenges*; Springer: Singapore, 2020; pp. 583–592. [CrossRef]
65. Honda, Vehicle Electrification—Benefits and Technologies | Honda. 2023. Available online: https://automobiles.honda.com/vehicle-electrification?source=https://automobiles.honda.com/clarity?source=https%253a%252f%252fautomobiles.honda.com%252fclarity-electric&statusCode=301&statusCode=301 (accessed on 6 July 2023).
66. Model 3 | Tesla. 2023. Available online: https://www.tesla.com/model3 (accessed on 6 July 2023).
67. Model S | Tesla. 2023. Available online: https://www.tesla.com/models (accessed on 6 July 2023).

68. Chevrolet. Discontinued Chevrolet Cars, Trucks, and SUVs. 2023. Available online: https://www.chevrolet.com/discontinued-vehicles (accessed on 6 July 2023).
69. Insideevs. New 2017 Renault ZOE ZE 40: 400 km Range*, 41 kWh Battery. 2023. Available online: https://insideevs.com/news/331773/new-2017-renault-zoe-ze-40-400-km-range-41-kwh-battery/ (accessed on 6 July 2023).
70. Guideauto, 2017 Renault Twizy 40 Specifications—The Car Guide. 2023. Available online: https://www.guideautoweb.com/en/makes/renault/twizy/2017/specifications/40/ (accessed on 6 July 2023).
71. Autocar. Mitsubishi i-MiEV 2011–2015 Review (2023) | Autocar, (2023). Available online: https://www.autocar.co.uk/car-review/mitsubishi/i-miev-2011-2015 (accessed on 6 July 2023).
72. Volkswagen. New Volkswagen e-Golf | Volkswagen UK. 2023. Available online: https://www.volkswagen.co.uk/en/new/e-golf.html (accessed on 6 July 2023).
73. cars.com. 2018 Ford Focus Specs, Price, MPG & Reviews | cars.com. 2023. Available online: https://www.cars.com/research/ford-focus-2018/ (accessed on 6 July 2023).
74. Nissan. Build & Price a Nissan LEAF | Nissan USA. 2023. Available online: https://www.nissanusa.com/shopping-tools/build-price?models=nissan-leaf#configure/AnY/version (accessed on 6 July 2023).
75. Kia. 2018 Kia Soul EV Specifications. 2023. Available online: https://www.kiamedia.com/us/en/models/soul-ev/2018/specifications (accessed on 6 July 2023).
76. Toyota. 2023 Toyota Prius Prime Features | Toyota.com. 2023. Available online: https://www.toyota.com/priusprime/priusprime-features/technology/ (accessed on 6 July 2023).
77. BMWUSA. BMW All-Electric Vehicles | BMW USA. 2023. Available online: https://www.bmwusa.com/all-electric.html (accessed on 6 July 2023).
78. Fiat 500e Review, Pricing, and Specs. 2024. Available online: https://www.caranddriver.com/fiat/500e (accessed on 1 November 2024).
79. Shang, M.; Zhang, Z.; Yin, C. Mitigating HV battery malfunctions in a 48 V P0 mild hybrid system: A novel voltage control strategy. *Adv. Mech. Eng.* **2024**, *16*, 1–20. [CrossRef]
80. Tatrari, G.; Ahmed, M.; Shah, F.U.; Yang, W.; Chen, J.; Xue, Z.; Shu, T.; Ye, J.; Zou, H.; Chen, S. Enabling fast-charging via layered ternary transition metal oxide design as anode materials for lithium-ion batteries. *Coord. Chem. Rev.* **2024**, *214*, 20586.
81. Waseem, M.; Lakshmi, G.S.; Sreeshobha, E.; Khan, S. An Electric Vehicle Battery and Management Techniques: Comprehensive Review of Important Obstacles, New Advancements, and Recommendations. *Energy Storage Sav.* 2024; *in press*. [CrossRef]
82. Waseem, M.; Lakshmi, G.S.; Ahmad, M.; Suhaib, M. Energy storage technology and its impact in electric vehicle: Current progress and future outlook. *Next Energy* **2024**, *6*, 100202. [CrossRef]
83. Srivastava, K.; Maurya, R.; Kumar, S.; Pandey, S.K. EV battery charging infrastructure in remote areas: Design, and analysis of a two-stage solar PV enabled bidirectional STC-DAB converter. *J. Energy Storage* **2024**, *102*, 114188. [CrossRef]
84. Luo, Z.; He, F.; Lin, X.; Wu, J.; Li, M. Joint deployment of charging stations and photovoltaic power plants for electric vehicles. *Transp. Res. D Transp. Environ.* **2020**, *79*, 102247. [CrossRef]
85. 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]
86. Zhang, Q.; Li, H.; Zhu, L.; Campana, P.E.; Lu, H.; Wallin, F.; Sun, Q. Factors influencing the economics of public charging infrastructures for EV—A review. *Renew. Sustain. Energy Rev.* **2018**, *94*, 500–509. [CrossRef]
87. Karaşan, A.; Kaya, I.; Erdoğan, M. Location selection of electric vehicles charging stations by using a fuzzy MCDM method: A case study in Turkey. *Neural Comput. Appl.* **2018**, *32*, 4553–4574. [CrossRef]
88. Grenier, M.; Thiringer, T.; Aghdam, M. Design of on-board charger for plug-in hybrid electric vehicle. In Proceedings of the 5th IET International Conference on Power Electronics, Machines and Drives (PEMD 2010), Brighton, UK, 19–21 April 2010. [CrossRef]
89. Illmann, U.; Kluge, J. Public charging infrastructure and the market diffusion of electric vehicles. *Transp. Res. Part D Transp. Environ.* **2020**, *86*, 102413. [CrossRef]
90. 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]
91. Fox, G.H. Electric vehicle charging stations: Are we prepared? *IEEE Ind. Appl. Mag.* **2013**, *19*, 32–38. [CrossRef]
92. Sheikhi, A.; Bahrami, S.; Ranjbar, A.; Oraee, H. Strategic charging method for plugged in hybrid electric vehicles in smart grids; a game theoretic approach. *Int. J. Electr. Power Energy Syst.* **2013**, *53*, 499–506. [CrossRef]
93. Schroeder, A.; Traber, T. The economics of fast charging infrastructure for electric vehicles. *Energy Policy* **2012**, *43*, 136–144. [CrossRef]
94. Ahmed, M.A.; Kim, Y.-C. Performance Analysis of Communication Networks for EV Charging Stations in Residential Grid. In Proceedings of the DIVANet 2017—Proceedings of the 6th ACM Symposium on Development and Analysis of Intelligent Vehicular Networks and Applications, Co-Located with MSWiM, Miami, FL, USA, 21–25 November 2017. [CrossRef]
95. Brenna, M.; Foiadelli, F.; Zaninelli, D.; Graditi, G.; Di Somma, M. The integration of electric vehicles in smart distribution grids with other distributed resources. In *Distributed Energy Resources in Local Integrated Energy Systems: Optimal Operation and Planning*; Elsevier: Amsterdam, The Netherlands, 2021. [CrossRef]

96. Gschwendtner, C.; Sinsel, S.R.; Stephan, A. Vehicle-to-X (V2X) implementation: An overview of predominate trial configurations and technical, social and regulatory challenges. *Renew. Sustain. Energy Rev.* **2021**, *145*, 110977. [CrossRef]
97. Rao, R.; Zhang, X.; Xie, J.; Ju, L. Optimizing electric vehicle users' charging behavior in battery swapping mode. *Appl. Energy* **2015**, *155*, 547–559. [CrossRef]
98. Wu, H. A Survey of Battery Swapping Stations for Electric Vehicles: Operation Modes and Decision Scenarios. *IEEE Trans. Intell. Transp. Syst.* **2021**, *23*, 10163–10185. [CrossRef]
99. WAlharbi; Humayd, A.S.B.; Praveen, R.P.; Awan, A.B.; Anees, V.P. Optimal Scheduling of Battery-Swapping Station Loads for Capacity Enhancement of a Distribution System. *Energies* **2023**, *16*, 186. [CrossRef]
100. Bobanac, V.; Pandzic, H.; Capuder, T. Survey on electric vehicles and battery swapping stations: Expectations of existing and future EV owners. In Proceedings of the 2018 IEEE International Energy Conference (ENERGYCON), Limassol, Cyprus, 3–7 June 2018. [CrossRef]
101. Adu-Gyamfi, G.; Song, H.; Asamoah, A.N.; Li, L.; Nketiah, E.; Obuobi, B.; Adjei, M.; Cudjoe, D. Towards sustainable vehicular transport: Empirical assessment of battery swap technology adoption in China. *Technol. Forecast. Soc. Change* **2022**, *184*, 121995. [CrossRef]
102. Sheng, E.C.E.; May, C.C.M.; Sakundarini, N.; Garg, A. Conceptualizing A Battery Swapping Station: A Case Study in Malaysia. In Proceedings of the 4th IEEE International Conference on Artificial Intelligence in Engineering and Technology (IICAIET), Kota Kinabalu, Sabah, 26–28 August 2024.
103. Tian, X.; Chau, K.T.; Liu, W.; Lee, C.H.T. Selective Wireless Power Transfer Using Magnetic Field Editing. *IEEE Trans. Power Electron.* **2020**, *36*, 2710–2719. [CrossRef]
104. Liu, W.; Chau, K.T.; Lee, C.H.T.; Cao, L.; Han, W. Wireless Power and Drive Transfer for Piping Network. *IEEE Trans. Ind. Electron.* **2022**, *69*, 2345–2356. [CrossRef]
105. Sanguesa, J.A.; Torres-Sanz, V.; Garrido, P.; Martinez, F.J.; Marquez-Barja, J.M. A Review on Electric Vehicles: Technologies and Challenges. *Smart Cities* **2021**, *4*, 372–404. [CrossRef]
106. Chowdhury, S.; Bin Tarek, T.; Sozer, Y. Design of a 7.7 kW Three-Phase Wireless Charging System for Light Duty Vehicles based on Overlapping Windings. In Proceedings of the ECCE 2020 IEEE Energy Conversion Congress and Exposition, Detroit, MI, USA, 11–15 October 2020. [CrossRef]
107. Patil, D.; McDonough, M.K.; Miller, J.M.; Fahimi, B.; Balsara, P.T. Wireless Power Transfer for Vehicular Applications: Overview and Challenges. *IEEE Trans. Transp. Electrif.* **2017**, *4*, 3–37. [CrossRef]
108. Mohsan, S.A.H.; Amjad, H. A comprehensive survey on hybrid wireless networks: Practical considerations, challenges, applications and research directions. *Opt. Quantum Electron.* **2021**, *53*, 1–56. [CrossRef]
109. Sakamoto, H.; Harada, K.; Washimiya, S.; Takehara, K.; Matsuo, Y.; Nakao, F. Large air-gap coupler for inductive charger [for electric vehicles]. *IEEE Trans. Magn.* **1999**, *35*, 3526–3528. [CrossRef]
110. Ahmad, A.; Alam, M.S.; Chabaan, R. A Comprehensive Review of Wireless Charging Technologies for Electric Vehicles. *IEEE Trans. Transp. Electrification* **2017**, *4*, 38–63. [CrossRef]
111. Lukic, S.; Pantic, Z. Cutting the Cord: Static and Dynamic Inductive Wireless Charging of Electric Vehicles. *IEEE Electrif. Mag.* **2013**, *1*, 57–64. [CrossRef]
112. Maglaras, L.A.; Jiang, J.; Maglaras, A.; Topalis, F.V.; Moschoyiannis, S. Dynamic wireless charging of electric vehicles on the move with Mobile Energy Disseminators. *Int. J. Adv. Comput. Sci. Appl.* **2015**, *6*, 239–251. [CrossRef]
113. Kan, T.; Lu, F.; Nguyen, T.-D.; Mercier, P.P.; Mi, C.C. Integrated Coil Design for EV Wireless Charging Systems Using *LCC* Compensation Topology. *IEEE Trans. Power Electron.* **2018**, *33*, 9231–9241. [CrossRef]
114. Negarestani, S.; Fotuhi-Firuzabad, M.; Rastegar, M.; Rajabi-Ghahnavieh, A. Optimal sizing of storage system in a fast charging station for plug-in hybrid electric vehicles. *IEEE Trans. Transp. Electrif.* **2016**, *2*, 443–453. [CrossRef]
115. Yoldaş, Y.; Önen, A.; Muyeen, S.M.; Vasilakos, A.V.; Alan, İ. Enhancing smart grid with microgrids: Challenges and opportunities. *Renew. Sustain. Energy Rev.* **2017**, *72*, 205–214. [CrossRef]
116. Dharmakeerthi, C.; Mithulananthan, N.; Saha, T. Impact of electric vehicle fast charging on power system voltage stability. *Int. J. Electr. Power Energy Syst.* **2013**, *57*, 241–249. [CrossRef]
117. Habib, S.; Kamran, M.; Rashid, U. Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks—A review. *J. Power Sources* **2015**, *277*, 205–214. [CrossRef]
118. Yilmaz, M.; Krein, P.T. Review of the impact of vehicle-to-grid technologies on distribution systems and utility interfaces. *IEEE Trans. Power Electron.* **2013**, *28*, 5673–5689. [CrossRef]
119. Dai, Q.; Cai, T.; Duan, S.; Zhang, W.; Zhao, J. A smart energy management system for electric city bus battery swap station. In Proceedings of the IEEE Transportation Electrification Conference and Expo, ITEC Asia-Pacific 2014—Conference Proceedings, Beijing, China, 31 August–3 September 2014. [CrossRef]
120. Martínez-Lao, J.; Montoya, F.G.; Montoya, M.G.; Manzano-Agugliaro, F. Electric vehicles in Spain: An overview of charging systems. *Renew. Sustain. Energy Rev.* **2017**, *77*, 970–983. [CrossRef]
121. Erdinc, O.; Tascikaraoglu, A.; Paterakis, N.G.; Dursun, I.; Sinim, M.C.; Catalao, J.P.S. Comprehensive Optimization Model for Sizing and Siting of DG Units, EV Charging Stations, and Energy Storage Systems. *IEEE Trans. Smart Grid* **2018**, *9*, 3871–3882. [CrossRef]

122. Li, T.; Zhang, J.; Zhang, Y.; Jiang, L.; Li, B.; Yan, D.; Ma, C. An optimal design and analysis of a hybrid power charging station for electric vehicles considering uncertainties. In Proceedings of the IECON 2018—44th Annual Conference of the IEEE Industrial Electronics Society, Washington, DC, USA, 21–23 October 2018. [CrossRef]
123. Gabbar, H.A. Fast-Charging Infrastructure for Transit Buses. In *Fast Charging and Resilient Transportation Infrastructures in Smart Cities*; Springer: Cham, Switzerland, 2022. [CrossRef]
124. Shanmugam, Y.; Narayanamoorthi, R.; Ramachandaramurthy, V.K.; Bernat, P.; Shrestha, N.; Son, J.; Williamson, S.S. Machine Learning Based Optimal Design of On-Road Charging Lane for Smart Cities Applications. *IEEE J. Emerg. Sel. Top. Power Electron.* **2024**, *12*, 4296–4309. [CrossRef]
125. Arulvendhan, K.; Nagaratnam, S.K.; Narayanamoorthi, R.; Milyani, A.H.; Alghamdi, S.; Alruwaili, M. Primary Side Hybrid Reconfigurable Compensation for Wireless EV Charging with Constant Current/Constant Voltage Control. *IEEE Access* **2024**, *12*, 149960–149976. [CrossRef]
126. Liu, J.; Lee, C.-K.; Pong, P.W.T. A Guided Wireless Electric Vehicle Charging Strategy Based on In-Plane Magnetic Field. *IEEE Sens. J.* **2024**, *24*, 22916–22925. [CrossRef]
127. Rashid, S.S.; Etta, D.; Ciabattoni, M.; Maji, S.; Monticone, F.; Afridi, K.K. A High-Power-Density Reduced-Fringing-Field Multi-MHz Capacitive Wireless Power Transfer System. In Proceedings of the 2024 IEEE Applied Power Electronics Conference and Exposition (APEC), Long Beach, CA, USA, 25–29 February 2024. [CrossRef]
128. Constantinou, S.; Papazachariou, D.; Costa, C.; Konstantinidis, A.; Mokbel, M.F.; Zeinalipour-Yazti, D. EcoCharge: A Framework for Sustainable Electric Vehicles Charging. In Proceedings of the 2024 25th IEEE International Conference on Mobile Data Management (MDM), Brussels, Belgium, 24–27 June 2024. [CrossRef]
129. Rahman, M.S. Development of Novel Controllers to Address the Misalignment Problem of Dynamic Wireless Charging of Electric Vehicles, Electronic Theses and Dissertations. 2024. Available online: https://digitalcommons.memphis.edu/etd/3529 (accessed on 2 November 2024).
130. Gjelaj, M.; Traholt, C.; Hashemi, S.; Andersen, P.B. Cost-benefit analysis of a novel DC fast-charging station with a local battery storage for EVs. In Proceedings of the 2017 52nd International Universities Power Engineering Conference (UPEC), Heraklion, Greece, 28–31 August 2017. [CrossRef]
131. Ghareeb, A.T.; Mohamed, A.A.; Mohammed, O.A. DC microgrids and distribution systems: An overview. In Proceedings of the IEEE Power and Energy Society General Meeting, Vancouver, BC, Canada, 21–25 July 2013. [CrossRef]
132. Martinez, C.M.; Hu, X.; Cao, D.; Velenis, E.; Gao, B.; Wellers, M. Energy Management in Plug-in Hybrid Electric Vehicles: Recent Progress and a Connected Vehicles Perspective. *IEEE Trans. Veh. Technol.* **2016**, *66*, 4534–4549. [CrossRef]
133. Thingvad, A.; Andersen, P.B.; Unterluggauer, T.; Træholt, C.; Marinelli, M. Electrification of personal vehicle travels in cities—Quantifying the public charging demand. *eTransportation* **2021**, *9*, 100125. [CrossRef]
134. Boulanger, A.G.; Chu, A.C.; Maxx, S.; Waltz, D.L. Vehicle Electrification: Status and Issues. *Proc. IEEE* **2011**, *99*, 1116–1138. [CrossRef]
135. Onn, C.C.; Chai, C.; Rashid, A.F.A.; Karim, M.R.; Yusoff, S. Vehicle electrification in a developing country: Status and issue, from a well-to-wheel perspective. *Transp. Res. Part D Transp. Environ.* **2017**, *50*, 192–201. [CrossRef]
136. Zhuge, C.; Wei, B.; Dong, C.; Shao, C.; Shan, Y.; Zhuge, C.; Wei, B.; Dong, C.; Shao, C.; Shan, Y.; et al. Exploring the future electric vehicle market and its impacts with an agent-based spatial integrated framework: A case study of Beijing, China. *J. Clean. Prod.* **2019**, *221*, 710–737. [CrossRef]
137. Cheng, P.-H.; Huang, T.-H.; Chien, Y.-W.; Wu, C.-L.; Tai, C.-S.; Fu, L.-C. Demand-side management in residential community realizing sharing economy with bidirectional PEV while additionally considering commercial area. *Int. J. Electr. Power Energy Syst.* **2019**, *116*, 105512. [CrossRef]
138. Li, J. (Invited) Battery Design for Fast Charging. *ECS Meet. Abstr.* **2022**, *MA2022-01*, 223. [CrossRef]
139. Bae, S.; Kwasinski, A. Spatial and temporal model of electric vehicle charging demand. *IEEE Trans. Smart Grid* **2012**, *3*, 394–403. [CrossRef]
140. Habib, S.; Khan, M.M.; Abbas, F.; Tang, H. Assessment of electric vehicles concerning impacts, charging infrastructure with unidirectional and bidirectional chargers, and power flow comparisons. *Int. J. Energy Res.* **2018**, *42*, 3416–3441. [CrossRef]
141. Habib, S.; Khan, M.M.; Abbas, F.; Ali, A.; Faiz, M.T.; Ehsan, F.; Tang, H. Contemporary trends in power electronics converters for charging solutions of electric vehicles. *CSEE J. Power Energy Syst.* **2020**, *6*, 911–929. [CrossRef]
142. Solanke, T.U.; Khatua, P.K.; Ramachandaramurthy, V.K.; Yong, J.Y.; Tan, K.M. Control and management of a multilevel electric vehicles infrastructure integrated with distributed resources: A comprehensive review. *Renew. Sustain. Energy Rev.* **2021**, *144*, 111020. [CrossRef]
143. 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.* **2012**, *28*, 2151–2169. [CrossRef]
144. Sortomme, E.; El-Sharkawi, M.A. Optimal charging strategies for unidirectional vehicle-to-grid. *IEEE Trans. Smart Grid* **2011**, *2*, 131–138. [CrossRef]
145. Mastoi, M.S.; Zhuang, S.; Munir, H.M.; Haris, M.; Hassan, M.; Alqarni, M.; Alamri, B. A study of charging-dispatch strategies and vehicle-to-grid technologies for electric vehicles in distribution networks. *Energy Rep.* **2023**, *9*, 1777–1806. [CrossRef]
146. Kern, T.; Dossow, P.; Morlock, E. Revenue opportunities by integrating combined vehicle-to-home and vehicle-to-grid applications in smart homes. *Appl. Energy* **2021**, *307*, 118187. [CrossRef]

147. Schwenk, K.; Meisenbacher, S.; Briegel, B.; Harr, T.; Hagenmeyer, V.; Mikut, R. Integrating Battery Aging in the Optimization for Bidirectional Charging of Electric Vehicles. *IEEE Trans. Smart Grid* **2021**, *12*, 5135–5145. [CrossRef]
148. Kisacikoglu, M.C.; Kesler, M.; Tolbert, L.M. Single-phase on-board bidirectional PEV charger for V2G reactive power operation. *IEEE Trans. Smart Grid* **2015**, *6*, 767–775. [CrossRef]
149. Seth, A.K.; Singh, M. Unified adaptive neuro-fuzzy inference system control for OFF board electric vehicle charger. *Int. J. Electr. Power Energy Syst.* **2021**, *130*, 106896. [CrossRef]
150. Wang, Z.; Zhou, J.; Rizzoni, G. A review of architectures and control strategies of dual-motor coupling powertrain systems for battery electric vehicles. *Renew. Sustain. Energy Rev.* **2022**, *162*, 112455. [CrossRef]
151. Fachrizal, R.; Ramadhani, U.H.; Munkhammar, J.; Widén, J. Combined PV–EV hosting capacity assessment for a residential LV distribution grid with smart EV charging and PV curtailment. *Sustain. Energy Grids Networks* **2021**, *26*, 100445. [CrossRef]
152. Rahman, S.; Khan, I.A.; Khan, A.A.; Mallik, A.; Nadeem, M.F. Comprehensive review & impact analysis of integrating projected electric vehicle charging load to the existing low voltage distribution system. *Renew. Sustain. Energy Rev.* **2022**, *153*, 111756. [CrossRef]
153. Patil, H.; Kalkhambkar, V.N. Grid Integration of Electric Vehicles for Economic Benefits: A Review. *J. Mod. Power Syst. Clean Energy* **2021**, *9*, 13–26. [CrossRef]
154. Ul-Haq, A.; Cecati, C.; Strunz, K.; Abbasi, E. Impact of Electric Vehicle Charging on Voltage Unbalance in an Urban Distribution Network. *Intell. Ind. Syst.* **2015**, *1*, 51–60. [CrossRef]
155. Prakash, P.; Tavares, B.C.; Prata, R.; Fidalgo, N.; Moreira, C.; Soares, F. Impact of Electric Vehicles in Three-Phase Distribution Grids. In Proceedings of the CIRED 2021—The 26th International Conference and Exhibition on Electricity Distribution, Online, 20–23 September 2021.
156. Ma, G.; Jiang, L.; Chen, Y.; Dai, C.; Ju, R. Study on the impact of electric vehicle charging load on nodal voltage deviation. *Arch. Electr. Eng.* **2017**, *66*, 495–505. [CrossRef]
157. Khalid, M.R.; Alam, M.S.; Sarwar, A.; Asghar, M.J. A comprehensive review on electric vehicles charging infrastructures and their impacts on power-quality of the utility grid. *eTransportation* **2019**, *1*, 100006. [CrossRef]
158. Karmaker, A.K.; Roy, S.; Ahmed, R. Analysis of the Impact of Electric Vehicle Charging Station Power Quality Issues. In Proceedings of the 2nd International Conference on Electrical, Computer and Communication Engineering, ECCE, Cox's Bazar, Bangladesh, 7–9 February 2019. [CrossRef]
159. Bowermaster, D.; Alexander, M.; Duvall, M. The Need for Charging: Evaluating utility infrastructures for electric vehicles while providing customer support. *IEEE Electrif. Mag.* **2017**, *5*, 59–67. [CrossRef]
160. Hadley, S.W.; Tsvetkova, A.A. Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation. *Electr. J.* **2009**, *22*, 56–68. [CrossRef]
161. Yong, J.Y.; Ramachandaramurthy, V.K.; Tan, K.M.; Mithulananthan, N. A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects. *Renew. Sustain. Energy Rev.* **2015**, *49*, 365–385. [CrossRef]
162. Yan, Q.; Kezunovic, M. Impact analysis of Electric Vehicle charging on distribution system. In Proceedings of the 2012 North American Power Symposium, NAPS 2012, Champaign, IL, USA, 9–11 September 2012. [CrossRef]
163. Durante, L.; Nielsen, M.; Ghosh, P. Analysis of non-sinusoidal wave generation during electric vehicle charging and their impacts on the power system. *Int. J. Process. Syst. Eng.* **2017**, *4*, 138. [CrossRef]
164. Godina, R.; Rodrigues, E.; Paterakis, N.; Erdinc, O.; Catalão, J. Innovative impact assessment of electric vehicles charging loads on distribution transformers using real data. *Energy Convers. Manag.* **2016**, *120*, 206–216. [CrossRef]
165. Domínguez-Navarro, J.; Dufo-López, R.; Yusta-Loyo, J.; Artal-Sevil, J.; Bernal-Agustín, J. Design of an electric vehicle fast-charging station with integration of renewable energy and storage systems. *Int. J. Electr. Power Energy Syst.* **2018**, *105*, 46–58. [CrossRef]
166. Saber, A.Y.; Venayagamoorthy, G.K. Plug-in Vehicles and Renewable Energy Sources for Cost and Emission Reductions. *IEEE Trans. Ind. Electron.* **2011**, *58*, 1229–1238. [CrossRef]
167. Donateo, T.; Congedo, P.M.; Malvoni, M.; Ingrosso, F.; Laforgia, D.; Ciancarelli, F. An integrated tool to monitor renewable energy flows and optimize the recharge of a fleet of plug-in electric vehicles in the campus of the university of salento: Preliminary results. *IFAC Proc. Vol.* **2014**, *47*, 7861–7866. [CrossRef]
168. Hofmann, M.; Raab, S.; Schaefer, M.; Ponomarov, P.; Ackva, A. Measurements on vehicle to grid application in industrial power grid for peak load reduction: Robust bidirectional charger for series production electric and plug-in hybrid vehicles. In Proceedings of the 2015 IEEE 6th International Symposium on Power Electronics for Distributed Generation Systems, PEDG 2015, Aachen, Germany, 22–25 June 2015. [CrossRef]
169. Kristoffersen, T.K.; Capion, K.; Meibom, P. Optimal charging of electric drive vehicles in a market environment. *Appl. Energy* **2011**, *88*, 1940–1948. [CrossRef]
170. Garwa, N.; Niazi, K.R. Impact of EV on Integration with Grid System—A Review. In Proceedings of the 2019 8th International Conference on Power Systems: Transition towards Sustainable, Smart and Flexible Grids, ICPS 2019, Jaipur, India, 20–22 December 2019. [CrossRef]
171. Rehman, U.U.; Riaz, M. Retracted: Vehicle to grid system for load and frequency management in smart grid. In Proceedings of the ICOSST 2017—2017 International Conference on Open Source Systems and Technologies, Lahore, Pakistan, 18–20 December 2017. [CrossRef]

172. White, C.D.; Zhang, K.M. Using vehicle-to-grid technology for frequency regulation and peak-load reduction. *J. Power Sources* **2010**, *196*, 3972–3980. [CrossRef]
173. Visakh, A.; Selvan, M.P. Feasibility assessment of utilizing electric vehicles for energy arbitrage in smart grids considering battery degradation cost. *Energy Sources, Part A Recover. Util. Environ. Eff.* **2022**, *44*, 4664–4678. [CrossRef]
174. Tian, W.; He, J.; Niu, L.; Zhang, W.; Wang, X.; Bo, Z. Simulation of vehicle-to-grid (V2G) on power system frequency control. In Proceedings of the 2012 IEEE Innovative Smart Grid Technologies—Asia, ISGT Asia 2012, Tianjin, China, 21–24 May 2012. [CrossRef]
175. Guille, C.; Gross, G. A conceptual framework for the vehicle-to-grid (V2G) implementation. *Energy Policy* **2009**, *37*, 4379–4390. [CrossRef]
176. Wu, Q. *Grid Integration of Electric Vehicles in Open Electricity Markets*; Wiley: Hoboken, NJ, USA, 2013. [CrossRef]
177. Venegas, F.G.; Petit, M.; Perez, Y. Active integration of electric vehicles into distribution grids: Barriers and frameworks for flexibility services. *Renew. Sustain. Energy Rev.* **2021**, *145*, 111060. [CrossRef]
178. Ding, X.; Guo, Q.; Qiannan, T.; Jermsittiparsert, K. Economic and environmental assessment of multi-energy microgrids under a hybrid optimization technique. *Sustain. Cities Soc.* **2021**, *65*, 102630. [CrossRef]
179. Thakur, R.; Natale, A. High efficiency wireless power transmission at low frequency using permanent magnet coupling. *Cardiol. Clin.* **2009**, *27*. [CrossRef]
180. 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]
181. Arias, N.B.; Hashemi, S.; Andersen, P.B.; Træholt, C.; Romero, R. Assessment of economic benefits for EV owners participating in the primary frequency regulation markets. *Int. J. Electr. Power Energy Syst.* **2020**, *120*, 105985. [CrossRef]
182. Ullah, K.; Basit, A.; Ullah, Z.; Albogamy, F.R.; Hafeez, G. Automatic Generation Control in Modern Power Systems with Wind Power and Electric Vehicles. *Energies* **2022**, *15*, 1771. [CrossRef]
183. King, C.; Datta, B. EV charging tariffs that work for EV owners, utilities and society. *Electr. J.* **2018**, *31*, 24–27. [CrossRef]
184. Fokui, W.S.T.; Saulo, M.J.; Ngoo, L. Optimal Placement of Electric Vehicle Charging Stations in a Distribution Network with Randomly Distributed Rooftop Photovoltaic Systems. *IEEE Access* **2021**, *9*, 132397–132411. [CrossRef]
185. Hasan, M.K.; Habib, A.A.; Islam, S.; Balfaqih, M.; Alfawaz, K.M.; Singh, D. Smart Grid Communication Networks for Electric Vehicles Empowering Distributed Energy Generation: Constraints, Challenges, and Recommendations. *Energies* **2023**, *16*, 1140. [CrossRef]
186. Bessa, R.J.; Matos, M.A. The role of an aggregator agent for EV in the electricity market. In Proceedings of the 7th Mediterranean Conference and Exhibition on Power Generation, Transmission, Distribution and Energy Conversion (MedPower 2010), Agia Napa, Cyprus, 7–10 November 2010. [CrossRef]
187. Bessa, R.J.; Matos, M.A. Economic and technical management of an aggregation agent for electric vehicles: A literature survey. *Eur. Trans. Electr. Power* **2012**, *22*, 334–350. [CrossRef]
188. Nazari-Heris, M.; Abapour, M.; Mohammadi-Ivatloo, B. An Updated Review and Outlook on Electric Vehicle Aggregators in Electric Energy Networks. *Sustainability* **2022**, *14*, 15747. [CrossRef]
189. Traut, E.J.; Cherng, T.C.; Hendrickson, C.; Michalek, J.J. US residential charging potential for electric vehicles. *Transp. Res. Part D Transp. Environ.* **2013**, *25*, 139–145. [CrossRef]
190. Mazhar, T.; Asif, R.N.; Malik, M.A.; Nadeem, M.A.; Haq, I.; Iqbal, M.; Kamran, M.; Ashraf, S. Electric Vehicle Charging System in the Smart Grid Using Different Machine Learning Methods. *Sustainability* **2023**, *15*, 2603. [CrossRef]
191. Rimal, B.P.; Kong, C.; Poudel, B.; Wang, Y.; Shahi, P. Smart Electric Vehicle Charging in the Era of Internet of Vehicles, Emerging Trends, and Open Issues. *Energies* **2022**, *15*, 1908. [CrossRef]
192. Bautista, P.B.; Cárdenas, L.L.; Aguiar, L.U.; Igartua, M.A. A traffic-aware electric vehicle charging management system for smart cities. *Veh. Commun.* **2019**, *20*, 100188. [CrossRef]
193. Zhang, G.; Tan, S.T.; Wang, G.G. Real-Time Smart Charging of Electric Vehicles for Demand Charge Reduction at Non-Residential Sites. *IEEE Trans. Smart Grid* **2017**, *9*, 4027–4037. [CrossRef]
194. Hussain, S.; Kim, Y.-S.; Thakur, S.; Breslin, J.G. Optimization of Waiting Time for Electric Vehicles Using a Fuzzy Inference System. *IEEE Trans. Intell. Transp. Syst.* **2022**, *23*, 15396–15407. [CrossRef]
195. Zamponi, M.E.; Barbierato, E. The Dual Role of Artificial Intelligence in Developing Smart Cities. *Smart Cities* **2022**, *5*, 728–755. [CrossRef]
196. Aung, N.; Zhang, W.; Sultan, K.; Dhelim, S.; Ai, Y. Dynamic traffic congestion pricing and electric vehicle charging management system for the internet of vehicles in smart cities. *Digit. Commun. Netw.* **2021**, *7*, 492–504. [CrossRef]
197. İnci, M.; Büyük, M.; Özbek, N.S. Sliding mode control for fuel cell supported battery charger in vehicle-to-vehicle interaction. *Fuel Cells* **2022**, *22*, 212–226. [CrossRef]
198. Hadba, H. Teachers' Perceptions of and Attitudes Toward the Change to a Task-Based Curriculum in an English Programme at a University in Qatar. Ph.D. Thesis, The University of Exter, Exter, UK, 2019.
199. Minel, A.H. The Relationship Between Theory X/Y Management Styles and Job Satisfaction: Moderation Roles of Self-Efficacy and Gender. Master's Thesis, Linnaeus University, Växjö, Sweden, 2019.
200. Sravanthi, K.; Shamila, M.; Tyagi, A.K. Cyber Physical Systems: The Role of Machine Learning and Cyber Security in Present and Future. *Comput. Rev. J.* **2019**, *4*, 66–80.

201. Park, J.; Kim, Y. Supervised-Learning-Based Optimal Thermal Management in an Electric Vehicle. *IEEE Access* **2019**, *8*, 1290–1302. [CrossRef]
202. Hossain, M.S.; Kumar, L.; Assad, M.E.H.; Alayi, R. Advancements and Future Prospects of Electric Vehicle Technologies: A Comprehensive Review. *Complexity* **2022**, *2022*, 3304796. [CrossRef]
203. Roy, H.; Roy, B.N.; Hasanuzzaman; Islam, S.; Abdel-Khalik, A.S.; Hamad, M.S.; Ahmed, S. Global Advancements and Current Challenges of Electric Vehicle Batteries and Their Prospects: A Comprehensive Review. *Sustainability* **2022**, *14*, 16684. [CrossRef]
204. İnci, M.; Savrun, M.M.; Çelik. Integrating electric vehicles as virtual power plants: A comprehensive review on vehicle-to-grid (V2G) concepts, interface topologies, marketing and future prospects. *J. Energy Storage* **2022**, *55*, 105579. [CrossRef]
205. Khan, S.A.; Kadir, K.M.; Mahmood, K.S.; Alam, I.I.; Kamal, A.; Al Bashir, M. Technical investigation V2G, S2V, and V2I for next generation smart city planning. *J. Electron. Sci. Technol.* **2019**, *17*, 100010. [CrossRef]
206. Schuller, A.; Flath, C.M.; Gottwalt, S. Quantifying load flexibility of electric vehicles for renewable energy integration. *Appl. Energy* **2015**, *151*, 335–344. [CrossRef]
207. Hu, X.; Zou, Y.; Yang, Y. Greener plug-in hybrid electric vehicles incorporating renewable energy and rapid system optimization. *Energy* **2016**, *111*, 971–980. [CrossRef]
208. Birnie, D.P. Solar-to-vehicle (S2V) systems for powering commuters of the future. *J. Power Sources* **2009**, *186*, 539–542. [CrossRef]
209. İnci, M. Connecting multiple vehicular PEM fuel cells to electrical power grid as alternative energy sources: A Case Study. *Int. J. Hydrogen Energy* **2024**, *52*, 1035–1051. [CrossRef]
210. Mouli, G.R.C.; Kefayati, M.; Baldick, R.; Bauer, P. Integrated PV charging of EV fleet based on energy prices, V2G, and offer of reserves. *IEEE Trans. Smart Grid* **2019**, *10*, 1313–1325. [CrossRef]
211. Kwon, M.; Choi, S. An Electrolytic Capacitorless Bidirectional EV Charger for V2G and V2H Applications. *IEEE Trans. Power Electron.* **2017**, *32*, 6792–6799. [CrossRef]
212. Khan, W.; Ahmad, F.; Ahmad, A.; Alam, M.S.; Ahuja, A. Electric vehicle charging infrastructure in India: Viability analysis. In Proceedings of the 3rd International Conference and Exhibition on Smart Grids and Smart Cities, Lecture Notes in Electrical Engineering, New Delhi, India, 7–10 March 2017. [CrossRef]
213. Kore, H.H.; Koul, S. Electric vehicle charging infrastructure: Positioning in India. *Manag. Environ. Qual. Int. J.* **2022**, *33*, 776–799. [CrossRef]
214. Vatsala; Khan, R.H.; Varshney, Y.; Ahmad, A.; Alam, M.S.; Chaban, R.C. Technical and economic feasibility analysis for deployment of xEV wireless charging infrastructure in India. In *Lecture Notes in Electrical Engineering*; Springer: Singapore, 2018. [CrossRef]
215. Sachan, S.; Singh, P.P. Charging infrastructure planning for electric vehicle in India: Present status and future challenges. *Reg. Sustain.* **2022**, *3*, 335–345. [CrossRef]
216. Coffman, M.; Bernstein, P.; Wee, S. Electric vehicles revisited: A review of factors that affect adoption. *Transp. Rev.* **2017**, *37*, 79–93. [CrossRef]
217. Veerendra, A.S.; Ravindra, M.; Ramesh, A.; Reddy, K.M.K.; Sekhar, C.P. Electric vehicles charging in India: Infrastructure planning and policy aspects. *Energy Storage* **2022**, *4*, e335. [CrossRef]
218. Vatsala; Khan, R.H.; Varshney, Y.; Ahmad, A.; Alam, M.S.; Chaban, R.C. Challenges and Potential Solutions for the Deployment of Wireless Charging Infrastructure for xEVs in India, Compendium of Technical Papers. In Proceedings of the Indian Smart Grid Week 2017, New Delhi, India, 8–10 March 2017.
219. Nair, S.; Rao, N.; Mishra, S.; Patil, A. India's charging infrastructure—Biggest single point impediment in EV adaptation in India. In Proceedings of the 2017 IEEE Transportation Electrification Conference, ITEC-India 2017, Pune, India, 13–15 December 2017. [CrossRef]
220. CTC-N, Batteries for Electric Cars: Challenges, Opportunities, and the Outlook to 2020 | Climate Technology Centre & Network | Fri, 09/08/2017. 2023. Available online: https://www.ctc-n.org/resources/batteries-electric-cars-challenges-opportunities-and-outlook-2020 (accessed on 16 October 2022).
221. Thomas, C.S. How green are electric vehicles? *Int. J. Hydrogen Energy* **2012**, *37*, 6053–6062. [CrossRef]
222. Malen, D.E. Preliminary Vehicle Mass Estimation Using Empirical Subsystem Influence Coefficients. In *Report Prepared for the FGPC-Mass Compounding Project Team, Auto/Steel Partnership*; University of Michigan: Ann Arbor, MI, USA, 2007.
223. Jerome, S.; Udayakumar, M. A Study on Cost-Effective Electric Vehicle Charging Infrastructure in India Through Open Access Power Procurement. *Arab. J. Sci. Eng.* **2021**, *46*, 12509–12524. [CrossRef]
224. Deb, S.; Tammi, K.; Kalita, K.; Mahanta, P. Charging Station Placement for Electric Vehicles: A Case Study of Guwahati City, India. *IEEE Access* **2019**, *7*, 100270–100282. [CrossRef]

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