Review of Technologies, Charging Methods, Standards, and Optimization Techniques for Electric Vehicles

A. Srilatha[1]
Assistant Professor
Electrical & Electronics Engineering,
Vidya Jyothi Instuite of Technology
Hyderabad

K.Satish Kumar[2]
Assistant Professor
Electrical & Electronics Engineering,
Vidya Jyothi Instuite of Technology
Hyderabad

Abstract

This article provides an up-to-date analysis of electric vehicle technology, charging procedures, industry standards, and optimization approaches. The important characteristics of Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) are discussed. After that, recent findings on EV charging techniques such as Battery Swap Station (BSS), Wireless Power Transfer (WPT), and Conductive Charging (CC) are discussed. The discussion of EV standards, including charging rates and their configurations, follows next. The most popular optimization methods for determining the size and location of EV charging stations are then examined. Finally, based on the insights gained, several recommendations are put forward for future research.

Keywords: *electric vehicle; hybrid electric vehicle; EV charging; EV standards; optimization*

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1. Introduction

Five major global trends are driving rapid growth in electric vehicles (EVs):

i) Fossil fuel depletion and subsequent increase in fuel prices; (ii) more people are becoming aware of and want to fight climate change; (iii) technological advancements and the viability of renewable energy technologies commercially; (iv) the development of electric motors and electronic steering systems for use in electric vehicle propulsion; and (v) EV support technologies, such as Grid-to-Vehicle (G2V) and Vehicle-to-Grid, have advanced (V2G)

Fossil fuels are under pressure globally, thus the majority of nations are turning to sustainable, dependable, efficient, economical, and environmentally friendly energy sources. Due to their significant contribution to CO2 emissions, fossil fuels constitute one of the biggest risks to the ecosystem on Earth. Figure 1 shows the percentage contribution of CO_2 emissions by the (i) electricity and heat sector, (ii) transportation sector, (iii) industry sector, (iv) residential sector, and (v) other areas, according to the International Energy Agency [1].

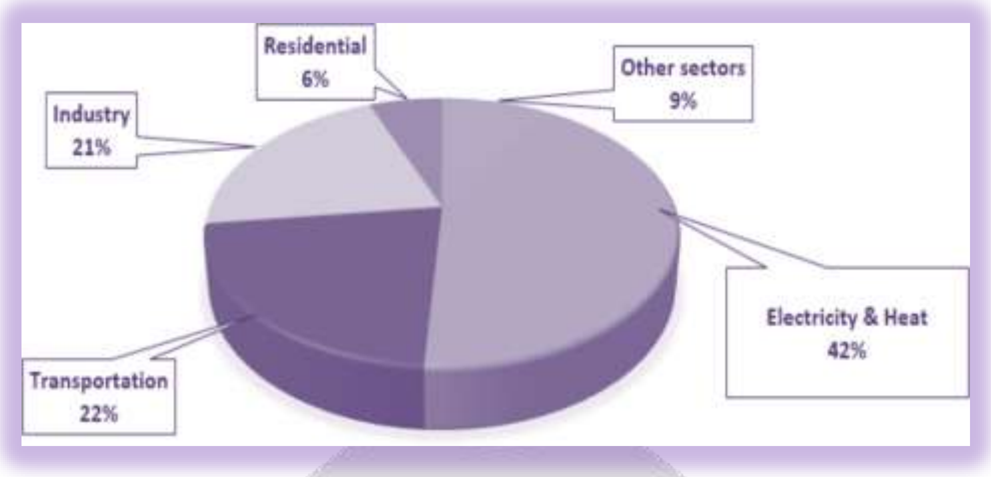


Figure 1. CO_2 emissions by different sectors.

Transportation is one of the major emitting industries, accounting for 22% of all CO2 emissions in 2020 [1]. Internal combustion engines power the majority of public and private vehicles (ICE), It is one of the primary factors contributing to climate change. EVs, on the other hand, don't directly release CO2 and are less vulnerable to rising oil prices.

To overcome the global emissions problem, most electric utility industries should move towards renewable resources, e.g., wind, solar, and wave/tidal. Less than 1% of the U.S.'s electricity was produced by PV-based energy in 2015. Nevertheless, solar energy production will increase due to falling PV panel costs. According to projections, solar energy could supply 30% of the country's energy needs by 2050 and close to 15% by 2030 [3,4].

The social and economic advantages in the transportation and energy sectors have expanded due to the development of EV technology. Despite these advantages, there are restrictions on battery technology, including weight, longevity, and storage capacity, as well as high battery costs. [5,6] are still the major hindrances to the broad acceptance of EVs. However, numerous organisations, businesses, and nations involved in the automobile industry are spending money on EV battery research and development. For instance, Google invested $10 million and the US government $2 billion in the creation of an electric vehicle battery [2,6,7].

This review study examines current EV technologies in relation to various charging protocols and industry norms. The paper's major contributions are its in-depth analysis and discussion of EV and related technologies, including:

1.Charging standards as defined by the Society of the Automotive Engineers (SAE);
2. On-board and off-board electric vehicle charging systems, and
3. Optimization methods for designing and positioning EV charging stations under various restrictions and goals.

2.Vehicle Technology

The primary problem with ICE vehicles is the usage of fossil fuels and the increase in fuel prices, which results in two issues: energy safety and environmental CO2 emissions. Considering the pressure on fossil fuels and the rise in CO2 emissions, EVs lessen transportation's dependency on crude oil and lower greenhouse gas emissions (GHG).

As seen in Figure 2, the four basic categories [8,9] of vehicle technology are normally ordered from left to right, increasing the electrification. Petrol or diesel fuel, which are the principal sources of carbon radiation in the atmosphere, is used to power conventional vehicles. As a result, a hybrid's carbon emission rate is lower than that of vehicles powered by traditional internal combustion engines. The third and fourth categories, which rely on batteries and hydrogen fuel cells respectively, are also referred to as zero-emission vehicles (measured at the exhaust). The sections following will go into the specifics of the various technologies.

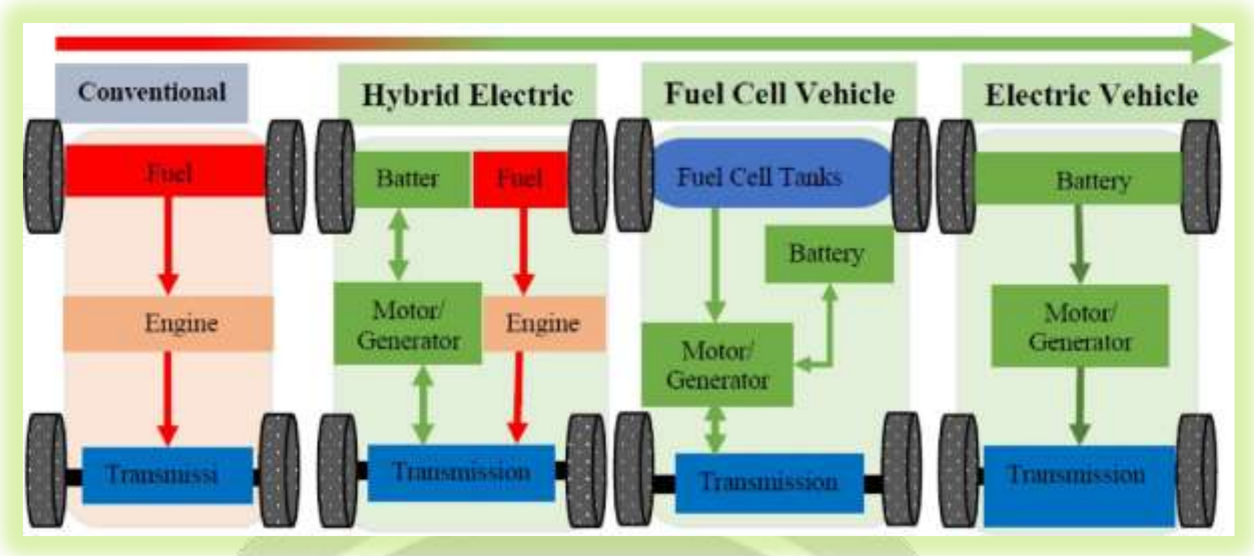


Figure 2. Electrification of Transportation.

2.1 Hybrid Electric Vehicle

A battery or an ICE engine may be the source of energy in hybrid electric vehicles (HEVs), which contain both an ICE engine and a battery that are used to power the vehicle. As a result, the HEV is also referred to as a vehicle with two power sources. Because the battery may be recharged by recapturing the vehicle's kinetic energy into the battery through regenerative braking, HEVs are superior for city driving. When travelling in cities, the car frequently starts and stops. HEVs are therefore preferable than country or highway travel for city driving. Since completely electric vehicles are still in the early stages of development, HEVs appear to be the most affordable option so far, at least for the next ten years[9]. The HEV makes the most energy-efficient use of the ICE engine and electric motor to reduce emissions. Improved fuel economy and performance, lower fuel costs, lower CO2 emissions, and the ability to recover some energy when braking are all benefits of HEVs. using a gas station already in place, The drawback of the battery is a higher starting cost. The drivetrain is made up of a number of parts that transmit energy from the vehicle's engine or battery to the wheels. HEV drivetrains are available in three types:i)series hybrid, (ii) parallel hybrid, and (iii) series-parallel hybrid [10,11]. The series drivetrain, which powers the electric motor, is the simplest design. In the parallel drivetrain, the ICE and motor work in parallel to generate power that moves the car. The motor draws power either from a generator run by a diesel/petrol engine or from the battery pack. The series-parallel hybrid, however, combines the complexity and benefits of both parallel and series drivetrains. A series-parallel hybrid is an example, such as the Toyota Prius. The series-parallel hybrid vehicle with a combustion engine, an electrical system, and a power split mechanism was employed by the authors in [12].

The controller uses the vehicle dynamics to obtain data on the motor, generator, brake, and acceleration speeds. The electrical component determines when to charge and discharge the battery by obtaining generator torque and motor torque from the controller. Regenerative braking is the process whereby the motor turns into a generator and begins to recharge the battery whenever the brakes are applied [13,14]. If not, the motor will draw power from the battery. A synchronous motor and drive, a synchronous generator and drive, a DC-DC converter, and a battery bank make up the electrical part.
The ICE obtains the throttle position from the controller used to regulate the amount of fuel or air entering the engine. The power split device is the brain of a hybrid vehicle that controls how the gasoline engine, generator, and electric motor work together. It allows the car to operate in series or parallel (independently, both the motor and ICE engine and both can power up the car) [13]. The vehicle dynamic provides vehicle speed which depends upon the vehicle body, road inclination, and wind resistance. Typical HEVs have four modes of operation [15].
The modes of operations are as follows:
i)Start and Low to Mid-range Speeds: When the vehicle is starting or travelling at low to mid-range speeds, the engine shuts off and the motor alone drives the car forward.
ii) Operating Under Normal Circumstances: The power split device transmits some power to run the generator and the remaining power is used to directly drive the wheels. If there is excess electricity, the battery gets charged with it.

iii)Sudden Acceleration: Both the battery and engine provide power during sudden acceleration.
iv)Deceleration: The high-performance battery stores the kinetic energy that is converted to electrical energy by the regenerative braking system.

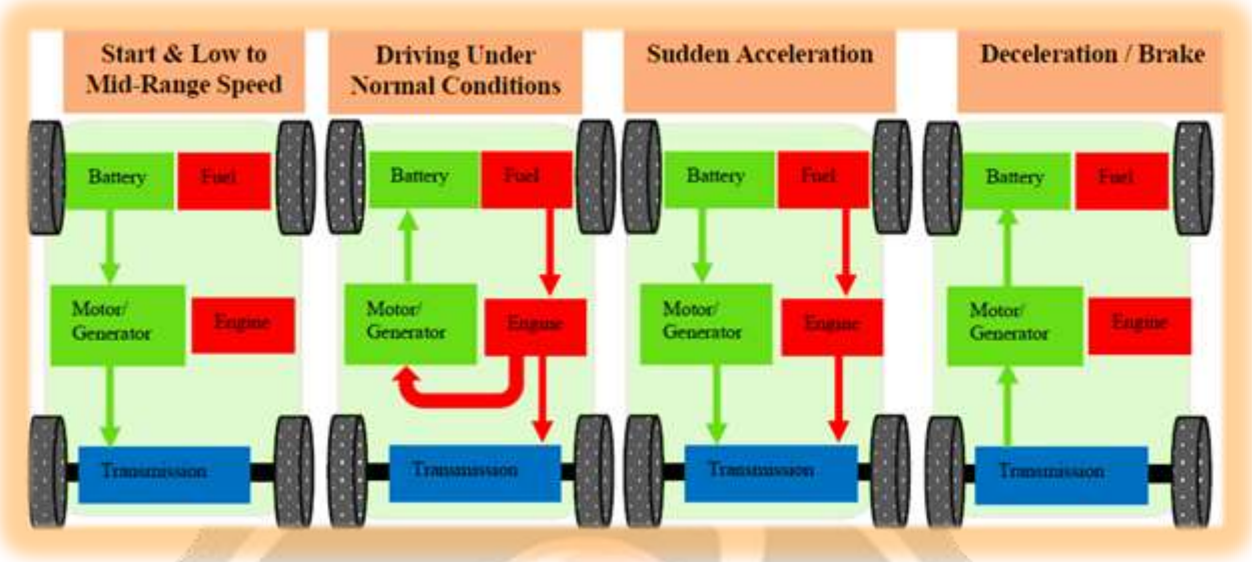


Figure 3. Hybrid Electric Vehicle mode of operations.

2..2 Electric Vehicle (EV)

The series-parallel hybrid was changed into a fully EV by the authors [16] because of the prospective advantages of EVs. This fully EV can use real EV movement data to forecast the State of Charge (SOC) of vehicles based on factors like road slope, vehicle weight, and wind resistance.
The only source of propulsion for a fully electric vehicle is a battery pack. Consequently, EVs are more effective at reducing global warming than HEVs. The EVs include a regenerative braking system that converts the kinetic energy of the vehicle back into electrical energy that can be stored in the battery and only uses the battery to power the motor that pushes the car. Consequently, EVs are superior for city driving since city driving frequently involves starting and stopping, which causes the vehicle to recuperate part of the kinetic energy into the battery. As seen in Figure 4, the EVs only have two modes of operation compared to regular HEVs:
i)All times: The battery powers the vehicle whenever it needs to move.
ii)Deceleration or Braking: Using regenerative technology, the vehicle recaptures the kinetic energy lost during acceleration or braking into the battery.

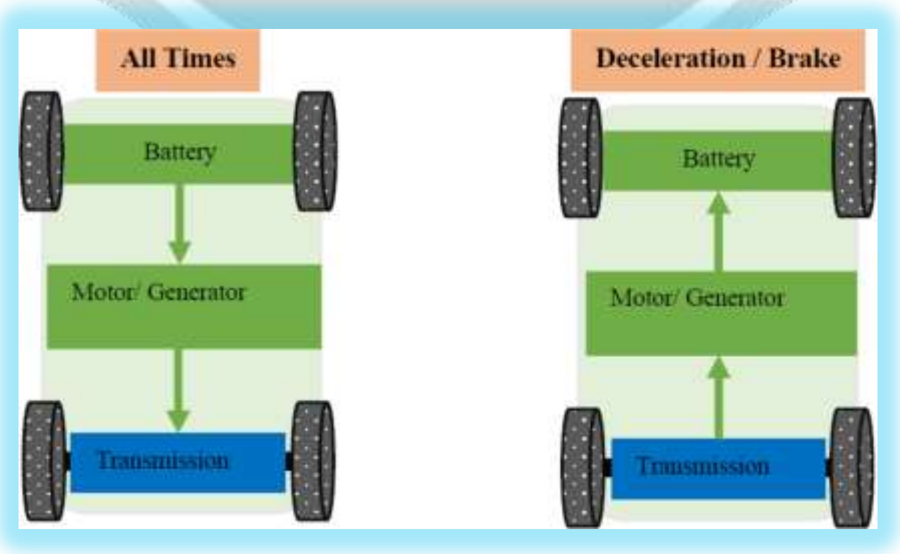


Figure 4. Electric Vehicle mode of operations.

2.3 Fuel Cell Electric Vehicle (FCEV)

Like electric vehicles (EVs), fuel cell electric vehicles (FCEVs) include an electric drivetrain; however, the fuel cell tank uses hydrogen as its energy source. As there are no emissions from the tailpipe, the car is regarded as zero-emission. The FCEV is divided into two categories based on the powertrain configuration, namely.

i)Fuel Cell Electric Vehicle.

ii)Fuel Cell Hybrid Electric Vehicle (FCHEV).

The typical powertrain configurations of FCEV and FCHEV are shown in Figure8

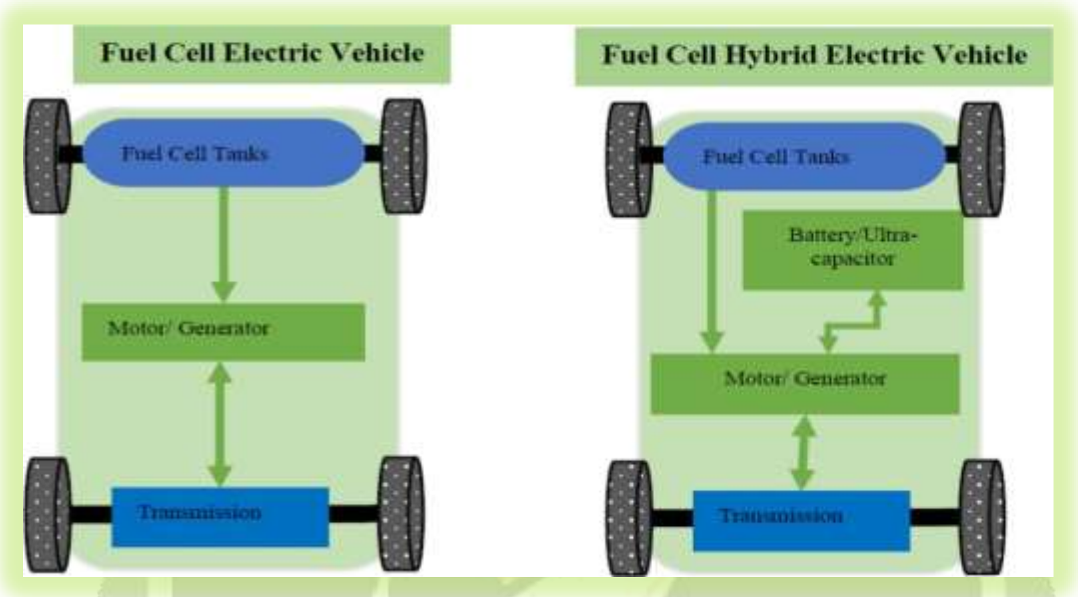


Figure 5. FCEV and FCHEV Powertrain configurations.

Buses, forklifts, trams, and other slow-moving, smooth-power-demand applications are all good choices for the FCEV [17]. Today, FCEV manufacturers like Hyundai, Toyota, and Honda use a variety of energy management approaches to create high-performance FCEV vehicles in terms of vehicle efficiency and fuel economy [18].

For high-speed operation, FCHEV adds an additional Energy Storage System (ESS) or ultracapacitor to the powertrain, which may be charged and discharged in accordance with the demand and supply of power for the vehicle. The primary energy source is a fuel cell tank, and an ESS or ultracapacitor is employed to provide a smooth and effective functioning [19]. The FCHEV's added weight as a result of the extra ESS or ultracapacitor in the powertrain is its only drawback.

3.EV Charging Methods

The three primary charging methods are battery exchange, wireless charging, and conductive charging. According to Figure 6, the conductive charging is further separated into pantograph (Bottom-up and Top-down) and overnight charging.

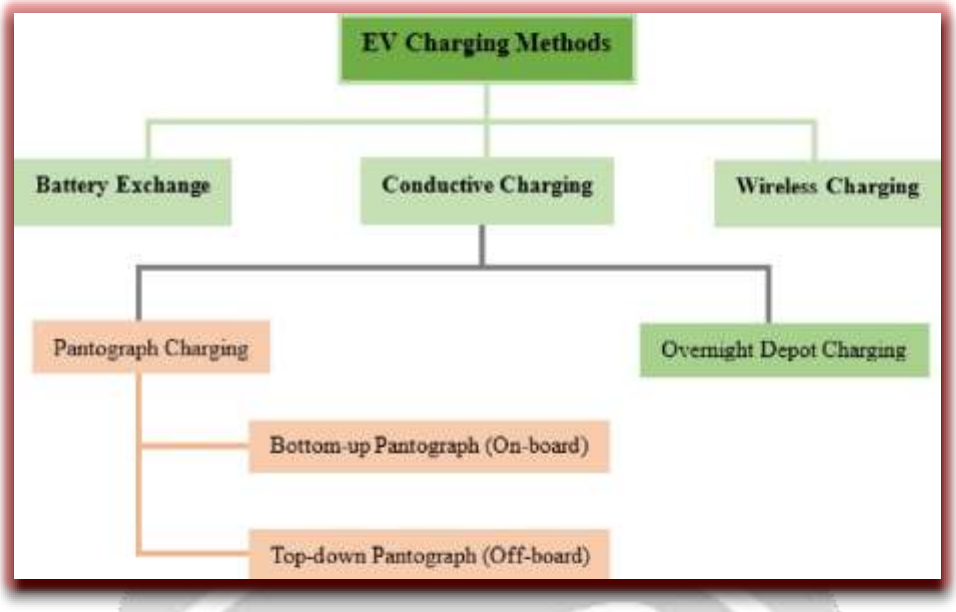


Figure 6. EV charging methods.

3.1 Battery Swap Station (BSS)

The "Battery Exchange" approach to battery switching is based on paying the BSS owner a monthly rent for the battery. The BSS's delayed charging technique contributes to a longer battery life [20]. The BSS system can more easily be integrated with locally produced Renewable Energy Sources (RESs), such as solar and wind. One of the key benefits of this technology is that the drivers may quickly replace the drained battery without having to exit the car. Additionally, the station's battery can take part in the V2G (vehicle-to-grid) effort [21,22].

However, because the BSS owner owns the EV batteries, this type of EV charging strategy may be more expensive than refueling the ICE engine due to the high monthly rental rates charged by the BSS owner. This method needs several expensive batteries and a sizable space to store them, which can need expensive real estate in a busy region. Additionally, the battery at the station might be a specific model, but the batteries in the vehicles might follow different specifications [23,24].

3.2 Wireless Power Transfer (WPT)

Two coils are used in this electromagnetic induction-based technology. The secondary coil is located inside the car, and the primary coil is placed on the road. WPT technology has recently attracted interest in EV applications due to its capacity to enable the EV to recharge conveniently and safely. Additionally, it can charge even while the car is moving and does not need a conventional connector (but does need a standard coupling technology) [25].

The air space between the transmitter and receiver coils should be between 20 and 100 cm for effective power transmission, as inductive power transfer is typically weak [26]. If the transmitter coil is not turned off, eddy current loss is another another problem in the WPT. Since real-time information transfer between the transmitter and the EV is required, communication latency is possible [27].

3.3 Conductive Charging (CC)

Conductive charging offers various charging capabilities, such as level 1, level 2, and level 3 charging, and has a high charging efficiency since it involves a direct electrical connection between the car and the charging input. For a public charging station, the two power charging levels (Level 2 and Level 3) are used. The distribution system is not as significantly affected by the first two levels (Levels 1 and 2).

Conductive charging offers a V2G facility, lowers grid loss, maintains voltage, prevents grid overloading, supports active power, and has the potential to compensate for reactive power by using the vehicle's battery [28,29].

Level 3 has a variety of effects on the distribution system, including voltage deviation [30], system dependability, and transfer/power loss. It impacts the transformer life in addition to raising peak demand [30, 31]. Additionally, a complicated infrastructure, restricted access to the power grid, and a uniform connector/charging level are required [41]. The V2G technology necessitates intense grid and vehicle connectivity. Additionally, because the battery is frequently charged and discharged during V2G operation, the battery's lifespan is decreased.

The two charging methods listed below are used for applications that demand bigger battery capacities and quick charging, like buses and trucks:

Overnight Depot Charging: Both slow and fast charging options are possible for the overnight station charging system. It serves as a night charging station and is often positioned at the end of the lines. Due to the low impact of delayed charging on the distribution grid, this makes it the best alternative [33,34]. However, the Pantograph charging technique is appropriate for applications requiring bigger battery capacities and rapid charging.

Pantograph Charging: One of the charging possibilities is this kind of charging. Applications with bigger battery capacities and power requirements, such buses and trucks, employ this type of charging infrastructure. Although the cost of the bus investment is reduced due to this charging method's lower investment in the bus battery, the cost of the charging infrastructure is increased [35]. The following two types further divide pantograph charging:

i)**Top-down Pantograph:** The charging system is referred to as an off-board top-down pantograph since it is installed on the bus stop's roof. The high power direct current provided by this technology has already been tested in Singapore, Germany, and the United States [36].

ii)**Bottom-up Pantograph:** This type of charging procedure is appropriate for uses where the bus already has the necessary charging hardware installed. An on-board bottom-up pantograph is another name for this [36].

4.Review of EV Charging Configurations, and Standards

This section explains EV charging configurations including on-board and off-board, charging standards like IEC and SAE, and the infrastructure and connectors for EV charging per nation.

4.1 EV Charging Configurations

Given that the average daily driving distance in the US is less than 100 miles [37], charge anxiety is a more important problem than range anxiety. To combat the charge anxiety, the off-board charger is a superior solution because it generally gives higher kW transfer and removes weight from the car. The term "off-board charger" refers to a charger that powers the EV battery pack with DC power while being located outside of the car. Figure 7 representation of the off-board EV charging system [38] demonstrates how SAE levels 1 and 2 and IEC mode 4 are used.

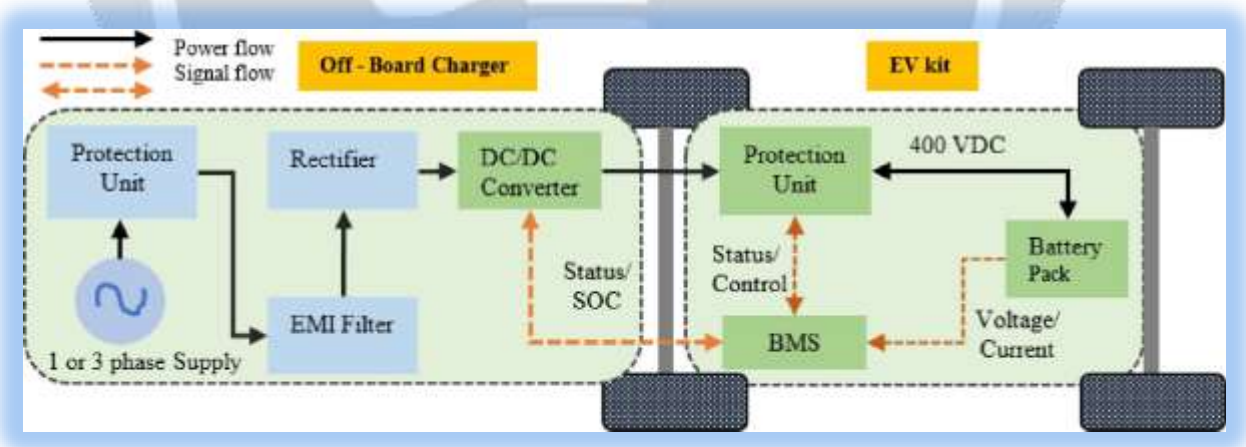


Figure 7. EV charging configuration for off-board (DC Levels 1 and 2 or Mode 4).

On the other hand, on-board charging weighs the vehicle down and provides a lower kW transfer. Single-phase on-board chargers can only transfer a limited amount of high power due to weight, space, and cost restrictions [39,40]. In comparison to off-board charging, it requires more time to charge. Figure 8 illustrates the EV charging arrangement for AC (Modes 1 and 2 and Level 1 and 2, respectively, for IEC and SAE standard) requirements with on-board charger [41,42].

The IEC and SAE suggested AC and DC charging standards for the US and EU in [43] while taking into account voltage levels, current, etc. due to the rise in electric vehicles (EVs) (see Table 1). In the following subsection, the specifics are further detailed.

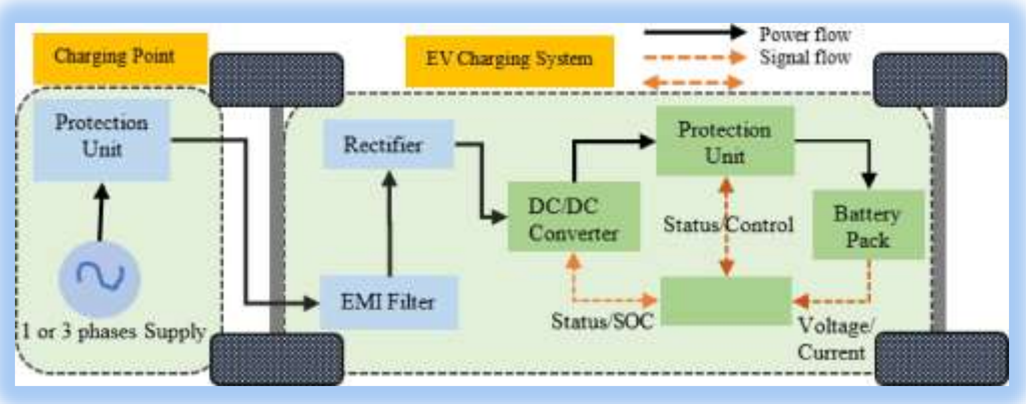
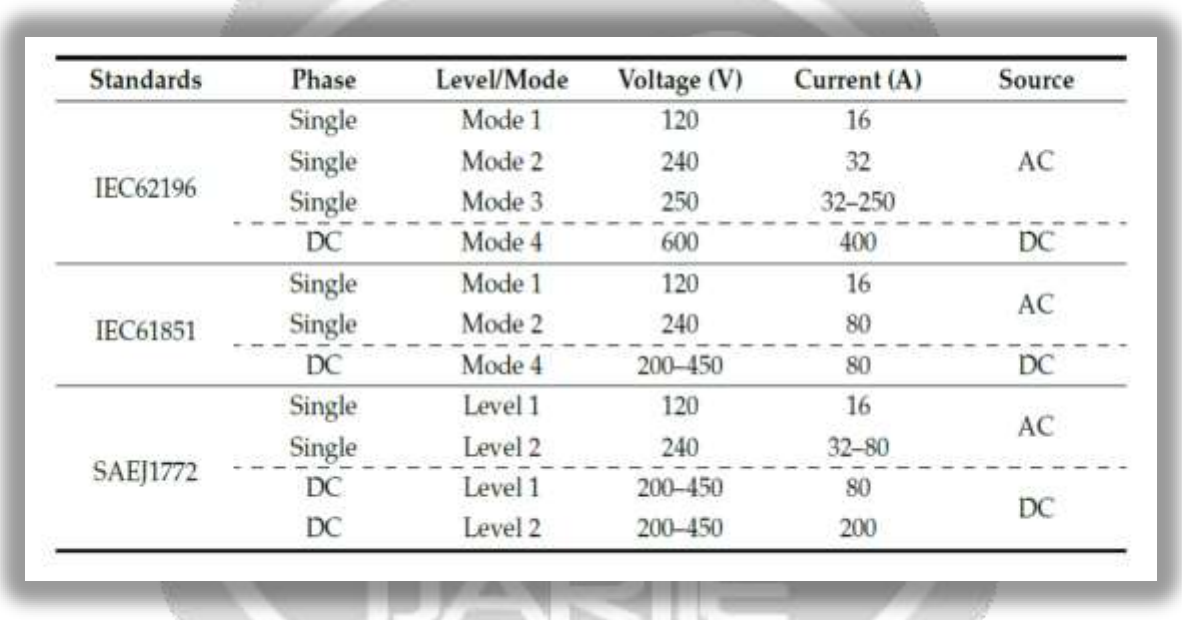


Figure 8. EV charging configuration for on-board (AC Levels 1 and 2).

Table 1. IEC and SAE standards: Current and voltage level for AC and DC charging.



Standards	Phase	Level/Mode	Voltage (V)	Current (A)	Source
IEC62196	Single	Mode 1	120	16	AC
	Single	Mode 2	240	32	
	Single	Mode 3	250	32–250	
	DC	Mode 4	600	400	DC
IEC61851	Single	Mode 1	120	16	AC
	Single	Mode 2	240	80	
	DC	Mode 4	200–450	80	DC
SAEJ1772	Single	Level 1	120	16	AC
	Single	Level 2	240	32–80	
	DC	Level 1	200–450	80	DC
	DC	Level 2	200–450	200	

4.2. EV Charging Standards

To cope with EV charging infrastructure, a number of EV charging standards are used globally. For instance, whereas Japan and Europe utilise the CHAdeMO charging standard, the U.S. employs the IEEE and SAE standards. Similar to the IEC standard, the Standards Administration of China (SAC) employs GB/T standards. The word "Level" is used to describe the power level in SAE, whereas "Mode" is used in IEC. Table 1 provides an overview of the ICE and SAE charging standards. For overnight slow charging, Level 1/Mode 1 is typically utilised in homes or offices. Both public and private charging stations employ Level 2/Mode 2 and Level 3/Mode 3 charging modes, while mode 4 in IEC and SAE is used for fast charging.

5.Optimization Techniques

Optimization is the optimum use of the resources at hand to create the best design for the desired outcome. Identifying the values of a variable that maximises or minimises the objective function while satisfying the restrictions is what is meant by optimization. The widespread implementation of the smart grid faces various obstacles as a result of the combination of RESs and EVs. For instance, wind and PV resources are very unpredictable [29], and when EVs are integrated into the smart grid, both supply and demand are becoming more irregular and leading to energy losses in the distribution system [44]. Because of the various conflicting constraints and goals involved, Distributed Generator (DG) sizing, placement, and EV charging (schedule) are particularly challenging unit commitment problems. To solve these problems, optimization techniques are employed. According to [45], 60% of all EVs are charged during off-peak hours, and depending on the charging tactics, energy loss might rise to 40%. As a result, it might endanger the grid's dependability and stability [46].. In addition to resolving the mentioned problems, an EV charging station that is operating properly will also increase profits [47–49]. Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Simulated Annealing (SA), and integer algorithms like mixed-integer linear programming (MILP) and Mixed Integer Programming (MIP). are the three primary heuristic optimization techniques used in the research of EV charging stations. There are many optimization techniques in the literature. These optimization techniques are used to achieve a variety of goals, including outage management, issues with the mismatch between DG unit electricity production and load consumption, energy trading between upstream (aggregator) and downstream (PL), annual profit maximisation of PEV-PL by selling electricity to PEV, sizing and positioning of the fast-charging station, sizing of ESS in a fast-charging station, ESS sizing for power loss, voltage deviation, and other goals. The following subsections will explain the above-mentioned objectives in detail.

5.1Optimization Method and Objectives

The advanced optimization methods use for the energy resource allocation are as follow:

1.Mixed-integer linear programming.

2.Mixed-integer programming.

3.Second-order conic programming (Convex Optimization).

4.Markov chain Monte Carlo simulation.

5.Particle swarm optimization and Voronoi diagram.

6.Simulated annealing approach.

7.Quadratic programming.

8.Standard linear programming with the root-mean-square objective function.

The above optimization methods are used in the state-of-the-art research to: (i) enhance the reliability of the electrical grid using the available energy in the parking lot;(ii) maximize EV penetration; (iii) minimize total system loss; (iv) maximize parking lot owner profit; (v) minimize distribution system operator costs; (vi) minimize the station energy cost and ESS storage cost; and (vii) minimize the distribution power loss.

5.2 Services and Test System

To improve the grid reliability and to encourage EV owners by providing the following services are provided to EV and Parking lot owners:

1.Vehicle to Grid.

2.Grid to Vehicle.

3.Parking lot to grid.

4.Parking lot to Vehicle

The above services are tested on: (i) IEEE-34-node test system; (ii) IEEE-33 bus test system with 66 generators, 32 loads, and 1000 grid-able vehicles; (iii) IEEE-6-Bus power system; (iv) Modified IEEE-118-bus system; and (v) Alibeykoy feeders Hamikoy feeders (Istanbul, Turkey).

It is significant to note that due to national and local zero-emission target and EV adoption regulations, the market's EV penetration differs from county to county and even province to province. It is also depending on the:

(i) availability of charging stations; (ii) renewable energy share; (iii) subsidies on EV; and (iv) income (as EVs are more expensive than ICE vehicles).

6.Future Research Recommendations

Following are some suggested future study areas based on the completed literature review:

1. By supplying green electricity to homes and businesses, research on the use of BESS and the bi-directional power transfer capability of EVs in a distribution system can more creatively address the problem of global warming. Additionally, adding BESS of the right size helps lessen the intermittent nature of PV [57]. Incorporating battery exchange to give customers extra value will also increase the earnings of the parking lot owner.

2. Deterioration of EV battery life can be brought on by frequent charging and draining [58]. Therefore, utilising BESS as a backup energy storage system and selling electricity to the building in place of continuously discharging the EV battery will prolong its life.

3. When the arrival and departure schedules are known, the suggested PEB charge scheduling algorithms [33] can be used to plan the charging of private EVs and Electric Ferries. To reduce the cost of the vehicle, the battery capacity optimization for a certain route can also be assessed.

4. Because EV charging that is not coordinated can result in a peak load on a distribution system, research on coordinated charging should be done. EVs might be a good way to resolve these issues. In general, during peak load times, the majority of vehicles are parked. Electrical peak load would therefore be decreased by utilising the electricity that is stored in the battery of the vehicle to power the grid (V2G).

5. Particles are trapped in local minima when using the conventional PSO algorithm for the optimal sizing, and the number of iterations required increases [59,60]. As a result, research could be done to find a solution to the local trapping issue and improve computational speed, for instance by hybridising it with another heuristic technique. The literature at the time took eco-charging methods into account (consisting of PV, ESS, and the electrical grid). However, combining other renewable DGs, such wind energy and biomass energy, can strengthen the ecosystem and make it more sustainable while also resolving the intermittent problem brought on by Wind and

6. Research might be done on the PEBs' charging and discharging model with regenerative braking, which could result in a more accurate calculation of the SOC of PEBs.

7. The current literature took into account the energy trading between the ecosystem's components (PV, ESS, buildings, grids, and PEBs). However, employing renewable energy sources to generate power in several depots and conducting energy trading between them can lessen the grid's overloading.

8. Vehicle-to-Vehicle (V2V) and Vehicle-to-Grid (V2G) energy trading can reduce peak demand [61,62] on the grid and promote depot owner engagement in the energy reserve market.

9. It is possible to conduct an assessment of the risks associated with charging PEBs on the distribution grid, including overcurrent and undervoltage, power losses, and strain on the distribution transformer.

7.Conclusions

This article gave a comprehensive overview of EV technologies, covering BSS, WPT, and CC EV charging methods, EV charging standards, and optimization methods for creating the best EV charging schemes. The limits of the current technology were covered in the paper. The report also noted several research recommendations that needed to be taken into consideration.

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