

Review

A Comprehensive Review of Electric Vehicles in Energy Systems: Integration with Renewable Energy Sources, Charging Levels, Different Types, and Standards

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Abstract: Due to the rapid expansion of electric vehicles (EVs), they are expected to be one of the main contributors to transportation. The increasing use of fossil fuels as one of the most available energy sources has led to the emission of greenhouse gases, which will play a vital role in achieving a sustainable transportation system. Developed and developing countries have long-term plans and policies to use EVs instead of internal combustion vehicles and to use renewable energy to generate electricity, which increases the number of charging stations. Recently, to meet the charging demand for EVs, the main focus of researchers has been on smart charging solutions. In addition, maintaining power quality and peak demand for grids has become very difficult due to the widespread deployment of EVs as personal and commercial vehicles. This paper provides information on EV charging control that can be used to improve the design and implementation of charging station infrastructure. An in-depth analysis of EV types, global charging standards, and the architectures of AC-DC and DC-DC converters are covered in this review article. In addition, investigating the role of EV collectors, as well as EV penetration, in electric energy systems to facilitate the integration of electric energy systems with renewable energy sources is one of the main goals of this paper.

Keywords: electric vehicle; vehicle to grid; grid to vehicle; smart charging; hybrid vehicles; plug-in hybrid vehicles



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1. Introduction

The high emission of toxic gases is influential in destroying the ecological system. The transportation sector is responsible for 25% of carbon emissions and 55% of global oil consumption [1]. Today, the electricity industry plays a strategic role in any country's economic and social stability and is used as one of the influential factors in protecting the environment. Therefore, it is predicted that in the next 10 years, the use of energy sources such as gasoline will reach half of its current amount, and electrification will significantly increase in the transportation sector to transfer energy toward a carbon-free economy [2–4]. Recently, various types of cars, such as hydrogen cars and plug-in hybrids, have been designed and produced as an alternative to gasoline and diesel cars worldwide. Still, EV are a more suitable alternative [5]. The first EV was introduced in the late 1800s, but due to the limitation in the speed and distance of these cars and the mass production of cheap gasoline cars, the growth of these cars was severely prevented. However, now, after several decades, EVs have regained global fame due to the advancement of technologies in the electrical industry, and also due to the energy crisis [6]. Because EVs have electric motors and supply their energy through lithium batteries, their emissions are zero, and they do not cause any damage to the environment. In addition, when it comes to EVs, smart charging is a critical topic discussed in this article [7]. In general, smart charging is a set of smart functions that provide a flexible environment for charging and discharging EVs,

which are stable and cost-effective, and they improve the energy efficiency of chargers by communicating between EVs and the power grid. Therefore, the charging time of EVs must match the refueling time of internal combustion vehicles, and the production of electrical equipment with higher power levels must rapidly increase to charge EVs at super speed. High-power converters and smart-charging-coordinated control techniques can effectively reduce the charging time of EVs [8]. Smart charging can increase power transmission efficiency and help reduce electricity demand by the grid. In addition, charging EVs based on solar and wind power can be made into more sustainable products. Further, smart charging can provide a new stream of functionality for EV owners, such as adjusting the frequency. By providing ancillary services, smart charging of EVs will reduce energy costs related to EVs by 60% [9]. Moreover, EV batteries play a vital role in the charging cycle of EVs and energy storage for injection into the power grid. EV charging systems can be one-way or two-way. As shown in Figure 1, if we use EV batteries to return power to the power grid, it is called V2G [10], which requires multidirectional electric loads that exchange power between the grid and the battery [11,12]. Yet, if electricity is injected from the grid into the EV, it is called G2V, which requires one-way electric chargers. Additionally, G2V has higher reliability and is very simple to control [12]. To provide ancillary services by EV through EV, V2G and G2V technologies are required for two-way power exchange. By definition, V2G EVs are generally connected to the network to improve network characteristics during peak hours. However, in G2V, EVs receive electricity from the grid to supply the energy required by the battery [13].

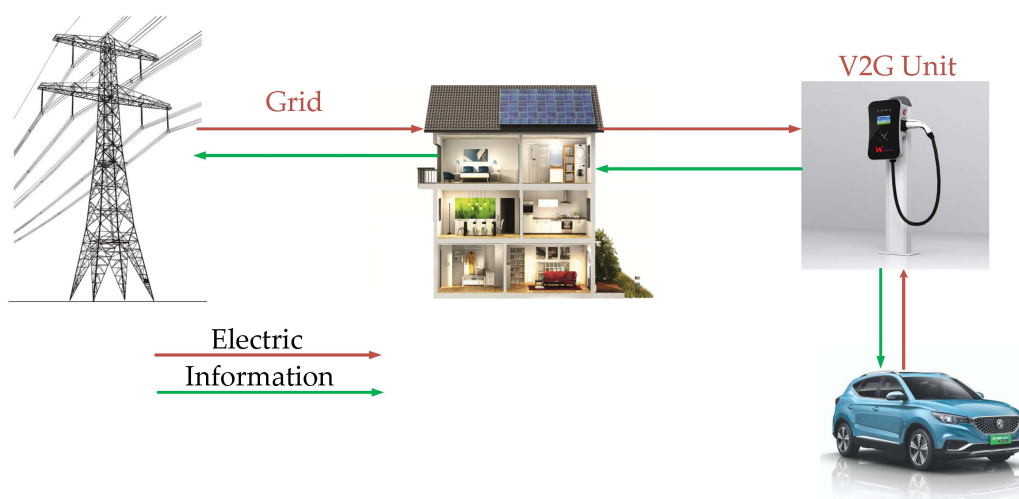


Figure 1. V2G architecture.

Figure 2 shows the schematic diagram for smart charging of V2G in power systems [14]. In the review of the literature related to EVs, the authors in reference [15] examine the opportunities that will be able to directly or indirectly affect the public charging infrastructure. In reference [16], researchers examine the positive and negative effects of charging EVs on power systems. According to the reviews in reference [17], we found that the authors are mostly focused on optimal charging techniques. In another work, researchers focused on centralized or decentralized charge planning, data mining methods, and mid-term, short-term, and long-term load forecasting [18]. According to the research in reference [19], the authors focused on EV charging systems based on energy storage and diesel generators. In reference [20], Siddhant Kumar et al. focused on different battery charging topologies. Available batteries' chemistry, categorization, material, and impacts of charging speed are all detailed and described in [21,22]. Additionally, it describes which battery to choose, dependent on the application. In the literature [23], researchers have conducted studies on the EV energy management system to reduce the fluctuations caused by wind power connections. In the literature [24–26], distributed PVs and wind power aim to reduce

the operating costs of EV charging stations and improve the rate of renewable energy consumption in EV charging station planning. The authors in reference [27] examined the charging methods of EVs in Germany, focusing on the standards and development of EV technologies. In reference [28], researchers conducted studies on the effects of EV integration with the power grid. Finally, in reference [22], EVs as a service are reviewed, with a focus on existing challenges and related applications.

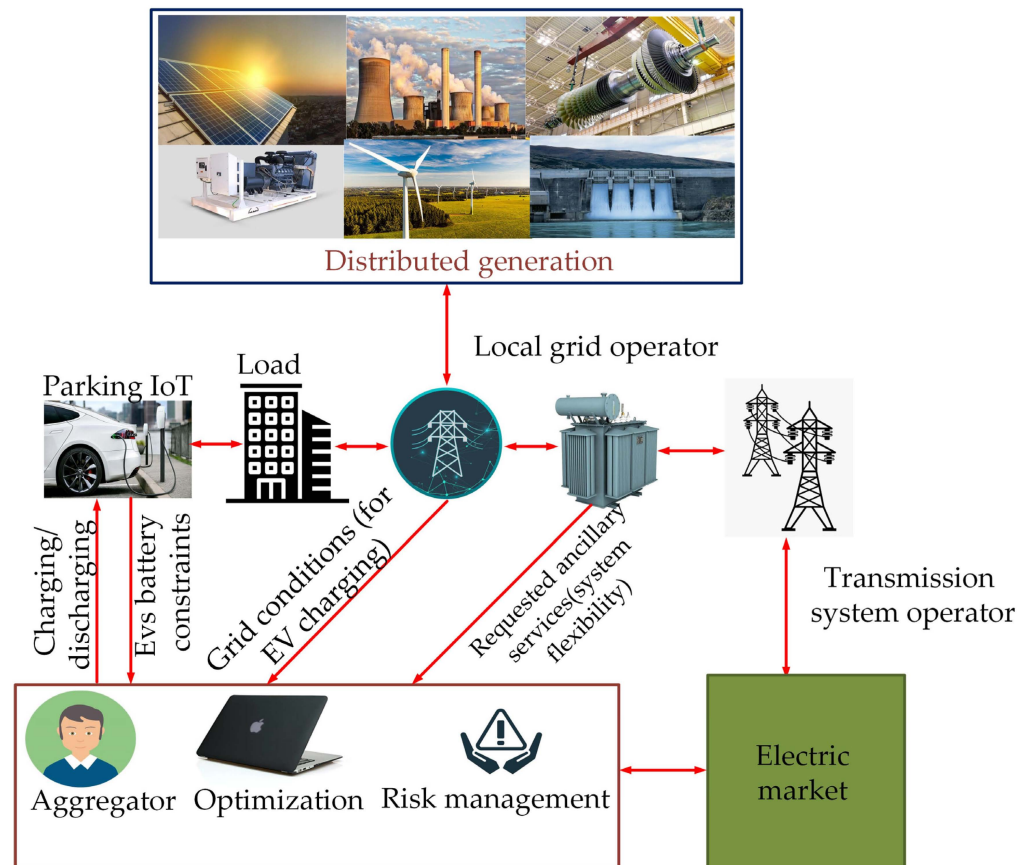


Figure 2. Schematic diagram showing the smart charging of V2G in power systems.

2. Paper Organization

Section 3 compares smart charging and dumb charging. In Section 4, the function and role of EV aggregators are investigated. In Section 5, the mathematical model for optimal planning of an EV aggregator is shown. In Section 6, international EV charging standards are examined, and two important and practical standards (SAE and IEC) are explored in the following sections. Authors in Section 7 check the types of EVs, and in Section 8, different models and charging levels are discussed. In Section 9, research is presented on EV converters. In Section 10, the integration of EVs with the power grid is discussed. Section 11 provides explanations of EV charging infrastructures, and the sub-sections of this section discuss EV charging control. Section 12 provides a description of government policies and incentives to promote the growth of EVs through the replacement of internal combustion vehicles. Finally, Section 13 of this article is dedicated to the conclusion.

3. Dumb and Smart Charger Comparison

The smart battery charger is another name for microprocessor-controlled chargers. These chargers are only designed to work with smart EV batteries. This is because smart batteries have special microchips programmed to communicate with a charger of the same brand. This article is focused on the IEC 61851 EV charging station test standard, and based on it, the difference between dumb and smart chargers is investigated. “Dumb” chargers do

not connect to a dedicated app. They are pure Plug and Play devices. However, like a 3-pin socket, your EV will still collect primary data from charging sessions, such as charging time and kWh added. Smart chargers are superior to dumb chargers, but if all you want to do is plug in and charge, and your vehicle app controls charging sessions, a dumb charger could be all you need. Dumb chargers charge at speeds up to 7.4 kW on single-phase, adding up to 30 miles of range per hour; thus, they are just as fast as smart chargers. Dumb chargers are jacked-up power outlets, nothing more. They do not know when to stop charging and will continue charging your car all day. On the contrary, smart chargers give you complete control over charging, including scheduled charging times, kWh price caps, and solar integration to charge a car with solar panels. In other words, a smart charger compliments your smart EV. The significant disadvantage of dumb chargers is they do not collect energy usage data, which is not good when you run your car on electricity. In smart charging, it is possible to schedule charging and discharging for the intraday and day ahead. Smart chargers may also be used for V2G. However, dumb charging is considered an uncontrollable load. It cannot be used for V2G, and EVs are connected to the electricity and the charging cycle continues until the batteries are full [29]. They only have one battery. The Environmental Protection Agency designates BEVs as zero-emission EVs because they have no direct or indirect emissions. The speed limit of BEVs (due to low battery capacity) and the low number of public charging stations have led to the growth of PHEVs [30].

4. Examining the Role of EV Aggregators in Smart Charging

Aggregators are relatively new electrical energy systems that act as interfaces between power systems and consumers, and they can influence a number of grid-connected units [31]. Aggregators are players in electric energy markets whose primary goal is to succeed in energy program optimization and power system control services [32]. Aggregators may be of different types, such as demand response aggregators, retail aggregators, and EV aggregators [33]. An example of the duties of demand response aggregators is to provide consumption reduction contracts for subscribers who participate in demand response programs [34]. Currently, the increasing prominence of EV integrators in power systems has attracted more attention to modeling their behavior. As an interface, EV aggregators aim to support the V2G mechanism by collecting EVs in the role of distributed energy sources. EV aggregators may also be used to manage the battery state-of-charge (SOC) estimation of geographically distributed EVs [35]. In addition, these aggregators will be responsible for supplying electricity and controlling EV charging and discharging in a specific contracted area. Figure 3 shows the role of aggregators in EV smart charging.

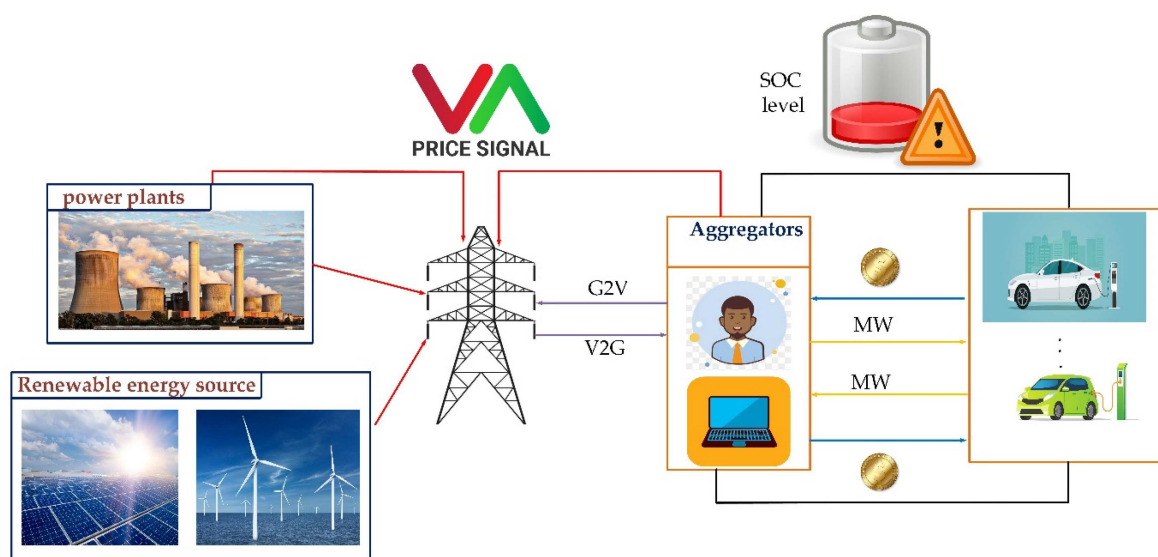


Figure 3. Examining the role of EV aggregators in smart charging.

In addition, EV aggregators generate necessary signals, with the aim of EV fleet coordination based on data shared among the energy market supplier, the transmission system operator, and the distribution system operator. Figure 4 vividly demonstrates the aggregator frameworks, alongside other forms of the framework.

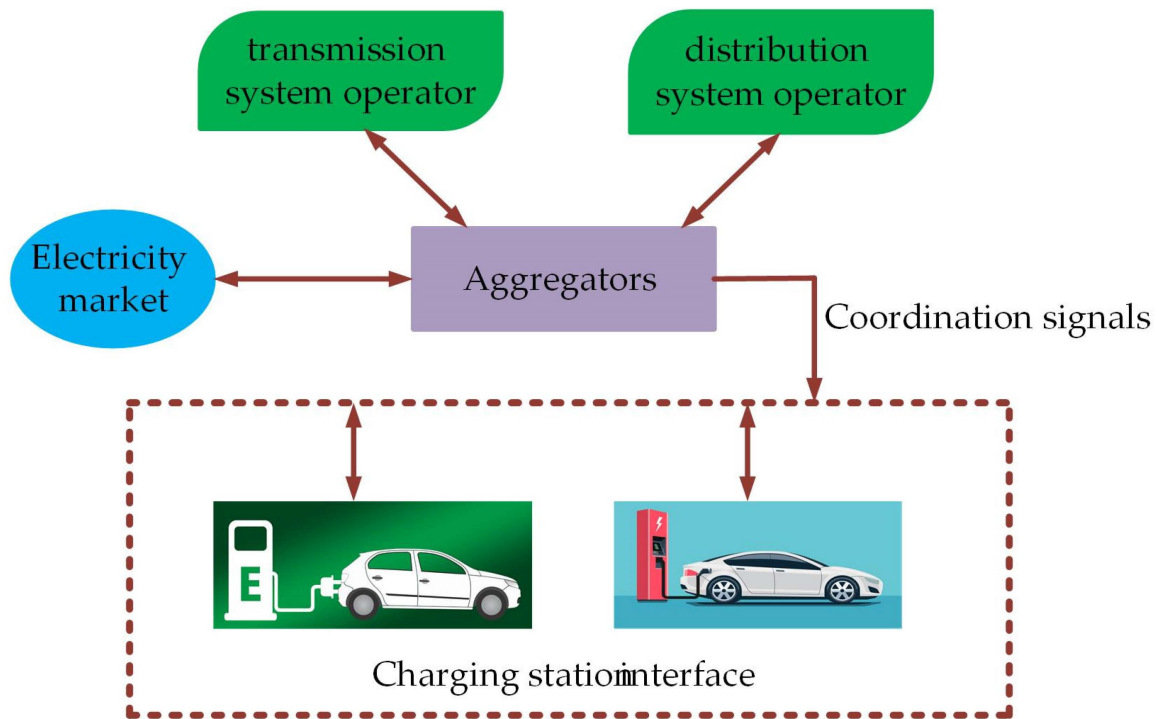


Figure 4. Coordination framework of EVs with aggregators.

5. Optimal Scheduling for EV Aggregators

In this section, a review of the mathematical model related to EV aggregators is presented. In the mentioned model, EV aggregators participate in energy markets and exchange power between EVs in the parking lot and the upstream network. An optimal schedule for EV aggregators is formulated in the following equations. Equation (1) represents the objective function, which is the profit increase of EV aggregators here [36].

$$\sum_{t=1}^T (\zeta^{OW} P_t^{EV} - \zeta_t P_t^{EV} - \zeta^{FT} P_t^{DCA}) \times \Delta \quad (1)$$

In general, the objective function consists of the following three parts:

- Part 1: The contract of income from energy among the owners of EVs and parking.
- Part 2: Income and costs related to the amount of energy discharged, as well as charged.
- Part 3: Paying incentives to EV owners in exchange for reduced battery life.

Equation (2) shows the maximum limit of discharged power. Equation (3) shows the maximum battery charge, and Equation (4) shows the trading power of EVs.

$$0 \leq P_t^{CA} \leq P_t^{CA,Maximum}, \forall t \quad (2)$$

$$0 \leq P_t^{DCA} \leq P_t^{DCA,Maximum}, \forall t \quad (3)$$

$$P_t^{EV} = P_t^{CA} - P_t^{DCA}, \forall t \quad (4)$$

Relationships (5) and (6) show the maximum charging and discharging rates of six EV models in the lot.

$$P_t^{CA,Maximum} = \sum_{U=1}^U \sum_{EV=1}^{EV_U} P_U^{CA,Maximum} Y_t^{EV}; \forall t \quad (5)$$

$$P_t^{DCA,Maximum} = \sum_{U=1}^U \sum_{EV=1}^{EV_U} P_U^{DCA,Maximum} Y_t^{EV}; \forall t \quad (6)$$

In Equation (7), the cost of EV battery destruction is shown to be directly related to the investment cost of EV battery services. In contrast, battery capacity has an inverse relationship with battery life.

$$\zeta^{FT} = \frac{1000COK}{LCO \times DOD \times EC} \quad (7)$$

Equation (8) shows the maximum amount of energy of EV accumulators in each time period t .

$$E_t^{Maximum} = \sum_{U=1}^U \sum_{EV=1}^{EV_U} G_U^{Maximum} y_t^{EV}; \forall t \quad (8)$$

Equation (9) calculates the increased energy capacity of the parking lot based on the energy of an EV arrived to the parking lot.

$$E_t^{ARR} = \sum_{U=1}^U \sum_{EV_{U,t}^{ARR}=1}^{EV_{U,t}^{ARR}} (G_U^{Maximum} - G_{U,t}^{ARR}); \forall t \quad (9)$$

Then, the amount of reduced parking energy to EVs that are moved at time t is expressed in Equation (10).

$$E_t^{DERP} = \sum_{U=1}^U \sum_{EV_{U,t}^{DERP}=1}^{EV_{U,t}^{DERP}} G_U^{Maximum}; \forall t \quad (10)$$

Equations (11)–(13), respectively, indicate the amount of energy stored at time t , show the equality of the amount of energy stored at time t with the amount of initial energy, and limit the stored energy of the parking lot.

$$E_t = E_{t-1} + E_t^{ARR} + \omega^{CA} P_t^{CA} \times \Delta t - (E_t^{DERP} + \frac{P_t^{DCA} \times \Delta t}{\omega^{DCA}}); \forall t \quad (11)$$

$$E_0 = E_T \quad (12)$$

$$0 \leq E_t \leq E_t^{Maximum}; \forall t \quad (13)$$

6. EV Charging Standards

In general, EV charging standards are categorized as follows [37]:

- International Electro Technical Commission (IEC) standard is widely used in Europe.
- The US uses standards from the Society of Automotive Engineers (SAE) and the Institute of Electrical and Electronics Engineers (IEEE).
- CHAdeMO standard is used in Japan.
- China uses the Guobiao (GD) standard.

In this article, IEC and SAE standards, which are the most widely used standards for EV charging, are examined. In SAE, the term for the power level is “level,” but in IEC, the power level is determined by the “mode”.

6.1. IEC Standard

In general, IEC is one of the organizations affiliated with the International Standard Organization (ISO), whose task is to compile the standards required by the electricity industry.

6.1.1. IEC61851

The IEC61851 standard covers a general function for EV conductive charging systems. According to this standard, the rated voltage level of supply up to 1000 V AC or a maximum of 1500 V DC can be used for charging EVs.

6.1.2. IEC61980

This is a standard for EV wireless power transmission systems. In addition, the IEC61980 standard can be used for the supply voltage level up to 1000 V AC and the voltage level of 1500 V DC.

6.1.3. IEC62196

The IEC 62196 standard applies to PHEV, sockets, connectors, and vehicle inlets—EV directional charging.

6.2. SAE Standards

SAE Standards is a standard development organization for various engineering disciplines. SAE's world headquarters is in Warrendale, Pennsylvania, 20 miles north of Pittsburgh, Pennsylvania. The main emphasis of this standard is on global transportation industries, such as EVs. The organization chose the name SAE to indicate a greater focus on mobility.

6.2.1. SAE J2293

In North America, SAE J2293 specifies standards for EVs and the off-board EV supply equipment used to transmit electrical energy from a utility system to an EV. This document specifies, either directly or by references, the characteristics of the whole EV Energy Transfer System to ensure the technical compliance of an EV and Supply Equipment of the same physical system architecture [38]. In general, this standard consists of two parts. In the first part, the necessary energy and system architecture are discussed for the three operating conditions of conductive AC, conductive DC, and induction, known as the J2293-1 standard. In the J2293-2 middle, the communication requirements and the network architecture for EV charging are studied.

6.2.2. SAEJ1772

By definition, in the SAEJ1772 standard, the ratings of all equipment, such as circuit breakers and charging voltage, are studied for charging EVs. A summary of the levels of voltages and currents is shown in Table 1 for this standard [39].

Table 1. Summary of voltage and current levels in SAEJ1772 standard.

Standard	Source	Level	Voltage (V)	Phase	Max Current
SAEJ1772	AC	Level 1	120	Single	16
		Level 2	240	Single	32–80
	DC	Level 1	200–450	DC	80
		Level 2	200–450	DC	200

6.2.3. SAEJ1773

This SAE better establishes the minimal connection similarity standards for EV inductively linked charging in North America. Typically, this kind of inductively linked charging is used to transmit electricity at a frequency far higher than power lines. Inductive coupling

systems that use automated connecting techniques or are designed to transfer electricity at power line frequencies are not covered by this standard section [40,41].

6.2.4. SAEJ2847

SAEJ2847 and SAEJ2836 standards determine the charging infrastructure and communication requirements between EVs, respectively. In Table 2, the subsections related to the application fields are specified.

Table 2. Section in SAEJ2847 & SAEJ2836 standards.

Section	Titles
SAEJ2847/1-2	Including the connection between EV and power grid and PHEV and off-board DC chargers.
SAEJ2836/1-2	Use cases for communication between PHEV and the power grid, and PHEV off-board DC chargers, respectively.
SAEJ2836/3	PHEV communication use scenarios as a distributed electricity source.
SAEJ2836/4	Use cases for PHEV customers, wireless charging, and diagnostics, in that order.

6.2.5. SAEJ2931

This standard specifies requirements for digital communication between PHEVs, EV supply equipment, energy service interfaces, advanced metering infrastructure, and the local network. In Table 3, four subsections of this standard are classified.

Table 3. Subsections related to the standard SAE J2931 [42].

Section	Explaining of the Subsections Standard SAE J2931
SAE J2931/1	This article, SAE J2931/1, defines architecture and general requirements, including association, registration, security, and home area network requirements, as well as mapping to other SAE documents.
SAE J2931/2	Specify a medium access control and Physical layer implementation using SAEJ1772 pilot wire and frequency shift keying, narrow band orthogonal frequency-division multiplexing, and baseband orthogonal frequency-division multiplexing.
SAE J2931/3	SAE J2931/3 is under development and is proposed to define medium access control and physical layer implementation of digital communications, using either the narrow band orthogonal frequency-division multiplexing SAE J1772 Pilot wire or mains.
SAE J2931/4	SAE J2931/4 defines the medium access control and physical layer implementation of digital communications, using broad band orthogonal frequency-division and either the SAE J1772 Pilot wire or mains.

6.2.6. SAEJ2954

This standard, with the aim of wireless power transmission for EVs, supports three charging speed classes, as follows:

- Charging level 1, 3.7 KW
- Charging level 2, 7.7 KW
- Charging level 3, 11 KW

7. An Overview of the Types of EVs

All EVs consist of the following three parts:

- One or more electric motors.

- Controllers.
- Charging system with a battery to store electric energy.

Unlike internal combustion systems, EVs use rechargeable batteries to provide the necessary energy for movement and enable users to move without needing to consume fuel and pollute the environment. Moreover, the electricity required to charge the batteries will be available through the electricity available in homes or charging stations [43]. Various techniques, such as extracting power from the braking system, also help increase EVs' efficiency. According to Figure 5, EVs are generally divided into two categories:

- Hybrid Vehicles (HV)
- All EVs (AEV)

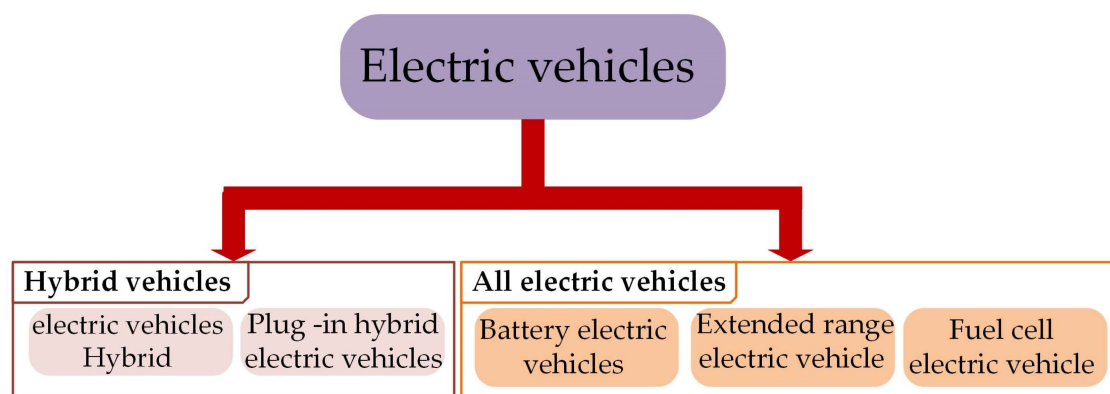


Figure 5. Classification of HV and AEV types.

As shown in Figure 5, HVs are divided into two categories:

- Hybrid EV (HEV)
- Plug-in Hybrid Vehicles (PHEV)

By definition, HEVs are capable of using batteries and internal combustion sources. HEVs cannot be connected to the mains to charge the batteries, and the motor is seized through internal combustion. Therefore, their battery capacity is deficient. Further, PHEVs are improved versions of HEVs powered by a gasoline motor and an electric motor. PHEVs are able to connect to the grid to charge their batteries. One of the positive points of PHEVs is that users can use only the electric motor or both motors installed on the vehicle, based on the battery's remaining charge. The total charging time of PHEVs depends on the size and capacity of the batteries and the charging method. AEVs are divided into the following three categories [44,45]:

- Battery EV (BEV)
- Fuel Cell EV (FCEV)
- Extended-range EV (ER-EV)

By definition, BEVs have a higher priority for charging at charging stations because they only have one battery [46]. The Environmental Protection Agency designates BEVs as zero-emission EVs because they have no direct or indirect emissions. The low speed limit of BEVs (due to low battery capacity) and the low number of public charging stations have led to the growth of PHEVs. Therefore, the energy density of their batteries should be increased to increase BEV production. By definition, FCEVs do not emit any greenhouse gases and are more practical, compared to internal combustion vehicles. The power source of FCEVs is hydrogen, and they only produce steam and hot air. The installation of FCEVs and the hydrogen infrastructure needed to fuel them is still in its early phases. The U.S. Department of Energy is spearheading the development of economical, safe, and ecologically sustainable hydrogen-powered cars. The Energy Policy Act of 1992 classifies hydrogen as an alternative fuel, making it eligible for alternative fuel vehicle tax credits. ER-EVs are AEVs with many

of the benefits of purely electric models. ER-EVs help combat range anxiety, lower fuel costs, are highly efficient, and maximize their use by constantly operating their motor [37]. An ER-EV comprises an electrical drivetrain (one or more electric motors and battery pack) and an internal combustion motor to charge the battery pack. The electric motor only drives the range-extender vehicle, and the sole purpose of the internal combustion motor is to recharge the battery pack of the EV. Therefore, ER-EVs must be restored from the power grid and refueled at a petrol station.

8. Charging Modes and Levels

In general, EV chargers can be classified as indoor and outdoor chargers, as well as one-way and two-way EV chargers. Figure 6 shows the types of charging technologies for EVs, which are generally divided into the following three categories [46]:

- Conductive charging
- Battery swapping [47]
- Wireless charging

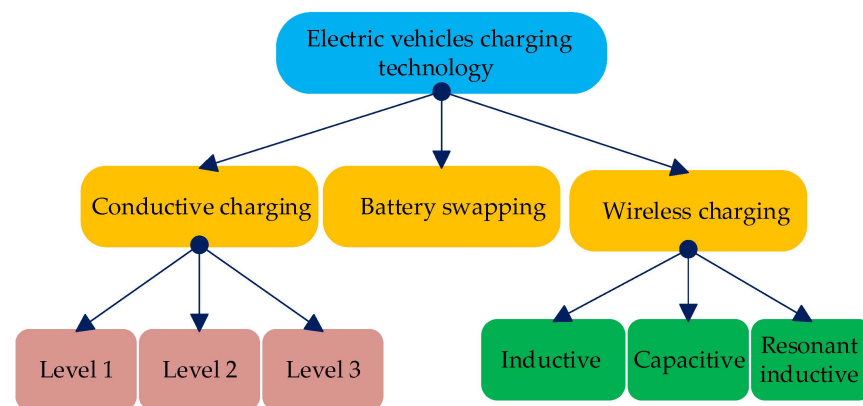


Figure 6. Three categories of technology related to EV charging.

In conductive charging technology, contacts replace wires and cables, and the term conductive wireless charging may also be used for this technology. Generally, the charging infrastructure, in the form of a board or rail, delivers electricity to a charging device equipped with a suitable receiver. Power transfer takes place when the infrastructure detects a valid receiver [48]. EVs can exchange their discharged batteries with a charged battery through battery exchange stations. Battery swapping is mainly used in electric forklifts. In general, there are two charging methods in EV charging stations with the conductive charging method:

- AC chargers or internal chargers
- DC chargers or external chargers

Unlike internal chargers, DC chargers have high flexibility in power levels, which allows charging the battery from 0 to 80% in only 20 min. However, this number may vary, depending on the condition of the battery and the quality of the EV. The AC method to charge EVs must be connected to a power outlet. Charging EVs with this method takes longer, unlike the DC method, and requires EVs to be equipped with an internal charging unit, which increases the weight of EVs.

Finally, in the description of wireless charging systems, it should be mentioned that these systems are located around cities and in the parking lots of EV owners. With the advent of wireless charging technologies, there is no longer a need to connect EVs to charging via cables—drivers park on a coil buried in the ground or placed on the floor. Conductive charging involves an electrical connection between the charging input and the vehicle, which follows three charging levels: Level 1, Level 2, and Level 3. In Table 4, the characteristics of these three levels are examined.

Table 4. Comparison of parameters related to different charging levels of EVs [49–53].

Characteristics	Level 1	Level 2	Level 3
Charging power	1.44–1.9 kW	3.1–19.2 kW	120–240 kW
Charging station type	AC charging station	AC charging station	DC charging station
AC supply voltage	Single phase-120/230 V	Split phase-208/240 V	Single phase-300/600 V
Current	12 to 16 A	15 to 80 A	400 A
Charging time	200 KM: ± 20 h	200 KM: ± 5 h	80% of 200 KM: ± 30 min
Charge location	Residential	Private and commercial	commercial
Standard	SAEJ1772, IEC62196-2 IEC61851-22/23, GB/T202343-2	IEC61851-23/24, IEC62196-3	IEC62196, SAEJ2836/2&J2847/2
Battery capacity	15–50 kW	15–50 kW	15–50 kW
Charge type	Onboard-slow charging	Onboard-semi fast charging	Off-board charger fast charging
Description	Opportunity charger	Primary dedicated charger	Commercial fast charger

Level 1 and 2 charging use AC power. Level 3 charging uses DC power. The easiest way to charge an EV is to use standard wall outlets at home. Most cars have a tow cord that plugs into wall outlets. This method is called Level 1 charging, and although the process is not very fast, it is the cheapest way to charge the car battery. Through Level 1 charging, it takes an average of 16 to 20 h to charge an empty battery fully. In Level 1 charging, it is better to charge EVs at night to save time. Level 2 charging is usually done via 240 V devices, and it cuts the waiting time in half. This method is fast to charge the car, but 240 V sockets are rare. Therefore, users should be able to quickly charge EV batteries at home by installing a charging station in a regular outlet. Usually, commercial charging stations all work with Level 2 charging. This charger can fully charge EV motor batteries in about 8–12 h. In Level 3 charging, EV batteries are connected to a 480 V station. At Level 3 charging, 0 to 80% of EV batteries are charged within 20 to 30 min. Stations that offer this service have large charging devices with unique plugs that connect to vehicles. Setting Level 3 is the fastest way to charge EV batteries, but this device is only available at a station.

Wireless charging is divided into three categories, which are:

- Inductive
- Capacitive
- Resonant inductive

Inductive charging uses electromagnetic induction to power EV batteries. EVs can be placed near a charging station or induction pad, without requiring precise alignment or making electrical contact with a dock or plug. Resonance charging is a method that is used in short distances (3–5 m); this method is generally used when more energy is needed. In this paper, we focus on the application of resonant charging to power the EV battery. In this method, parking and the EV are equipped with copper coils. A parking lot contains a transmitter, while an EV is equipped with a receiver. The transmitter supplies the room with a non-radioactive magnetic field. It regulates the power transmission field and creates a strong correlation between the transmitter and the receiver unit, thereby delivering the charge to the EV battery. The operation of wireless capacitor charging that works in the frequency range of 100 to 600 m is based on the displacement current created by the changes in the electric field caused by the electric charge. Coupling capacitors are used here for wireless power transmission. AC voltage increases efficiency in the first stage, reducing transmission losses and maintaining voltage levels. This AC voltage creates a sinusoidal electric field and, through electrostatics, leads to a displacement current in the receiver scale. In addition, factors such as frequency, voltage, and air gap between the transmitter and receiver influence the amount of electrical energy transfer.

9. Review of EV Power Converters

As shown in Figure 7, this section examines the three primary power converters in an EV, which are:

- On-board charger
- Battery converter
- Auxiliary battery converter motor

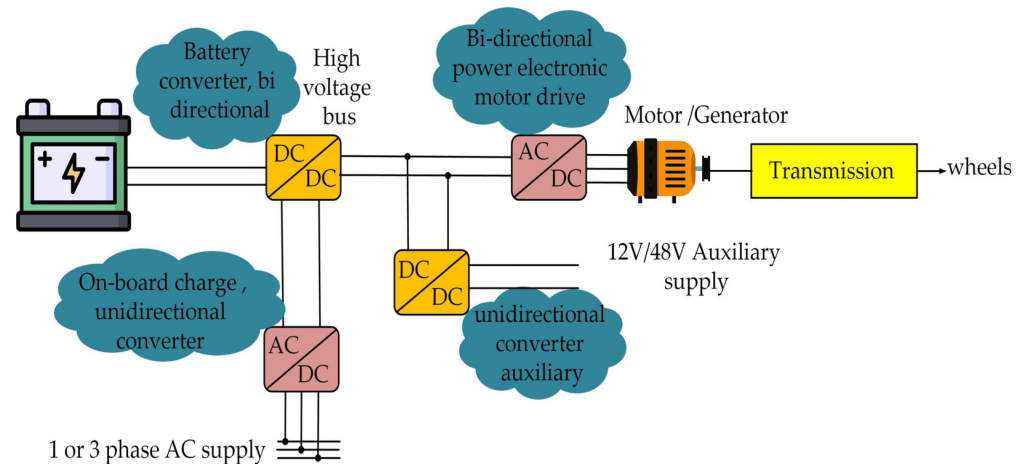


Figure 7. Block diagram of main converters of EVs.

Table 5 compares the isolation, AC or DC, and direction of these four primary converters. An EV uses a central DC bus to exchange power between various electrical components, called a high voltage bus. The on-board charger is responsible for converting the AC to the main DC path of traction batteries.

Table 5. Checking isolation, direction and AC, DC power converters of EVs.

Converter	AC & DC	Being Isolated	Direction
on-board	AC-DC	Isolated	One-way
Battery converter	DC-DC	Isolated	two-way
Drive motor	DC-AC	Isolated	two-way
Auxiliary battery converter motor	DC-DC	Isolated	One-way

Hence, it is an AC-to-DC converter [54]. Therefore, the battery converter is responsible for charging and discharging the batteries by drawing or giving voltage from the high-voltage path. The battery converter is a bidirectional DC-to-DC converter. In the same way, the auxiliary battery converter helps to charge this battery by taking power from the DC voltage path. Finally, the motor drive is a DC-to-AC converter that controls the AC motor. In addition, the injection of energy into the motor leads to movement and acts as a one-way AC to DC converter when braking the vehicle. (If the motor is DC, the motor drive can be a DC to DC converter.) One thing to note is that the internal charger and battery converter must be isolated for safety reasons. Additionally, the battery converter and motor drive must be bi-directional.

Next we take a deeper look at the multi-directional flow of power converters in EVs. Every EV must have the ability to drive forward and brake in this mode, as well as the ability to move in the opposite direction and brake [55]. According to Table 6, the process in the first part is when the polarity of the torque and the motor speed is positive, leading to the motor's forward movement. In the second part, the motor has positive speed polarity and negative torque polarity. This is when the wheels are moving forward, but the torque is in the opposite direction, resulting in braking and deceleration of the vehicle. In the third

part, the speed and torque of the motor both have negative polarity, which will result in movement in the opposite direction. Finally, in the fourth part, the polarity of the torque has a positive value, and the polarity of the speed has a negative value, which causes braking and reduces the car's speed on the opposite side. Moreover, if you use a DC motor and a DC electric drive, you can generalize the amount of torque, the direction of which depends on the amount of current and its conductance. Similarly, the speed of rotation and its approach depend on the amount of voltage and its polarity. Therefore, a motor driver is required to maintain the motor current and voltage to control the motor torque and process. EVs mostly use AC motors to manage rather than DC motors. The torque, speed, voltage, and current of each of these four parts are compared in Table 6.

Table 6. Comparison of torque, speed, voltage, and current related to the movements of EVs.

Section	Current	Voltage	Speed	Torque
One	+	+	+	+
Two	−	+	+	−
Three	−	−	−	−
Four	+	−	−	+

10. Examining the Integration of EVs with the Power Grid

Recently, the participation of transportation sectors with electric facilities has led to the emergence of challenges in electric energy systems. In addition to these challenges, EVs also have significant benefits for power grids, as shown in Figure 8. The key part of EV battery charging is EV network integration. EVs may play an essential role in harmonic reduction, reactive power supply, peak demand correction, etc. In general, for the widespread integration of EVs with the power grid, the existence of a regulatory organization that specializes in the field of EV aggregators is required. As in Section 3, it was mentioned that EV aggregators generally categorize EVs intending to maximize business opportunities in the electricity industry based on the preferences of EV owners. Of course, EVs alone cannot help the electricity industry, and their effect on the electricity industry is minimal. Yet, if EVs are combined with accumulators, they can significantly affect the electricity industry [56]. Climate change has recently led to adverse environmental and sustainability effects. Therefore, the tendency to use a combination of electrical energy systems, such as cooling, heating, and electricity, has increased dramatically [57]. Integrating electrical energy systems allows several components to meet different needs simultaneously. Thus, the penetration of EVs in integrated energy systems is essential because changes in electric load lead to changes in the performance of energy conversion systems, such as electric motors and boilers. In reference [58], as in the previous sections, EVs can be used as energy storage to balance the supply and demand curve in integrated energy systems. In [59], the authors have investigated the penetration effect of EVs in integrated energy systems of electricity and heat regionally.

10.1. Investigating Electrical Energy Systems with Penetration Systems with EVs

Extensive developments in the field of V2G promise unprecedented improvements in operational efficiency, which leads to the provision of conditions for prosumer and consumer participation in the energy business. Consumers equipped with rooftop solar power systems can emerge as EV-prosumers and self-supply during peak periods or power outages using Vehicle-to-home (V2H) integration [60]. The emergence of EVs will play an essential role in future power grids, as energy consumers and producers are called investors [61]. One of the main goals of this article is to focus on the potential role of EVs in facilitating the integration of electric energy systems with renewable energy sources. Smart grids will help operate electrical energy systems by using topologies of communication, control, and power electronics, as well as technologies related to electrical energy storage,

to balance production and consumption at all levels. The presence of EVs in renewable energy sources will lead to EVs absorbing additional energy related to renewable energy sources and using this absorbed energy for transportation. In addition, if EVs are integrated into energy systems, attention should be paid to the energy sources of the networks that are examined for charging EVs. As shown in Figure 9, the charging of EVs may be done from the primary power grid or the distributed energy source (renewable or non-renewable energy sources). In Figure 10, the penetration of EVs in six different networks is shown, and in the following sections, the penetration of EVs in these six networks is studied for the smart charging of EVs [62].

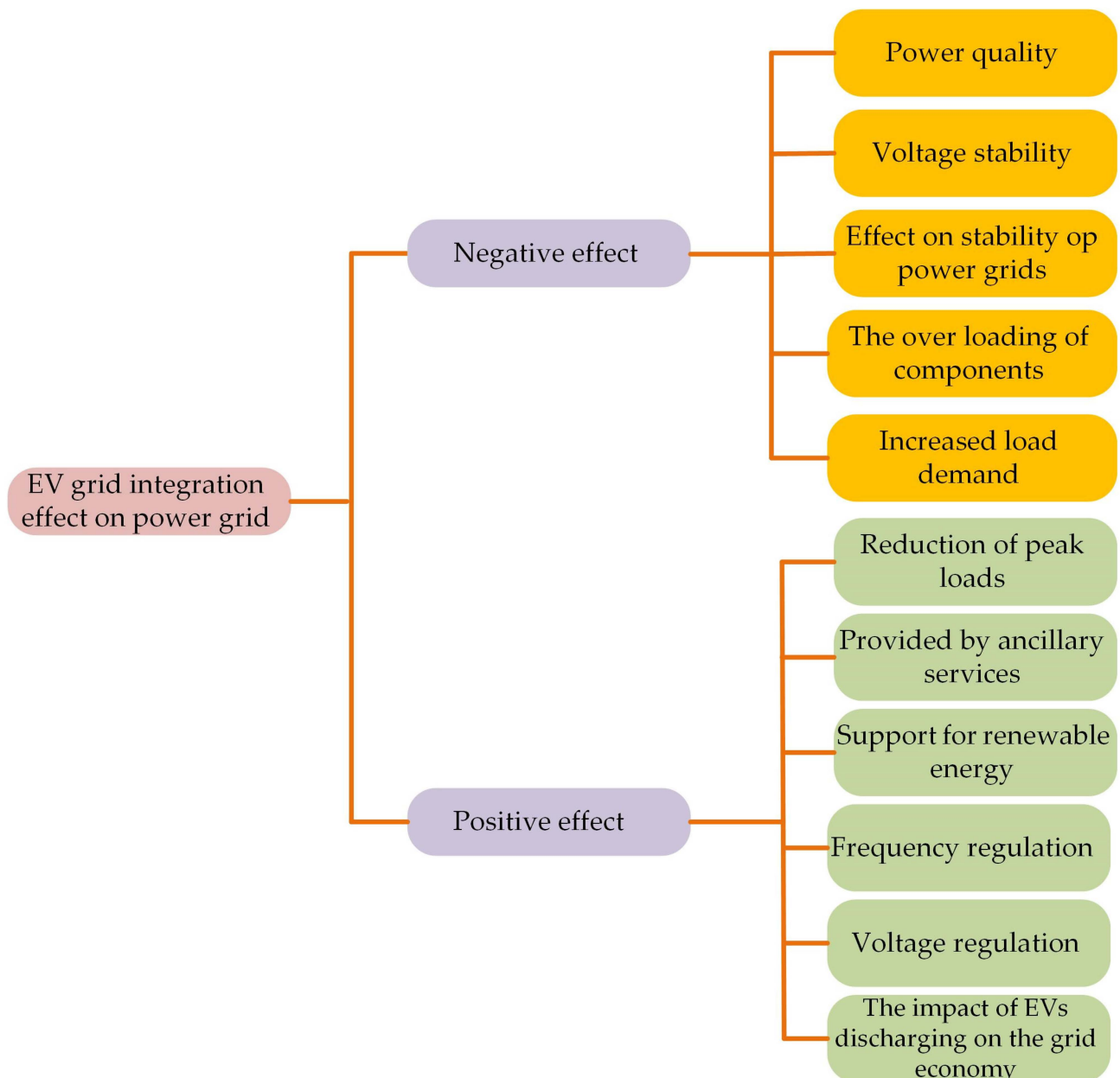


Figure 8. Examining the positive and negative effects of EVs when integrated with the power grid.

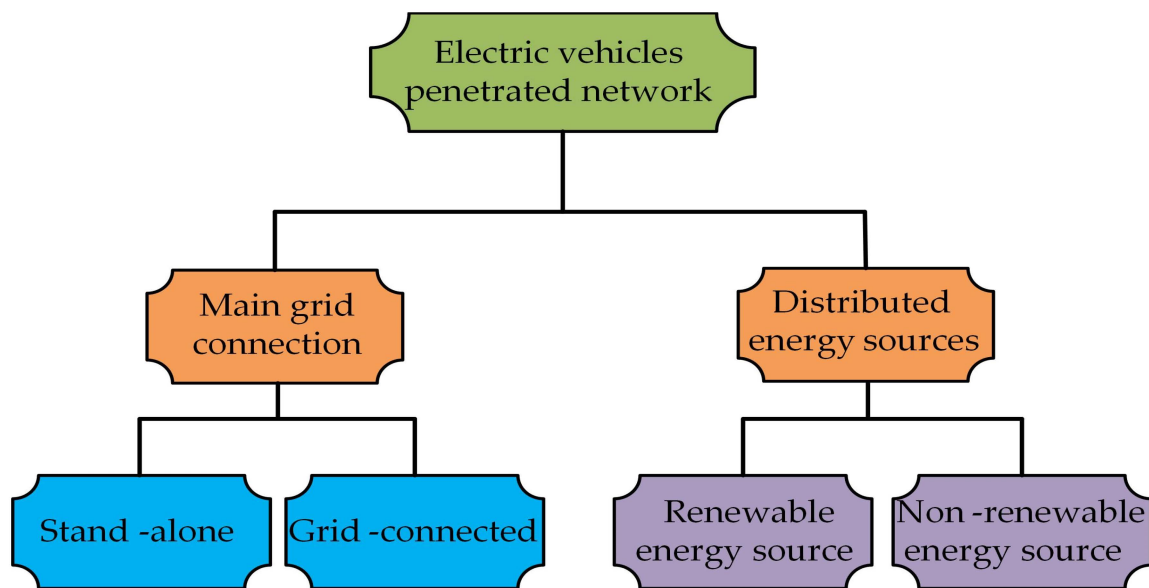


Figure 9. Penetration of EVs in main power grids and distributed energy sources.

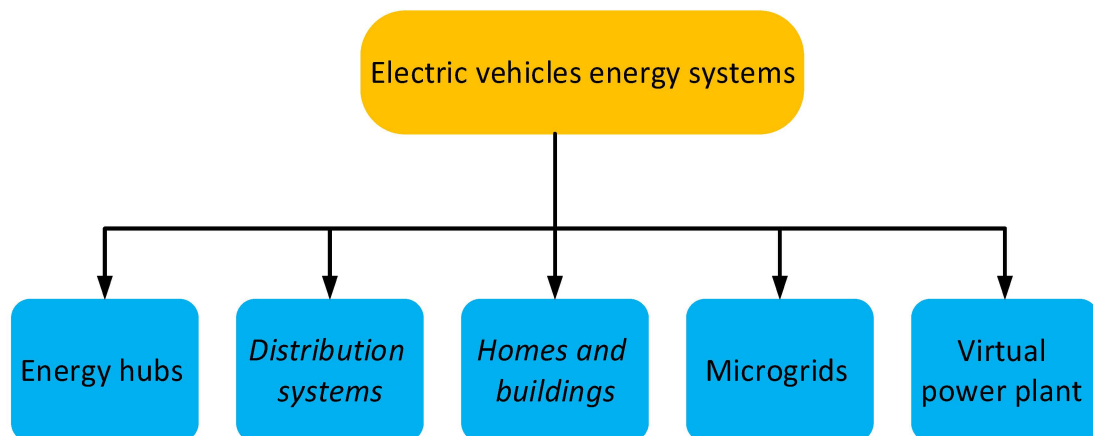


Figure 10. EV penetrated energy system.

10.1.1. Distribution Systems

The recent emergence and integration of EVs has led to significant progress in green transportation. In general, EVs are targeted as emerging large loads in the power industry. As mentioned in the previous sections, in addition to the fact that EVs can be used as a source of energy storage and provide the amount of energy needed by the power grid and subscribers, they will be able to act as a distributed energy unit [63]. In this situation, EVs can support the stability, reliability, and flexibility of the electricity distribution network if necessary. In reference [64], the authors conducted studies on the integration of parking lots with high penetration of EVs with distribution systems. In the research project [65], EV parking lots in distribution systems benefit from selective participation in price-based load response programs. The studies carried out in reference [66] show that EVs are integrated with off-grid distribution systems to create a two-way smart charging environment. Bharati et al. in reference [67] present an optimal framework for coordinating EVs in a distribution system, using two-level V2G hierarchical optimization. The necessity of implementing the proposed framework is the possibility of information exchange between EV collectors and the network controller. Finally, EV charging is planned and managed based on minimum losses in the distribution network.

10.1.2. Microgrids

Energy managers are diversifying their production mix by adding significant amounts of renewable energy sources to reduce consumers' dependence on fossil fuels. Therefore, this category of intermittent generating of sources in the form of micro generators is called a microgrid [68]. Microgrids support EVs for smart charging to increase reliability, optimal management of energy consumption, and economic aspects. In reference [69], the authors introduce renewable energy sources and EVs as an essential solution for managing energy consumption, reducing costs, and reducing environmental effects in microgrid systems. Moreover, in reference [70], to increase the profits of EV owners and reduce operating costs, the integration of EVs with microgrids is analyzed once in a grid-independent mode and again in a grid-connected manner. In reference [71], researchers conducted extensive studies on the incentive schemes that EV owners receive in exchange for participating in microgrid demand response programs. Finally, in reference [72], extensive research was done to design hybrid island systems, such as EV parking and energy storage, to minimize operational and construction costs by considering various uncertainties. In this research, we concluded that EV parking significantly reduced the costs associated with installing energy storage.

10.1.3. Homes and Buildings

Many EVs will be linked to homes or other structures in the upcoming years; hence, they may be charged using the main network or distributed energy systems. Further, by charging and discharging at the correct times, EVs reduce peak demand and the electricity bill of smart homes. With the optimal performance of EVs, the overall efficiency of smart homes and smart networks is optimized. The authors in reference [73] conducted extensive research on the integration of EVs with houses equipped with wind turbines, energy storage, and combined heat and power generators to optimize energy consumption management. In references [74,75], Wang et al. conducted extensive studies on integrating smart buildings with PHEVs. The overall goal of combining these two emerging technologies is to increase the reliability of the power supply and optimal management of energy consumption [76,77].

10.1.4. Energy Hubs

In recent years, the study of multi-carrier energy systems with the ability to transfer, convert, and store different carriers under the title of "Energy Hub" has received much attention from researchers [76]. The penetration of EVs in energy hubs requires optimal energy consumption management plans because this penetration may upset the demand balance in such systems. In reference [78], the authors conducted studies on energy consumption management of energy hubs. In addition, in reference [79], studies were done on reducing the purchase cost and tax of building an energy hub integrated with EVs. Finally, in reference [80], researchers discussed the energy consumption management of an energy hub unit combined with an EV for optimal establishment of operational costs; considering thermal loads and flexible power, they did extensive research.

10.1.5. Virtual Power Plant

A virtual power plant is a network of decentralized and medium-scale power generation units, power consumers, and flexible storage systems [81]. Several EVs may, in addition to appearing in the role of large-scale energy storage, also have the possibility of receiving the energy needed for transportation and improving the economic performance of the virtual power plant. In [82], the role of EVs in improving the frequency response of virtual power plants is investigated. Moreover, in reference [82], the impact of EVs on the power storage of virtual power plants was investigated. In references [83–85], wind turbines are integrated with EVs as a virtual power plant. Finally, in order to improve the CO₂ emission of virtual power plants, the role of intelligent charging and discharging of EVs was investigated in reference [86].

the overloads of transformers. Coordinated charging happens when the charging operation of EVs is not at peak load and the network load is at its lowest [87].

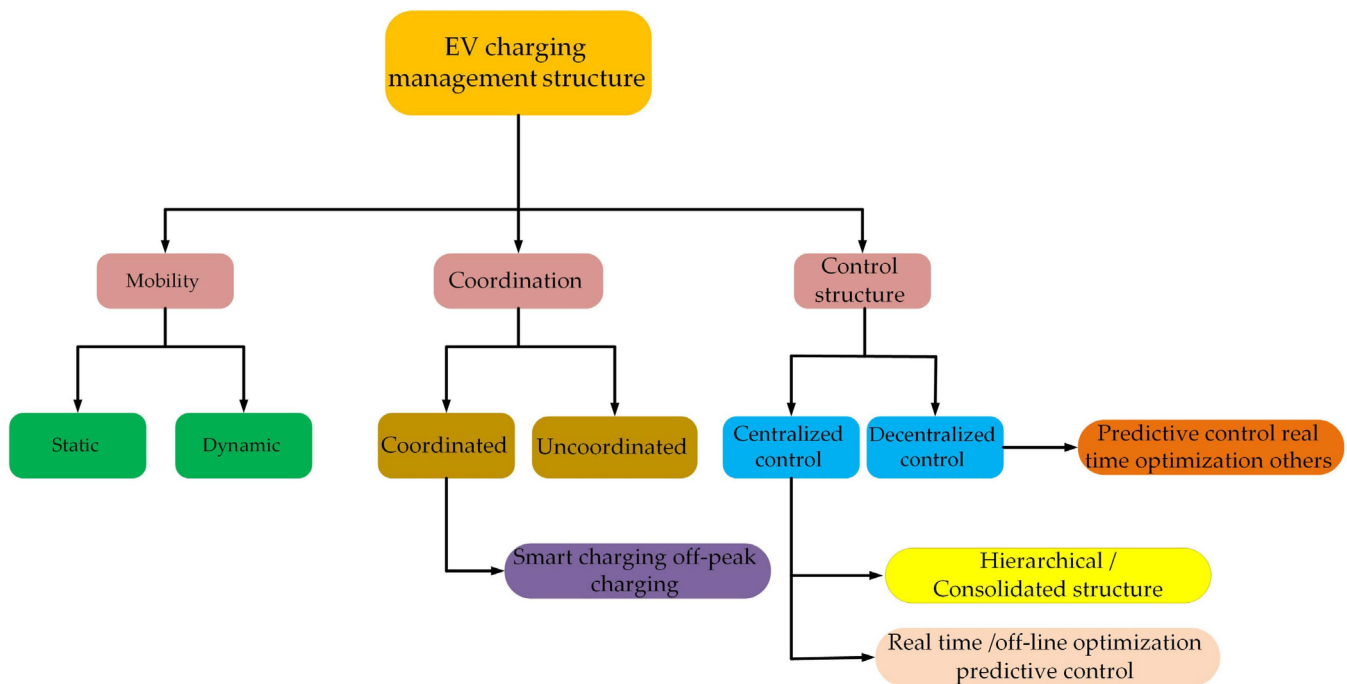


Figure 12. Classification of different control strategies related to EV charging systems.

Considering the mobility of EVs, it is possible to use fixed and dynamic charging infrastructure for EVs. Stationary charging stations allow EV owners to charge their EVs while parked. However, the dynamic charging topology, or mobility-aware technology, is familiar with various movements, for example, the unplanned entry and exit of EVs, which will be more realistic due to the spatial-temporal relationship between EVs. Therefore, these issues have become more complex and should be accompanied by more advanced control infrastructures [88].

In examining the control structure, it should be pointed out that EV charging stations are spatially distributed through a distribution network. Furthermore, the power distribution of EV charging stations may be controlled by methods such as centralized and decentralized charging [89].

11.1.1. Centralized Control Method

By definition, in a centralized charging cycle, a key controller determines the timing and charging rate of EVs. The structure of centralized charging is such that the information is processed centrally. Finally, an optimal method is presented, taking into account EV owners' preferences and the power grid's limitations. Usually, centralized charging should be limited according to the size of the optimization problem, and it will increase if there are many EVs in an area. Control architectures have recently been presented to solve the mentioned problem, which can separate the loads related to EVs according to their geographical location. Each category has its local controllers, which are responsible for their EV management's distributed power. Yet, this is different in the central controller, which only manages the group's demand [90].

11.1.2. Decentralized Control Method

In the decentralized control method, EV owners are guaranteed an optimal charging process when deciding on their charging patterns [91]. However, EV loads can be matched

with the grid rules, with the correct acceptance and implementation of electricity tariff mechanisms and EV owners' responsibility, as shown in Figure 13.

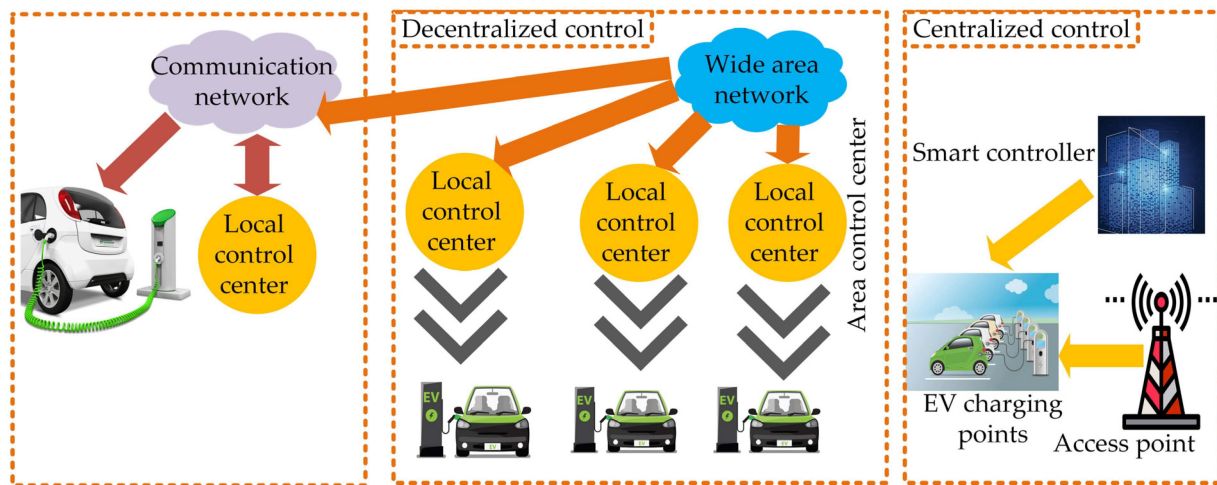


Figure 13. An example of an EV charging system with Centralized control and decentralized control.

12. Incentive Policies and Plans

In general, policies and incentive plans for EVs are highly dependent on the current state of EVs. To accelerate the use of EVs, the laws related to EVs and charging stations should be fully and quickly implemented. In general, most of the policies and incentive schemes provided by the government to users are based on tax exemptions and credits, reduction of unit costs, and access to essential points for parking. These incentive plans determine the functional role, specific goals, and objectives of the electricity industry in accelerating the acceptance of the benefits of EVs for users and the replacement of internal combustion vehicles with EVs. Some of these policies are as follows:

- Around the world, in some cities, old cars with high emissions are not allowed to drive. Even in some cities around the world, due to air pollution, there are strategies, such as car traffic on even and odd days, where EVs are exempt from this law and can travel throughout the city on all days of the week.
- Incentive schemes, such as public charging stations where users can charge their EVs, may be placed by the municipality in the city.
- With a travel ban for internal combustion vehicles likely in coming years, EVs will be significantly more attractive than their competitors.

13. Conclusions

With the increasing use of electric vehicles, the need to analyze and develop charging technology and power converters to provide a flexible charging environment with high reliability and economy for EV batteries is felt increasingly. In addition, it is expected that increased grid integration and technological advancements, such as smart charging infrastructure and coordinated charging systems for EVs, will be made to achieve maximum efficiency. This study has conducted extensive research on EV charger technologies, the description of international EV charging standards, and the analysis of IEC and SAE application standards. Furthermore, the types of electric cars and their penetration in six different energy system models have been investigated. In this paper, the authors have conducted studies on power converters for EV charging systems based on AC-DC, DC-DC, and the performance of EV accumulators. Moreover, this research work has thoroughly explored different levels and models of EV charging. Table 4 analyzes these three levels in terms of current, charging time, charging location, alternating voltage power source, charging power, battery capacity, standard, and charging (Onboard and Off-board). Due to the widespread use of electric vehicles in the future and as a result of the wide band

gap, the use of semiconductor devices and noise filters will significantly increase the ability to control the power of converters. In addition, some new techniques to improve power quality and grid stability should be applied for widespread EV charging.

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