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Review

Optimizing Electric Vehicle Operations for a Smart Environment: A Comprehensive Review

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Abstract: The transportation sector is one of the main contributors to the emission of greenhouse gases globally, and the electrification of this sector can significantly reduce the emission of pollutants. The widespread connection of electric vehicles (EVs) to the power grid may bring challenges, such as increasing the peak load of the network. Therefore, the optimal use of EVs is necessary to improve the network's economic, security, and stability indicators. This review article examines the deterministic control model and centralized control model, the types of EV models, and their tabular comparison. Additionally, expressing the communication standards to deal with compatibility challenges in charging stations, the effects of EV integration with the power grid, and various methods such as smart charging, dumb charging, and flexible charging are the main goals of this review article. In addition, since batteries play a crucial role in the electric vehicle industry, this research investigates the oldest type of rechargeable battery to the latest battery technology and the energy management system of these batteries. Finally, the authors have conducted studies on government incentives, the adverse effects of these incentives, and the combination of EVs with renewable energy sources.

Keywords: electric vehicles (EVs); battery technology; plug-in hybrid electric vehicle (PHEV); charging stations; charging controllers

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1. Introduction

In general, carbon causes severe damage to the ecological system and causes its destruction over time. According to studies, a quarter of the total carbon emitted comes from vehicles [1–3]. Today, in the countries of the world, the energy industry plays a vital role in the economic stability of each country and is considered an effective factor for the protection of environmental factors. Electric vehicles (EVs), due to the replacement of gasoline internal combustion engines with electric motors, play an effective role in the optimal use of electric energy. Although the development of EVs and their widespread use in the field of transportation in the coming years will lead to a reduction in adverse effects on the environment, charging EVs is one of the main problems facing the electricity industry [4]. Therefore, there will be a need to develop EV charging infrastructure as well as charge and discharge control. Additionally, from the point of view of power systems, EVs can be considered as producers or consumers, depending on the operational mode of charging or discharging. In addition, EVs, based on existing control strategies, may create challenges or opportunities for the smart grid. In smart grids, accessibility and accuracy are systematically important, and confidentiality is less of a priority [5].

In general, they may have negative effects such as overload, unauthorized overloading of the transformer, line losses, and voltage imbalance on the network [6,7]. The authors, in reference [8], concluded that EVs as controllable loads lead to increased system efficiency and demand side management (DSM). Additionally, in reference [9], the authors conduct studies on EVs providing ancillary services, such as regulation and storage services. This is especially important for electrical energy systems in the presence of a high share of intermittent renewable energy sources, where system inertia is a crucial issue. Additionally, in reference [10], the authors have studied the integrated operation of EVs and renewable energy production in an intelligent distribution system. Authors in two references [11,12] discussed the objectives and types of EV charge and discharge management methods. Reference [13] examines the benefits of integrating EVs with the power grid. In [14], a one-day optimization framework for sustainable energy supply is proposed for an electric vehicle charging park and a hydrogen refueling station equipped with the power to provide hydrogen conversion facilities in a local multi-energy system. Additionally, in [15], the authors provide an instrumental description of the flexibility services at the distribution level that will be able to be supplied by EVs and their requirements. In [16], a comprehensive framework is proposed for the planning and development of mobile energy hubs based on the optimization of life cycle cost, access distance, and parking duration, considering the temporal variation in EV recharging demands. In [17], the authors focused on the issues that exist for the deployment of charging infrastructure. In another research work, the authors demonstrate that machine-learning-based classifiers can show insights about consumer behavior in 72 identified languages, including Chinese [18]. Finally, in reference [2], Kamran et al. investigate the connection of the Vehicle to the Grid (V2G), and the connection of the Grid to the Vehicle (G2V), and discuss different types of charging systems such as induction charging. According to the definition, V2G is a new concept that, as an energy storage technology, can bi-directionally enable the flow of electricity between the EV battery and the power grid [19].

Figure 1 represents a schematic diagram for the smart charging of V2G in the power grid. Additionally, companies support V2G due to increased reliability, power grid flexibility, and energy storage. In addition, EV owners will be able to earn money when EVs are parked, and, in general, this will be able to provide valuable economic incentives to EV owners. To participate in energy markets, the V2G capabilities of many EVs are combined by aggregators and then offered to appropriate markets. Figure 2 shows an example of aggregating EVs.

The rest of this review article is organized into the following sections: In Section 2, this article studies EV types, charging levels, the impact of connecting EVs to the power grid, and communication standards of EVs. Additionally, in Section 3, the charging methods of EVs have been reviewed. Section 4 focuses on examining EVs' centralized and decentralized control methods. In Section 5, the authors reviewed studies on six battery models related to EVs and compared their specifications. In Section 6, energy management related to EV batteries is reviewed. Then, the development of charging infrastructure for EVs and government incentives for people to use EVs are discussed in Section 7. Additionally, in Section 8, the authors investigate the importance of integrating EVs with renewable energy sources. In Section 9, the authors focus on system operation and optimization. Finally, Section 10 of this article is dedicated to the conclusion.

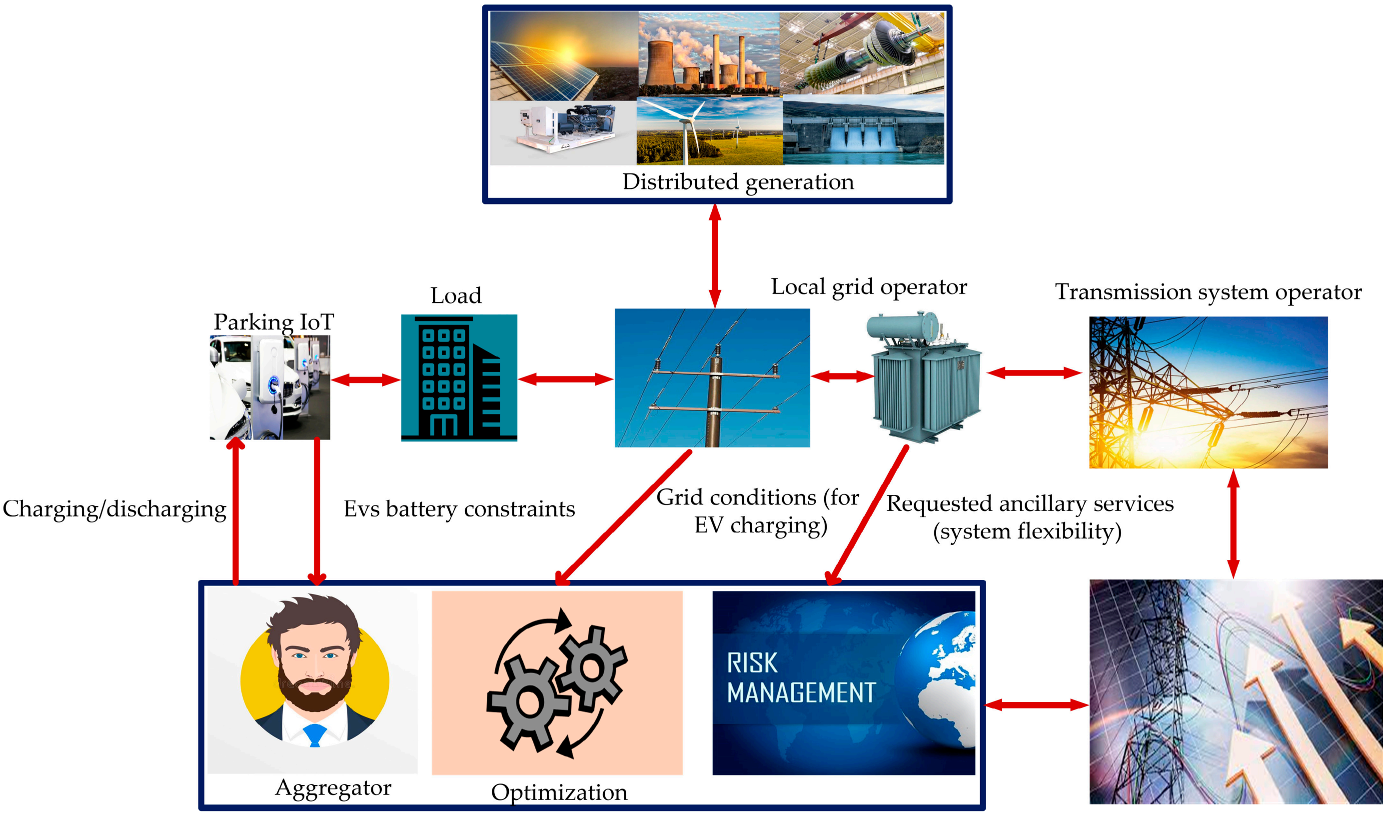


Figure 1. An example of V2G smart charging in electric energy system.

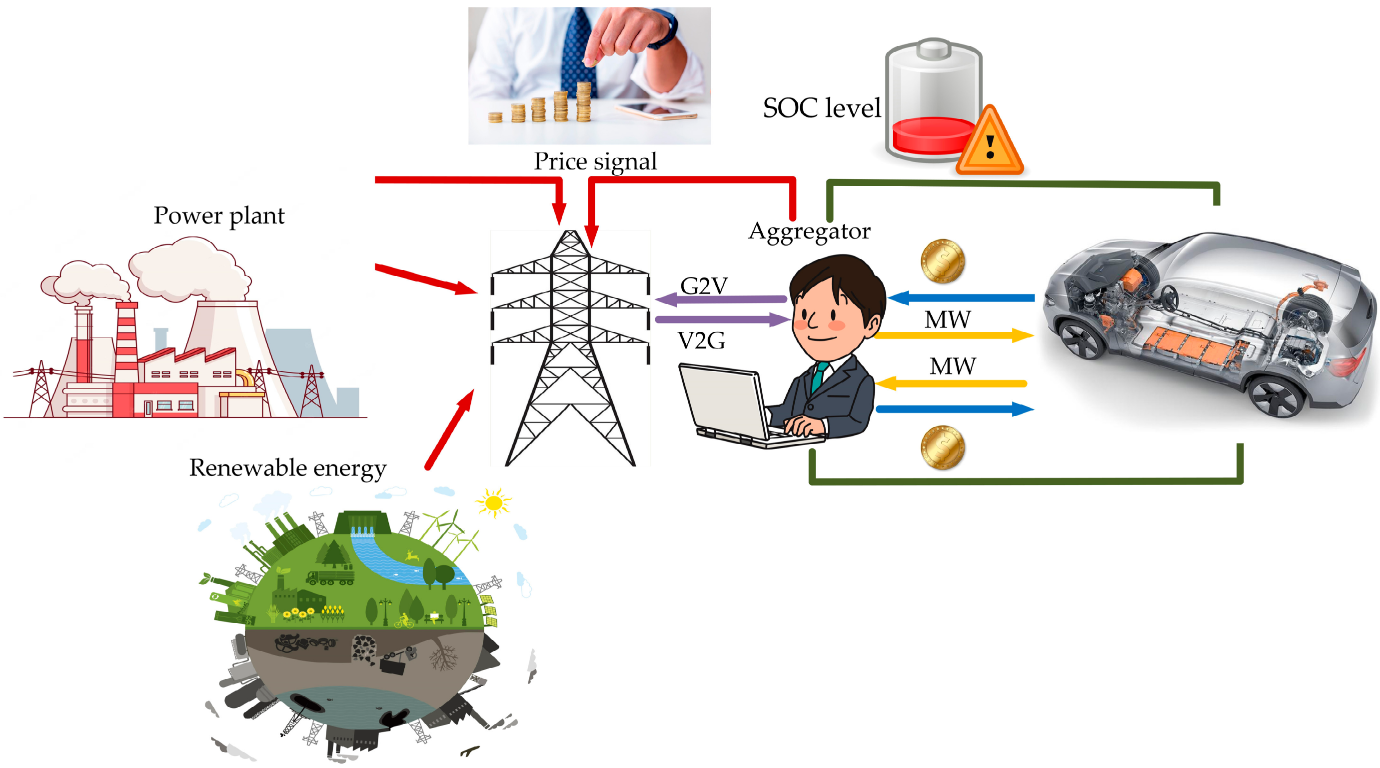


Figure 2. Examining the role of EV aggregators in smart charging.

2. Background

According to the studies, at the beginning of the 20th century, competitive cars in the market were divided into the following three categories:

- Steam engines;
- Internal combustion engines;
- EVs.

EVs are generally more reliable than competitors and superior to steam and internal combustion engines due to fewer emissions. Electric motors power EVs. Electric motors are more efficient due to their high efficiency in converting electrical energy into mechanical energy and low environmental pollution [20]. Increased efficiency in electric motors will cause low energy losses and thus save fuel and energy.

Both steam engines and internal combustion engines have lower efficiency than electric engines. In them, a meager percentage of the energy the fuel produces is converted into mechanical energy. Therefore, energy losses will be high. Additionally, using fossil fuels and exhaust gas causes environmental pollution. Since electric engines do not emit gas and do not need to change oil, they cause much less pollution and are easier to maintain than the two types of cars mentioned above. They are quiet and low-vibration so that passengers can enjoy more comfort. Clean and renewable energy can charge electric EVs, which is impossible for EVs with a steam engine or an internal combustion engine. In addition to all the advantages of EVs, they have disadvantages such as short range and unavailability of charging stations. Therefore, cars with cheap internal combustion engines replaced EVs. In the 1970s and 1980s, EVs received attention again after the emergence of the energy crisis. Still, this interest did not lead to mass production and creating a competitive market. Finally, since 2008, due to the development of EV battery technology, the increase in air-related diseases and deaths, and concerns about the price of oil and the reduction in greenhouse gases, there has been a fundamental revolution in the production of EVs. If only plug-in EVs (PEVs) are considered, EVs can be divided into the following two categories:

- Battery EVs (BEV);
- Plug-in hybrid electric vehicle (PHEV).

Many automobile companies in the world are focused on the mass production of EVs. The ever-increasing increase in EVs and the popularity of use of these zero-carbon cars have caused automobile companies all over the world to face tight competition and each of them unveil their plans to design and produce better cars with more navigation power. In Table 1, specifications such as nominal capacity, maximum charge rate, and mileage range related to some commercial vehicles are mentioned [21].

EV manufacturing companies have generally installed three types of charging stations in the city:

- Level 1;
- Level 2;
- DC fast charging.

Charging EVs and PHEVs at level 1 is achieved using a power outlet with three plugs. Level 1 charging is also known as trickle charging because it can provide 3 to 5 miles of range per hour of EV and PHEV connectivity. At charging level 2, EV users will be able to charge EVs much faster than charging at level 1. Finally, charging level 3 is the best and fastest way to charge EV batteries; based on charging level 3, it will be possible to charge EV batteries from zero to eighty percent within a short time of 20 to 30 min. The stations that offer this service have large charging devices with a unique plug that are not available in all charging stations.

In addition, it is essential to mention that they are different in voltage and current ratings. Finally, DC fast charging provides high DC to the vehicle. In Table 2, the specifications of each charging level are reviewed [22–24].

Table 1. Specifications of some commercial EVs.

EV Model	Type	Capacity	Charging Rate	Range	Cost	Production	Body Style
Nissan Leaf	BEV	30 KWh	6.5 KW	107 miles	$29,000	2010–present	5-door hatchback
Tesla Model S	BEV	100 KWh	10 KW	316 miles	$71,000	2012–present	5-door sedan liftback
Chevrolet Bolt	BEV	60 KWh	7.5 KW	238 miles	$37,000	October 2016–August 2021	5-door hatchback
Toyota Prius	PHEV	10 KWh	3.4 KW	26 miles	$29,000	December 1997–present	4-door sedan (1997–2003) and 5-door liftback (2003–present)
Ford Fashion Energy	PHEV	8 KWh	3.4 KW	19 miles	$34,000	2008–2020	4-door sedan

Table 2. Specifications of three different charging levels of EVs.

Specification	Level 1	Level 2	DC Fast Charging
Charging power	1.44 kW–1.9 kW	3.1 kW–19.2 kW	120 kW–240 kW
AC or DC type of EV charging	AC	AC	DC
The amount of AC supply voltage	Single phase and 120/230 V	Split phase and 208/240 V	Single phase and 300/600 V
Current rate	12 to 17 A	15 to 82 A	420 A
Charge location	Residential	Private and commercial	Commercial
Unit cost range per (single port)	$300–$1500	$400–$500	$10,000–$40,000
Battery capacity	15–50 kW	15–50 kW	15–50 kW
Charging time	10–15 h	3.5–8 h	10–30 min
Charge model	On-board and slow-charging model	On-board and semi-fast charging model	Off-board and fast-charging model

2.1. Communication System

The development of an interface between the power grid and EVs in order to transfer information and choose the charging mode will create a complex communication structure [25]. Establishing integrated communication is a prerequisite for modeling EV charging stations [26]; therefore, communication technologies and specific standards have been devised to deal with compatibility challenges in EV charging stations, which manufacturing companies must follow [26]. In general, the standards set for V2G technology include the plugin, communication, and safety standards related to charging stations and methods. In V2G technology, all available data and power flows between EVs and the power grid are through two-way communication.

In Figure 3, communication and safety standards related to V2G technology are shown [27–29].

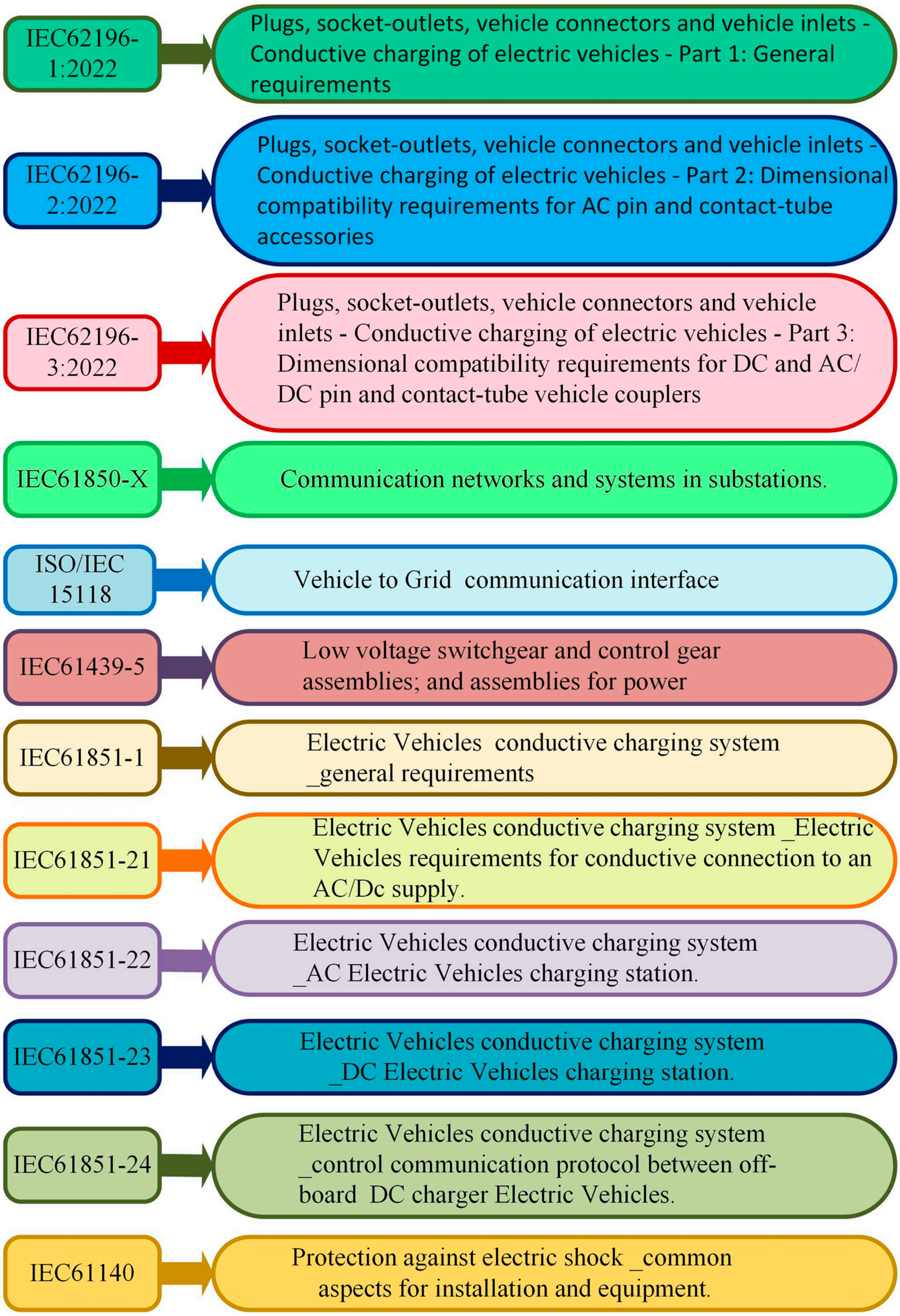


Figure 3. Communication and safety standards related to V2G technology [30–41].

2.2. Investigating the Effects of EV Integration with the Grid

Overall, the information in this section is very important to see the effects of EV integration in the grid. According to Figure 4, this section briefly discusses the advantages and disadvantages of EV integration with the grid [29,42].

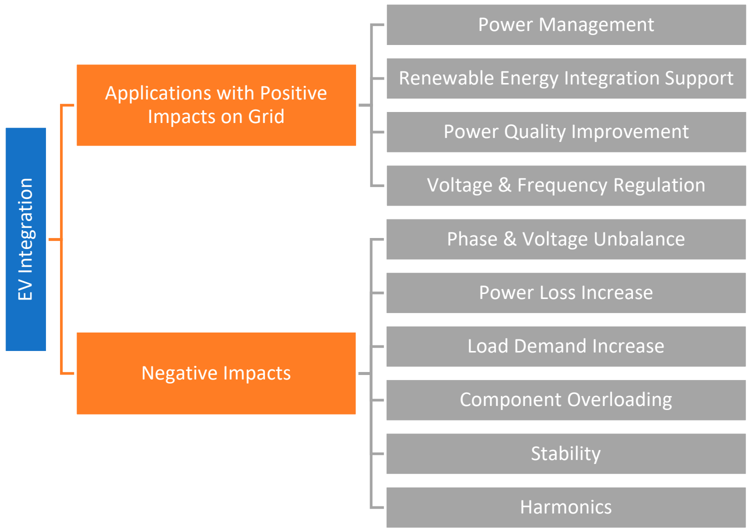


Figure 4. Disadvantages and advantages of connecting EVs to the grid.

2.3. Connectors

In EVs, there is an AC/DC converter through which batteries can be charged through traditional sockets such as Shoko, but in situations where users need to charge EVs quickly, they must directly charge their EV batteries by connecting to charging stations through connectors. Connectors have the following advantages:

- They are waterproof.
- Some of them will be able to perform the charging operation in three phases.
- They usually have an electronic or mechanical immobilizer, and when this immobilizer system is activated, the EV will not be able to move.
- The required amount of energy will be provided when the electrical or mechanical locking system is active.

Recently, there has been a wide range of connectors for electric vehicle charging on the market, including various standards such as SAE in America, IEC standard in Europe, and GB in China. In addition, J1772-2009 connectors may have different protection levels, and the most important feature is that they are waterproof. As shown in part A of Figure 5, the AC model is only modeled for single-phase 120 or 240 V voltage and has five pins as follows:

- AC pin, with two-phase and neutral pins to supply the energy required for EV batteries;
- The system of connecting the electrical system to the ground;
- User control, which allows communication with the vehicle.

As seen in part b of Figure 5, a newer model of connectors is designed for fast charging. In these connectors, much less time is needed to charge batteries, and 80% of EV batteries are charged in just 20 min.

This designed model, which is also known as a combined charging system, provides the possibility of slow AC charging or fast DC charging. This connector model looks very similar to the AC model, but the only difference between this model and the AC model is the presence of two additional DC charging bases. In addition, IEC-62196 follows the specifications of the IEC 60309 standard [43] as it has been used in its second edition, i.e., in IEC-62196-2. In general, four plug models are proposed as follows:

- Model 1, known as SAE-J1772-2009, is used to find a standard and optimal interface in the SAE-J1772 and IEC-62196-2 standards. According to Part A of Figure 5, this model is commonly used in EV charging equipment in Japan and North America.
- According to part c of Figure 5, the second model is known as VDE-AR-E 2623-2-2, which is limited to 230 volts in single-phase mode. This model consists of seven pins as follows:

- Four pins for three-phase mode;
- A pin for ground connection;
- Two more pins to connect with EVs.

For an example of this model used for EVs, we can refer to the ZOE EV manufactured by Renault. In addition, according to part d of Figure 5, the VDE-AR-E 2623-2-2 model has a combined charging system with a charging power of up to 400 kWh.

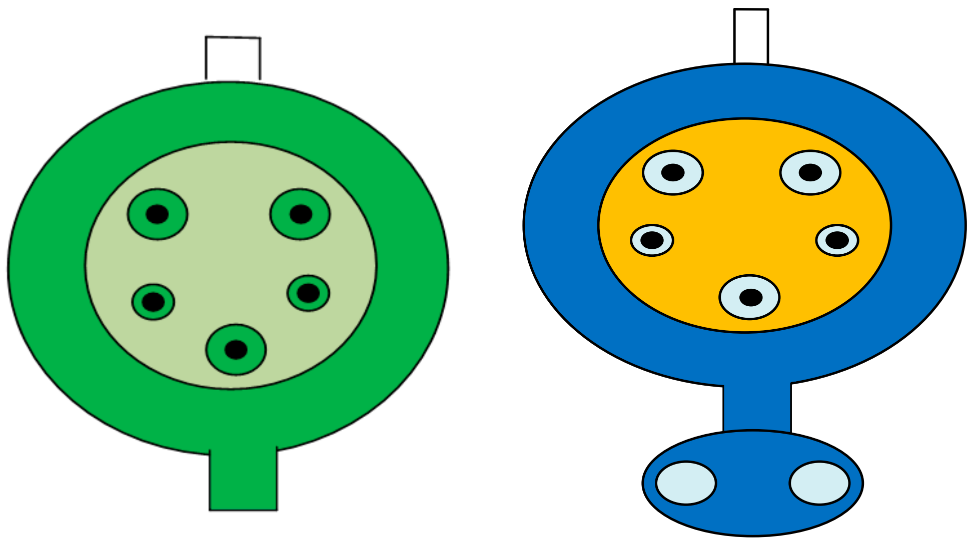
- According to part e of Figure 5, model 3, known as EV Plug Alliance, is a single-phase and three-phase connector. These connectors provide 230 V/400 V voltage and 16 A/63 A current. Model 3 was proposed in Italy and France for EV charging equipment, but due to the poor reception of this model, the production of these connectors has been stopped.
- Finally, according to part f of Figure 5, model 4, which is known as (EVS G105-1993) CHAdeMO, is used more in Japan compared to Europe and North America. This connector model provides a voltage of up to 400 volts and a current of 200 amps for the fast charging of EV batteries. In addition, this interface in its early versions and a power supply of 150 kW was designed for now, but now the goal is to supply power up to 350 kW. This connector has 10 pins as follows:
    - Two pins for the power supply;
    - One pin for ground;
    - Another seven pins to connect to the power grid.

The GB/T 20234 standard [44] is only used in China, and all cars manufactured and sold in China only use this standard as a charging port. The GB/T 20234 standard looks similar to model 2 but is actually completely incompatible with it. In general, there are two types of connectors for GB/T:

- First type of connector for AC charging;
- Second type of connector for DC charging.

In part g of Figure 5, this standard is shown. Tesla has considered two different connector models for selling EVs for

- Sale in Europe according to part c of Figure 5;
- Sales in the United States according to part h of Figure 5.



(**a**) (**b**)

Figure 5. *Cont.*

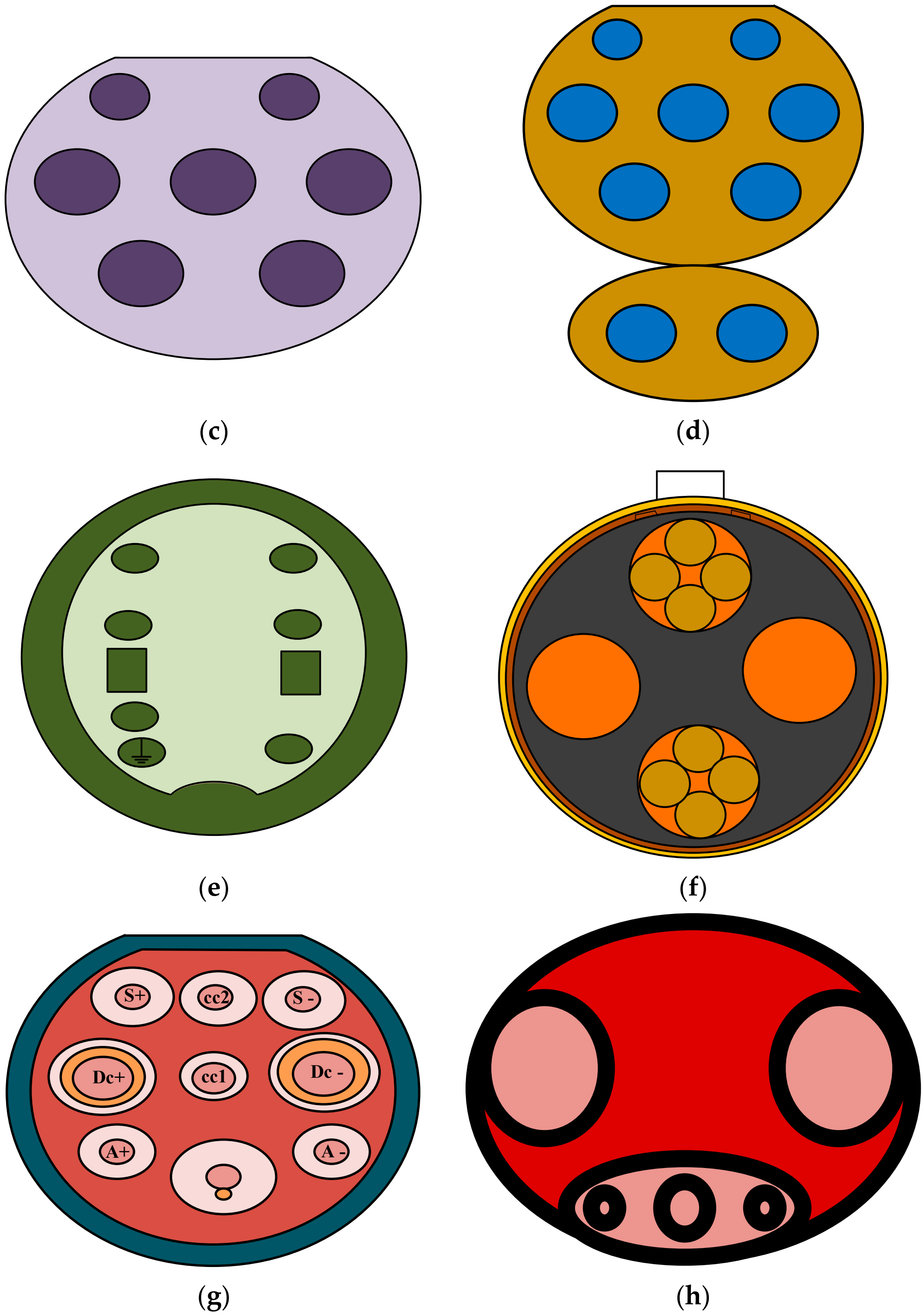


Figure 5. EV connectors considered by the different standards: (**a**) J1772-2009 Type 1 for AC charging; (**b**) J1772-2009 Type 2 for AC/DC charging; (**c**) IEC-63196 Type 2 (Mennekes); (**d**) IEC-62196 Type 2 (Mennekes CCS); (**e**) IEC-62196 Type 3 (Scame); (**f**) IEC-62196 Type 4 (CHAdeMO); (**g**) GB/T 20234 fast charging connector; (**h**) Tesla connector for United States.

3. Charging Methods

In general, EV charging methods are divided into the following four categories:

- Dumb charging;
- Smart charging;
- Flexibility charging;
- Smart charging model for V2G.

3.1. Dumb Charging

If the charging cycle is such that the electric vehicle owners charge according to their needs and this cycle is not based on any control, it is called a dumb charging system. Generally, "dumb" chargers do not connect to a dedicated app. They are pure plug-and-play devices. According to the existing infrastructure of electric energy distribution, there are many restrictions to integrating EVs into electric systems. If the regulations are not followed, the charging cycle of EVs may lead to an increase in peak demand. These chargers will only have the ability to connect to electrical outlets. They need to be smarter and know when to stop the charging cycle and continue charging their car all day. However, if you have more than one EV, installing a dumb charger will be cheaper and more convenient than a smart charger [45,46].

3.2. Smart Charging

With the development of communication technologies between EVs and the infrastructure of electric energy systems, in the smart charging method, a central operator will be able to coordinate and manage the amount of energy delivered to each EV connected to the electricity. One of the main differences between smart and standard charging information and communication technology facilities is related to chargers. In this method, there is no need for all EVs to be charged at their maximum capacity. Still, the central operator controls the charging cycle of EVs with intelligent measures based on peak load so that less pressure is applied to the power grid. Therefore, using the smart charging method to charge EVs, EV power consumption can be optimized based on the current state of the energy grid. EV owners can control their car's charge levels using smart chargers. They can schedule charging times or charge their EV using solar panels. In general, smart chargers are superior compared to dumb chargers, but smart chargers are more expensive than dumb chargers. If the only purpose is to charge EVs and control charging sessions, dumb chargers are more economical than dumb chargers [2,47].

3.3. Smart Charging Model for V2G

In general, V2G is one of the most important technologies in the electricity industry, which is very useful for energy storage. EV owners will charge their batteries during low demand and inject energy into the grid when needed, helping to meet the needs of electric energy systems. Finally, the smart charging model, which includes V2G in the production system, allows charging EVs during excess electricity generation and battery capacity [48,49].

3.4. Flexibility Charging

EV charging operations can be performed according to flexible demand when the peak load is low. To help the power grid, most of the energy related to electric vehicle charging can be provided from renewable energy sources. Creating such a charging environment is only possible with information and communication technology and meteorological knowledge, because it is possible to estimate the amount of energy production needed to charge EVs with renewable energy sources by using weather forecasts [50,51].

4. Control Methods of EVs

Today, EVs mainly work in G2V mode, i.e., in one direction. However, it is expected that with the development of EV infrastructure, they can work as G2V, EV to EV (V2V), and EV to Building (V2B). In the V2G section, the total power obtained from EVs can be used to support the grid or energy storage services, which EV owners should be given incentives to discharge. However, this process is not performed by EV owners but by an agent such as aggregators. Additionally, EVs can be used as V2B to build energy management to save building energy costs. Home automation, or building management systems, has been created to improve the quality of human life based on a flexible environment with high security [52]. Additionally, EVs can be used as energy storage, which will use the excess energy from renewable energy sources installed on the roofs of buildings [53]. V2V technology is a wireless network where cars exchange information about their status, such as speed, location, and distance [54]. This technology uses special short-range communication, usually covering the 5.9 GHz frequency range used for Wi-Fi systems. In other words, its range is up to 300 m (1000 feet) or 10 s of highway speed.

4.1. Deterministic Control Model

Researchers have recently found that EV integration negatively affects smart grids [54]. However, with optimal management, it is possible to dramatically reduce these effects and increase the penetration depth of EVs. In the following, two methods are introduced to control EV charging, which will neutralize the negative impact of EVs in smart networks [55].

4.1.1. EV Charging Based on a Centralized Model

Most smart charging management methods of EVs are generally modeled on this technology. EV control is performed centrally after collecting data related to the state of EVs and other system information. The central controller can be an aggregator. In addition, although centralized controllers will make optimal use of system resources, a communication infrastructure with high reliability is still needed [56,57].

4.1.2. EV Charging Based on a Decentralized Model

After centralized charging control, the remaining charging of EVs is based on a decentralized control strategy that uses communication infrastructure. In this controller, the aggregator or system operator does not process charging and discharging commands. Instead, the operator generates signals encouraging participating EVs to take specific actions. Therefore, sending private information from EVs to operators and aggregators is prohibited. EVs are responsible for charging and discharging rates based on their preferences. Figure 6 shows a model for EV charging technology based on two centralized and decentralized controller models [58].

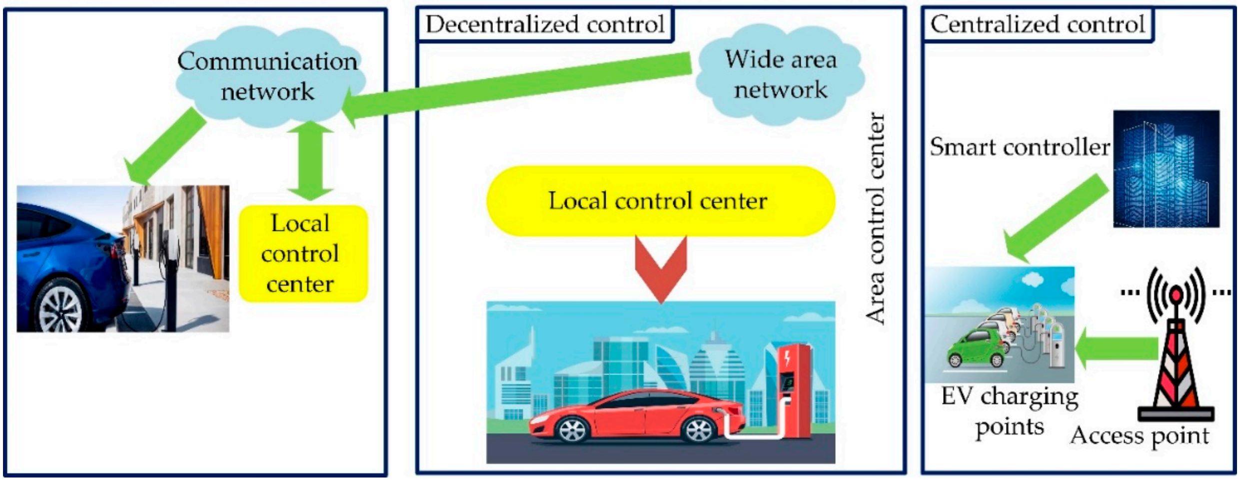


Figure 6. EV charging system based on centralized and decentralized charging.

Table 3 compares the advantages and disadvantages of two centralized and decentralized charge control methods [59,60].

Table 3. The advantages and disadvantages of EV control methods.

EV Controller Type	Advantages	Disadvantages
Centralized	Energy market on a much larger scale; Wide geographical reach; Ability to implement in real time; High profit; Different ancillary services are possible.	Very expensive; Complex communication infrastructure; Complex data to process; Compromises privacy.
Decentralized	Simple communication infrastructure; High flexibility; Enhanced fault tolerance; Scalable; Compatible with EV fleet applications; Compatible with energy management applications.	Limitation on ancillary services; Due to the limitation in ancillary services, profit is low; Uncertainty in the result.

5. Battery Technology

EVs with batteries have played an essential role in today's automotive industry. A variety of batteries may be used in the manufacture of EVs [61]. In this research work, six types of EV batteries are described, and Table 4 reviews the specifications of these six types of batteries.

Table 4. Specifications of six types of EV batteries.

Battery Type	Cell Voltage (V)	Energy Congestion (Wh/L)	Determined Power (Wh/kg)	Cycle	Operation Temperature (°C)
$Pb\text{-}PbO_2$	2.1	60–100	75–100	500–800	−20–45
Ni-Cd	1.35	60–150	120–150	2000	0–50
Ni-MH	1.35	100–300	250–1000	500	0–50
$Zn\text{-}Br_2$	1.79	60–70	80–100	>2000	20–40
Na-S	2.08	120–130	150–290	2500–4500	300–350
Li-ion	3.6	200–735	350–3000	400–3000	−20–60

5.1. Lead–Acid ($Pb\text{-}PbO_2$) Batteries

The $Pb\text{-}PbO_2$ battery is a type of rechargeable battery that was first invented in 1859 by the French physicist Gaston Plante, and has dominated the market for more than a century as the first commercial battery due to its low cost [62]. Lead–acid batteries have the lowest energy density compared to other rechargeable batteries. $Pb\text{-}PbO_2$ batteries are more sensitive and unstable than Ni-Cd batteries when the battery is completely discharged. Additionally, the cost of making these batteries is lower, and their operating temperature is suitable compared to other batteries. The most common way to charge $Pb\text{-}PbO_2$ batteries is to use constant current with voltage control.

5.2. Lithium-Ion (Li-Ion) Batteries

Li-ion batteries are rechargeable batteries and transmit the highest energy density (about 150 kW) [63,64]. In these batteries, unlike the performance of lead–acid batteries, if the battery charge is fully discharged, it will not affect its performance, and since these batteries are highly efficient and durable, they will not need any maintenance. Li-ion batteries are required to work in an operating environment with high reliability and safety controlled by voltage and temperature limits. Violating these limits leads to challenges such as rapid reductions in battery capacity, and according to the allowed temperature of electrolytes, it can lead to fire and even explosion. They work based on the exchange of lithium ions between the positive and negative electrodes (cathode and anode, which are usually made of cobalt and graphite) [65]. Li-ion batteries have a high charging speed, and their energy-to-weight ratio is better. However, these batteries have a very high manufacturing cost [66].

5.3. Zinc Bromine Battery (Zn-Br_2) Batteries

Zn-Br_2 batteries are batteries with high energy density and are economical. The battery is uniquely constructed using plastic storage tanks for the zinc bromide electrolyte and plastic bipolar electrode stacks. These batteries are a suitable alternative to Li-ion batteries because the water-based electrolyte prevents fire and the overheating of the batteries [67]. These batteries are divided into flow and non-flow and have advantages such as no need for cooling systems and easy recycling. On the other hand, lower charging and discharging rates compared to Li-ion and lower energy density compared to Li-ion are the main disadvantages of this type of battery.

5.4. Nickel–Metal Hydride (Ni-MH) Batteries

Ni-MH batteries are widely used as a source of energy in electrical devices and are produced in various sizes and types. Battery charging time is a significant feature and parameter in EVs that use rechargeable batteries as an energy source. Therefore, the ability to quickly charge and discharge Ni-MH batteries makes them suitable for EV use. Ni-MH batteries are far more economical than lithium-ion batteries in terms of manufacturing costs. The reason is related to using hydrogen, nickel, titanium, or similar metals for energy storage [68]. These batteries are safe due to the use of less toxic materials and have lower recycling costs [69]. On the other hand, these batteries can store less energy, up to 40%, compared to Li-ion batteries, and their heating speed is higher.

5.5. Sodium–Sulfur (Na-s) Batteries

Na-S batteries are a type of battery with a temperature above 300° [70]. Na-s battery is a type of molten salt battery made of liquid sodium [71,72]. The energy density of this battery is about five times higher than the Pb-PbO_2 battery [73]. Currently, more than 300 MW of energy from sodium–sulfur batteries has been used in 170 countries. Sodium–sulfur batteries have a very long life and can have 5000 charge–discharge cycles. They are also more economical compared to Li-ion batteries.

5.6. Nickel–Cadmium (Ni-Cd) Batteries

This is a type of rechargeable battery in which nickel and cadmium oxide are used, and potassium hydroxide solution with a concentration of 20 to 35% of the total volume of the electrolyte solution is allocated to it. Compared to other rechargeable batteries, Ni-Cd batteries have a better duty cycle, but their most important advantage is to provide rated capacity even at high discharge [74]. These batteries have a higher price than lead–acid batteries and have a higher self-discharge rate. On the other hand, as the number of battery discharges increases, the lifespan of these batteries decreases. Ni-Cd batteries are limited in production due to the environmental hazards of cadmium. This battery has a higher price and higher cost than the Pb-PbO_2 type and has a higher mass and volume density.

6. Energy Management System Related to EV Batteries

The battery energy management system is a key technology for managing and controlling the battery unit of EVs. Today, Li-ion batteries, due to their high charge density and low weight, are the favorite battery of manufacturers of EVs [75,76]. These batteries must never be over-charged or over-discharged in situations that require voltage and current control. This process is complicated because many cells are assembled to form a battery pack in a car. Each cell must be individually controlled in terms of safety and effective performance, which requires a specially dedicated system called the battery management system. In this way, the battery energy management system copes with the pressure of individual cells. The battery energy management system generally consists of integrated power delivery unit, sensors, and integrated communication channels. In addition, battery energy management systems are also responsible for measuring the state of charge and calculating the driving range. Furthermore, although auxiliary equipment such as headlights and the cooling and heating unit related to EVs supply their energy from the battery pack, they are not associated with the battery management system. According to the mentioned cases, researchers have mentioned different cases for the architecture related to the energy management system of EV batteries. For example, in reference [73], as shown in Figure 7, researchers state the following requirements for an EV battery energy management system:

- Obtaining data;
- Processing and storage of obtained data;
- Energy, thermal, and safety management;
- Communications.

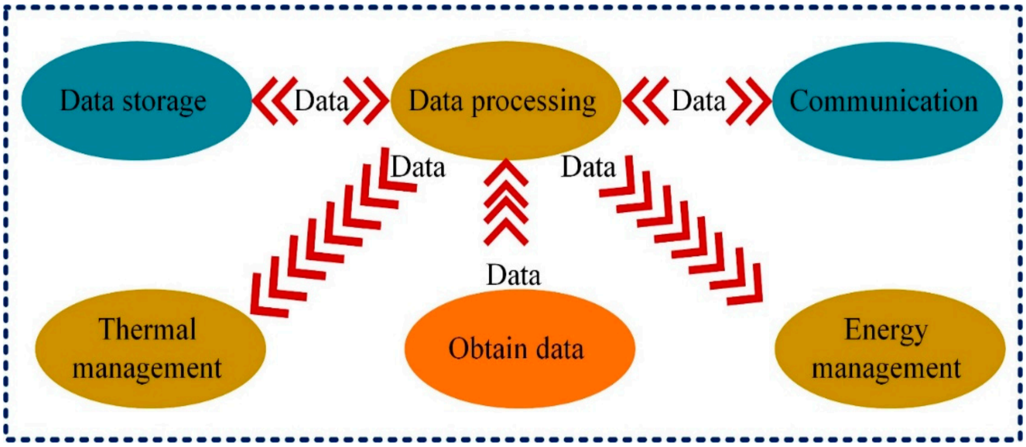


Figure 7. The architecture of a battery energy management system related to EV.

Depending on the type of application, various technologies may be used to exchange information. (e.g., controller area network/Flex Ray for inter-system communication and analog/digital I/O or pulse width modulation signals for communication with sensors and actors). One of the most critical blocks related to the energy management of EV batteries is thermal management, which is necessary for thermal balance in batteries, including increasing the temperature of batteries in cold weather. Therefore, in reference [77], researchers suggest a high-frequency sine-wave heater to improve the performance of Li-ion batteries at sub-zero temperatures. In reference [78], the authors proposed a compact high-frequency heater for effective self-heating for Li-ion batteries. Generally, based on the available resonance switch capacitors, the compact heater is powered only by the battery pack installed on the board.

7. Development of Charging Infrastructure for EVs and Government Incentives

As mentioned, because EVs do not cause pollution, they have appeared as a model of sustainability and respect for the environment. Such sustainability does not only appear as a result of the use of EVs, but the way they are modeled, the raw materials used in the construction of EVs, and the energy footprint during its use will significantly affect the sustainability cycle.

Another factor to be considered in the issue of sustainability is the amount of energy used to charge EV batteries when they are widely deployed. In addition, although EVs do not harm the environment, the energy required to charge the batteries can be supplied by fossil fuel power plants and thus indirectly harm the environment. For example, in Germany, where most production energy depends on coal, EV battery charging based on renewable energy sources is crucial. Additionally, if the life of EV batteries ends, their correct recycling is essential for transportation technology because they may cause severe environmental damage [79].

Moreover, for the development of EV charging infrastructure, the role of new energy should be prominent so that it can replace traditional energy, and in general the energy required to supply EV battery energy is entirely provided by renewable energy sources. This brings green transportation without CO_2 emission [80]. According to National Petroleum, today's EV culture is supported by about 135,000 outlets with about 1.4 million pumps. This network balances the competing demands of low cost and efficiency, locational convenience, and capacity utilization. There are now three essential principles for developing the transportation system, including autonomous vehicles, shared mobility, and electrification. Therefore, the charging infrastructure design for EVs requires considering the synergy and interaction between these three essential principles [81]. In general, there are six principles for the development and operation of EV charging infrastructure that, in a competitive market, EV manufacturing companies seek to strengthen their business:

- Devise your charging scheduling;
- Procure the optimal hardware;
- Develop an EV fleet charging management solution;
- Incorporate a smart energy management solution;
- Integrate with other EV management components;
- Introduction of intelligent battery management.

Moreover, the policies and incentive schemes for EVs are highly dependent on the current flow. Usually, the incentive plans that the governments of developed countries use to encourage people to use EVs are based on exemptions and financial credits. For example, high EV sales, mainly in Norway, result from government incentives. However, some of these incentives provided by the government may have adverse effects; for example, in Norway, exemption from tolls has significantly reduced toll revenue. Additionally, we can point to a decrease of about 5% in public transport passengers in one month in Norway. Although this decrease may be related to other factors, it is considered that this decrease is directly related to the widespread sale of EVs.

In general, the development of smart electric energy networks, due to the integration of distributed photovoltaic EVs, leads to many economic benefits and improves environmental factors. The results of extensive research show that the interaction of EVs and distributed photovoltaics leads to an enhanced clean energy utilization rate of EVs and significantly reduces the adverse effects.

8. Integration of EVs with Renewable Energy Sources

Energy resources are one of the essential factors and determining elements in sustainable development. After human power, having a suitable energy source is the most important economic factor in industrialized societies [82], because energy is a basic need for the continuation of industrial and economic development, social welfare, and improving the quality of life and security of the community. So, investigating the penetration and integration of renewable energy sources into electrical energy systems has become a hot research area. In addition, energy production from these sources is unpredictable and may be higher or lower than the needs of the power grid, but studies show that supplying the needs of the power grid through wind and photovoltaic systems has high reliability. However, the existence of energy storage systems and controllable distribution loads help generate energy through renewable energy sources and help create a stable grid [83]. With the electrification of transportation, EV batteries act as energy stores and, by absorbing the surplus energy produced by renewable energy sources, deliver it to the grid when needed.

8.1. Integration of EVs with Photovoltaics

Solar electricity is generated from the sun's rays to solar cells embedded in solar panels. With the development of EVs, this solar energy may provide the energy needed to charge EVs and support the power grid [84,85]. So, we see a decrease in energy demand in the network due to EVs charging locally through solar panels in a "green" way. Smart charging creates a flexible environment to help achieve a balance point between EV charging and photovoltaic generation [86]. Additionally, according to the studies carried out in references [87,88], the authors have investigated, planned, and managed optimal production by considering V2G operations in solar systems to reduce operating costs and improve network stability. In [84], the daily charging behavior of EVs based on sunlight radiation on different parking spots has been investigated. The results of this study show that if EVs are integrated with solar cells and charged according to this method, CO_2 emissions will be reduced by about 0.6 tons annually [89]. Furthermore, in reference [87], a bidirectional DC charger is modeled for the interaction of EVs with a grid powered by photovoltaics. Figure 8 shows an example of a solar-cell-based charging station based on a two-way converter. According to the figure, the existing charging stations represent the charging points connected to the distribution network, and the EVs in the stations indicate that EVs can support the network as energy storage. Therefore, EVs equipped with a two-way DC charger will be able to absorb energy by connecting to the solar cell controller.

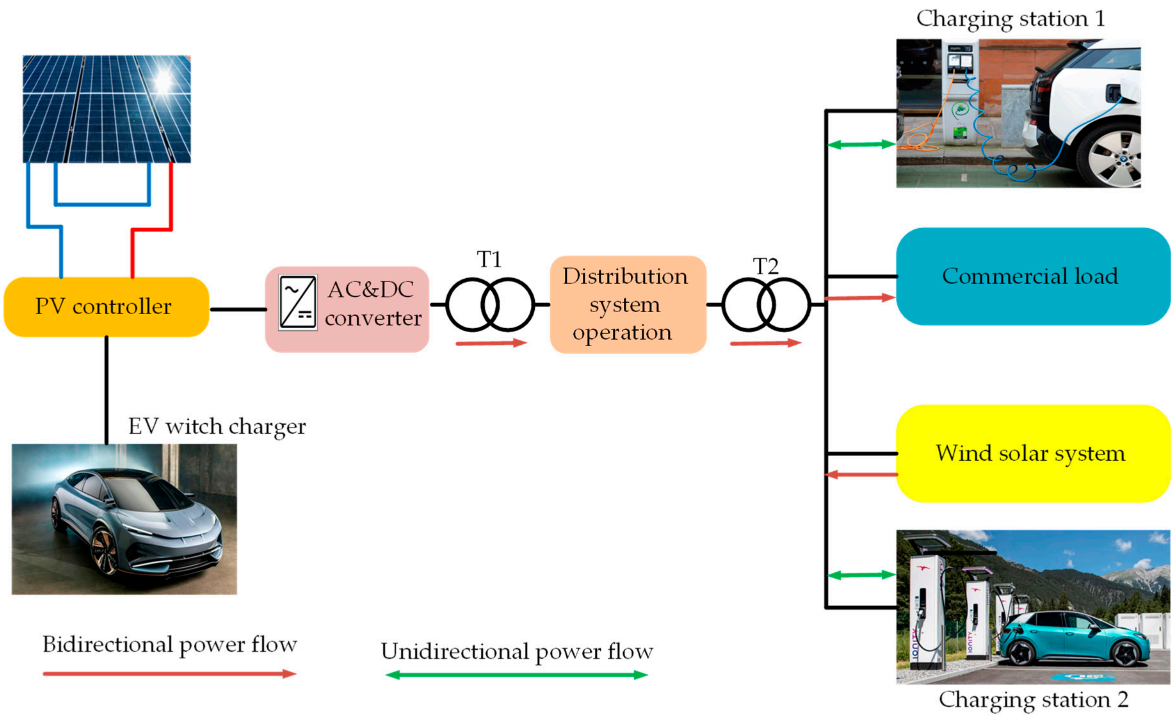


Figure 8. EV charging station based on photovoltaics.

8.2. Integration of EVs with Wind Power

Renewable energy is an essential solution to climate change [90]. The comprehensive integration of these resources should be considered to create a balance between supply and demand. With the development of EVs, the potential to deal with imbalances between supply and demand increases [91,92]. In general, the integration of wind energy systems to provide the energy needed to charge EVs has become an attractive research field that various researchers widely investigate to analyze the impact of wind energy integration on the grid. In [93], Lopes JAP and colleagues conduct studies on the amount of safe wind intensity and the participation of EVs in setting the initial frequency and evaluating their interactions in the smart charging cycle. This study considers all EVs based on average charging to contribute to the power grid. In reference [94], studies on an isolated power network to integrate a large amount of wind energy based on the hourly energy model have been carried out. EV batteries in the V2G field are used to adjust the frequency that has become unstable due to the fluctuations caused by the influence of wind power. In another research work, researchers have examined the results of wind energy integration in the microgrid based on PHEVs [95].

9. System Operation and Optimization

Today, EVs are considered essential players in the future of the electrification of the transportation sector and have become a hot research topic. The unpredictability of EVs may lead to increased system complexity and challenges. Therefore, solving these challenges and increasing sophistication is necessary by providing a suitable algorithm to optimize EVs. Considering that the integration of EVs with the power grid will increase nonlinear variables, but the unit commitment problem (UC) is a typical mixed integer nonlinear programming problem to determine optimal distribution timing, various optimization algorithms have been proposed for unit commitment problems. The most famous and suitable optimization methods for V2G problems include genetic algorithm and particle swarm optimization. The genetic algorithm is an iterative method that can search for the optimal solution under an execution time limit. Still, the particle swarm method is a memory computing algorithm used for the overall optimal state in a population of random solutions generated by updating resources. The particle swarm algorithm has the advantage of requiring less computing time and memory. In addition, with the help of optimization methods, it is possible to optimize the goals of V2G and ancillary services and maximize the profit of EV users. Figure 9 shows the types of V2Gs, benefits, objectives, and optimization constraints [96]. In addition, modeling EVs to determine the energy capacity of charging stations, determining the optimal location and size of these stations, charging management methods, and planning charging stations with different purposes are essential issues that should be considered. Additionally, to determine the optimal location of charging stations, various indicators such as distribution network losses, reliability, and other important matters should be considered.

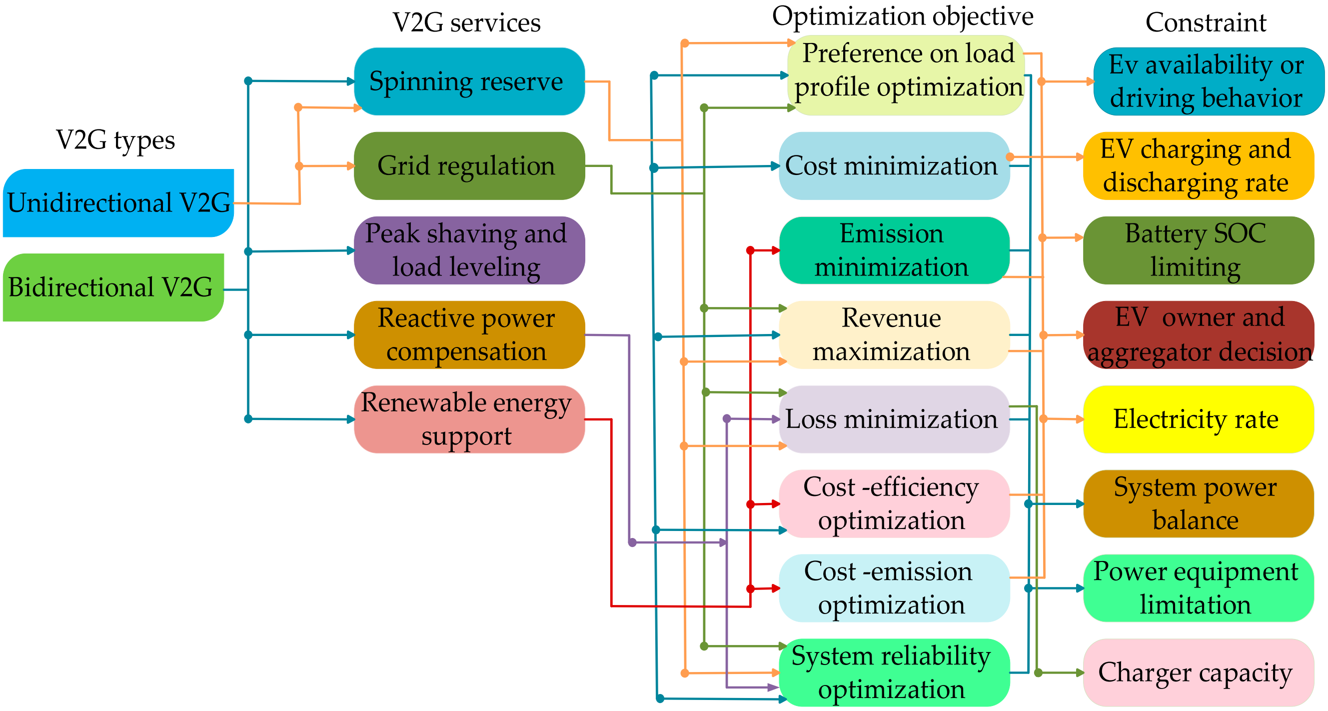


Figure 9. Relationship diagram of different V2G types, V2G-related services, optimization goals, and desired constraints.

10. Conclusions

The development of EVs and the electrification of the transportation industry have improved the power supply of EV batteries through renewable energy sources such as wind and photovoltaics. Additionally, developing charging technology and the optimal use of EVs is necessary to create a flexible charging environment, improve economic indicators, and increase reliability. In this research, studies have been carried out on different charging levels of EVs and the positive and negative points of integrating electric EVs with the power grid have been assessed. In this article, the authors also briefly explain the policies and incentive schemes of the governments of developed countries. Additionally, the use of incentives such as paying loans to buy EVs, removing traffic restrictions, eliminating city tolls, and discounting the cost of charging EVs to increase users' desire to purchase EVs are recommended and can be investigated more widely in future research. In addition, due to the progress of EV charging technology, there are still many challenges, such as choosing a reliable charging system, the need for more development of charging stations based on the Internet of Things, and protecting users' privacy. Researchers can focus on these challenges in future research work.

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