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Review article

An in-depth analysis of electric vehicle charging station infrastructure, policy implications, and future trends

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ABSTRACT

A significant transformation occurs globally as transportation switches from fossil fuel-powered to zero and ultra-low tailpipe emissions vehicles. The transition to the electric vehicle requires an infrastructure of charging stations (CSs) with information technology, ingenious, distributed energy generation units, and favorable government policies. This paper discusses the key factors when planning electric vehicle charging infrastructure. This paper provides information about planning and technological developments that can be used to improve the design and implementation of charging station infrastructure. A comprehensive review of the current electric vehicle scenario, the impact of EVs on grid integration, and Electric Vehicle optimal allocation provisioning are presented. In particular, this paper analyzes research and developments related to charging station infrastructure, challenges, and efforts to standardize the infrastructure to enhance future research work. In addition, the optimal placement of rapid charging stations is based on economic benefits and grid impacts. It also describes the challenges of adoption. On the other hand, future trends in the field, such as energy procurement from renewable sources and cars' benefits to grid technology, are also presented and discussed.

Contents

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1. Introduction

The escalation in need for conventional energy sources has caused multiple outcomes that negatively affect the environment. Resources are depleted, and CO_2 is released in high amounts, causing the greenhouse effect and undesirable global warming (Wang and Cheng, 2020). As a result of the Paris Agreement, CO_2 emissions were reduced, and the planet's temperature was controlled (Saerbeck et al., 2020). Clean energy resources and related technologies have been developed to mitigate these problems. Although technological advancements have significantly reduced greenhouse gas emissions from transportation, about one-quarter of these emissions come from the sector (Napoli et al., 2019). According to Outlook (2010), the growing population and freight movements will contribute to a 77% increase in transportation by 2055. Due to the above reasons, research and adoption of electric vehicles (EV) deserve exorbitant attention. By emitting very low or no tailpipe emissions and making very little noise, electric vehicles significantly reduce traffic congestion and contribute to a healthier living environment (Sanchez-Sutil et al., 2015; Abid et al., 2022; Huang et al., 2022; Chakir et al., 2022; Lan et al., 2022; Soares et al., 2022; Guo and Zhao, 2015). As a result of this transition to zero-emission vehicles, the automotive industry is switching to zero-emission vehicles (Bräunl et al., 2020; Domínguez-Navarro et al., 2019). Approximately 1.5 million new battery electric vehicles (BEV) have been added to the global fleet of BEVs (Martins et al., 2021) in 2019, with approximately 4.8 million BEVs in use globally.

At their optimal locations, electric vehicle charging stations are essential to provide cheap and clean electricity produced by the grid and renewable energy resources, speeding up the adoption of electric vehicles (Alhazmi et al., 2017; Sathaye and Kelley, 2013). Establishing a suitable charging station network will help alleviate owners' anxiety around electric vehicles, allowing the EVs to compete with internal combustion engines in terms of performance (Clemente et al., 2014). The market share of electric vehicles must be raised to emphasize continuous improvements in recharging technology. The current challenge with adopting electric vehicles is the "chicken or the egg" theory (Greene et al., 2020). A proper charging infrastructure that guarantees successful trip completion with no or minimal charging time delays is eagerly anticipated by consumers. Therefore, investors are waiting for enough electric vehicles to be on the road to make the charging infrastructure business profitable. Stakeholders disagree on whether fast-charging or smart charging is more appropriate for EV charging stations. The government's policies also play an essential role in resolving these issues (Wolbertus et al., 2020). The lack of reasonably priced batteries that can store enough energy over a more extended period of time to improve the range of EVs is another essential factor affecting EV adoption (Benysek and Jarnut, 2012; Nie and Ghamami, 2013; Ghosh, 2020).

Additionally, the optimal location of EVCSs and the impact of EVs on the distribution system have become prominent research topics in recent years (Lam et al., 2014). Consequently, the authors review the DNO approach, EVCS users' approach, and EVCS owner approach in this paper to determine where to position EVCS. Numerous studies on the positioning of EVCSs using the DNO approach have already been published, such as minimizing the voltage on buses, minimizing the power loss at the distribution system, and maximizing reliability. EVCS investors have been examined for the placement of EVCS in other research, while EV users have been less widely studied.

According to Liu et al. (2012), the modified primal–dual interior-point algorithm was used to determine the optimal location of EVCS by considering the investment, operation, maintenance, and network loss costs. In Ref. Islam et al. (2018) proposed a multi-objective optimization problem to locate FCSs with the least cost in transportation, station build-up, and substation energy loss. Further, the authors of Pal et al. (2021) presented an initial research study by integrating energy loss, voltage deviation, EV population, and land cost. With the 2 m point estimation method (2 m PEM), the uncertain variable of electric vehicles is efficiently controlled, and Harris Hawks Optimization (HHO) is used to solve the optimization problem. In Ref. Gampa et al. (2020) proposed a two-stage fuzzy approach for locating distributed generation (DG), shunt capacitors and charging stations optimally. As a first approach, the DGs and SCs were placed using a multi-objective optimization problem, and a multi-objective placement problem was implemented as a second approach. In order to solve the optimization problem, power loss and voltage profiles were utilized. A grasshopper optimization algorithm (GOA) was finally used to solve the proposed problems.

Currently, three revolutions are underway in the transportation sector: autonomous vehicles, shared mobility, and electrification. Therefore, designing the charging infrastructure for electric vehicles requires considering the synergies and interactions among these three booming revolutions. In response to the increase in electric vehicle adoption, the electricity demand on the power grid will increase significantly, requiring an infrastructure upgrade (Green II et al., 2011). Transmission lines cannot transport as much energy as the distribution grid, limiting how much power is transported (Zhang et al., 2011). To meet the changing requirements of EVs, it is necessary to reconfigure the distribution grid on a large scale. A comprehensive assessment is essential to evaluate network performance's potential effects on large-scale grid-connected renewable energy production systems (REG) and electric vehicle charging stations (EVCS). Power utilities can perform such analyses to develop efficient equipment (Farhoodnea et al., 2013). Charging levels at each charging station in Fig. 1 illustrate the charging infrastructure for electric vehicles (Borlaug et al., 2020). According to a study (Lee et al., 2020), residential charging facilities are the most popular and essential charging location for battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). Developing an efficient charging infrastructure requires an effective communication network for information exchange, an optimization unit to reduce the charging time at the charging station, and a prediction unit to aid the optimization unit in making the best decisions (Shukla and Sengupta, 2020). Adopting many electric vehicles at once is a tremendous challenge for the energy sector. Several measures have been taken to address these issues.

There have already been several articles that summarize the structure and configuration of electric vehicles (Tie and Tan, 2013). The cost of batteries, the charging strategies' efficiency, the charging stations' interoperability, and the impacts of EV integration with the grid need to be addressed to make EVs competitive in the market (Singh et al., 2013). The development of international standards and codes, universal infrastructures, peripherals, and user-friendly software will be crucial to EV growth over the next decade (Arancibia and Strunz, 2012). There are enormous numbers of researchers working in these fields around the world. To expand the EV market, a comprehensive understanding of the development of EV charging infrastructure and its impact on the grid is essential. Many authors have summarized the charging infrastructure for electric vehicles (Yilmaz and Krein, 2012a), the integration of EVs with smart grids (Tan et al., 2016), the impact of vehicle-to-grid technology (Habib et al., 2015), and the interaction between EVs and smart grids (Mwasilu et al., 2014) in their works. The rapid advancements in this field over the past few years have rendered those reports quite outdated. The paper aims to analyze the recent developments in the field of charging stations, from the planning and designing stages to the operational management of the stations. In addition, the paper discusses how to make the grid more flexible by better using renewable energy resources. Following are some research gaps identified in this study that could provide valuable information for future research:

- Examine the various types of electric vehicle charging stations (EVCS) and electric vehicle charging infrastructure to understand the interaction between EVs better.
- Electric Vehicle charging technology and the various types and methods of EV charging stations.
- Concepts related to economics and the power grid are used to determine the optimal placement of EVCS.

1.1. Main contributions

A study analyzing recent EV developments and charging infrastructure challenges is presented in this work. Detailed findings from the study are presented below. Optimal charging scheduling techniques can take advantage of EVs' flexibility as a load while minimizing solar and wind systems' impact on the grid. Current research indicates that using metaheuristic techniques coupled with optimization software can significantly affect the efficient use of available resources. EV charging infrastructure can be planned and managed using these tools, including locating the optimal location for charging stations and determining the optimal charging station location. EV owners are reassured by mobile charging stations that they will have access to a charging facility if they cannot find an adjacent charger as part of planning infrastructure for EV charging. Using V2G technology, energy can be bi-directionally exchanged, and ancillary services are provided to the grid. Charging infrastructure available with minimal charging times is critical for adopting EVs. In order to minimize the impact on the primary power grid, battery swap stations regulated the charging schedule of EV battery packs. Furthermore, it can serve as a backup unit and provide power for the primary grid in peak demand periods. As EVs and their charging infrastructure are developed, and renewable energy sources are utilized, harmful emissions can be drastically reduced in the transportation sector. Unfortunately, any damage to the environment this new infrastructure might cause has not been assessed. In future electric vehicles, hydrogen energy and fuel cells will replace the batteries currently used in battery energy storage systems.

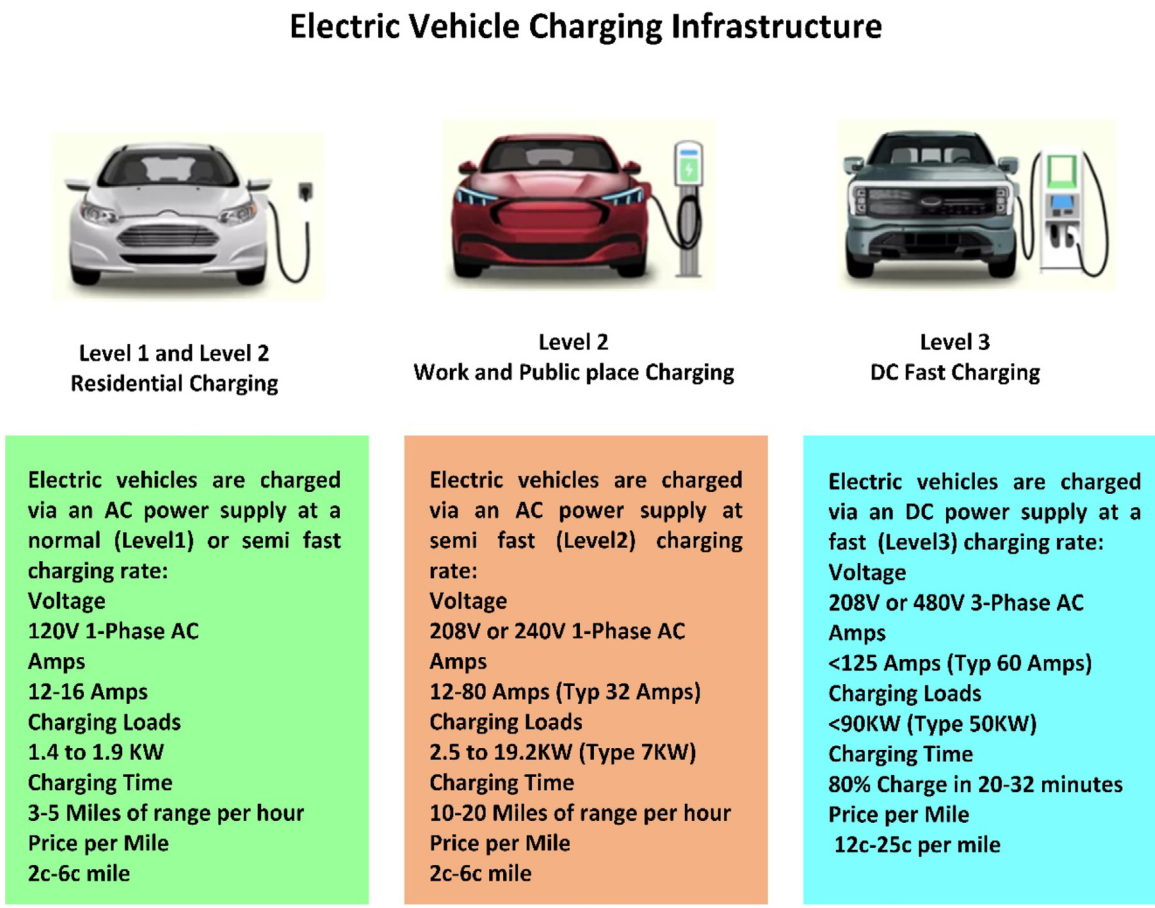


Fig. 1. Overview of charging infrastructure for electric vehicles (EVs).

1.2. Search strategy

This systematic review used a search method to identify relevant research. Scopus and Web of Science databases were searched using the following search terms: "Electric Vehicle Charging Technology" and "Electric Vehicle Charging modes and methods". EVGI and Electric Vehicle Infrastructure". OR "EV Charging Technology and communication infrastructure analysis". Fig. 2 shows the articles based on the subject area and type.

In this paper, we discuss the Charging station type for electric vehicles (EVCS), Electric vehicle charging technology, Infrastructure for charging electric vehicles, and Integrated power systems for electric vehicles. Our decision to separate these works was based on the fact that several works address the routing of vehicles without including the charging constraint. As a result, either computation complexity is avoided, or electric vehicles are not considered.

This paper will be organized as follows: Section 2 discusses the different types of Electric Vehicle Charging Stations (EVCS); Section 3 describes the charging modes, methods, conductive charging, wireless power transfer, and battery swap stations; Section 4 outlines the electric vehicle charging infrastructure, including the different types of AC and DC charger connectors, current EV models, and control and communication infrastructures. It also outlines the communication network for electric vehicle charging, optimal locations for charging stations, and a constant current and voltage charging system; Section 5 discusses how electric vehicles can be integrated into power systems in various aspects and summarizes EV grid integration strategies and future EV charging infrastructure development, electric vehicles and the grid power interface modes, the need for renewable energy sources, the effects of electric vehicle integration on the grid and EVGI challenges and suggestions are discussed; Agent role in EVGI; EV aggregator's role in EVGI; A challenges between EV owners, aggregator and distributor; Section 6 describes policy incentives and the electric Vehicle Market Structure; Electric vehicle development and pilot project; Section 7 outlines future challenges and trends; Section 8 discusses the significant finding; The conclusion is presented in Section 9.

2. Type of electric vehicle charging station (EVCS)

Electric vehicles have gained tremendous traction as an alternative technology among various developed technologies, becoming an integral part of modern transportation. According to the source of electricity for the vehicle's propulsion, electric vehicles are generally classified into three categories based on Miele et al. (2020) and Thompson et al. (2018):

- Hybrid electric vehicles (HEVs)
- Plug-in electric vehicles (PEVs)
- Fuel cell electric vehicles (FCEVs)

An electric propulsion system is combined with an internal combustion engine to power hybrid electric vehicles. Compared to conventional internal combustion engine vehicles, this enables vehicles to be more fuel-efficient, have lower emissions, have longer drive ranges, etc. Sun et al. (2019). The types of PEVs include BEVs and PHEVs. Battery-powered BEVs are propelled by electric motors and powered by rechargeable batteries. When the

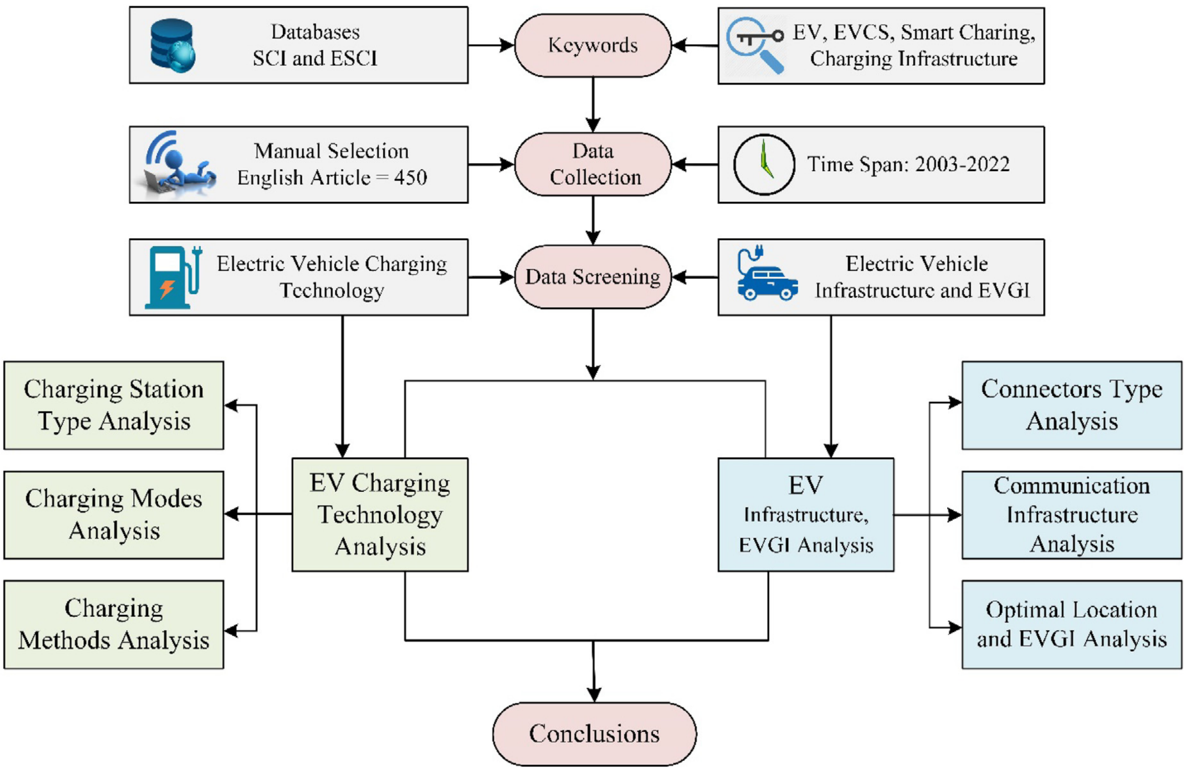


Fig. 2. A flow diagram showing how the bibliometric review is carried out.

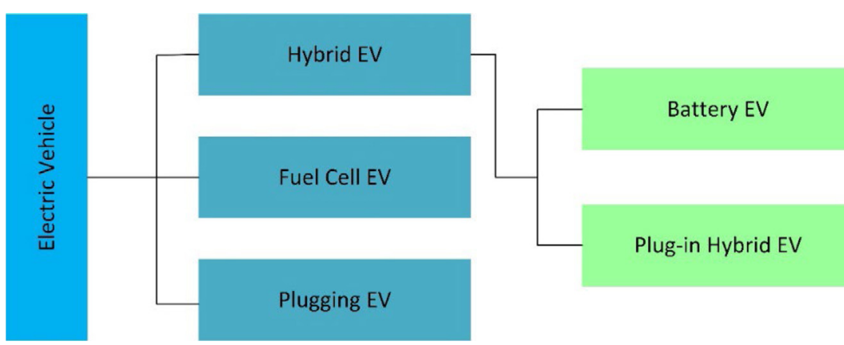


Fig. 3. Various types of electric vehicles.

battery runs out, a gasoline engine provides backup power. An electric propulsion system typically powers the PHEV but can be equipped with a gasoline engine. Vehicles powered by fuel cell technology have a propulsion system that uses fuel cells instead of batteries or a battery plus a supercapacitor—the classification of EV types is Presented in Fig. 3.

3. Charging technology for electric vehicles

This section provides information about different EV charging levels, modes of charging, and charging schemes, with a few international standards to consider when establishing an EVCS, as shown in Fig. 4.

3.1. Charging modes

EVCS are primarily refueling stations that provide electricity to charge electric vehicles. The charger point is integrated into the cable, charging port, and interface panel. Depending on a grid configuration, various parameters such as voltage rating, frequency rating, and transmission standards determine the power outlet configuration. The Electric Power Research Institute (EPRI), Society of Automotive Engineers (SAE), and the International Electrotechnical Commission (IEC) have a substantial role to play in categorizing charging modes and levels in each country as well as managing the differences in safety standards. Various charging types are outlined in established standards, including alternating current (AC) Level-1, alternating current (AC) Level-2, and direct current fast charging (DCFC). A new regulation specifies DCC's DC Level-1 and DC Level-2 (Brown et al., 2011). According to a study published in Schroeder and Traber (2012), residential charging infrastructure is the most common method for charging EVs, with Level-1 and Level-2 as the most popular There are many types of charging techniques, as shown in Table 1.

3.1.1. Level 1 charging

Level 1 (L1) charge cables are included with every EV. The device is universally compatible, does not require installation fees, and is pluggable into any standard grounding 120-V outlet. Depending on the price of electricity and the efficiency rating of your EV, L1 charging can cost anywhere from two to six dollars

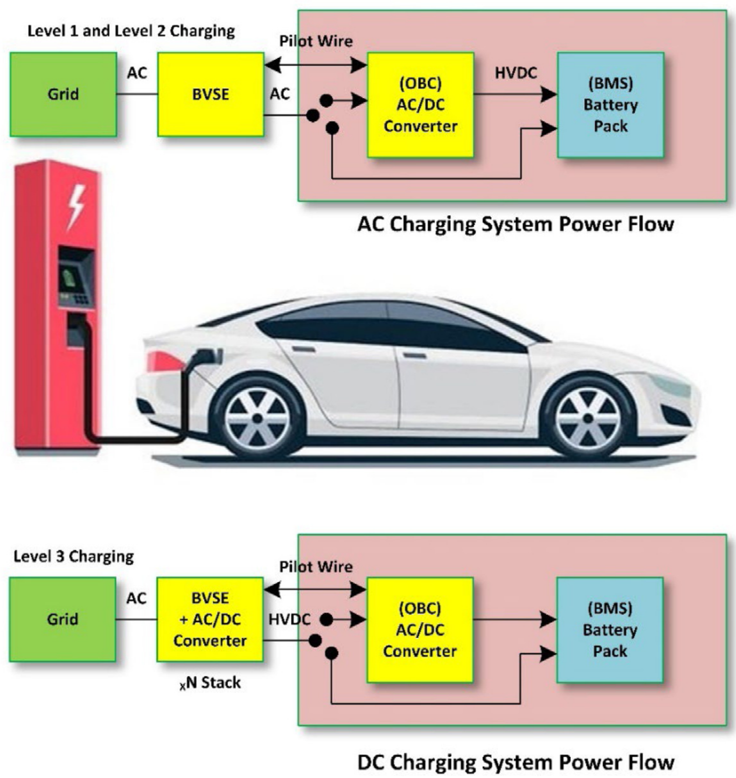


Fig. 4. Modes of charging at different levels.

Table 1
An overview of charging techniques.

	Using inductive charging	Using conductive charging	Batteries swapping
Aspects	Trickle charging Wireless charging Low efficiency Power losses are high Costliest infrastructure	DC fast public charging and AC public charging Wired charging Highly efficient Minimal power loss The onboard charging system The capability of charging off-board	Off-board charging Minimal power loss Extremely efficient Quick changeover A minimum management cost

per mile. With a maximum power rating of 2.4 kW, the L1 charger can recharge at approximately 40 miles per eight hours, with a speed of 5 miles per hour. For many people, this works well due to the average driver's 37 miles of driving per day.

Additionally, L1 chargers benefit people whose workplaces and schools offer L1 charging points since they can charge their electric vehicles throughout the day. Since the L1 charge cable cannot keep up with long commutes or weekend drives, electric vehicle drivers often refer to it as an emergency charge or trickle charger. Typical household outlets operate at 120 V for L1 charging. The maximum current passed through these chargers is 16 amps. This charging point provides a maximum power outlet of 1.9 kW and takes between 8 and 16 h to charge the battery according to its capacity fully. In order to connect the electric vehicle and the charging pillar, an SAE J1772 connector is used. Charges this way are the least expensive but the slowest of all charging methods. L1 charging can reduce charging costs even further when combined with a tariff-based charging system. In Fig. 3, you can see how L1 charging works.

3.1.2. Level 2 charging

Level 2 (L2) charging stations are most commonly used in public and residential locations. In order to meet L2 requirements for electric vehicles, charging stations must use a single-phase power supply of 240 V with a maximum current flow capacity of 40 A for residential and commercial installations and a three-phase AC power supply of 400 V with a maximum current flow capacity 80 A for public stations. Depending on its brand, power rating, and installation requirements, a Level 2 charger can cost anywhere between $500 and $2000 per unit. Based on the electricity rate and the vehicle's efficiency, L2 charge costs range from 2$ to 6$ per mile. In addition to the public-access L2 charging stations in parking garages, the charging stations are found at the entrances to businesses, schools, and colleges where students and employees use them. EVs with the industry-standard J-plug are universally compatible with SAE J1772 charging stations. The maximum charging power at L2 stations is around 12 kW, equating to about 100 miles of recharging every eight hours. For the average driver, who travels 37 miles per day, the charging time is about 3 h. L2 charging can provide a quick charge along the way if you are traveling further than the range of your vehicle (Tan et al., 2016). Furthermore, L2 charging is also advantageous for fast charging. Overcurrent voltage and overcurrent protection are built into L2 charging systems. As shown in Fig. 3, the layout of an L2 charger can be seen.

3.1.3. Level 3 charging

The fastest charging method for electric vehicles is Level 3 (L3). The L3 charging station primarily charges electric vehicles in public and commercial areas. Due to their rapid refueling capability, vehicles can be recharged quickly in high-traffic areas such as rest stops, shopping centers, and entertainment districts. It may be possible to charge fees based on an hourly or per-kWh basis. Charges for L3 charging can range from 12$ to 25$

Table 2
Electric vehicle charging standards and protocols.

EV charger topology	Charging connector	Charging communication	Charging power quality	Charging safety
IEC 61851-1	IEC 62196–1	ISO 15118/IEC 61850	IEEE 1547	IEC 60529
IEC 61851- 21	IEC 62196–2	SAE J2847/SAE J2836	SAE J2894	IEC 60364- 7-722
IEC 61851- 22	IEC 62196–3	SAE J2293-2/OCPP	IEC 1000-3-2	ISO 6469-3
IEC 61851- 23	SAE J1772	OCPI/OSCP/	NEC 690	SAE J1766
IEC 61851- 24	IEEE 1901	OpenADR	SAE J2380	SAE J2464

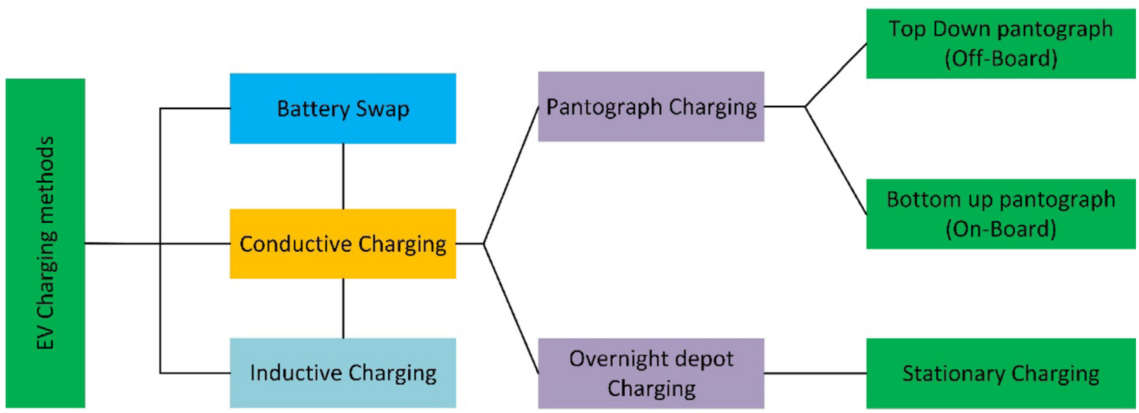


Fig. 5. Charging methods for electric vehicles.

per mile, depending on membership fees and other factors. In addition, L3 chargers do not comply with industry standards and are not universally compatible. By using DC charging technology, these stations are designed to provide a similar user experience to that of traditional filling stations. The charge time for a battery from 0 to 80% is usually 15 to 20 min with DC fast charging. All 20% of the remaining battery will always be charged in slow mode, regardless of the charging level. DC power is delivered to the electric vehicle by converting AC power from an off-board charger. Charging voltages for L3 typically range from 200 to 600 V, and power outputs range from 36 to 240 kW. DCFC can be divided into two categories based on SAE standards: DC Level 1 and DC Level 2. In addition to their 36-kW power output, DC L1 charging stations also have a current flow capacity of 80 A. Chargers with DC L2 power output have a current flow capacity of 200 A and a power output of 90 kW. Most DC power output charging stations are located in malls, government buildings, movie theaters, airports, and refueling stations (Mayfield and Ohio, 2012). DC charger connectors having the SAE/IEC J1772/IEC 62,196–3 standard are recommended by SAE and IEC. DC fast-charging stations have a significant drawback due to their high installation costs. See Fig. 3 for a visual representation of charging levels 1–3. The primary standards and protocols for EV charging are described below in Table 2.

3.2. Electric vehicle charging methods

There are various ways to charge a battery and control its current. Electric vehicles use rectifiers to convert AC into DC for charging their batteries. Several mechanisms can be used to transfer charge, including inductive charging, conductive charging, and battery swapping (Zheng et al., 2013; Miller et al., 2012; Wang et al., 2013). A comparison of charges of different charging stations is shown in Table 2. According to Fig. 5, conductive charging can be categorized as pantograph charging (total and bottom-up) and overnight charging.

3.2.1. Conductive charging (CC)

The benefits of conductive charging are its economic viability, ability to charge quickly, simplicity of operation, and high efficiency. In addition to onboard and offboard charging systems, conductive charging has also been categorized (Illmann and Kluge, 2020). Chargers installed onboard an electric vehicle, such as AC-DC converters, are usually slow chargers that charge the vehicle entirely inside. Offboard chargers, on the other hand, provide rapid charging. EV range can also be increased by reducing the vehicle's weight using offboard chargers (Khaligh and Dusmez, 2012).

- **Overnight Depot Charging:** A facility that provides overnight depot charging offers fast and slow charging options. The charge point is typically located at the end of the lines. It is used for charging at night. Due to the low charging impact on the distribution grid, slow charging is the most advantageous option (Arif et al., 2020, 2021). However, the Pantograph charging technique is most suitable for applications with high battery capacity and quick charge requirements.
- **Pantograph Charging:** With this charging method, various charging options are available. Typically, this charging infrastructure is used for applications requiring higher battery capacity and more power, such as buses and trucks. As a result of this charging technique, bus batteries require less investment, so the investment costs are reduced, but charging infrastructure costs rise (Meishner et al., 2017). Pantograph charging can be further categorized as follows:
  1. Top-down Pantograph: The charging setup is located on top of the bus stop, so it is commonly referred to as an off-board top-down pantograph. This method uses direct current to produce high power (Carrilero et al., 2018), which has already been demonstrated in Germany, Singapore, and the U.S.
  2. Bottom-up Pantograph: Buses have already been equipped with charging equipment, so this charging method is appropriate where the bus already has charging equipment. Alternatively, the bottom-up pantograph is called the onboard pantograph.

3.2.2. Inductive/wireless power transfer (WPT)

A two-coil system is used in this technology based on electromagnetic induction. When the installation is complete, the

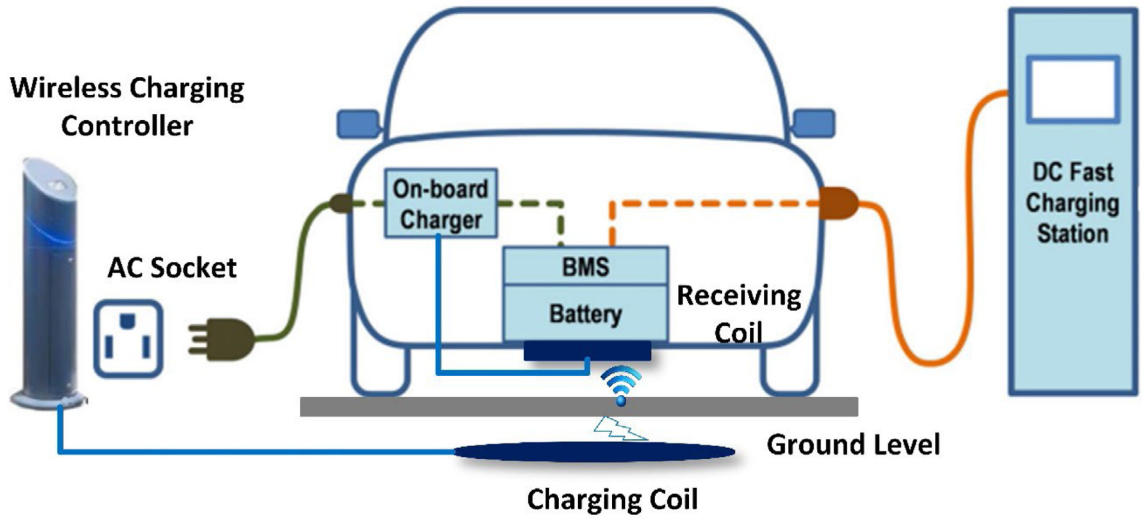


Fig. 6. Possible accommodation of charging circuit in EV.

receiving coil is installed in the vehicle, while the charging coil is placed on the road surface. Recent advancements in WPT technology have attracted interest in EV applications because they make it possible to recharge the vehicle safely and conveniently. A standard connector is unnecessary for the charger (but standard coupling technology is required), and the charger can be operated while driving (Sanguesa et al., 2021). Even so, inductive power transfer is not very efficient. There should be a 20 to 100 cm distance between the transmitter and receiver coils (Chowdhury, 2021). In the WPT, eddy current loss can also be a problem if the transmitter coil is not switched off. EV and transmitter should be able to exchange information in real-time, but there may be a slight communication latency (Patil et al., 2017). Fig. 6 shows an example of this.

3.2.3. Battery Swap Station (BSS)

Batteries are swapped through a method called "Battery Exchange'', which involves renting the battery from the BSS owner on a monthly basis. The BSS slows the charging process and gives batteries a longer life cycle (Ahmad et al., 2018). Solar and wind power, locally generated renewable energy sources, can be easily integrated into the BSS system. Using this technique, the user does not need to get out of the car, and the battery can be replaced quickly. Additional advantages of this battery are that it contributes to the V2G initiative (Gschwendtner et al., 2021; Brenna et al., 2021). Since the BSS owner owns the EV batteries, charging the EVs at this station is more expensive than burning fuel for the ICE engine because the BSS owner charges leasing fees. As a result of this technique, multiple batteries need to be purchased and a large space where they can be stored, which could be expensive in an area with high traffic. It is also possible that the station has a particular battery model, but the vehicles use different standards. An overview of the charging stations type, including CC, WPT, and BSS stations, can be found in Table 3.

4. Electric vehicle charging infrastructure

An adequate infrastructure allowing customers to recharge their electric vehicles would make it easier to adopt electric vehicles (Miller et al., 2012). Fast, reliable, and convenient technology will make it easier for consumers to adopt electric vehicles. Adopting electric vehicles promotes environmentally-friendly transportation and reduces our dependence on fossil fuels. In addition to electric vehicles, conventional power plants and other power generation units will also produce more emissions. The increasing energy demand should be met by a large-scale deployment of renewable energy sources, and the deployment of REG should be coordinated with the increasing number of EVs (Tulpule et al., 2013; Luo et al., 2020). A complete EV charging infrastructure involves power infrastructure, control and communication infrastructure, and charging ports and connectors meeting various standards, as depicted in Fig. 7 and Table 4. Below are aspects, challenges, and recent technological advances associated with electric vehicle charging station infrastructure.

4.1. Connectors for AC charging

A universal AC connector has not been agreed upon by EV manufacturers. The connector's pin-out, size, and shape vary depending on the charger's electric vehicle manufacturer, country, and power level. Different regions have different mains voltages and frequencies because of their specific AC mains voltages and frequencies. As a standard AC connector, most voltage-controlled devices have a few large pins for voltage sensing and a few smaller pins for communication. Here are the four types of AC connectors that are currently in use around the world:

4.1.1. Connector type 1

Using this connector, you can only charge your vehicle with single-phase AC power. The connector is a round configuration composed of five pins, including two AC lines, two signal lines, and one earth pin for protection. With a maximum voltage and current rating of 120 V or 240 V, the device can handle up to 80 A.

4.1.2. Connector type 2

This connector can charge your device with AC and DC power. Moreover, it is 3-φ AC compatible. A single-phase can have a maximum voltage rating of 230 V and a maximum current rating of 80 A; the maximum voltage rating for a three-phase can be 400 V at 63 A.

4.1.3. US tesla connector

This particular connector was designed by Tesla specifically for use in the United States. Using this connector, you can supply both single-phase AC and DC power. This charger can charge at a maximum of 17.2 kW at 240VAC.

Table 3
A summary of the reviews of charging methods.

Reference	Year	Types	Advantages	Disadvantages
Negarestani et al. (2016)	2016	CC	Providing multiple charging levels	Highly complex infrastructures
Yoldaş et al. (2017)	2017	–	Ensure high efficiency	Restrictions on the electricity grid
Dharmakeerthi et al. (2014)	2014	–	The V2G facility is coordinated	Voltage instability in the distribution system is caused by fast charging
Habib et al. (2018)	2018	–	Maintain the voltage level while reducing grid losses	A standard connector/charging level is needed
Yang et al. (2015)	2015	–	Overloading the grid can be prevented	Due to uncoordinated charging, the grid will be overloaded
Yilmaz and Krein (2012b)	2013	–	Support for active power	Battery life is reduced with V2G operation
Gabbar (2022)	2018	WPT	The EV can be recharged safely and conveniently without a standard connector	Generally, power is transferred weakly; the range for efficient power transmission is between 20 cm and 100 cm
Patil et al. (2017)	2018	–	Vehicles recharging while in motion do not require any standard sockets	A real-time transmitter and an EV with low communication latency are a must
Dai et al. (2014)	2014	BSS	A fully charged battery can be replaced quickly	Due to the monthly rent to BSS, it is more expensive than ICE vehicles
Martínez-Lao et al. (2017)	2017	–	By slow charging, BSS extends the battery's life	Equipment and batteries require a huge investment
Erdinç et al. (2017)	2017	–	With the help of V2G, BSS helps utilities balance demand and load	A large stock of expensive batteries is needed
Li et al. (2018b)	2018	–	An easy way to integrate with the locally generated RESs	Batteries need to be installed in many areas, and different EVs have different battery standards

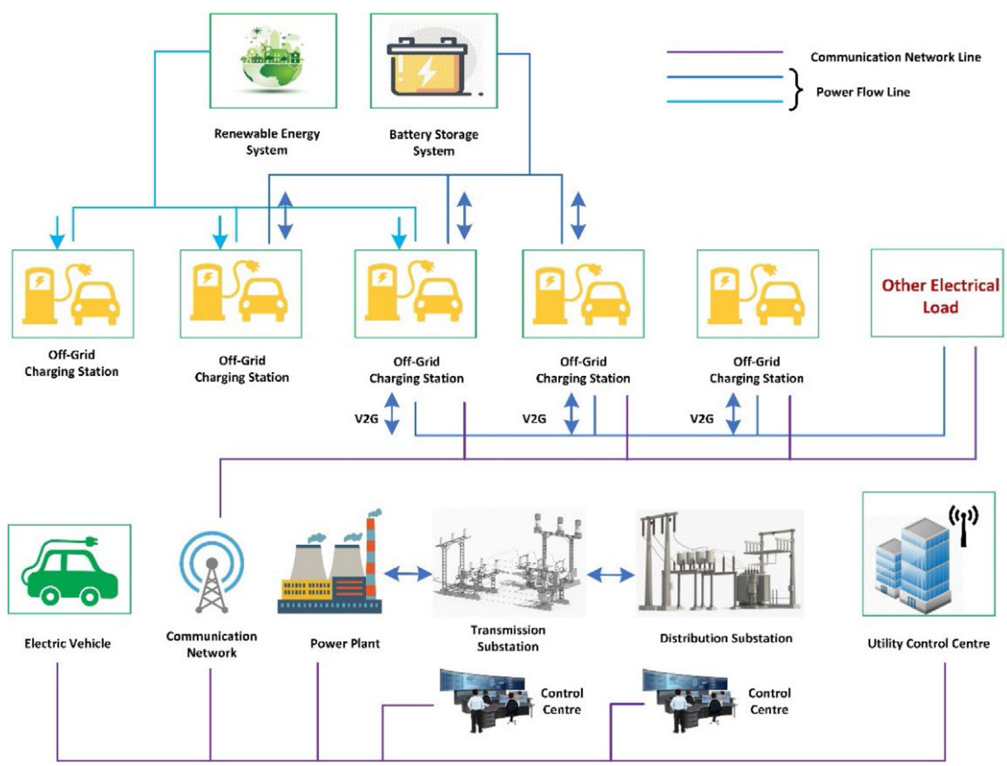


Fig. 7. Schematic diagram of charging infrastructure for electric vehicles.

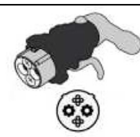
4.2. Connectors for DC charging

The DC fast charger can replace level 1 and level 2 chargers. According to the manufacturer, their power output varies from 50 kW to 500 kW. In addition to more excellent power capability, power conversion and control become more expensive and bulkier. DC fast chargers are typically deployed offboard to avoid interfering with the power lines. Another reason is safety considerations. As power converters and power handling components grow in size, passenger safety becomes a key concern. Currently, DC connectors have five major variants and are discussed as follows.

4.2.1. CCS combos 1 and 2

An electric vehicle charging interface initiative is a registered organization formed by Audi, BMW, Daimler, Mennekes, Opel, Phoenix Contact, Porsche, TÜV SÜD, and Volkswagen called CharIN e.V. ChargeIN is the organization that oversees Combo-type connectors. The Combined Charging System connector has the main advantage of performing AC and DC charging simultaneously. The connectors are defined by several standards, including IEC 62196–1, IEC 62196–2, and IEC 62196–3. Their maximum power handling capacity is 350 kW, and the connectors can handle voltages from 200 V to 1 kV up to 350 A.

Table 4
Schematic of charging ports and connectors according to various standards.

	GB/T 20234 DC	CHAdeMO	CCS Combo 1	CCS Combo 2
				
Charging Type	AC Charging	AC Charging	DC Fast Charging	DC Fast Charging
No. Of Pins	5	4	7	9
Capacity	Up to 187.5 kW	200 kW to 400 kW	50 kW - 100 kW	200 kW
Voltage	750 V to 1000 V	500 V	600 V	1000 V
Current Rating	250 A	125 A to 400 A	Up to 200 A	Up to 350 A
Compatibility	Yes	Yes	No	Yes
	SAE J1772 Type 1	**IEC 62196-2 Type 2**	**GB/T 20234 C**	**Tesla Supercharger**
				
Charging Type	AC Charging	AC Charging	AC Charging	DC Fast Charging
No. Of Pins	5	7	7	6
Capacity	7.68kW	12.8kW	12.16kW	140kW
Voltage	120V to 240V	400V	380V	480V
Current Rating	Up to 80 A	Up to 63 A	10A	250A
Compatibility	Yes	Yes	Yes	Yes

4.2.2. CHAdeMO

In 2010, Toyota Motor Corporation established the CHAdeMO Association to collaborate with Nissan Motor Co. Ltd., Toyota Motor Corporation, Nissan Motor Co. Ltd., Fuji Heavy Industries Ltd., and Tokyo Electric Power Company. CHAdeMO is a part of IEEE standards (IEEE Standard 2030.1.1TM-2015) and IEC standards (61851-23-6), as well as industry standards (61851–23, -24, and 62196–3). CHAdeMO, the first DC standard with a power handling capacity between 200 kW and 400 kW, enables V2X (vehicle to X, where 'X' may refer to the vehicle, the grid, infrastructure, etc.) with its version 1.1 protocol.

4.2.3. Tesla DC connector

Tesla's superchargers are equipped with their own charging connector in the US. The Tesla connector's unique feature is that AC and DC charging can be done via the same connector and pins. Additionally, an adapter can also connect CHAdeMO charging stations to the connector. A 120 kW power rating is available for each of these connectors.

4.2.4. GB/T China connector

The standard 20234.3–2015 defines a DC charging connector in China. The Controller Access Network (CAN) protocol communicates with connectors like this. This connector has the unique property of charging two batteries simultaneously; the low-voltage auxiliary battery and the high-voltage main battery. This product can deliver up to 250 A of current with a 750 V to 1 kV nominal voltage range.

4.3. Current models of EVs

As manufacturers introduce electric versions of existing vehicles or new EV models, the market for EVs and PHEVs has grown. From two-seat intelligent electric drive vehicles to Toyota's five-seat RAV 4 electric sport utility vehicles (SUVs), commercially available vehicles are in many sizes. In various markets, different types of vehicles are available. An overview of a select set of models, their charge times, ranges, and efficiency ratings are presented in Table 5.

4.4. Control and communication infrastructure for electric vehicle charging

The control and communication system controls and monitors an electric vehicle's charging system (Anon, 2010). Charging an electric vehicle increases the power demand for the power system.

4.4.1. Electric vehicle charging control architecture

Fig. 8 Shows how electric vehicle charging is controlled based on mobility, coordination, and control structures. The controls for EV charging involve the electric grid, EV charging stations, and EVs.

- **Considering the mobility of vehicles:** A static and dynamic charging infrastructure can be established for electric vehicles. Stations that allow charging while the vehicle is parked are static charging stations. In contrast, a dynamic or mobility-aware charging solution will consider different kinds of movement, such as the time when the EV arrives at the charging station and leaves it Sortomme and El-Sharkawi (2011b) and Sortomme and El-Sharkawi (2011a), as well as unplanned EVs' arrivals and departures (Mukherjee and Gupta, 2014), which would be more realistic because of the spatial–temporal relationship between the EVs. However, it is more complex and is associated with more advanced control infrastructure.
- **The coordination of charging:** EVs can be charged in two ways: uncoordinated charging control and coordinated charging control. An EV battery begins charging as soon as it is connected or after a fixed delay that the user can adjust.

Table 5
Comparison of charging times, battery size, and efficiency for selected EV models.

Reference	Manufacture	Model	Charging time		Electric-only driving range	Battery size (kWh)	Fuel economy
			120-volt AC	240-volt AC			
			Hours	Hours	Miles	kWh	MPGe
Onar et al. (2016)	Toyota	RAV4 SUV	44–52	6.5–8	103	41.8	76
Karamitsios (2013)	Tesla	Model S	30+	4–6	265	85	95
Zhang et al. (2010)	Toyota	Prius Plug-In (PHEV)	3	1.5	11–15	4.4	95 est.
Renault et al. (2011)	Renault	Fluence	–	6–9	115	22	–
Conlin (2006)	Opel	Ampera (PHEV)	–	4	46	16	235
Anele et al. (2015)	Renault	Zoe	–	3.5	130	22	–
Braun and Rid (2018)	Mitsubishi/Citroën/Peugeot	i-miEV/C-Zero/iON	22.5	7	62	16	112
Nissan (2012)	Nissan	LEAF	–	7	75	24	116
Gray and Shirk (2013)	Ford	Fusion Energi (PHEV)	7	2.5	21	8	100
Pelletier et al. (2014)	Mia	mia	–	3 or 5	50 or 78	8 or 12	–
Di Wu and Boulet (2015)	Honda	Fit EV	20+	4	82	20	118
Swiecki et al. (2013)	Ford	Focus Electric	20	4	76	23	105
Sovacool et al. (2019)	Fiat	500e	23	4	80 (est)	24	108
Schamel et al. (2013)	Ford	C-MAX Energi (PHEV)	7	2.5	21	8	100
Wang et al. (2019)	BYD	e6	20	8–9	186	61	97
Tarvirdilu-Asl and Bauman (2019)	Chevrolet	Spark	20+	7	82	20	119
Tribioli and Onori (2013)	Chevrolet	Volt (PHEV)	10–16	4	38	17	94

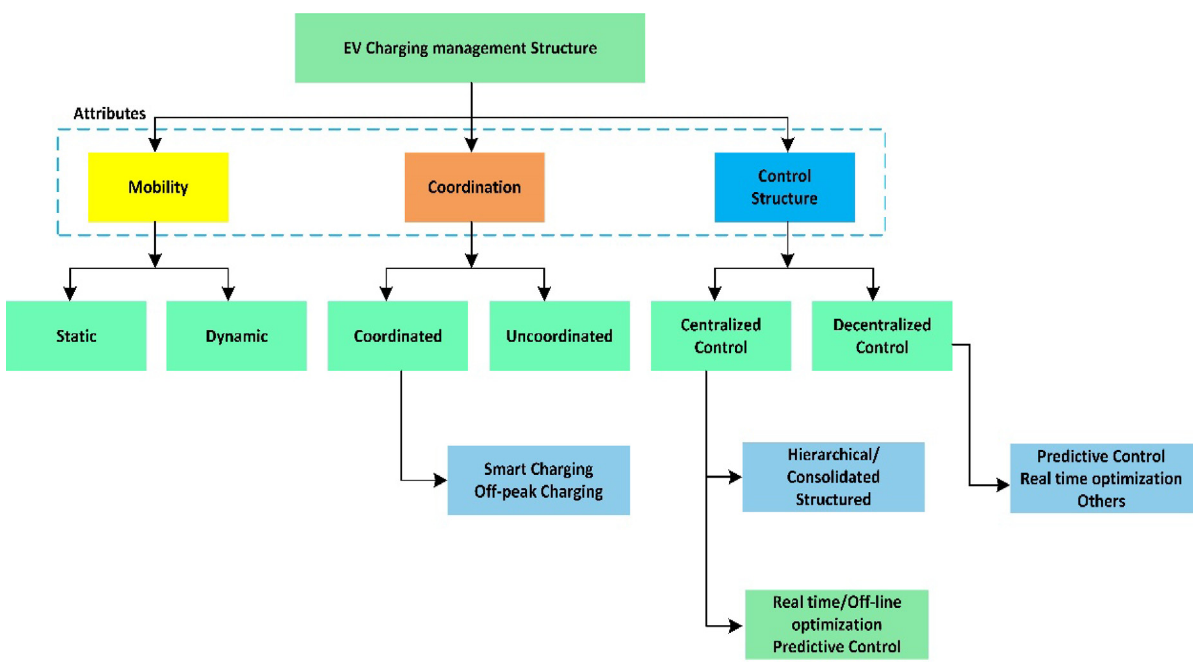


Fig. 8. EV charging systems are classified into different control strategies.

It continues to charge until it reaches its maximum capacity (Van Vliet et al., 2011; Galus et al., 2010). Charging operations are not coordinated when performed at peak times, increasing power losses, overloading distribution transformers, and reduced grid reliability (Masoum et al., 2012). Utility companies sometimes offer cheap nighttime rates (dual tariffs) for customers who own electric vehicles to alleviate peak load times (Kisacikoglu et al., 2014; Li et al., 2012). Smart charging, on the other hand, reduces peak load times. Chargers that use smart charging optimize the time and energy consumption (Qian et al., 2010) and reduce electricity costs, voltage deviations, currents, and transformer overloads (Fairley, 2010). A coordinated charging method using off-peak charging occurs at specific points during the day when grid loads are lowest, where electric vehicles are charged. Nonetheless, utility providers must be contacted for the days' time to determine whether this partially solves the overload problem. EV charging may also inconvenience EV users (Rangaraju et al., 2015).

- **Control structure consideration:** Charging stations for electric vehicles are distributed spatially via a distribution grid. The power flow of EV charging stations can be managed and controlled using several strategies, such as centralized or decentralized charging (Wang et al., 2017; Ahmed and Kim, 2017).

4.4.2. Centralized control

In centralized charging, electric vehicle charging schedules and rates are decided by a master control engine, which acquires information from the vehicles. The centralized structure processes the information centrally and provides an optimal global solution that considers grid constraints and user preferences.

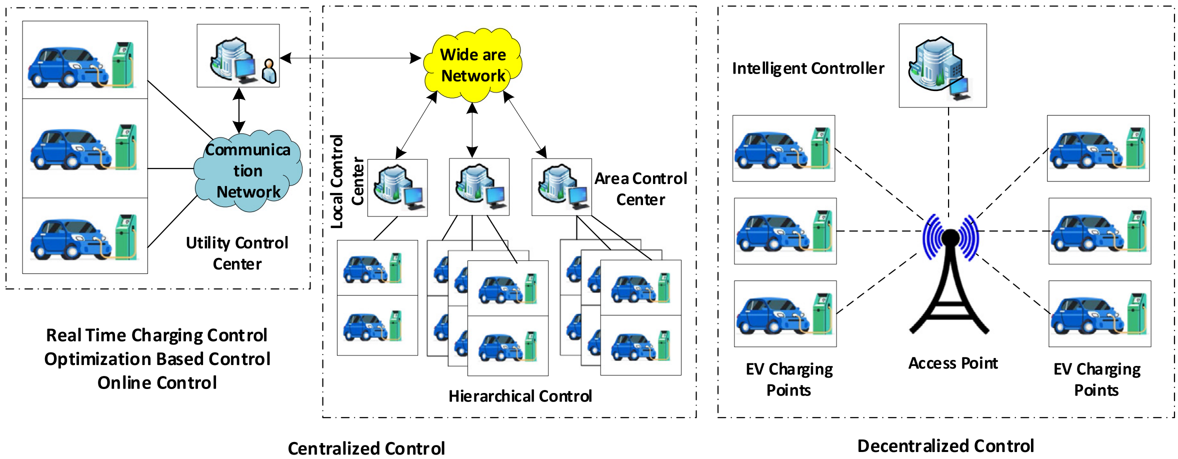


Fig. 9. An EV charging system with decentralized and centralized control.

In practice, centralized charging is limited by the optimization problem size, which grows when a particular area has many vehicles. Hierarchical-based control architectures, which separate EV loads according to their geographic location, are proposed to solve this problem. Each group has its local controller that manages the distribution of power to its individual EVs, while the central controller only handles group demands (Esmaili and Goldoust, 2015). Communication and computation requirements are improved when using the hierarchical control strategy. Centralized structures also allow various other control strategies, such as online control (Tang et al., 2014) and real-time pricing (De Hoog et al., 2014).

4.4.3. Decentralized control

The EV owners determine the charging schedule in a decentralized strategy known as charge control (Moeini-Aghtaie et al., 2013). This control method relies primarily on electricity price and user convenience to determine charge decisions (Ma et al., 2011). Decentralized control guarantees EV users will reach their charging targets when deciding their charging patterns. The overall system should be optimized at the global level. However, electric vehicle loads can be matched with grid requirements with the proper implementation of electricity tariff mechanisms and EV user responsibility as illustrated in Fig. 9.

4.4.4. A constant current and constant voltage charging system

The constant current (CC) and constant voltage (CV) passive charging schemes are based on pre-set instructions. A constant current must be maintained throughout CC charging. The charging current can be easily determined, even though it has a limited current to prevent overcurrent. In addition to nickel-cadmium batteries, the method is commonly used for charging lithium batteries. Despite this, the state of charge (SoC) estimation has a problem due to cumulative errors, which result in overcharging or undercharging, resulting in a diminished battery life cycle. As a result of the battery's self-discharging, CC charging is continuously applied to the battery at a shallow rate (0.01C-0.1C), called Trickle charging. Battery repairs and activations are commonly performed using this method. In the CV charging method, the charging current is controlled by the estimated SoC using a constant voltage power supply (Hussein and Batarseh, 2011; Suarez and Martinez, 2019; Fattal and Karami, 2015). The batteries may, however, be damaged by large currents during initial charging. With CC-CV, you can gain the benefits of both CC and CV methods while at the same time compensating for their drawbacks by optimizing the CC for initial and further CV changes. It is estimated that up to 85% of the CC-CV charging process for Li-ion batteries is carried out using CC charging. In addition to its many advantages, CC-CV charging is easy to design, implement, and operate since no knowledge of the battery model is needed (Wu et al., 2015; Liu et al., 2020). Despite its advantages, the CV process takes a significant amount of time, so it is unsuitable for fast charging; the battery polarization voltage increases as it ages, and the cells cannot be distinguished. Battery parameters like internal resistance and temperature are not taken into account. It may result in a reduction in efficiency. As described in Koleti et al. (2021), modern BMS have added CC-CV trickle charging. When the battery is deep discharged, trickle charging is activated in the first charging stage. In contrast, at the end of the charging process, the battery is charged until the charging current drops to a pre-determined threshold, thereby increasing the life cycle of Li-ion batteries very effectively. CV mode speeds up the charging process by 11 percent compared to CC mode, which is divided into five steps. CC mode, in particular, can cause a surge in temperature that results in a decrease in energy efficiency following pre-set charging. In (Shrivastava et al., 2019), a real-time charge control process is described based on SoC and SoH prediction. In the CC mode, a pre-accelerated charging method is used to reduce the charge time by using a high deaccelerating current before CC. However, temperature control is necessary for the safety and efficiency of the battery. CV mode is improved in Hu et al. (2018) with a variable current trajectory to increase charging efficiency by 7% by accelerating charging by 34%. It would be possible, however, to predict the charging current under CV mode by combining a real-time internal resistance measurement with a temperature-predicted close loop. Fig. 10 shows the waveform of voltage and current changes during charging.

4.4.5. Communication network for electric vehicle charging

A successful charging management system for electric vehicles depends on effective communication between EVs, EVSEs, and the grid (Markel et al., 2009; Gadh et al., 2015), as shown in Fig. 11. Various communications protocols are classified into wired and wireless technologies (Erol-Kantarci and Mouftah, 2014; Su et al., 2011). The use of electric vehicles (EVs) can be integrated into different private areas, including home area networks (HAN), industrial areas networks (IAN), building areas networks (BAN), and neighborhood areas networks (NAN), or field areas networks (FAN). Control and monitoring the charging/discharging of electric vehicles and other domestic electricity usage are handled through these networks. As discussed below.

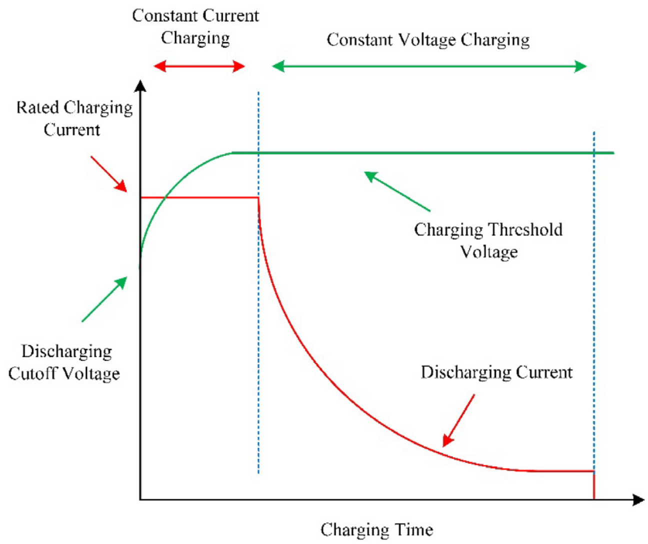


Fig. 10. Current and voltage changes during CC-CV charging.

- **Wireline Communication:** In large cities, EV charging stations are ideal for wireline technologies for long-distance data transfers. One of the most popular protocols in data communication in wireline technology is Power Line Communication (PLC). This technology uses the same power line for the transmission and reception of data. Due to its robustness and reliability (Ancillotti et al., 2013), it can be used in the event of interference. The PLC concept is used in several protocols, including Home Plug 1.0, Home Plug turbo, Home Plug AV, HD-PLC, and UPA (Galli et al., 2011). In wireline communication, optical and DSL protocols are also implemented. The significant advantage of optical communications is their significantly higher data rates (up to several Gbps) and transmission ranges (several kilometers) compared to PLC. Optical communication is also resilient against electromagnetic interference. As a result, data can be transmitted over a high voltage line using this technology. The DSL protocol can accomplish digital communication over a telephone line; therefore, there is no need to set up separate infrastructure.
- **Wireless Communication:** Providing data exchange between vehicles and charging stations requires wireless communication to complete the communication structure. EVs rely on this to provide information concerning their charging status. In wireless communication networks, electrical devices are connected using hierarchical mesh structures. The hierarchical mesh structure is made up of wireless LAN devices. Connecting an EV grid uses four popular wireless technologies: Zigbee, cellular, WIFI, and satellite networks.

4.5. Optimal location for electric vehicle charging stations

Electric vehicles can experience less range anxiety when their EVCS is in an optimal location (Luo et al., 2020; Xu et al., 2020). The location of a charging station is determined by several factors, including driver satisfaction with charging, operator concerns about economics, fleet losses from power outages, grid safety issues, and traffic problems in the transportation system (Kong et al., 2019). Research and developments regarding charging stations are summarized below in Table 6.

5. The integration of electric vehicles with the power grid

The transportation and electric power sectors have only recently become closely linked. Electric utilities have seen substantial disruptions because of the large-scale electrification of transport. As well as presenting significant challenges for the power grid, electric vehicles have also offered significant benefits.

Traditionally, the most critical part of charging an electric vehicle battery is the electric vehicle grid integration (EVGI). It might be possible for EVs to play a significant role in returning electricity to the grid and providing services such as harmonic reduction, reactive power supply, peak demand shaving, etc., in an intelligent energy management environment. The EVGI must be robust in technical and business operations to meet these goals. The community manages the distribution, generation, and control of electricity as part of the advancement of technology. Also included in the technical process are low-level management techniques that combine/coordinate electricity management and communications networks. Alternatively, Business Operations cover areas such as Power Generation (GENCO), Transmission (TSO), Distribution (DSO), Retailers (SA), also referred to as load-serving organizations and Customers who charge their electric vehicles at charging stations. A regulatory agency specializing in EV aggregation is needed to integrate EVs at a larger scale into the system. EV aggregators usually group EVs based on owner preferences to maximize commercial opportunities within the power industry. EVs alone contribute marginally and inefficiently to the industry, but the contribution can be enhanced if EVs and EV aggregators work together.

5.1. Electric vehicles and the grid: power interface modes

The power exchange interaction between EVs and grids can be uncoordinated or synchronized depending on EVs' charging technique. Many electric vehicles operate in uncoordinated charging modes regardless of the transmission's performance and utilization status, affecting quality and reliability significantly. The coordinated V2G mode is being developed to control many electric vehicles in the present control structure. There is no progress in developing an adaptive charging/discharging mechanism for EVs. Fig. 12 illustrates the electricity flow between the grid and PEV for uncoordinated charging and V2G (i.e., vehicle to grid) modes. In contrast, the electricity is transferred bidirectionally, i.e., from the grid to PEVs and vice versa. Tables 7 and 8 show

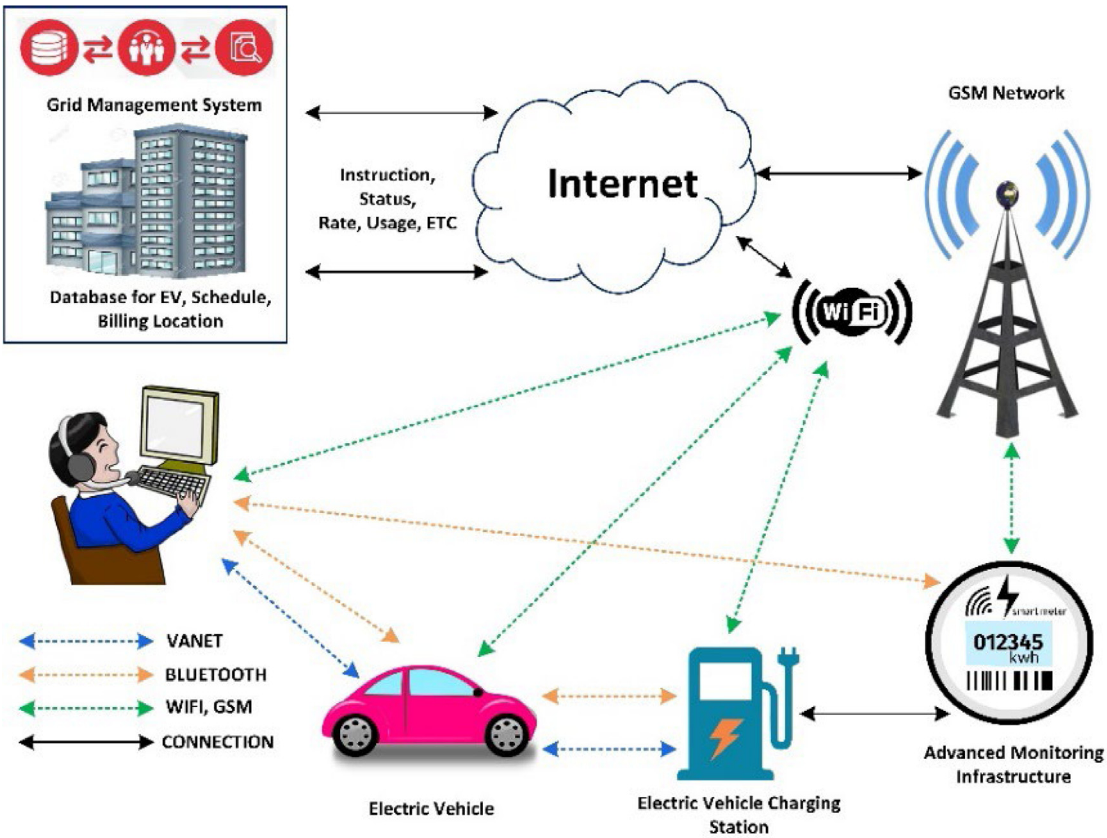


Fig. 11. Communication network for electric vehicle charging systems.

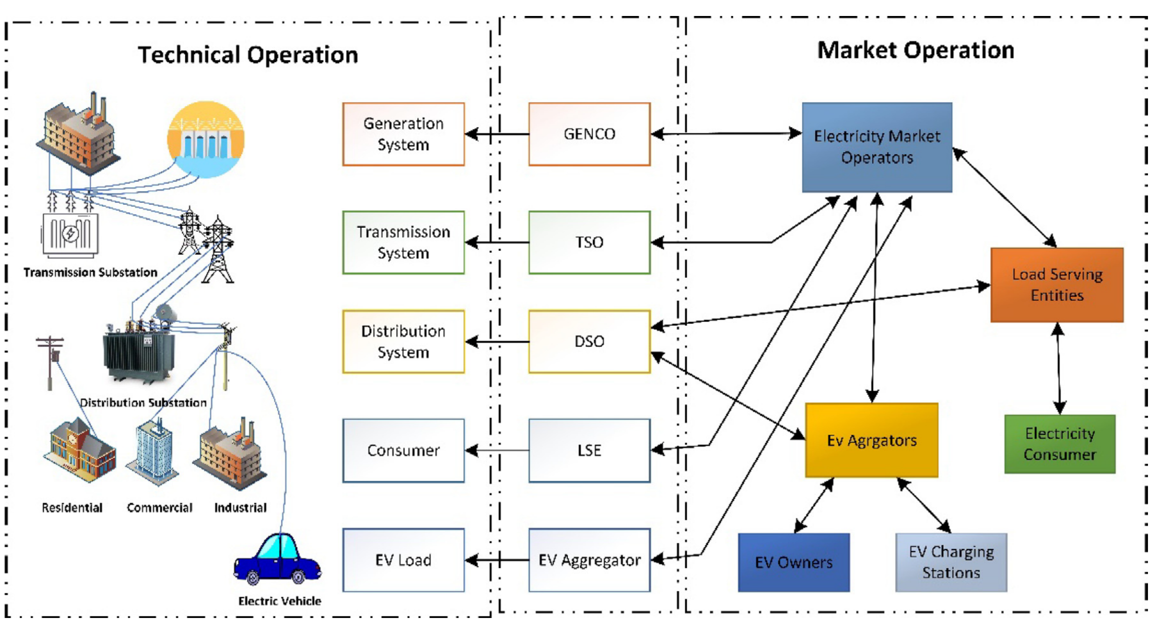


Fig. 12. Electric vehicle grid convergence system.

that the power flow orientation consists of three modes. The similarities and differences of each mode are listed.

5.2. Need for renewable energy sources

Carbon dioxide emissions come primarily from electricity production plants and the transportation industry. The health and environmental hazards have risen to a dangerous level. Renewable energy usage can mitigate global warming while promoting environmental protection. In addition, renewable energy sources are highly dependent on natural conditions for their generation. The major drawback of Green Energies is that they produce energy incoherently and unpredictably. Electric vehicles can solve the problems above by being integrated into the power grid. When renewable energy is generated inconsistently, powering an

Table 6
Summary of the work done in finding the optimal location for the charging station.

Reference no	Type of model	Type of charging station	Key points	Implications
Kadri et al. (2020)	This algorithm implements stochastic integer programming as a multistage stochastic algorithm using bender's decomposition and a genetic algorithm to solve problems.	Fast charging station	Identify the charging stations that should be opened at each interval to maximize the total recharging amount during the planning period.	1. The multistage stochastic programming model was found to offer many practical advantages over a deterministic model compared with simple deterministic models 2. The study devotes significant time and effort to stochastic and dynamic aspects of charging demand. 3. Numerical results suggest that both algorithms employed in this research outperform a standalone mathematical programming solver regarding computation time and solution quality.
Zhu et al. (2016)	A mathematical model and a Genetic Algorithm determine where charging stations should be located.	Plug-in charging station for electric vehicles	Study objectives include finding charging stations in the most efficient place, minimizing ownership costs, and reducing range anxiety among consumers.	1. Charge stations are located according to a model, and there are chargers at each station based on the model. 2. The model is also validated and illustrated by numerical results to demonstrate its expansion. 3. The proposed work has some limitations, including that it is only applicable during the weekdays or does not discuss what type of charging occurs at the charging stations.
Erdoğan et al. (2022)	EV fast-charging stations are located through an optimization-based approach, which prioritizes the deployment of stations according to the designated EV corridors.	Fast charging station	This research introduces two new objective functions based on the concept of corridor-utilizing and corridor-weighted traffic flow and a new constraint centered around the corridor building process.	1. Consider the benefits of creating a priority system between alternative solutions, whereby more charging stations along the corridor will be preferred over fewer stations. 2. A second scenario considered decisions made by decision-makers based solely on the location of charging stations on corridors.
Xi et al. (2013)	An optimization model based on simulation for locating a public charging station for electric vehicles	Public electric vehicle charging station	Simulation–optimization model is used in this study to identify where electric vehicle chargers should be located so that private electric vehicles can best use these chargers.	1. The location of slow chargers can be optimized to serve EVs efficiently. 2. EV owners' locations can be predicted, service rates can be simulated, and charger deployment optimized using an IP. 3. In this model, the central Ohio region is considered. Using level-one and level-two chargers together maximizes charging power. The cost-effectiveness of Level-one chargers is higher if only EVs need to use them under energy-maximization criteria, even if funds are insufficient.
Huang and Kockelman (2020)	With applications that include the cost of installing, operating, and maintaining equipment and land acquisition, genetic algorithms are being used to identify profitable station locations and designs.	Fast electric vehicle charging stations	Under elastic demand and price elasticity, this study examines the location problems associated with fast-charging stations under feedback from network congestion.	1. A complex location-and-sizing problem for fast-charging stations is addressed in this work design iteratively to maximize the profits of EVCS owners within a region. 2. Using the model, travelers can incorporate congested traveling and crowded charging feedback into their route selection. BEV owners can choose their charging stations based on elastic demand (for BEVs and non-BEVs) and charging price elasticity for BEV charging users. 3. The method provides specific station locations, cord counts, and cost details of charging stations (Level 3).

(*continued on next page*)

Table 6 (*continued*).

Reference no	Type of model	Type of charging station	Key points	Implications
Huang et al. (2016)	Optimizing public charging stations for fast and slow charging	Public charging station for both slow and fast charging	The project was primarily targeted at providing coverage and minimizing costs.	5. Canada has implemented two optimization models for fast and slow charging in public places. 6. Charged geometric objects represent demands as opposed to discrete points. 7. Polygon overlay methods solve partial coverage problems (PCP) in networked systems. 8. According to the results, the proposed models for locating charging stations are feasible and practical. This method provides more accurate results than complementary partial coverage (CP), eliminating PCP.

Table 7
Operation of power flows in three modes.

Functional mode	Power flow direction	A possible alternative
Process of charging that is uncontrolled	From grid to electric vehicle	Unregulated charging, dumb charging, and regular charging.
Unidirectional V2G	From grid to electric vehicle	Controlled charging, coordinated charging, and intelligent charging.
Bidirectional V2G	From grid to electric vehicle and vice versa	Coordinated charging and discharging, Controlled charging and discharging, Intelligent charging and discharging

Table 8
The differences between V2G power flows in unidirectional and bidirectional.

V2G power flow	Unidirectional	Bidirectional
A hardware-based infrastructure	A correspondence system	The charger of bi-directional batteries for communication systems
The level of power	Levels 1, 2&3	A level 1 and 2 are expected
Economy	Low	High
Facilities	Regulatory spinning reserve for the power grid	■ Provides active and reactive power support. ■ Enhance the reliability of the power grid by correcting the power factor. ■ The harmonic filter. ■ Regulating the frequency. ■ Control backup.
Various utilities	Reduce pollution by preventing overloading of the power grid	■ Power grid losses must be reduced. ■ Power grids should be protected from overloading. ■ Boost charging profile. ■ Make sure the voltage is maintained. ■ Intermittent renewable energy. ■ The failure recovery process. ■ Reducing pollution and maximizing benefits.

electric vehicle fleet provides a remedy for the inconsistent use of renewable energy. In the meantime, they serve as a source of energy to store excess electricity produced by renewable sources, preventing the source from being curtailed. The power system can be customized to take advantage of clean energy, EV energy storage, and connected grids. Electric vehicles are expected to boost the economy of the clean energy industry. In order to make EVs and the potential power grid more efficient and safer, it will be necessary to ensure adequate electricity storage between renewable energy resources and EVs.

5.3. The effects of electric vehicle integration on the grid

It is possible to classify the effects of electric vehicle integration on the grid into negative and positive aspects. In Fig. 13, these are outlined in more detail. Electric vehicles present significant challenges for power utilities. The excessive integration of electric vehicles into the distribution network affects the distribution grid's stability. This adverse effect is due to load profile changes, voltage and frequency imbalances, excessive harmonics injection, and power losses, as indicated in Table 9. Power quality degradation, peak loads, and power regulation issues can occur due to the excessive penetration of EVs into the grid. These problems can be solved using advanced power management techniques (Azadfar et al., 2015). In Table 10, the positive impacts of EV integration are summarized.

5.4. Agent role in EVGI

In Fig. 12, an agent is an independent program that can control its action based on its observations of the operating environment. Electric power agents should possess autonomy, intelligence, rationality, and the ability to learn and incorporate (Li, 2009). A non-regulated agent is an agent that operates in the wholesale energy market or the retail energy market, respectively, on the wholesale and retail markets. Others, such as TSOs and DSOs, are regulated agents. Although regulated agents operate in natural monopolies, incentive-based regulation is the basis of their regulation. In addition to these agents, EVGI may require other agents, including EV owners, EV suppliers-aggregators (EVSA), and charging point managers (CPM). In Table 11, all these agents are summarized by their roles.

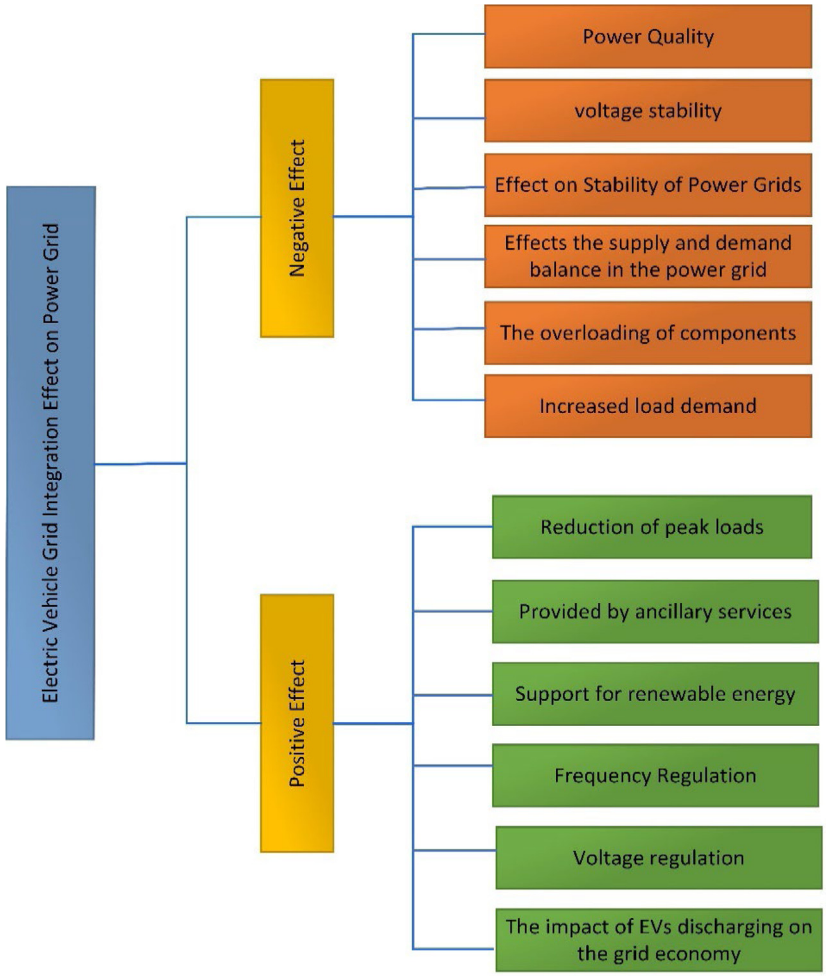


Fig. 13. Effects of electric vehicle grid integration on the power grid.

5.5. EV aggregators' role in EVGI

Using smart meters as an interface, EV aggregators act as a link between the grid and EVs, collecting the charge power demand and connection time from drivers and sending them to grid operators. Furthermore, EV aggregators provide information about charging stations and electricity prices to EV owners. In a market where multiple aggregators could coexist, an EV owner is better off selecting the aggregator that best fits his requirements. In collaboration with the DSO, the aggregators forecast the next day's energy demand and prepare their buy/sell prices. Analyzing and assessing the technical feasibility of demand forecasts is the responsibility of the DSO. An aggregator can proceed to market negotiations after receiving an acceptable forecast. In such a case, the DSO will require the aggregator to make the necessary changes to ensure its safety (Hui et al., 2013).

Furthermore, the aggregator must forecast the behavior and preferences of EV owners in addition to forecasting market prices. Time and distance of departure and arrival are the primary sources of uncertainty, as is preference (for example, when and how much to charge the battery). Electricity purchased by aggregators from the grid will be cheaper, plus they will be able to sell it during peak periods since they will take advantage of their clients' EV storage. When it comes to energy acquisition/sale, and as it pertains to GENCO, aggregators will compete directly with electricity retailers. As a result of this approach, EVs can also participate in secondary frequency control through the connection between the aggregators and TSOs. Aside from that, aggregators can also negotiate with other entities, such as parking services and battery suppliers (Sortomme and El-Sharkawi, 2010). Fig. 12 shows a market overview of EV aggregators.

5.6. EVGI challenges and suggestions

With the advent of smart grid technology, EVGI's current situation can improve further. It would be beneficial to study these issues further to implement a smart grid network that interacts between electric vehicles, electricity grids, and transportation networks.

- EVGI is only effective if there is an efficient operational mechanism. Despite current efforts, no success has been achieved in this area. Specific studies that develop EVGI mechanisms fail to consider EV mobility adequately.
- Electric vehicles are used as energy sources, transportation media, storage devices, and communication nodes on modern grids. In addition to interconnecting the electricity grid, traffic network, and communication network, they are also used to transport data. The earlier factors should be considered when designing a charging scheduling system for EVs.
- In the present system, off-peak charging is used for scheduling (Mullan et al., 2011; Kintner-Meyer et al., 2007). The grid-overloading problem can be solved by creating time- and power-variable customer charging rates (Level 2 or Level 3). To ensure the reliability and stability of the

Table 9
The negative effects of EV grid integration.

Effects	Summary
Effect on power quality	■ An electric grid's effects on a V2G network are assessed mainly by observing the nature of the power supply (Khalid et al., 2019; Durante et al., 2017). ■ The uncertainty associated with electric vehicle charging results in several problems, such as overvoltage in the grid, deterioration of power quality, increased line damage, and higher current faults (Godina et al., 2016). ■ Due to high-frequency converters, which convert AC power into DC power, for charging EVs, the grid is subject to harmonics, resulting in poor quality power (Karmaker et al., 2019). ■ Distribution transformers become overloaded due to harmonics, causing their life expectancy to decrease (Meyer et al., 2011).
Effect on voltage stability	■ The power system's instability is caused by nonlinear EV loads that draw large amounts of power over short periods (Dharmakeerthi et al., 2013). ■ Electric vehicles increase the likelihood of power system disruptions and make it take longer to return to a steady-state (Ul-Haq et al., 2015). ■ An adequately managed EVGI system can improve the grid's reliability (Ma et al., 2017).
Effect on stability of power grids	■ New EV loads must be added to the system, along with an evaluation of the IEEE 3 bus system with and without the use of charging stations. Before adding new EV loads to an electrical system that has been unstable, a stability analysis must be conducted (Onar and Khaligh, 2010). ■ The electric network is analyzed for small-signal stability. An electric vehicle is treated as a constant load and impedance (Das and Aliprantis, 2008). ■ EV modeled as constant power load was found unstable, so the intelligent control algorithm is used to control EV modeled as constant impedance load (Yan et al., 2010).
Effects on the supply and demand balance in the power grid	■ Harmonics are introduced into the grid system by EV charging stations. These harmonics are injected into the grid due to the power electronics converter. Hence, the charging architecture influences the variations in total harmonic distortion (Habib et al., 2015). ■ Harmonic distortion variability ranges from 7% to 99% for EV chargers (Mahalik et al., 2010). ■ Researchers found that EV penetration levels can be increased based on capacitor banks without causing voltage harmonic violations (McCarthy and Wolfs, 2010).
The overloading of components	■ The extra-large number of EVGI generates or transmits an additive load demand (Yong et al., 2015). ■ Some existing power system components are not designed to take on the additional loads, leading to overloaded components and shortened transformer lifespans (Yan and Kezunovic, 2012).
Increased load demand	■ A total of 1000 TWh of additional loads can be added (a 25% increase over current levels) (Bowermaster et al., 2017). ■ Charges during peak times increase due to uncontrolled EV charging, which significantly burdens utilities (Hadley and Tsvetkova, 2009).

Table 10
The positive effects of EV grid integration.

Effects	Summary
Reduction of peak loads	■ Using time-of-use (TOU) tariffs and coordinated charging strategies makes the grid more energy-efficient without adding more generating capacity (Kristoffersen et al., 2011). ■ Several bidirectional grid-connected EVs are used here as part of the industrial power grid. Battery management systems may provide limitations regarding the type and extent of usage-driven charge and discharge signals. The penetration of EVs into the grid system is adversely affected (Hofmann et al., 2015). ■ 96 percent of the peak demand on the power system can be reduced in practical circumstances. Whenever the electric vehicle battery has a large capacity, it will significantly benefit from reducing peak domestic and grid demand. Ultimately, this could lead to better use of the power system (Garwa and Niazi, 2019).
Provided by ancillary services	■ Services ancillary to power production ensure reliability, demand, supply, and grid stability (White and Zhang, 2011). ■ By using V2G technology, ancillary services can be provided, improving the electric grid's stability (Guille and Gross, 2009).
Support for renewable energy	■ Operating EVs as energy storage can reduce the uncertainty of renewable energy (Saber and Venayagamoorthy, 2010). ■ Using EVs as a renewable energy buffer reduces emissions, and money can be saved (Domínguez-Navarro et al., 2019).
Frequency regulation	■ Grid frequency deviation is corrected by frequency regulation (Garwa and Niazi, 2019). ■ Through V2G technology, the load can be balanced by regulating grid frequency (ur Rehman and Riaz, 2017). ■ EV integration can also help minimize frequency fluctuations caused by sudden changes in load when EVs are integrated with the grid (Tian et al., 2012).
Voltage regulation	■ Voltage regulation is fundamental to ensuring the supply and demand of reactive power are stable. Electric vehicles can react quickly to regulatory signals since they are autonomously controlled by the vehicle (Qiangqiang et al., 2012). ■ Electric vehicles autonomously process regulation signals, allowing them to react quickly to safety signals. EV charging is halted when the system voltage drops below a certain level and resumes when the system voltage reaches a certain level (Donadee and Ilić, 2012).

distribution system, it is best to use a coordinated smart charging system coupled with an aggregator.

- In the current state of wireless charging technology, it is designed only for G2V operations. Electrified vehicles fueled by wireless charging should be able to provide various grid services thanks to bidirectional WPT.

5.7. A challenge between ev owners, aggregators, and distributors

5.7.1. Ev owners

Costs are a significant challenge for owners of electric vehicles. Electric cars need to be able to hold massive amounts of charge and to do this, batteries require expensive materials, some of

Table 11
Agents and their roles in EVGI.

Title of the agent	Summary
CPM	EV charging and discharging stations are managed by charging point managers, who act as final customers.
EVSA/EV	Provides electricity to the owners of electric vehicles
Aggregator	Similar to other wholesale agents, they act in the same way
EV Owner	The EV load demand determines what ancillary services EVs can provide through V2G, and the EV provides the power to recharge the battery.
DSO	Assures a resilient and secure distribution network by taking care of the distribution grid. Maintain the whole system's stability and optimization, ensure a fair and economically viable distribution network, and facilitate a competitive energy market.
TSO	Manages the transmission system's operation security and the procurement of system services, including operational maintenance
LSE	It is the Supplier or Retailer Agent's responsibility to sell energy to end users and the DSO's responsibility to pay DSO fees associated with deregulation and other service charges.
GENCO	Assures profitable energy production and selling by bidding electricity prices into the electricity market.

which are hard to obtain, so they have to use expensive technology to produce them. Because electric cars are more expensive than comparable gasoline cars to manufacture, they are more costly to buy as well. They are thus less likely to be adopted by consumers (Liu et al., 2016). The problem with free-range chicken and organic eggs is that they are not free of chemicals. Economies of scale and ramping up production volumes could significantly reduce the cost of electric cars. Buying electric vehicles will require a significant price drop, which may not happen unless prices are brought down. The biggest challenge for electric car manufacturers is convincing consumers that they are worth the price. Some people are not convinced that electric cars are suitable for them. There is a range of anxiety problems here. There is a concern among electric car makers that people will lose their batteries before driving far in their electric cars. You can fill up your gasoline-powered vehicle at a gas station in about five minutes if you run out of gas; you pull into a gas station, fill up, and you are back on the road. It is not quite as simple as it seems to charge an electric car (Arias et al., 2020). There are only about 100 miles (160.9 kilometers) of range on the average electric vehicle when it hits the market. For example, unless you have access to a specialized charging station (currently in short supply), you will need to wait around eight hours for your battery to charge fully. Electric cars remain unsuitable for road trips, as most people drive less than 40 miles (64.4 kilometers) daily and can quickly set them overnight. Would not it be strange if you drove 80 miles (128.7 kilometers) in a day, came home, and then found out you had to go another 30 miles (483 kilometers) because of an emergency? It is difficult for electric cars to overcome a hurdle when consumers think of situations like that King and Datta (2018).

Another challenge is that charging stations can alleviate many consumer concerns about electric cars. There has been a significant change to the country's infrastructure with the introduction of electric vehicles. Several charging stations (including some at Best Buy that allow consumers to recharge while shopping) are out for trial, but most people charge at home in their garages. Consequently, people who live in shared housing or park on the street will have the most significant problem with the setting. Undoubtedly, more people would buy electric cars if the infrastructure and charging stations were improved. It will always take a considerable number of electrified vehicles to convince infrastructure to change (Pevec et al., 2020).

5.7.2. Aggregators

Aggregator agents are service providers who bridge the gap between plug-in electric vehicles (EVs) and system operators. System operators consider the aggregator a large generation or load source offering ancillary services such as spinning and regulating reserves. The uncoordinated charging of EVs may cause future problems for DSOs and TSOs. Moreover, residential load patterns can vary significantly from one day to another. TSOs and DSOs must utilize all available resources to deal with these problems. Clair et al. (2018) EV aggregators serve as mandatory partners for DSOs and TSOs providing technical services. The EV aggregator will act as an intermediary between operators, who will probably use market mechanisms to obtain necessary resources and consumers for EVs. Grid managers and other interested parties can take advantage of the flexible demand packages offered by this agent. EV users can use charging power modulation facilities to provide this flexible potential. In addition to offering its services to TSOs and DSOs for grid operations, the EV aggregator could be offered to other electricity partners to optimize their energy portfolio buying. Future TSOs and DSOs will likely have Demand Response aggregators to manage the variable loads from households, businesses and industries in their operation areas besides electric vehicle aggregators. Soares et al. (2018) The EV aggregator will be used with TSOs and DSOs to solve daily technical problems for moving this load. As a non-flexible load, this load will be considered, and it will interact with other aggregators to solve daily technical problems. By balancing this non-flexible load with the EV charging load, this EV aggregator will compensate for the non-flexible load. The aggregator modulates the charging curve for EVs based on network operating requirements to prevent exceeding the maximum available power for EV charging at any moment of the day (Peng et al., 2017).

5.7.3. Distributors

There are four fundamental challenges facing DSOs. First, there is the issue of aging assets. Developed economies such as western Europe, North America, and Japan are increasingly concerned about this issue. Additionally, decentralized power generation is challenging — from rooftop solar to significant wind and photovoltaic farms. As a result of thermal and voltage constraints on their networks, DSOs cannot connect as much new energy as they wish. Managing new demand is the third challenge. As a result, it needs to be reinforced to accommodate new generation resources. It is the charging of electric vehicles that is driving the electric vehicle industry (Hu et al., 2013). There are several charging points, from domestic AC chargers for a single vehicle (typically less than 3 kW) to high-speed DC charging up to 350 kW in public charging stations. The Nexans Asset Electrical has been specially designed to help DSOs take on these challenges by assisting them to strike a balance between performance, operating, and capital expenditures. Asset Electrical creates digital twins for your network. As part of this plan, you should include all the physical assets and your repair, renewal, and inspection strategies. It is easy to simulate different scenarios using this baseline. A unique asset-aging model even allows you to calculate the impact on different network assets. Getting the most out of your power network is more accessible with Asset Electrical, saving more than 10% of total expenditures and increasing your return on assets by over 20% (Li et al., 2013).

6. Policy and incentives

Zero tailpipe emissions will be produced when electric vehicles are combined with low carbon energy. Moreover, internal combustion engines emit significantly less greenhouse gas than alternative energy sources. These goals determine policies supporting the development and implementation of electric powertrains for transportation in many countries. 17 countries have committed to eliminating internal combustion engine vehicles or achieving zero-carbon emission standards for automotive vehicles by 2050. France became the first nation to legislate a deadline for this in December 2019 by setting a target date of 2040. Policy and incentive decisions regarding electric vehicles are heavily influenced by the current state of the electric vehicle industry. For electric vehicles to be adopted more quickly, the requirements for EVs and chargers must be implemented early. Public demonstration of the technology on government vehicles and public transportation is the best way to increase adoption, enabling businesses and organizations to lead by example. Most government policies and incentives revolve around tax exemptions and credits, unit cost reductions, and access to hotspots for parking. Regulations and financial incentives are likely to accelerate the adoption of electric vehicles, setting definite goals and objectives for the industry. In response to many of these regulations, many manufacturers are required to make hybrid cars and cars with higher fuel efficiency. The CO_2 standards of the European Union or the mandate for zero-emission vehicles in the United States and some provinces of Canada come to mind. In response to new EU emission regulations, vehicles must emit 95 grams of CO_2 per kilometer, increasing sales of hybrid vehicles throughout Europe. The Chinese government has announced a new credit policy with targets for 2021–2023. Because of the Safer Affordable Fuel-Efficient (SAFE) law implemented in March 2020, fuel efficiency requirements have been reduced from 4.7% in 2012 to 1.5% in 2021. Governments worldwide are taking initiatives and introducing policies to promote EV adoption faster and easier. These international policies are outlined below:

- **Exceptions to access restrictions to urban areas.** Some cities worldwide do not allow high-polluting vehicles, like those in Europe. Electric vehicles are exempt from these laws. The odd–even road access strategy is also not applicable to them since they have access to 100% of the roads.
- **Access to public parking spaces and parking reservations.** Incentives such as reserved parking spaces and public charging stations, typically enacted at the local or municipal level, are best enforced at the local or regional level (possibly through public incentives and regulations).
- **Lanes and tracks for buses and high-occupancy vehicles (HOVs).** Electric vehicles appear to be more valuable in the short term (because they have more uses), but adopting measures to promote their use over internal combustion engines (ICEs) on the road network can also impact their long-term finances. With a travel ban for polluting vehicles on the horizon, electric vehicles would be significantly more appealing on the secondary market than their competitors today (McKenzie, 2016).

6.1. Electric vehicle market structure

During 2022–2030, the total number of electric vehicles is expected to grow from 8151 thousand units to 39,208 thousand units, at a compound annual growth rate of 21.7%. Government subsidies & tax rebates have encouraged manufacturers to develop long-range, zero-emission vehicles worldwide due to the growing demand for low-emission commuting. As a result, electric vehicles have become more popular. Emission reduction targets have been set in countries worldwide based on their capacity to reduce emissions. OEMs will be able to expand their revenue stream and geographical presence as governments expand their investments in EV charging stations and hydrogen fueling stations around the globe. Due to the high demand for low-cost and low-emission vehicles, the Asia Pacific EV market is expected to grow steadily. In contrast, the North American and European markets are experiencing rapid growth due to government initiatives and growing high-performance passenger vehicle segments. The global market for electric vehicles is expected to grow at a modest pace due to relatively few electric vehicle charging stations and hydrogen fuel stations. High initial investment costs and performance constraints could also hinder this growth (Springel, 2021). EV charging business was moderately affected by pandemic lockdowns during early 2020. In 2021, due to government incentives worldwide, the demand for EV chargers increased during the pandemic. The COVID-19 pandemic, however, had adversely affected the extraction of materials such as steel, copper, and aluminum. In May 2021, copper's price hit USD 10,000 per ton for the first time in 10 years as raw materials rose. Meanwhile, top EV manufacturers have seen their sales overgrow over the past two years. Because of declining sales, Tesla laid off employees in October 2020. Due to earlier expansions to China, however, the company's overall revenue increased. Aside from COVID-19, the company performed well in 2021. Due to a Chinese lockdown in early 2022, its sales again declined. This EV market was less affected by the pandemic because governments worldwide have been pushing to phase out ICE vehicles (Li, 2019).

6.1.1. Electric vehicle market dynamics

Electric Vehicle Market Dynamics

6.1.2. Supporting cost-effective evs by reducing the cost of ev batteries

Due to technological advancements and the production of large volumes of EV batteries, the cost of EV batteries has decreased in the last decade. The EV batteries are one of the most expensive components of an electric vehicle, so this has reduced their cost. Electric vehicle batteries were priced at around USD 1100 per kWh in 2010. In 2021, however, the price fell to as low as USD 120 per kWh, reaching approximately USD 137 per kWh by 2020. China can purchase batteries for as little as USD 100 per kWh. Because manufacturing costs are reducing, cathode materials are becoming more affordable, and production is increasing, these batteries are less expensive to manufacture. Electric vehicles are expected to be cheaper than conventional ICE vehicles by 2030 as battery prices decline to approximately USD 60 per kWh (Li et al., 2018a).

6.1.3. Lack of EV charging infrastructure

In various countries, EV charging stations are few and far between. Due to this, there are fewer public chargers for electric vehicles, which reduces adoption. Although EV charging infrastructure is being installed in numerous countries, most countries have not been able to install the required amount of EV charging stations except in some states. As EV charging networks are developed worldwide, the demand for EVs is expected to increase. Such charging networks have not yet been developed in most countries. There are more EV chargers per 100 kilometers in the Netherlands than anywhere else. There are around 19–20 charging stations per 100 kilometers in the Netherlands, the world's highest density of charging stations. China is the second-best country with three to four charging stations per 100 kilometers. With its 2030 plans to phase out ICE vehicle sales, the UK will have approximately three charging points per 100 kilometers by 2030. In addition to Germany, UAE, Japan, Singapore, South Korea, Sweden, France, the US, and Russia, many charging stations have been set up to facilitate the shift to electric vehicles (Zhang et al., 2018).

6.1.4. Passenger cars are forecast to be the largest segment in the forecast period

The Asia Pacific accounts for the largest market for electric passenger vehicles, followed by Europe and North America. Asia's leading electric vehicle markets are China, Japan, and South Korea. In these countries, electric passenger vehicles are strongly supported by the government. The European countries with a growing demand for EV passenger vehicles are Germany, France, Netherlands, Norway, Sweden, the UK, etc. These countries have offered several subsidies, grants, and incentives to encourage people to switch to electric vehicles. Due to these measures, the increased demand for mini-EVs in China led Europe's EV sales to surpass China's in 2020; Europe sold more in 2021. US and Canadian states are also leading the electrification trend in North America. The MEA countries have accelerated the development of their EV markets and are expected to be the fastest growing markets soon (Yang et al., 2018).

6.1.5. By 2030, asia pacific will dominate the market

Electric vehicle sales are dominated by countries in the Asia Pacific region, such as China, Japan, and South Korea. Due to its EV production and use dominance, China dominates the EV market in the region. Their government has taken several steps, such as subsidies for EV buyers, compulsory laws requiring all car manufacturers to produce electric vehicles based on the number of cars they manufacture, extensive support for installing charging stations across major cities, and regulations against excessively polluting vehicles. In addition to Japan and South Korea, the EV market has grown in those countries (Shen et al., 2019). The governments in these countries have helped grow the EV market by installing charging stations, establishing emission standards, and setting deadlines for drivers to switch from ICE cars to full or hybrid EVs. India also makes efforts to increase the demand for EVs on the market. The country will become the region's fastest-growing EV market in the coming years due to the new scrappage policy that allows old vehicles to be scrapped to make way for low-emission ones. In addition to Thailand, Indonesia, Malaysia, and Vietnam, these countries are also implementing policies to reduce emissions from their vehicles and switch to electric vehicles (Ehrenberger et al., 2019).

6.1.6. The key players in the market

There are some established players in the electric vehicle market, including Tesla (US), Volkswagen AG (Germany), SAIC Motors (China), BYD (China), and Stellantis (Netherlands). EV sales are considered along with a certain percentage of segmental revenue for each company listed above in determining the EV market ranking. In addition to products and solutions for the automotive industry, these companies also offer extensive services and solutions. These companies invest heavily in R&D to develop new products and have strong distribution networks worldwide (Feng and Magee, 2020).

6.2. Electric vehicle developments and pilot projects

- A preview of MG Motors' newly-unveiled electric vehicle, the MG 4, was shown in February 2022. The car is expected to launch later in 2022 in India. The EV will have a battery pack that has a capacity of 61.1 kWh and should be able to run for around 400 kilometers.
- Skoda Enayaq iV would be the basis for Volkswagen's ID.5 model that will be announced in January 2022. The vehicle is expected to have around 300 miles per charge range.
- BYD launched its second-generation e6 electric vehicle in India in December 2021. By February 2022, deliveries of this model had begun. The range of this MPV is around 250+ miles per charge, thanks to its 71.7 kWh battery pack.
- BMW's new electric sedan, the i4, was introduced in November 2021. It has an estimated range of 300–367 miles. It takes four seconds for the vehicle to reach 100 kilometers per hour. The vehicle is equipped with an automatic transmission and connected vehicle features.
- The Opel/Vauxhall Mokka EV, a subsidiary of Stellantis, was launched in June 2021 with a maximum driving range of 209 miles and a battery capacity of 50 kWh. Besides being FWD, the car has connected vehicle capabilities.
- Chongqing, China, is where BYD will launch four new electric vehicle models equipped with Blade batteries in April 2021. E2 2021 and Tang EVs have advanced battery safety features, as do Qin Plus EV, Song Plus EV and Song Plus EV.
- A seven-seater EV produced alongside FAW and SAIC in China was revealed in April 2021 by Volkswagen. Currently, the vehicles are only available in China. 58 kWh and 77 kWh of battery capacity are available, along with four powertrain options.
- A new Volvo C40 Recharge model was introduced in March 2021. In addition to being a pure electric vehicle, it has many features in its XC60 counterpart.
- The Nissan Leaf model will be available in the United States starting in December 2021. Batteries ranging from 40 kWh to 62 kWh are available for the vehicle. Per charge, the battery can travel between 149 and 226 miles.

7. Challenges and future trends

7.1. Challenges

Electric vehicles have been considered a trend and the future of transportation because of their ability to overcome all current challenges regarding conventional sources, such as depletion of fossil fuels, increase in greenhouse gas emissions, and global warming. Despite this, it has been seen that EV adoption presents some disadvantages, including penetration into existing networks that increase the load, resulting in more blackouts and losses through overloading, the battery service capacity, range anxiety, and the overall high cost of EVs when compared to internal combustion engines. Several factors contribute to the impediment to widespread adoption of EVs, and these factors should be considered. As a result of the issues mentioned above, government and private organizations have been forced to help with the widespread adoption of EVs. The costs of EVs remain higher than those of internal combustion engines due to the charging infrastructure and the battery installation within the car. Lithium-ion batteries, for example, have a minimal life cycle and poor energy density.

Consequently, the battery must be changed frequently because of its limited life cycle, increasing the vehicle's cost. The new materials we will be using will make batteries last longer and perform better, considering the improvements in research. Conversely, EVs cannot be considered pollution-free. The electricity generation unit determines the pollution level caused by EVs. Accordingly, EVs emit the same level of greenhouse gas as internal combustion engines if most of the electricity is generated by coal and gasoline. EV penetration increases due to more energy required, putting more strain on the power plant and causing more pollution instead of reducing it. For the environment to become cleaner and more efficient, it is necessary to integrate renewable energies like solar and wind with the help of an intelligent grid. EVs must have an RCS, which is not widely available today, to function as next-generation transportation. Alternative fueling stations are available through RCS. Reduced charging time and range anxiety are the two main benefits of RCS.

As a result of the lack of RCS, user waiting times have been a problem, while improvements should be made to the future research process. V2G technology has not yet been implemented frequently in practice. In addition, the government should formulate a policy to encourage the use of V2G technology to make the grid stable and serve as a secondary source of income for a user. In contrast, V2G technology requires more investment as bidirectional meters must be installed, and the grid network must be upgraded. There is also an energy loss with frequent charging and discharging during energy conversion. Also, consumer emotions such as joy and pleasure play a vital role in accepting EVs. It has always been difficult shifting to new technology because it is a bit difficult. Due to this difficulty, the EV owner cannot access the proper system for ease of use.

7.2. Discussion on future development for EVGI

With the advent of energy internet technology, EVGI development can be enhanced even further. To establish an energy internet connected to EVs, grids, energy networks, and transportation networks, it is necessary to explore the following issues.

- At the moment, a prototype of the dynamic WPT system is being developed. A bidirectional power flow is yet to be developed to enable dynamic charging.
- It would be beneficial to focus future research on developing a bidirectional dynamic WPT system.
- In order to implement connected mobility, VANET technology needs to be expanded. VANET's capacity could include the power grid, the traffic network, and electric vehicles. This will improve the EVGI experience.
- In the L2 phase of autonomous EV development, they can be accelerated to reach the L5 phase. Under EVGI, fully autonomous EVs can significantly benefit transportation networks and power grids.
- The shared economy concept can fully realize the benefits of autonomous electric vehicles and electric grids. A well-designed business model can benefit EV owners, users, and utility companies.
- A vital aspect of the future grid is integrating power, transportation, energy, and communications networks using electric vehicles. In order to create a fully functional energy network, there needs to be plenty of development across each sector.

7.3. Future trends

The following future research trends have been identified in light of the above discussion. Due to technological advancements, existing grids are being transformed into smart grids, securely storing and analyzing data to boost the system's efficiency. As a result of smart grids, EV customers will use the bidirectional power flow to reduce their capital investment and create a second income source from the V2G technology. In addition to helping EV users, this V2G technology also helps service providers maintain the scalability of the network, making it more reliable, reducing blackouts, system degradation, and losses related to overload. Range anxiety must be addressed by increasing battery capacity or RCS penetration in the existing grid for better EV adoption. It is possible to switch to lithium-sulfur batteries since they have higher capacity and longer life. A sulfur-based battery can be easily manufactured due to the availability of sulfur. With its integration into smart grid implementation and its optimal seat position, RCS will significantly reduce range anxiety for EV drivers and make EV charging more convenient for users. It will be convenient for them to charge their vehicles without waiting in a long line or traveling a long distance. We will need to study how to reduce service provider costs while providing convenience for electric vehicle owners in the future. The current grid may not be able to meet the load with an increase in EV penetration if there is an increased cost focus. Upgrades and stabilization of the grid are essential. It will be necessary to discuss the integration of DG systems because they can reduce the environmental effects of coal- and gasoline-fired power plants and be easily installed. There is more to future scenarios than connecting two goals; they are about connecting all goals in a way that facilitates each other. Despite running the entire network simultaneously, a smart grid does not compromise any of them.

8. Major findings

A study analyzing recent EV developments and charging infrastructure challenges is presented in this work. Detailed findings from the study are presented below. Optimal charging scheduling techniques can take advantage of EVs' flexibility as a load while minimizing solar and wind systems' impact on the grid. Current research indicates that using metaheuristic techniques coupled with optimization software can significantly affect the efficient use of available resources. EV charging infrastructure can be planned and managed using these tools, including locating the optimal location for charging stations and determining the optimal charging station location. EV owners are reassured by mobile charging stations that they will have access to a charging facility if they cannot find an adjacent charger as part of planning infrastructure for EV charging. Using V2G technology, energy can be bi-directionally exchanged, and ancillary services are provided to the grid. Charging infrastructure available with minimal charging times is critical for adopting EVs. In order to minimize the impact on the primary power grid, battery swap stations regulated the charging schedule of EV battery packs.

Furthermore, it can serve as a backup unit and provide power for the primary grid in peak demand periods. As EVs and their charging infrastructure are developed, and renewable energy sources are utilized, harmful emissions can be drastically reduced in the transportation sector. Unfortunately, any damage to the environment this new infrastructure might cause has not been assessed. In future electric vehicles, hydrogen energy and fuel cells will replace the batteries currently used in battery energy storage systems.

9. Conclusion

The popularity of electric vehicles is expected to grow significantly in the next decade due to technological progress, charging infrastructure, and grid integration. Furthermore, further technical improvements such as intelligent charging infrastructure, reliable communication systems, and coordinated charging systems are essential for EVs with distributed generators to achieve the maximum benefits. A future grid technology based on the Energy Internet can enable the electrical grid to become fully automated with advanced energy management systems. A discussion of EV charging and grid integration infrastructure is presented in this paper. EVs and their charging infrastructure must have unified norms and standards worldwide to gain popularity in the market. Future researchers will be given a clear picture of the specification requirements for EV charging and grid integration based on our discussion of the most prominent standards. In addition, different aspects of the existing charging and grid integration infrastructure are examined rigorously in terms of their advantages and disadvantages, including power, communication, control, and coordination. Besides suggestions for future research, this paper also includes perspectives on overcoming current challenges. It is evident from the discussion of the prospects of EVs that a review of this area is necessary. With this review, researchers and engineers will clearly understand the current state of EV charging and grid integration research.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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