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Review Article

An Extensive Critique on Electric Vehicle Components and Charging Systems

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Nowadays the demand for electric vehicles has been increasing due to their dropping price range and zero emission of carbon. This article initially discusses the development of various electric vehicles from the past to the present. Since the electric motor plays a significant role in EVs, various motors suitable for EVs have been identified and surveyed in this work. The battery storage system is a critical component of EVs; hence, the article goes over all the different types of batteries, from lead acid to lithium ion. Additionally, the other vehicle components such as converters required for charging the batteries, intelligent controllers, electric vehicle charging process, power management, and battery energy management concepts that are available are discussed in detail. Moreover, we bring our work to a conclusion by outlining the research opportunities that remain for the academic and industrial groups. Therefore, the proposed work intends to assist as a state-of-the-art reference for researchers in the field of various electric vehicle configurations, storage systems, converter configurations, charging techniques, control methods, and modulation methods.

1. Introduction

Combustion of fossil fuels for the production of electrical power releases harmful greenhouse gases (GHGs) and pollutes the atmosphere. There has been a dramatic increase in global warming and melting of ice caps due to the release of harmful gases in the environment [1]. Environmental monitoring and timely precautionary services are required to slow the deteriorating impacts of climate change. According to International Energy Agency (IEA) projections, the average world temperature rise must be limited to only two degrees Celsius by 2050 [2]. If no measures are considered to address this problem, GHG emissions are estimated to double up by 2050 [3]. In 2018, the automotive sector emitted 25% of all energy-related GHG emissions [4]. Several initiatives are being proposed to minimize the transportation-related pollution. The objective is to lower GHG emissions while also improving the performance of the vehicle by innovating and developing new fuels from the renewable energy sources. Using electricity to power vehicles is a viable option that has numerous advantages. Figure 1 illustrates the motor, storage system, converter, and the charging system of an EV. Electric vehicles (EVs) have the potential to reduce environmental impact by reducing emissions from the vehicle's tailpipes. Moreover, the use of more efficient topology and electric motors in EVs results in superior performance than that of IC engine vehicles. Developed and developing countries all over the globe are taking various steps to promote the use of electric vehicles. Promotion of EVs includes providing financial incentives for

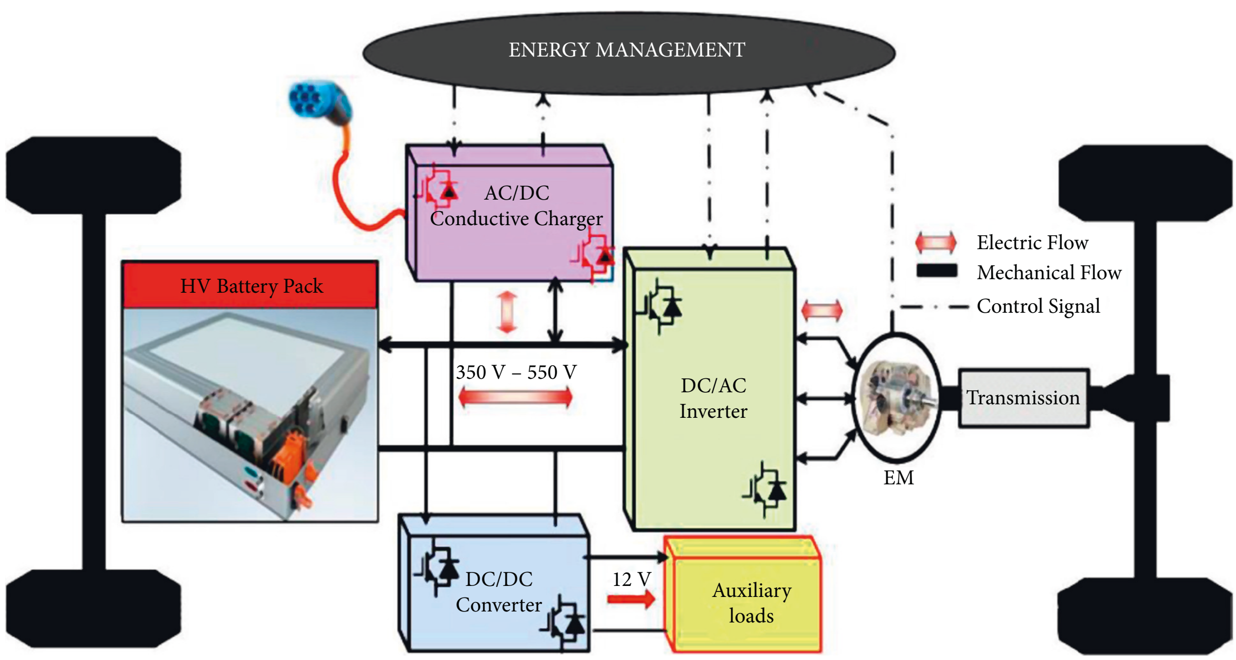


Figure 1: Electric vehicle components and its charging system.

the purchase of EVs, building charging infrastructure, and raising awareness of the public about their benefits. EVs are gaining interest in achieving public acceptability, indicating the efforts that have been fruitful. The development in design of EV, selection of battery, and charging methods have received much attention during the course of research and development. Researchers have modelled the series, parallel, and series-parallel configurations [5] of the EVs to fulfil various challenges faced by the conventional EVs. The introduction of extremely effective electric motors in the EV topologies could improve fuel efficiency and increase the driving range of the vehicle [6]. In [7], the authors have reviewed the effects in EV charging load distribution and the impact of EV chargers in polluting the grid and degrading the power quality. In [8], the authors discussed mostly the deployment of charging infrastructure and the charging services. In [9], the authors discussed the importance and classification of resonant converters for EV applications. The drawbacks of the conventional converter configurations are mainly pointed out and modular resonant configurations are discussed.

In [10], the authors reviewed various DC/AC converter topologies for EV applications. The drawbacks such as control complexity and voltage stress on the switches are pointed out for various configurations. In [11], the authors reviewed about the various batteries used for EV applications. The authors in [12] dealt with the technology of reducing the charging time for EVs. In [13], the authors presented various state of charge estimation methods for EV charging applications. From the literature, it has been identified that EVs have some limitations such as poor driving range, increased charging time, and bulky battery packs, which add weight to the vehicle, and EVs are not cheaper.

Considering all the benefits and drawbacks of EVs, this article provides the following insights and contributions:

(i) This article is justified by the necessity to examine the unexplored areas of current surveys by examining the most recent research provided in the literature.
(ii) This review discusses the history and present state of electric vehicle configurations around the world.
(iii) This review focuses on various motors used in various EVs around the globe.
(iv) This review concentrates on the recently developed battery systems and their energy management strategies.
(v) This review presents different converter configurations and modulation and control methods for EV applications.
(vi) At last, the review concludes with a discussion of the various EV charging standards, connector types, EV chargers, and charging stations.

This paper is structured as follows. Section 1 presents the introduction of EVs, Section 2 presents the history of EVs, Section 3 presents the types of EVs, Section 4 presents the various motors used in EVs, Section 5 presents the batteries and the battery management methods used in the EVs, Section 6 presents the converter configurations used in the EVs, Section 7 presents the conventional and intelligent controllers used in EV applications, Section 8 presents the modulation methods used in EV applications, Section 9 discusses the EV chargers, Section 10 discusses the levels and standards of charging station, Section 11 discusses the architecture and energy management methods in charging stations, and finally the conclusion section is presented.

2. History of Electric Vehicles

The first steam-power vehicle was originally designed as a toy for the Chinese Emperor by Ferdinand Verbiest in 1672 [14]. The steam powered vehicles were gradually converted into internal combustion engine (ICE)-based vehicles [15], which are still considered the common type of vehicles available. The purpose of conversion was mainly focused on converting chemical energy to mechanical energy. However, this conversion strategy led to serious problems such as fuel shortage and environmental depletion. The oil crises [16] in 1973 and 1979 made the oil-dependent countries to invest on alternative energy sources for implementing them as fuel in the transportation sector. Moreover, the inefficient operation of ICEs made the manufacturers to invest on environment friendly system. In the perspective of the efficiency and capability, electricity is the most interesting and flexible energy carrier. This made the researchers to look for new solutions using electricity-based transportation sector. In the nineteenth century, the history of electric vehicle was started with the invention of the electric motor [17]. The first EV was invented in the year 1834 with a non-rechargeable battery [18]. The first rechargeable EV was built with the lead-acid battery in 1874. In the year 1894, Salom and Morries developed an electric automobile named "Electroboat" [19]. After 1894, different countries like England, United States, and France were involved in developing electric automobiles [20]. After the invention of a rechargeable battery-based storage system, EVs had two significant developments. The first one was a reduction in the price of EV. The second development was in the year 1950 by the California Air Resources Board (CARB), and the development was commercializing the EV usage, which is reducing the emission by 2% [21]. General Motors developed three experimental EVs named Electrovair, Electrovan, and Electrovette in the years between 1966 and 1979 [22]. At the same time, the National Aeronautics and Space Administration (NASA) developed a lunar rover in 1971 that runs with electricity [23]. This concept helped to raise the usage of the electric vehicle. The market share started growing till the introduction of the Ford Model T [24]. Later, the market was completely taken over by the gasoline-based vehicles due to the replacement of the hand crank by an electric starter [25]. Due to the limited driving range of electric vehicles and the cheap availability of petrol, gasoline-based vehicles again became popular. It seemed that the electric vehicle may not have any future until the start of climate issues at the end of the twentieth century. People started realizing the changes in climate due to the emission of harmful gases from gasoline-powered vehicles. Electric vehicle entered the market again in the second decade of the twenty first century with the introduction of battery electric vehicles [26] (BEVs) and PHEVs [17]. Nissan initialized the research and development of battery storage based on lithium-ion battery technology. However, Nissan released the first lithium-ion battery-based EV by the name Prairie Joy EV [27]. Besides, Nissan developed another EV named Altera, which is driven by the permanent magnet synchronous motor drive. This popular product was developed as Nissan Leaf [28] in 2010. The Tesla Roadster [29] was more popular in the year 2008 because it covered 200 miles at one charge. Different companies followed Tesla's model and developed their own hybrid and pure electric vehicles. Tesla developed EVs named Model S, Model 3, Model X, and Model Y with different driving ranges like 630 km, 519 km, 565 km, and 509 km with different specifications. In recent years, EVs are very popular because they lead the conventional road transportation. The prevalent model everyone knows is Tesla and Nissan. Tesla developed and launched different electrical vehicles. For example, it is ranging from initial model Roadster to recent model Model Y. This contemporary model gives the range of 370 km in standard level and long-distance range of 507 km. Similarly, different companies produced EVs like BMW i3 Chevy Bolt. But these are plug-in hybrid electric vehicles (PHEVs). Though the charging of EV does not depend on the coal-fired power plant, it has a significant level of emission reduction. Emission is reduced effectively by renewable-based power plant charging. Thus, the photovoltaic or wind-powered charging [30] gives the solution. The growth of the PHEV over the past decade and its contribution to reduce the emission is seen as a positive trend for the society. However, the high penetration of PHEV makes redesign of the distribution grid essential.

3. Types of Electric Vehicles

EVs based on energy conversion types can be categorized into battery electric vehicle (BEV), hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), fuel cell electric vehicle (FCEV), and solar electric vehicle (SEV).

3.1. Battery Electric Vehicle (BEV). Due to the fact that BEVs are exclusively powered by the charge stored within the battery packs, the mobility of these vehicles is directly related to the size of the battery. Most of them have a range of 100–250 kilometers [31], while the best models have a range of 300–500 kilometers [31]. A number of factors influence the range of BEV. These include the driver's style and habits, automobile design, road surfaces, climatic condition, battery type, and lifespan. BEVs have significant benefits of being easy to configure, operate, and convenient to use. Because they do not release any greenhouse gases (GHGs) or make any noise, these are environmental friendly. Even at slower speeds, the electric propulsion system delivers significant torque instantly. Due to such benefits and their own limited range, electric vehicles are ideal for city driving. BEVs such as the Nissan Leaf, Tesla, and several Chinese models are some of the best-selling automobiles in the world. Figure 2 presents the structure of a BEV. In BEV, the batteries supply electric power to the motor, which makes the tyres to rotate. A power electronic driver circuit controls the operation of the motor. Most of the time, driving the vehicle is done between 2200 and 4800 rpm with a large quantity of torque. Since vehicles used in cities frequently start and stop, they must run at torques of up to 125 Nm to keep their rpm low.

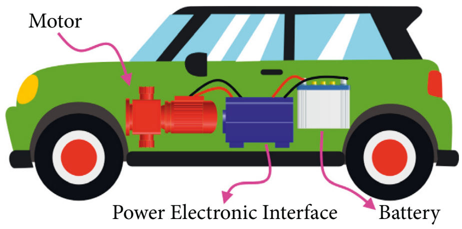


Figure 2: Battery electric vehicle.

3.2. Hybrid Electric Vehicle (HEV). HEVs are designed in a hybrid version that combines an internal combustion engine (ICE) with an electric motor. There are several ways to combine the two propulsion systems. Whenever an automobile requires less power to drive, the HEV will employ its electric propulsion system. It is a huge benefit while driving in slow-speed locations like cities, and it also saves gasoline because the IC engine is not running when you are driving the automobile in the traffic. This functionality has the additional benefit of lowering GHG emissions. In order to achieve faster speeds, the HEV will operate with the ICE. In order to enhance the efficiency, the electrical and mechanical systems can also be used in conjunction with one another. To lessen or fully eradicate turbo lag from cars such as Acura's NSX with turbocharging [32], combined gasoline and electric energy systems are widely employed. Additionally, it improves performance by bridging the time during gear shifts and supplying extra speed when needed. While ICEs can use electricity to recharge their batteries, HEVs use regenerative braking [33] to recover energy. As a result, hybrid electric vehicles (HEVs) are largely internal combustion engine (ICE)-powered vehicles with an electrical drive system. The use of HEV setups by automakers is becoming increasingly common to achieve these benefits. Figure 3 shows how energy moves via a standard HEV. First, the ICE makes the motor operate as a generator to generate energy, which is then stored in the battery. Overtaking necessitates increased speed, which is provided by both the ICE and the motor. The HEV uses regenerative braking to store energy in the battery while braking, allowing the motor to act as a generator. ICE starts charging the battery during driving by making the motor operate as a generator. When the automobile comes to a halt, the energy flow is cut off. In a hybrid electric vehicle, power is shared among the internal combustion engine (ICE) and electric motor (EM) depending on the speed of the vehicle, rider input, battery capacity, and speed of the motor in order to maximize fuel economy.

3.3. Plug-In Hybrid Electric Vehicle (PHEV). HEVs will play a vital role in delivering a low carbon environment which is essential to deal with the prevailing environmental depletion. Around the world, many initiatives are intended to promote this emission-free transportation policy. As a result, the use of PHEV [34–36] is growing. PHEV is popular because of heavy duty electric motor. In contrast to HEV, the battery capacity of PHEV is increased to extend the range. Also, PHEV provides an option for vehicle-to-grid

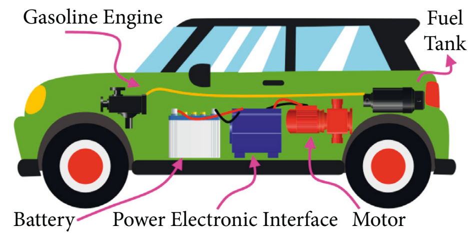


Figure 3: Hybrid electric vehicle.

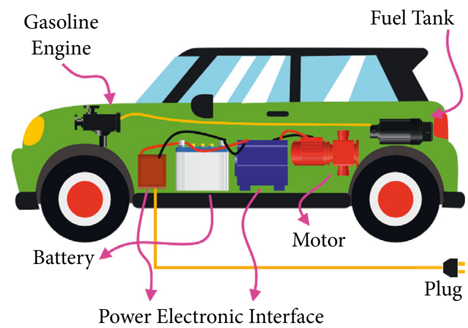


Figure 4: Plug-in hybrid electric vehicle.

connection [37]. PHEV always runs through the electric battery and during low battery condition, ICE helps to charge the battery pack [38, 39]. The range of driving is extended in PHEV that provides the regenerative breaking-based charging. Figure 4 presents the PHEV. The penetration of PHEVs can cause problem in the distribution system with respect to voltage fluctuations and system losses [40]. If all the PHEV owners decide to charge their vehicles at the peak moment of the day, it can create overload on the substation transformer. Hence, along with selecting suitable location for placing the charging station (CS), optimal scheduling of PHEVs is also taken into account. However, considerable difficulties are faced in managing the new loads with the prevailing generations. Hence, integrating distributed generation (DG) in a suitable location is also considered.

3.4. Fuel Cell Electric Vehicle (FCEV). FCEVs are also known as fuel cell automobiles (FCV). The word fuel cell refers to the fact that the automobiles' power source is obtained by chemical reactions rather than combustion. Fuel cells use hydrogen gas as the preferred fuel for production of energy. Therefore, they can be renamed as "hydrogen fuel cell cars." Additional ingredient used in the power generation process is the oxygen gas. Usually, in FCVs, hydrogen gas is carried in high-pressure cylinders and oxygen gas is obtained by sucking the air from the atmosphere. Power is produced by the fuel cell technology and is given as an input to the motor for driving the wheels of the vehicle. Battery packs, supercapacitors, and ultracapacitors are good options for storing extra energy. FCVs like the Toyota Mirai and Honda Clarity [41], which are readily accessible, employ batteries to power the motor. Fuel cell vehicles (FCVs) only produce water as a by-product of their power-generating process, which is

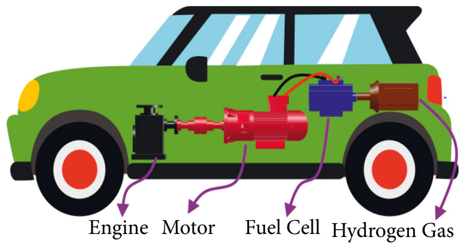


Figure 5: Fuel cell electric vehicle (FCEV).

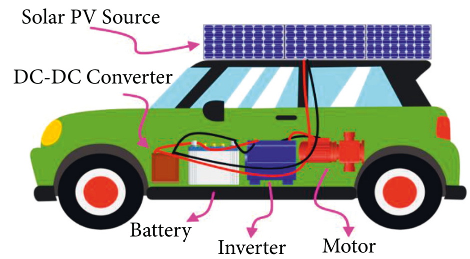


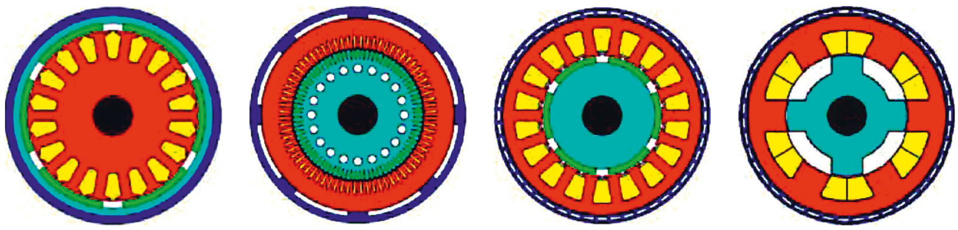
Figure 6: Solar electric vehicle (SEV).

ejected from the vehicle through the exhaust pipes as waste. Figure 5 presents the FCEV. Having the ability to generate its own electricity, without the emission of carbon, gives these vehicles an advantage over other EVs in terms of reducing your carbon footprint. Another significant advantage of these vehicles is that they can be refilled in the same amount of time as a traditional vehicle at a petrol station. Hence, there is a higher chance of using the FCV and hybrid vehicles in the coming years. The shortage of hydrogen filling pumps is certainly a key hurdle to the implementation of this system, although charging points for BEVs or PHEVs were not frequent even a few decades ago. From the report given by the Department of Energy (DOE) of U.S., it has been identified that the FCV costs greater than the ICE [42, 43]. Concerns have also been raised about the safe operation of the system in the event that combustible hydrogen leaks from the tanks. FCVs have a tremendous opportunity in becoming the best future cars if all these limitations are addressed. One of the primary downsides of FCEVs is the expense of fuel, as there is no inexpensive, sustainable, and environmentally acceptable means to produce hydrogen, and the refueling infrastructure is behind that of BEVs. However, these issues may be resolved in the future. According to Rajashekara, FCVs have a different future than what is projected in [44]. He demonstrated a battery-dominant plug-in fuel cell vehicle (PFCV) with a larger battery and a smaller fuel cell. PFCVs will be the future of transportation if hydrogen for these vehicles can be produced from renewable sources.

3.5. Solar Electric Vehicle. Solar electric vehicles are the future of automobile industry because they require renewable and sustainable form of energy. It uses photovoltaic cells to convert solar energy from sunlight to electrical energy. These vehicles are also known as green vehicles because they prevent environmental pollution. Figure 6 presents the solar electric vehicle. The initial cost of solar vehicles is high, but they require less maintenance since solar energy is unlimited and free. "Sunmobile" was the first solar vehicle [45]. William Cobb demonstrated Sunmobile at General Motors Powerama auto show held in Chicago, Illinois. Solar electric vehicles utilize solar energy for their traction [46]. The vehicles are fitted with solar panels, and the generated electrical power may be used right away or may be stored in a battery for later use. Usually, such vehicles are flat shaped with more surface area to incorporate more solar panels. Sudevan and Selvakumar developed a feasible solar car that can reach up to a top speed of 100 kmph [47]. Even though many solar cars were developed, there are no commercially available solar cars in the market.

4. Types of Electric Motors for EVs

Electric motor plays a major role in the design of EV. Electric motor is the heart of an EV. In the nineteenth century, the history of electric vehicle was started with the development of the electric motor [17]. In EVs, the motor is used as the propulsion system. Induction motor was invented by Nikola Tesla (1889) [48]. The stator winding of three-phase induction motor [49] and three-phase brushless DC [50] motor is virtually identical. The essential difference between the two machines lies in their rotor construction. When three-phase induction motor is excited with three-phase AC supply, a rotating magnetic field is developed which in turn produces a torque which makes the motor to accelerate. In the case of permanent magnet brushless DC motor, flux produced by the permanent magnet cannot be adjusted. Whenever maximum torque is required, especially at low speeds, the magnetic field strength is to be adjusted. But in PMBLDC motor [51], practically it is not possible to adjust flux density. In induction motor, the flux density can be adjusted by controlling the voltage/frequency (V/F) ratio, and the motor accelerates quickly even at low speeds. Thus, an efficient design of inverter will provide quicker acceleration which cannot be done in the case of PMBLDC motors. Owing to the above reasons, an induction motor is widely used in EV propulsion schemes for their simplicity, rugged construction, less maintenance, higher efficiency, and cost effectiveness [52]. Figure 7 presents the cross-sectional view of various motors used in EVs. The authors in [53] explained a brief overview of electric motors which are widely used in EV which include the design and analysis of the induction motor and permanent magnet brushless AC motor. Among the AC motor group, induction motors and permanent magnet motors give greater importance. The selection of motor for EV application is based on dimension, torque, and efficiency. However, the authors did not concentrate on the effects on magnetic loading and temperature variations. The authors in [54] reviewed different analysis and design technique to drive the motors in Prius hybrid EV and examined the alternative spoke type magnet rotor and induction motor arrangements. According to their work, these machines run at high resolution with transient thermal operation and the design of the high saturation machine was



(a) (b) (c) (d)

Figure 7: Cross section of traction motors. (a) DC motor. (b) IM. (c) SPM. (d) SRM.

less straightforward than the standard industrial machines. In electric vehicle application, thermal analysis on the motor is also required because of frequent acceleration and retardation. In addition, another magnet-less machine such as switched reluctance motor (SRM) [55] and novel permanent magnet machines like flux reluctance machine were also used for electric vehicles and hybrid EVs. However, these machines require more complex control schemes. Figure 8 presents the different types of EV motors used in various HEVs.

Cao et al. [56] dealt with the comparative study of flux switching permanent magnet (FSPM) motor with interior permanent magnet motor for EV and HEV applications. First, they analyzed Prius interior permanent magnet using finite element modelling (FEM). Later with the same FEM method, the stator permanent magnet motor named flux switching permanent magnet was investigated. By using the above method, the motor was compared with its overall dimensions, phase current, and current density. Finally, it is found that FSPM possesses better results than FEM with smaller torque ripples and better mechanical integrity for high-power applications. Owing to the high cost and low magnet utilization ratio of FSPM, the importance towards automotive and other applications was reduced. The authors in [57] proposed various aspects of power train system for EV applications. The authors made comparison between induction motor and permanent magnet motor. Based on power demand for an increase in weight and acceleration, different cases were analyzed. Finally, the authors concluded that the permanent magnet motor is the better choice for EV. However, the permanent magnet motor suffers from aging, cost, and shifting of operating points due to temperature variations.

5. Energy Storage Systems/Battery Storage Systems for EVs

Energy storage technologies are in charge of supplying a steady supply of energy to the motors, but they are prone to unreliable operation, power loss, and sluggish variable reactions. The battery storage system (BSS) is an excellent candidate for providing a continuous supply of power over an extended period of time because of its small size, high energy density, and proven durability [58]. For EV applications, many requirements have to be considered for energy storage such as energy management system, driving range, power electronics interface, conversion efficiency, safety,

HEV Model	Propulsion System
 PSA Peugeot-Citroen/Berlingo (France)	Dc motor
 Holden/ECOmmodore (Australia)	Switched Reluctance Motor
 Nissan/Tino (Japan)	Permanent Magnet Synchronous Motor
 Honda/Insight (Japan)	Permanent Magnet Synchronous Motor
 Toyota/Prius (Japan)	Permanent Magnet Synchronous Motor
 Renault/Kangoo (France)	Induction Motor
 Chevrolet/Silverado (USA)	Induction Motor
 DaimlerChrysler/Durango (Germany/USA)	Induction Motor
 BMW/X5 (Germany)	Induction Motor

Figure 8: Various motors implemented in various EVs.

and protection. The conventional batteries are electrochemical batteries, in which energy is transformed from chemical energy to electrical energy and vice versa through a reversible process. These batteries store and release electrical energy by going through charging and discharging phases, and during the process, no harmful emissions are produced and they require little maintenance. The battery life depends

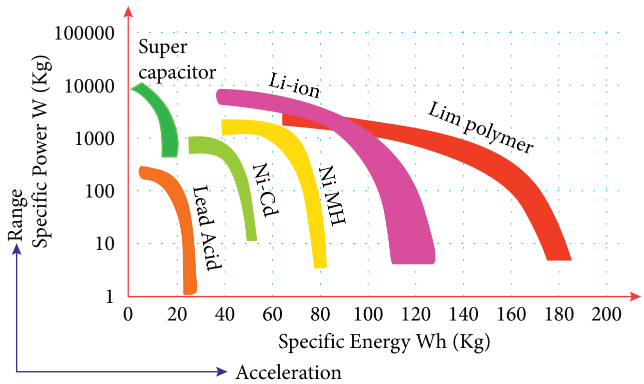


Figure 9: Relation between specific energy and specific power of various storage systems used in EVs.

on the charging temperature, discharge rate, and other parameters of the vehicle. However, battery life gets affected as chemical reactions take place continuously and the condition will get worse if it is operated exceeding the limits of their specifications. A battery management system (BMS) or energy management system (EMS) is therefore necessary for monitoring the health of batteries. There are two types of electrochemical storage systems. The first one includes flow batteries, and the second one includes the secondary batteries. Redox flow batteries (RFBs) provide certain advantages, such as the partition of power and energy elements, rapid recharging, long cycle lifespan, being maintenance free, and having a tolerant nature to overcharge/overdischarge. Few flow batteries used in EV applications are bromine-polysulfide, vanadium-vanadium, vanadium-bromine, iron-chromium, zinc-bromine, zinc-cerium, and soluble lead RFBs [59]. Flow batteries have not been seriously studied for transportation due to their low specific energy density of electrolytes. Secondary batteries are considered the most widespread group for portable applications. Secondary batteries are also known as rechargeable batteries and they consist of two electrodes: anode and cathode, a suitable separator and an electrolyte contained in a suitable case. They have gained wide acceptability because of their good characteristics such as high-power density, high specific energy, flat discharge profile, and a wide range of operating temperatures [60]. There are many types of secondary batteries available in the market currently, such as nickel-based (Ni Cd, Ni-MH, Ni-Fe, and Ni-Zn), lead acid, lithium-based (Li-ion, Li-polymer, Li-Al-FeS2, and Li-Al-FeS), sodium-based (Na-S and Na-NiCl2), zinc-based (Zn-Br2 and Zn-Cl2), and metal-air based (Al-Air, Fe-Air, and Zn-Air) batteries. Among them, few varieties contain toxic materials, which have to be treated carefully while disposing battery. The specific energy and specific power relation for various battery technologies such as Li-ion, Ni-MH, Ni–Cd, Li-Po, lead acid, and supercapacitors are illustrated in Figure 9. For driving 200 km, EV requires 500 kg of lead-acid battery. But, using lithium-ion batteries reduces the weight to 150 kg. The Ni-MH battery technology employed in Toyota Prius hybrid vehicles has an energy density between 60 and 80 Wh/kg. Mostly, recent research depends on lithium-ion battery technology because of its high energy density [61]. The lithium-ion battery made with different composition provides the long-term and short-term evaluation. Figure 10 presents the size comparison of fuel, lead-acid battery, and lithium-ion battery used in EVs. Table 1 presents the different types of batteries used in different EVs with their ratings. In [62], the authors discussed the common welding and metallurgy defects in designing the steel-copper, steel-aluminum, aluminum-copper, and steel-nickel batteries.

In order to meet the rising expectations, hybridization of the power sources in EV has become inevitable. Although the SCs have a low energy density, they are capable of rapid charging and discharging, which makes them suitable for delivering power quickly at high acceleration [63]. Because of this, the hybrid energy storage system that combines BSSs and supercapacitors (SCs) can deliver benefits in the form of a long lifecycle, fast reaction, and low stress to the batteries; nevertheless, the cost of the total storage system increases [64]. Fuel cells, on the other hand, have a number of drawbacks, including high cost, delayed dynamic reaction, and limited supporting infrastructure. Despite these drawbacks, fuel cells offer a high energy density.

5.1. Battery Charging Characteristics. The size of the battery, the capacity of the battery, and the type of the EV determine the type of charging. The time required to charge a battery is determined by the charger setup and infrastructural facilities. When the rechargeable battery pack is empty, it takes a long time to recharge when compared with refueling an ICE car. Generally, it takes up to 36 hours to fully recharge the batteries [65, 66], and even though there are faster options, none of them can match the quickness with which a petrol tank can be refilled. The significant proportion of SOC is used to determine the battery's operating capacity. The SOC range of 20% to 30% is considered low, whereas the range of 80% to 90% is considered high. Battery operating voltage, battery model, and the charging intensity affect the charging time of batteries. It is possible to charge a battery by using either constant voltage (CV) or constant current (CC). Both of these methods can be used to charge a battery effectively. Often, both tactics are employed at the same time. For example, lithium-ion battery uses both CC and CV charging. Once the cell potential hits a threshold, the charging current is controlled. CV charging is then used to charge the battery.

5.1.1. Constant Current-Constant Voltage (CC-CV). The standard type of charging lithium-ion battery is the two-step process, CC-CV, as shown in Figure 11 [67]. During CC stage, the current rate and the cut of voltage depend on the lithium-ion battery chemistry. The battery manufacturer shows the battery parameters; most of the lithium-ion battery manufacturers define the current below 20 A. This method has been used for the lithium-ion battery charging since it is more suitable for low to high charging rates. The main drawback of this CC-CV charging method is long charging time; for example, in general, CC-CV charging takes two hours for charging. The main advantage of this

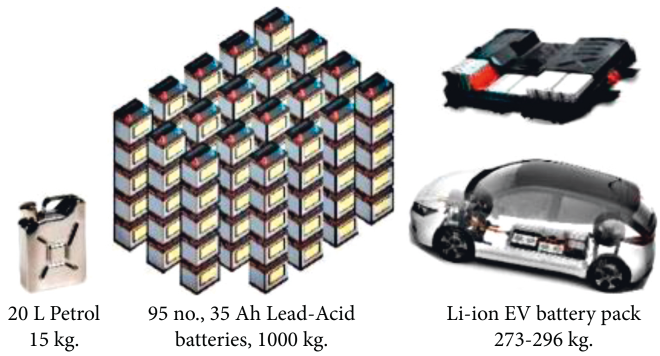


FIGURE 10: Size comparison of three systems for a travel range of 250 km.

TABLE 1: EV batteries in different EVs.

EV manufacturer	Car model	Battery chemistry	Battery capacity (kWh)
Mitsubishi	BEV	LMO	16
Nissan	Leaf	LMO	4.4
GM	Spark	LFP/LMO	16.5
Toyota	Prius Alpha	Ni-MH	1.3
Toyota	Prius	LNCA	4.4
Honda	Accord/PHE	LMO-NMC	6.7
BYD	E6/BEV	LFP	75
Tesla	Tesla models	LMO	85
Chrysler	Fiat 500e	LFP	24

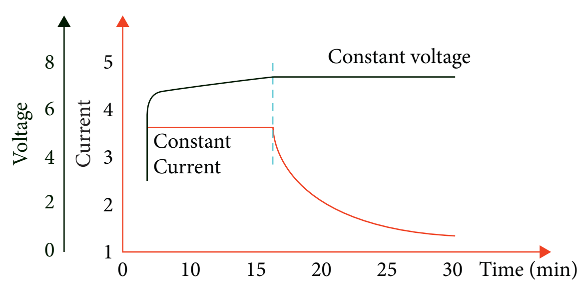


FIGURE 11: CC-CV charging.

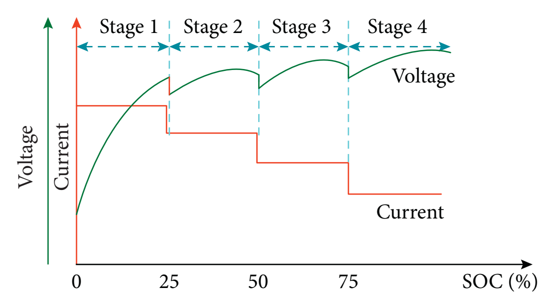


FIGURE 12: Four-stage constant current (FSCC) charging methods.

charging is preventing the overcharging and reducing the temperature during charging. However, for reducing the charging time, the chargers with higher current rating are used. However, it reduces the charging efficiency due to the joule heating, and it creates lithium deposition during the end of CC stage.

5.1.2. Constant Voltage Charging. The straightforward strategy is reducing charging time. In this method, the charging terminal provides CV directly to the battery based on the reference level [68]. The battery charging process terminates when the charging current decreases to a certain level. This type of continuous charging damages the battery due to battery electrolyte oxidation. Therefore, CV charging reduces battery life.

5.1.3. Multistage Charging. The multistage charging method (MCM) follows different charging stages with ascending and descending of current based on the battery. The parameters of the battery like internal resistance and temperature are estimated for the design of MCM. The MCM provides charging current without exceeding the maximum voltage [69]. During CV charging, electrolyte oxidation is avoided by reducing the high value of SOC. Following MCM, other battery technologies such as Lithium Manganese Oxides (LMO) can allow a maximum charging rate of 2C. The four-stage charging method (FSCM) proposed with the SOC of 25% as the minimum value is shown in Figure 12 [70]. This FSCM gives better charging performance with increased energy efficiency. The MCM provides healthy and quick charging with the proper design of internal resistance and SOC value.

5.1.4. Varying Current Method (VCM). In this method, the charging current is continuously varied based on the lithium concentration, battery electrolyte, and impedance evaluation. The cutoff voltage of the charging is set during extended charging to avoid the risk. The impedance evaluation with

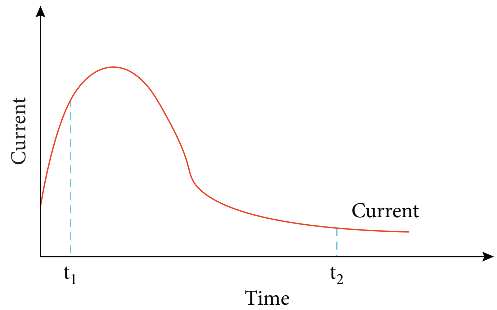


Figure 13: Varying current method [71].

SOC shows the decaying current profile as shown in Figure 13. The charging parameters are estimated from the equivalent circuit model. It shows better life cycle compared to other charging methods. The main disadvantages of this method are the online estimation of the internal resistance and SOC calculation.

5.1.5. Pulse Charging. This method uses short discharging periods along with charging. This type of charging is used to determine the concentration of electrode or electrolyte. It is worth to mention that it reduces the lithium deposition on lithium-ion battery during fast charging. It gives better results based on the battery technology and the charging profile. The pulse charging reduces the charging time and losses; also, improvements can be achieved by the trial and error method [72].

5.1.6. Fast Charging. Fast charging is achieved based on the lithium-ion battery architecture. Fast charging requires a thicker electrode for high energy density. Also, the temperature of the battery and physical properties of the material are the quantities to be considered for fast charging. During low ambient temperature, the charging rate and voltage should be kept low in order to enhance safer operation. Fast charging follows the temperature threshold value based on the C-rate and cell parameters. It depends on the temperature, power converter efficiency, BMS, and power levels. This charging is not suitable for all charging due to its failure in safety.

5.2. Battery Management Systems. A BMS is used in the battery pack which monitors various parameters during charging and discharging and provides safe operating conditions. The main parameters monitored through the BMS is the state of charge (SOC) and state of health (SOH) [73]. The monitored parameters are communicated to the on-board or off-board control system. Also, BMS is responsible for operating the EV safely and efficiently. Generally, battery packs are made with the series and parallel combinations of cells [74]. The cell characteristics differ based on internal resistance and chemical reactions. Cell balancing is needed during charging and discharging for an increased lifetime. Passive and active balancing methods are available. Active cell balancing is the monitoring of voltage and current of each cell. It increases the lifetime of the cell and avoids explosion. Different parameters, their measurements, and BMS functions are as follows:

(i) Battery parameter detection: it includes the voltage and current of the individual cell, temperature, impedance, and smoke detection.
(ii) Battery state estimation: it includes the SOC, SOH, and state of function (SOF).
(iii) On-board diagnosis (OBD) is the fault detection that includes sensor and actuator faults. In addition, it detects the overcharge, overdischarge, and insulation faults.
(iv) Charge control established on the battery and power rating of the charger and the charging current from the charger.
(v) Battery equalization makes the SOC level remain within the limits.

6. Converters for Electric Vehicles

Each DC-DC converter requires particular requirements and specifications for integrating the storage systems with the drivetrain's HVDC link. The bidirectional DC-DC converters support the process of regenerative braking, thereby increasing the system efficiency [75–77]. The major role of converter is to perform quick charging and discharging operations in a supercapacitor-based ESS, but for timely operations, proper regulation methods and pulse-width modulation strategies are required [64, 78, 79]. Therefore, the converters with reduced component count are mostly implemented while connected with supercapacitors [80]. Due to the long interval charging profiles of BSSs, the batteries' lifespan can be increased [81]. Most of the charging stations contain a high-voltage gain DC-DC converter for producing high power at its output [82]. Since the power obtained from the batteries and supercapacitors is very low, a high-voltage DC-DC converter must be established for meeting the requirements of the load [83]. A reliable DC-DC converter produces less ripples, less cost, and high output power with very few components [84]. There are two types of converter configurations in electric vehicles: non-isolated and isolated. Non-isolated topologies are opted for high-power EVs [85], while isolated topologies are suitable for low-power EVs [86]. Some of the non-isolated topologies used in EVs are discussed below.

6.1. Non-Isolated Converter

6.1.1. Cuk Converter (CC). Figure 14 shows the design of CC for EV applications. The CC contains 2 inductors, 2 capacitors, and 2 switches. The capacitor transfers energy alternately between switches via commutation. Inductors L1 and L2 also aid in the transformation of energy from the storage system to the motor. The CC-based charging system was developed by Deshmukh et al. [9] for charging the batteries of EVs. In [87], the authors used a switched inductor in CC for charging the batteries of EVs. In [88], the

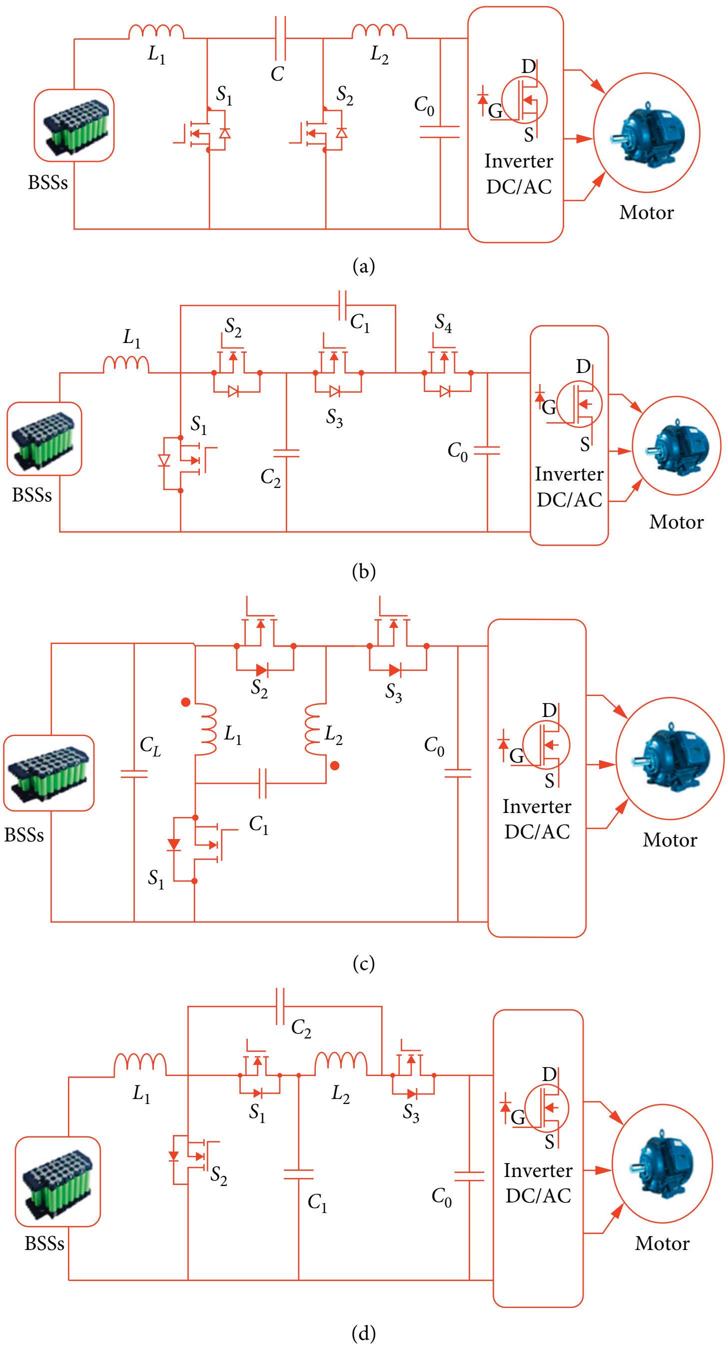


Figure 14: Various non-isolated DC-DC converters for EVs: (a) Cuk converter, (b) capacitor switched bidirectional converter, (c) bidirectional converter with couple inductor, and (d) quasi-Z-source converter.

CC was implemented with the PI-based controller to activate the EV's motor.

6.1.2. Bidirectional DC-DC Converter. Conduction in a bidirectional DC-DC converter based on switched capacitor is mostly accomplished through synchronous rectification. As shown in Figure 14(b), this converter is made up of 3 capacitors, an inductor, and 4 switches (S1, S2, S3, and S4). The suggested bidirectional converter can be operated in both buck mode as well as in the boost mode. During the boost operation, the switches S1 and S3 operate, and the switches S2 and S4 are turned off. In this boost mode, C1 is charged by C2 and current is transmitted from the BSSs to L. During the buck mode, the commutation is done by operating S2, S4 and S1, S3, respectively. In the buck mode, C2 charges L, whereas C1 receives charge current from C0. L, C2, and C0 provide energy to the motor [89]. Zhang et al. [89] developed a SCBC for EV applications and achieved 90% efficiency. For an EV application, the authors [90] suggested a voltage boost converter based on switched capacitor. The proposed topology reduced the size of the filter circuit by replacing the typical voltage source inverter (VSI). For hybrid energy source-based EVs, the authors in [91] designed an interleaved bidirectional DC-DC converter using switched capacitor. Under wide-ranging voltage gain, the proposed SCBC resulted in lower voltage stress. To test the characteristic and theoretical analyses, the authors created an experimental prototype of a 400 W converter.

6.1.3. Coupled Inductor Bidirectional Converter. A coupled inductor-based bidirectional converter (CIBC) is mostly preferred for EV applications since it has a higher voltage transformation ratio and lower voltage stress on the switches [92]. Furthermore, the CIBC has secondary leakage inductance, resulting in limited output diode reverse recovery [93]. Moreover, the proposed converter eliminates the current ripples and iron loss unlike a power boost converter which uses a hefty inductor for its operation [94]. Additionally, the suggested converter provides features like as voltage transformation, circuit impedance change, and galvanic isolation. The major limitation of the proposed bidirectional converter is the leakage inductance. The presence of leakage inductance leads to voltage swell and resonance in the circuit [95]. The authors in [94] implemented the coupled inductor-based bidirectional converter for controlling the DC voltage of an electric vehicle. The efficiency of CIBC is tested using the buck and boost modes of operation, which yielded positive results. CIBC topology is implemented in EV to make bidirectional power flow from the DC sources to AC inverter and vice versa [90]. Hu et al. [96] presented a CIBC converter with fewer components for EV charging applications. In comparison to existing traditional DC-DC converters in EVs, the suggested converter has a lesser number of components. CIBC improves the voltage gain and reduces the switching voltage stress [97]. To evaluate the converter's performance, an experimental model rated at 1 kW and operating from 40–60 V to 400 V was created. In comparison to multicore solutions of other converter topologies, the CIBC provides a reduction in overall volume. As illustrated in Figure 14(c), the CIBC has a single magnetic core that enables a smaller capacity when compared with other configurations.

6.1.4. Quasi-Z-Source Bidirectional Converter. Figure 14(d) shows a switched-quasi-Z-source network. A unique bidirectional QZBC for EV applications was presented by Tao et al. [98]. The control method implemented a constant switching frequency modulation. The issues related to voltage and current across the capacitor are solved using the proportional-integral-derivative (PID) controller. Diaz et al. [99] developed a QZBC-based battery storage system for electric vehicles. Intelligent controllers are used to optimize battery current stress and dynamic power regulation.

6.2. Isolated Converter. The converter transformer has three conversion stages, namely, DC, AC, and DC. To promote galvanic isolation and high-voltage gain, a high-frequency transformer (HFT) is used.

6.2.1. Push-Pull Converter. Figure 15(a) depicts the configuration of the push-pull converter (PPC) used in EVs. The transformer plays a key role in the PPC's operation. An improved PPC is implemented for EV applications in [100]. When compared to a traditional three-phase architecture, the proposed configuration demonstrated reduced switching losses and good efficiency. For charging the EV, Ghalebani et al. [101] used the PPC topology. The PPC structure decreases low current and voltage harmonics, enhancing the system's efficiency, according to simulation studies.

6.2.2. Flyback Converter. The flyback converter (FC) presented in Figure 15(b) is obtained from the conventional buck-boost converter with a transformer [102–104]. The authors in [105] developed a FC with a resistor, transformer, and integrated circuit. The probability density distribution model was used to calculate performance deterioration and system fault circumstances. Simulation and experimental studies were used to validate the model. For an EV application, the authors in [106] designed a combined boost-FC converter. To achieve high-voltage gain, the proposed architecture combined boost with an FC.

6.2.3. Resonant Converter. In a resonant converter, the resonating tank is composed of memory elements (inductors and capacitors) which make the converter suitable for electric vehicle applications. For the purpose of fine-tuning the output, a resonant tank is employed in this converter. Figure 15(c) presents the resonant converter. The converter's resonant element is the magnetization inductance. Reduced magnetization current also fixes the converter control problems in no-load condition.

In [107], the authors implemented the resonant converter for EV application. The implementation of ZVS and ZCS for the resonant converters improves the efficiency of the system and reduces the output voltage and current ripples. Therefore, this converter with the soft switching methods is applicable for the battery charging applications in EV [108]. Nonetheless, the resonant converter has some limitations like heating and complex design of transformer [109]. A modified resonant converter using gallium nitride (GaN) switches was developed for electric vehicles in [110]. The use of gallium nitride (eGaN) switches in the suggested design increases the efficiency and switching speed. In [111], a novel resonant converter with LLC circuit was developed for charging the batteries of EV. The proposed system used the soft switching methods to charge the batteries. A two-way operated resonant converter was developed in [112] for the plug-in hybrid EVs to feed power to the grid (vehicle-to-grid (V2G) application). The proposed DC-DC RC topology improves the efficiency and has a high-voltage transformation ratio.

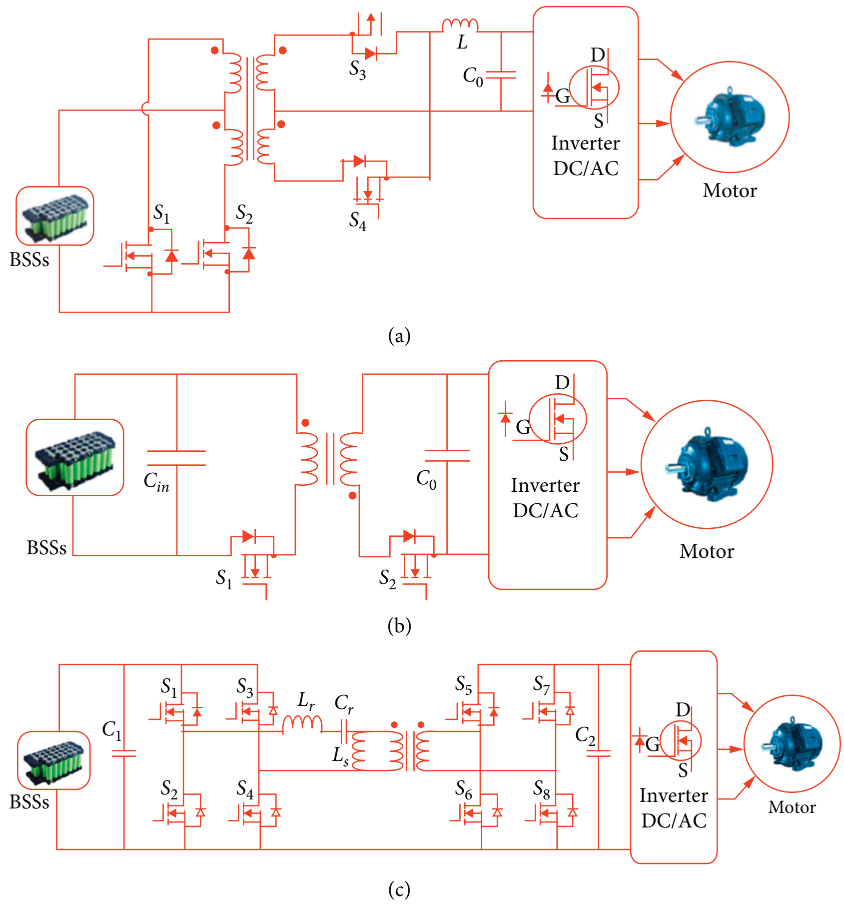


Figure 15: Topologies of transformerized DC-DC converter for EVs: (a) push-pull converter, (b) flyback converter, and (c) resonant converter.

7. Conventional and Intelligent Controllers

Due to the implementation of modern technologies, many advancements have been made in EV control tactics in recent years. To achieve best performance, high-speed digital signal processor (DSP) controllers are used. Table 2 presents the various controllers used in EVs.

Table 2: Literature of different controllers in EVs.

Type	Controllers	Ref
Conventional controller	PI	[113–116]
Intelligent controller	FLC	[117–119]
	Neuro fuzzy	[120]
	Fuzzy PI	[121, 122]
	ANN	[123]
	SMC	[124–130]
Optimization controller	PSO-FLC	[131]
	PSO-SMC	[132]
	CSO	[133]
	FWA	[134]
	FFA-GBDT	[135]

7.1. PI Controller. PI controller is a conventional controller basically used for controlling the output voltage of the DC-DC converter. In [113], the PI controller was implemented for the integrated charging system. The implementation of the PI controller in EV applications improved the stability of the entire system. Figure 16 presents the implementation of PI controller for battery charging applications. This system has a benefit of requiring no additional capacitance, resulting in a decrease in size and price of the system. From Figure 16, it is observed that the reference current $i * Bt$ determines how the DC-DC current controller operates in constant current (CC) mode, whereas the reference voltage $V * Bt$ determines how the controller operates in constant voltage mode (CV).

7.2. PI Controller for 3-Level Converter. In [114], a PI-based voltage controller is implemented for controlling a universal three-level bridge converter via input voltage and output current management. Figure 17 depicts the control architecture. There are two types of controllers: current type controller and voltage type controller. The DC link voltage is controlled by the PI-voltage type controller, whereas the d-q component of the current is controlled by the current controllers. This control system balances the flow of active power by controlling the active current component id.

7.3. PI Controller for an Interleaved Converter. In [115], a cascaded controller is implemented for the interleaved

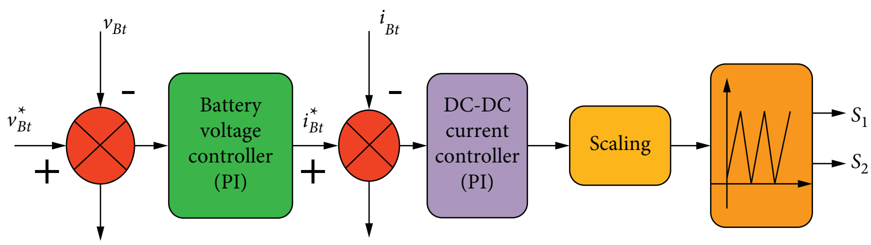


Figure 16: PI-based CC and CV controllers.

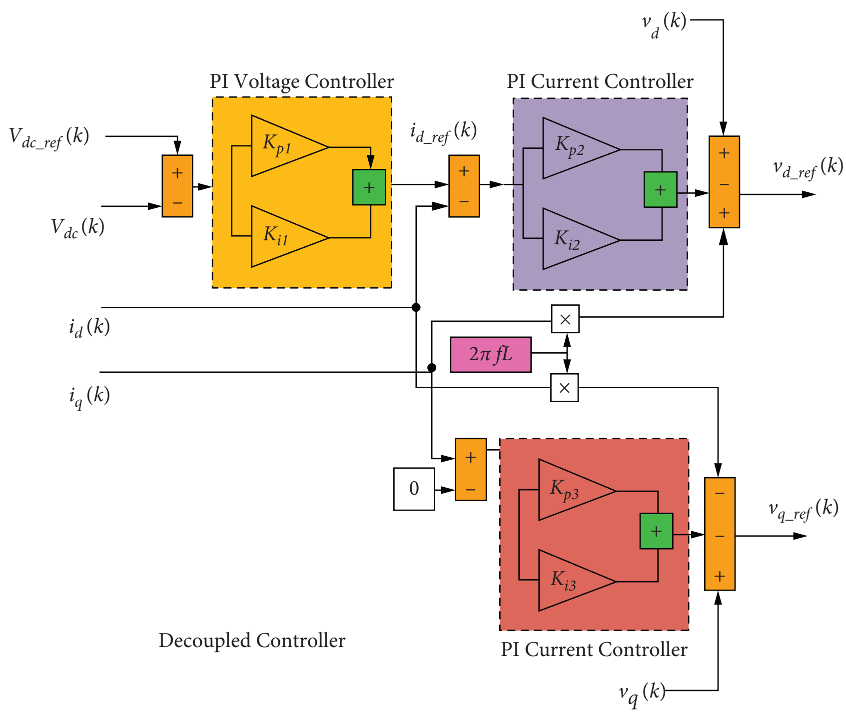


Figure 17: Decoupled controller for EV.

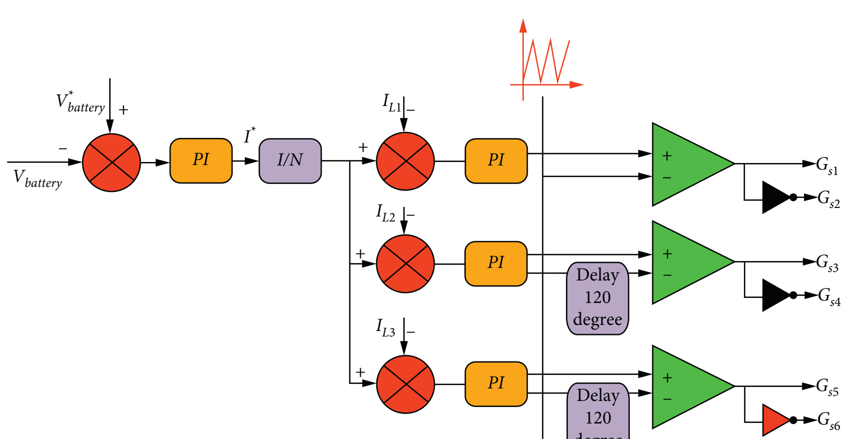


Figure 18: Cascaded controller for a BIHC.

hybrid converter. Figure 18 presents the implementation of the cascaded controller. At first, the battery voltage is processed in a PI-voltage type controller which produces the current signal as output and these current signals are compared with the respective inductor currents for producing the error. Then, these error signals are further processed with a PI-current type controller to produce the gating signals for the proposed converter. This design has advantages which improves battery life and dependability [116].

The rule-based controller's robustness and dependability are determined by the specifications, designer knowledge, limitations, and practical considerations. Several rule-based control approaches utilized in EVs are described in this section.

7.4. Fuzzy Logic Control. As illustrated in Figure 19, a multiport converter was introduced in [117] for EV applications. The BSSs, SCs, and FCs are employed in the proposed system. The proposed converter connects the DC bus, the storage systems, and the DC generator. The fuzzy system coordinates energy flow among the sources and the loads while guaranteeing adequate traction system functioning conditions. Although FLC produces excellent results, it may not always indicate the best answer in certain scenarios. In [118, 119], the authors implemented the FLC controller for battery charging applications. The results showed that the converter produced good results when compared with other controllers.

7.5. Neuro-Fuzzy Logic Control. The adaptive neuro-fuzzy inference system (ANFIS) combines neural networks and fuzzy inference systems to produce a faster and more accurate system than the classic fuzzy system. Figure 20 presents the implementation of ANFIS controller for EV [120]. The suggested ANFIS controller is implemented to extract the maximum power from the fuel cells. The ANFIS controller outperforms well and reduces the time required to attain the maximum power.

7.6. Fuzzy PI Control. In [121], the authors implemented the fuzzy-based PI controller for managing the power flow in the BSSs and SCs of a HEV. The fuzzy controller deals with power sharing, whereas the PI controller regulates overcharging of the storage system. Both control systems are in charge of changing the battery. In [122], the functioning of a buck-boost converter is carried out using the load demand, supply status, and control switching signals. The inductor current is controlled in the proposed technique by altering the individual source current for a given load. Figure 21 presents the implementation of fuzzy PI type controller for speed control in EVs. The PI controller functions below the speed error limit, whereas the fuzzy controller operates above it.

7.7. Artificial Neural Network Control. The ANN controller extends the battery life and improves energy efficiency, allowing EVs to get more kilometers per charge. The mean square error is used to assess the performance of the ANN-based controller. In [123], the ANN controller is implemented for the bidirectional converter that can control energy flow in two stages: energy regeneration and dual-source powering. In terms of fast reaction and minimized current ripple, the simulation results showed that the ANN control outperformed the PI control.

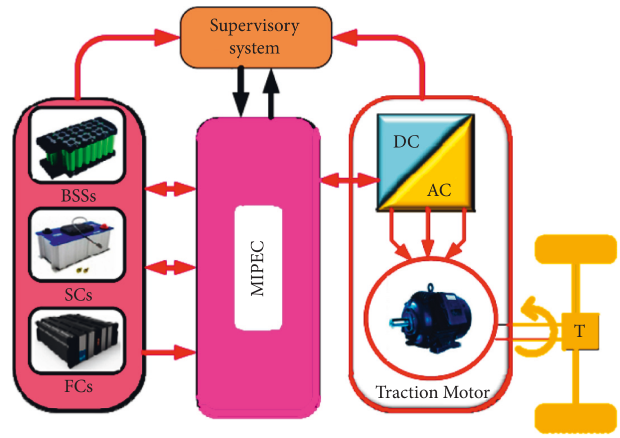


Figure 19: PI-based bidirectional controller.

7.8. Sliding Mode Control. An adaptive sliding mode control (ASMC) approach was developed in [124] for EV applications. The optimal reaching law improves ASMC's control operation (EORL). The ASMC maintains stable energy flow, tracking control, and convergence time. A new way for controlling a buck-boost bidirectional converter using sliding mode (SM) control is presented in [125–127]. The proposed technique is durable since it reduces the requirement of an additional sensor and exhibits high sturdiness when subjected to variations in input voltage and current due to change in converter load. A boost converter based on adaptive fractional-order sliding mode control (AFSMC) is designed in [128]. Using the adaption criteria, a Lyapunov function is created. The simulation results show that the proposed architecture is more successful than the traditional SMC system. Wu et al. [129] used a limited generalized predictive control (GPC)-based charging control technique to charge a LiFePO4 battery utilizing a unique coupled thermoelectric model. The proposed approach is intended to achieve quick charging while still keeping the battery's internal temperature within a safe limit. The GPC controller was self-tuned using a controlled autoregressive integrated moving average (CARIMA) model. In [130], an optimal charging control method with multiobjective optimization is implemented to improve the charge controller reliability and reduce the computational complexity. The proposed charging control strategy was validated using a variety of tests. From the results, it is evident that the proposed optimization method performs well when compared with other methods.

8. Modulation Methods

The modulation methods are implemented in power converters for regulating and reducing the output power and harmonics in the system. Advanced and hybrid modulation methods are implemented to reduce the losses in the system and increase the efficiency of the system. In a converter, the hybrid modulation technique aims to reduce the component count and development time.

In EV applications, many modulation methods are used to regulate DC-DC converters. The goal of employing PWM

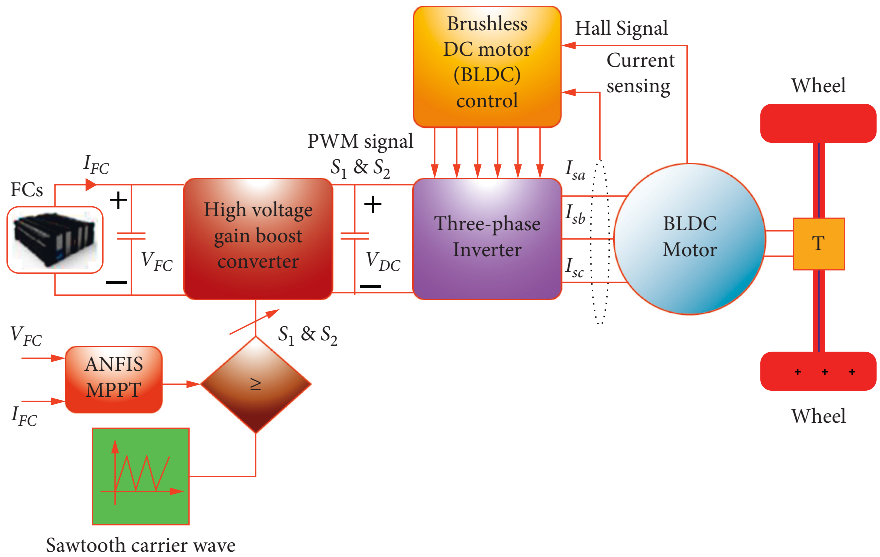


FIGURE 20: Adaptive neuro-fuzzy system (ANFIS) for EV.

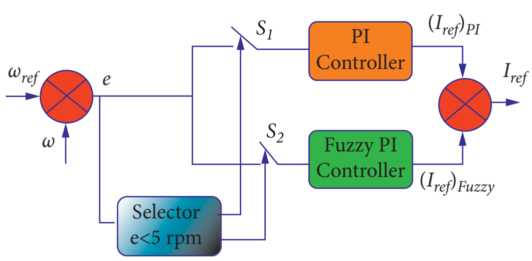


FIGURE 21: PI-based fuzzy controller [121].

TABLE 3: Literature of different modulation methods in EV converters.

Type	Converter	Ref	Modulation techniques
Non-isolated converter	CC	[9]	PWM
	SCBC	[89]	PWM
	CIBC	[131]	HPWM
	QZBC	[136]	PWM
	MDIBC	[137]	PWM
Isolated converter	PPC	[101]	PWM
	FC	[105]	Fixed frequency PWM
	RC	[110]	Quasi-resonant PWM
	ZVSC	[138]	Enhanced PWM
	MPIC	[132]	Modified PWM

is to find the best point for attaining the desired current and voltage amplitude, frequency, and phase [139]. Pulse-width modulation is the most extensively utilized modulation method in EV applications. Table 3 shows the usage of various modulation techniques for the DC-DC converters in EV applications.

9. EV Charger

EVs use motors for propulsion, and the power supplied to the motor is from a battery pack. When the motors are in use, the battery discharges and again the battery is charged using chargers. The EV chargers are classified into two types based on the location of the charger: on-board and off-board chargers. Figure 22 presents the on-board and off-board chargers [140]. If the charger is positioned internally inside EV, it is called on-board charger. If it is positioned externally outside EV, it is called off-board charger. The EV can be charged in three ways: (1) conductive coupled charging, (2) wireless charging, and (3) battery swapping [141, 142]. The conductive coupled charging is simple, which has a conductive cable between the charging port and EV. Here, an electrical outlet with the plug-type connector is used to charge the EVs. The wireless charging is done by inductive and capacitive coupling. In contrast to the on-board charger, the off-board charger is designed for wider systems such as DC fast charging applications [143]. The off-board chargers provide quick charging and vehicle-to-grid integration. The advantages and drawbacks of on-board and off-board chargers and battery swapping technology are shown in Table 4. The commercial on-board charger is implemented with a two-stage operation. The first stage provides the circuit for power factor correction (PFC) for adopting different types of connectivity from the main supply. Also, this type of on-board charger provides a constant AC supply [145]. The second stage employs a DC-DC converter, which provides the isolation between the AC supply and HV bus in the EV. The commercially available 3.7 kW on-board charger is shown in Figure 23 [146].

Different companies manufacture off-board chargers. In India, Revolt and other companies are developing EV chargers; in other countries like China, Wuhan Hiconics Intelligent Electric Co. Ltd. is developing EV chargers. The charger designed with the European standard follows either CHAdeMO or CCS2 or both [147].

9.1. Conductive Coupled Charging. The conductive-based charging connection between EV and charging outlet is connected in three ways.

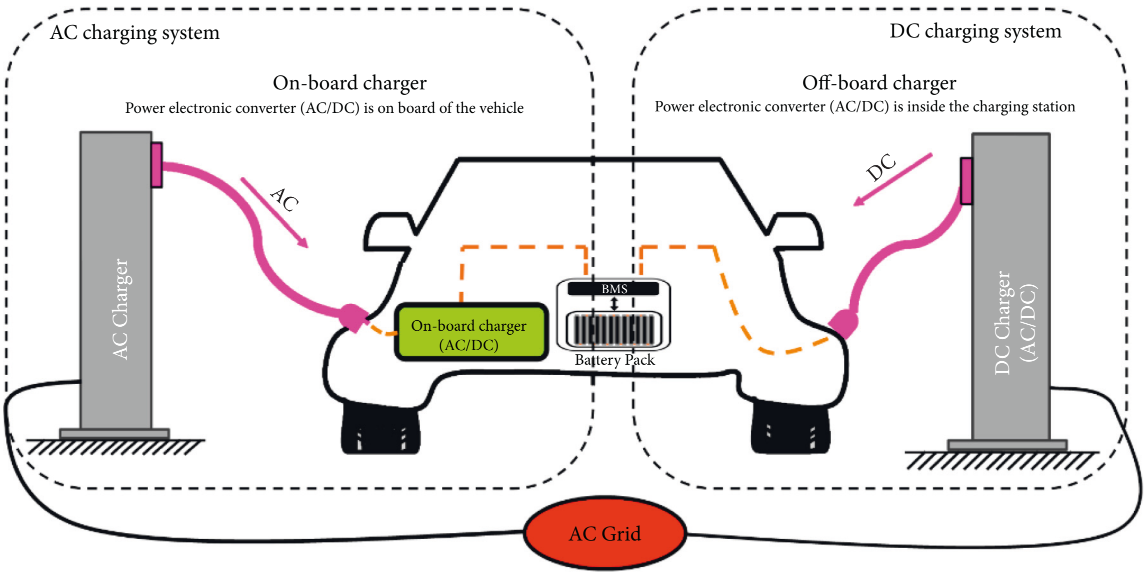
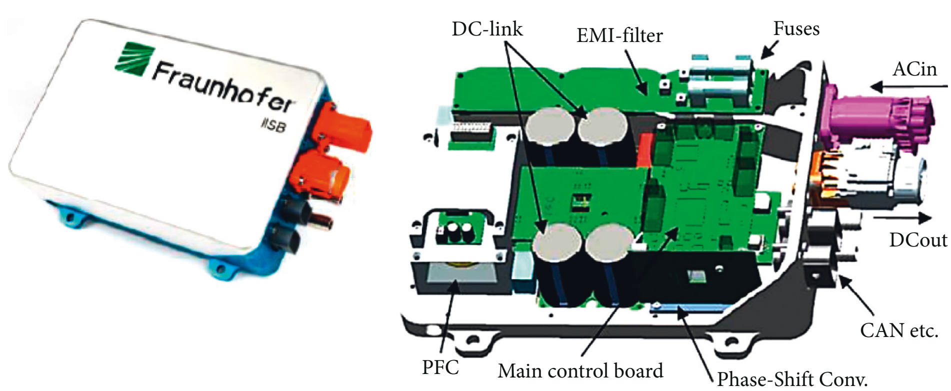


Figure 22: On-board and off-board chargers.

Table 4: Advantages and limitations of types of charging [11, 144].

Charger	Advantages	Challenges
On-board	Battery heating problem is avoided, charging is possible at all places with available electric outlet, simple BMS can be used	Less power transfer, slow charging, difficulty in V2X charging, weight of charger is added to EV
Off-board	Used in higher power rating fast charging, weight of EV reduces, BMS can be implemented with all features, less complex BMS	Battery heating issue, it is challenging to allocate the place
Battery swapping	Battery replacement is done in less than 1 minute, there is possibility of vehicle to grid in swapping station with the help of swapping, distance travelled is increased	Standardizing required for the battery, charging station should be able to manage more number of batteries, user is responsible for battery maintenance



(a) (b)

Figure 23: (a) 3.7 kW on-board charger. (b) Internal component organization of the 3.7 kW charger [146].

(i) In the first case (Case “A”), the permanent connection cable and plugs are permanently attached with the vehicle. This type is used in a light vehicle.

(ii) The second type (Case “B”) uses detachable connectors. This is utilized in semi-fast-charging connection.

(iii) In the third case (Case “C”), vehicle connector and charging port are permanently connected. Since it carries heavy current, it is used for fast charging. This type is more suitable for public charging.

9.2. Wireless Charging. The conductive coupled charging uses a physical connector. Because of high-power charging, during plugging and unplugging, it produces spark. Due to these reasons, wireless charging is the convenient charging method. Many companies are developing wireless

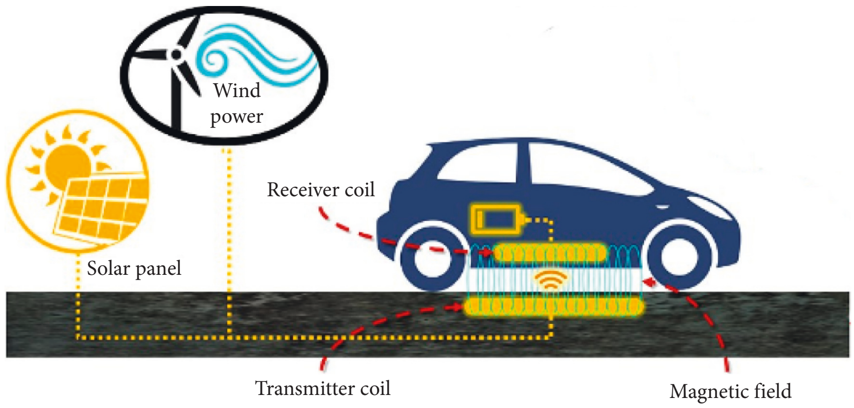


Figure 24: Wireless charging.

Table 5: Levels of EV charging.

Type	Supply	Voltage (V)	Current	Power output (kW)	Charging time	Types of charger	EV connector
AC level 1	1∅AC	120–240	16A, 13–16A	1.9–3	7 h	On-board	J1772™/AC
AC level 2	1∅AC/3∅AC	208–240	80 A	20	3 h	On-board	J1772™/AC
AC level 3	3∅AC	300–600	400 A max	120–240	30 min	On-board	CHAdeMO
DC level 1	DC	200–500	<80 Aa	40	22 min	Off-board	J1772™/AC
DC level 2	DC	200–500	<200 A	100	10 min	Off-board	CHAdeMO/DCSAE/DC
DC level 3	DC	200–600	<400 A	240	30 min	Off-board	CHAdeMO/DCSAE/DC

charging, namely, BMW, Tesla, and Nissan. The first wireless power transfer was developed by Nikola Tesla for the lightning bulb. Tesla tested wireless power transfer through the high-frequency AC transfer for lamp application [148]. The technical challenges in the developed wireless charging are slow charging time, power transfer limit, and reduction in efficiency with increase in distance. Wireless power transfer (WPT) is done using two methods: inductive power transfer (IPT) and capacitive power transfer (CPT) [149]. Inductive coupling involves the employment of two independent coils to transmit power. The receiving coil is a coil that is installed in the car. Another coil is used to transfer power. The IPT method can be used for high-power applications since it is capable of transferring power with significant air gaps (several meters). On the other hand, CPT is used for low-power applications. It allows power transfer with a relatively short air gap. Hyundai developed 'WiTricity' and exhibited it in the new Kona EV, as shown in Figure 24.

10. Levels and Standards of Charging Station

The distance travelled per charge is one of the reasons for not using EVs extensively. The EVs require a suitable charging infrastructure in international levels and standards. EV charging has three levels and different power rating as shown in Table 5. In terms of on-board chargers, level 1 [150] and level 2 [150] are primarily defined, whereas level 3 is an off-board charger. The public sector is the region where you will find the majority of level 3 [151] chargers implemented with microgrids. The availability of power in the grid is taken into consideration while determining the range of charging station. There are three main types of electric vehicle chargers based on voltage: DC level 1 (200 V– 450 V, 80 A up to 36 kW), level 2 (200 V– 450 V, 200 A up to 90 kW), and level 3 (200 V–600 V, 400 A up to 240 kW) [152]. The price required for charging, the time required for charging, the equipment usage in charging station, and the power used by the grid are determined by the charging station's charging power levels.

10.1. Standards of the Charging Station. The major components of EVCS are charging cords, attachment plugs, and charging station power outlets. The charging station has to follow different standards. As specified by the Society of Automotive Engineers (SAE), multiple charging wire and charger standards [153] have been developed. Electrical and physical features of the communication protocol are specified by the IEC-61851 and SAEJ1772 standards, respectively [154]. It is essential that the rectification and uniform voltage control of electric vehicles adhere to SAEJ1772 [154]. SAEJ2293 [155] defines the specifications for charging an EV from a utility or microgrid employing an off-board charger. In order to integrate the system, one must adhere to SAEJ2836 [155]. The various standards, their scopes, types of charging, and year of implementation are summarized in Table 6. Different types of cars and plugs used in EV require standardization. Combined charging systems are used because CCS with J1772 provides high-speed charging through high-speed charging pins. Different types of connectors used in AC and DC levels are shown in Figure 25 [156].

Table 6: Standards of EV charging.

Standard	Type	Year
SAEJ1772	Conductive	2010
SAEJ2293-2	Conductive	2014
SAEJ2847-1	Conductive	2010
SAEJ2847-2	Conductive and inductive	2015
SAEJ2954	Inductive	2019
IEC61980-3	Inductive	2019
IECTS62840-1	Battery swapping	2016
IEC61851-1	Conductive	2017
IEC61851-21-1	Conductive	2017
IEC61851-24	Conductive	2014
IEC60364	Conductive	2017
GB/T29317	Battery swapping	2012

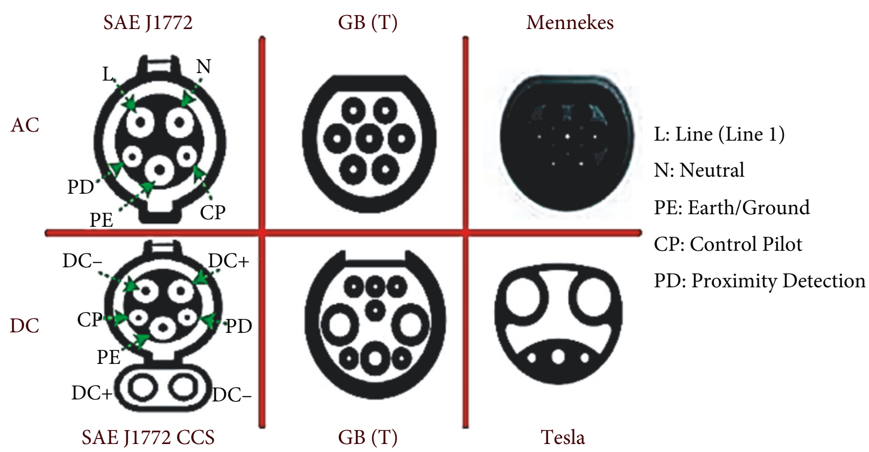


Figure 25: Various EV charging connectors.

11. Architecture of Charging Station and Its Energy Management Strategies

The EV battery charging system contains an electric power source, power converter, and battery. Different sources, such as utility grids, renewable sources, and standalone systems, are used. The different configurations of the battery charging system are commercial, solar-based fast, slow and medium charging, universal battery charging, grid-connected PV powered EV charging, and standalone PV charging. The various power converters used for EV charging are AC-DC converter, DC-DC converter, bidirectional DC-DC converter, and bidirectional inverters. The renewable energy source fed charging station electrification with utility grid provides an option for high efficiency and emission reduction [157]. Since electric vehicles (EVs) have become more popular, demand for charging stations has increased. Malfunction may occur in the distribution system [158] as a result of this increase in demand on the grid. Tesla and Nisan [159], two of the most popular electric vehicle (EV) manufacturers, have built their own charging station to support charging. The fee implemented for charging and emission of harmful pollutants are further reduced by incorporating renewable energy. Multiport charging and real-time prediction of charging station technology have cut down the number of charging stations needed because of the financial and environmental implications [160]. Figure 26 depicts a basic multiport charging system with a hybrid energy system. Solar panels, energy storage unit (ESU), power grid, charging stations, and bidirectional and generic converters are all the components present in the multiport charging system. It is significant to note that solar influences the DC link voltage level radiation that strikes the PV panel in a PV integrated microgrid. The battery can be charged with the necessary voltage provided by the DC-DC converter. The MG offers local control of power with the local generation; it provides high efficiency and reduces the cost of the power system. Tables 7–12 present various parameters of commercial and solar powered charging stations.

11.1. Energy Management and Control of Charging Stations. The energy management strategy (EMS) algorithm depends on the source available at the charging station. However, when demand increases at the local consumer loads, overloading of the utility grid system is unavoidable. Hence, the mobile charging station (MCS) with battery swapping (BS) provides an option to reduce overloading of the utility grid and reduce the charging time. The SOC and SOH of the battery are measured by Coulomb counting, Kalman filter, and open-circuit voltage. Even though the BS is more dependable for extended trips, the issue with battery swapping

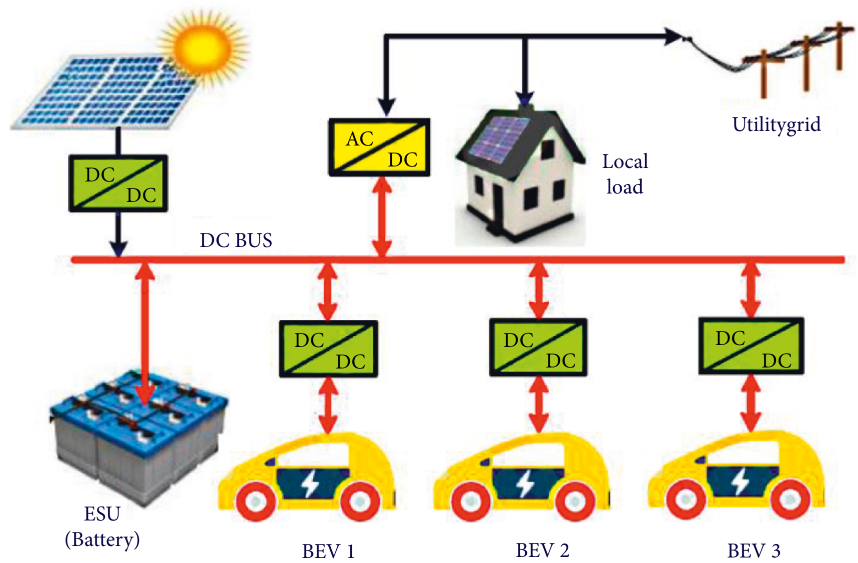


Figure 26: Multiport charging station architecture.

Table 7: Commercial fast charging station [131].

Types of chargers	Chargers installed	Charging points per charger	Vehicles charged at a time	Power sold/day (in KWh)	Cost (in Rs.)
CHAdeMO	2	1	2	2000	27,00,000
Type2-AC	3	1	3	1320	3,60,000
Bharat DC-001	1	1	1	200	2,47,000
Bharat AC-001	3	3	3	198	65,000
Total	9	6	9	3818	33,72,000

Table 8: Commercial medium charging station [131].

Types of chargers	Chargers installed	Charging points per charger	Vehicles charged at a time	Power sold/day (in kWh)	Cost (in Rs.)
CHAdeMO	1	1	2	1000	13,50,000
Type2-AC	3	1	3	1320	3,60,000
Bharat DC-001	3	1	1	900	7,41,000
Bharat AC-001	3	3	9	594	1,95,000
Total	10	6	15	3814	26,46,000

Table 9: Commercial slow charging station [131].

Types of chargers	Chargers installed	Charging points per charger	Vehicles charged at a time	Power sold/day (in kWh)	Cost (in Rs.)
Type2-AC	2	1	2	880	2,40,000
Bharat DC-001	3	1	3	900	7,41,000
Bharat AC-001	2	3	6	396	2,40,000
Total	7	5	11	2176	11,11,000

Table 10: Solar powered fast charging station [131].

Types of chargers	Chargers installed	Charging points per charger	Vehicles charged at a time	Power sold/day (in kWh)	Cost (in Rs.)
Type2-AC	2	2	2	44	2,40,000
Bharat DC-001	2	2	2	30	4,94,000
Bharat AC-001	1	3	3	9.9	65,000
Total	5	7	7	84	7,99,000

Table 11: Solar powered moderate charging station [131].

Types of chargers	Chargers installed	Charging points per charger	Vehicles charged at a time	Power sold/day (in kWh)	Cost (in Rs.)
Type2-AC	1	1	1	22	1,22,000
Bharat DC-001	1	1	1	15	2,47,000
Bharat AC-001	1	3	3	9.9	65,000
Total	3	5	5	47	4,32,000

Table 12: Slow solar powered charging station [131].

Types of chargers	Chargers installed	Charging points per charger	Vehicles charged at a time	Power sold/day (in kWh)	Cost (in Rs.)
Bharat DC-001	1	1	1	22	1,20,000
Bharat AC-001	1	3	3	9.9	65,000
Total	2	4	4	32	1,85,000

is that it calls for standardisation of battery type and ongoing health monitoring.

Therefore, the Internet of Things (IoT) within the EV provides continuous health monitoring of the battery. It will help the MCS in fixing the charging cost and time of replacing the battery. Even though the BS and MCS with EMS support the power balance at the charging station, the DC microgrid-based PV powered charging station requires an intelligent power management strategy for controlling power flow and regulating the DC grid voltage. The charging stations are controlled through a centralized controller when the charging station is small [161]. The decentralized controller is more suitable when the charging station is of high capacity and connected with different sources [162]. The fuzzy logic controllers provide priority-based charging or discharging of ESU at the charging station. Moreover, the fuzzy logic controller is suitable to control the power level at the charging station.

12. Conclusion

Electric vehicles (EVs) have the potential to transform transportation and save the globe from impending disasters associated with global warming. They are considered a feasible replacement for traditional vehicles that rely on fossil fuels that are running out. In this article, at first, the history of EV is discussed followed by the different types of EVs, various motors in EVs, different storage systems, different power converters, controllers, PWM methods, chargers, and charging methods. By working with smart grids and facilitating the integration of renewable sources, the main technology aspects of each component have been outlined in terms of how they may contribute to the development of an environmentally friendly and more effective energy system. The aforementioned sections could have significant impact in designing and implementing highly efficient storage systems, modular converters, hybrid PWM methods, intelligent controllers, and effective charging systems with BMS in automobile applications. Furthermore, this review article can provide a clear understanding on various components of EVs to researchers and academia.

While progress in the field of electric vehicles has been rapid in recent years, we discuss some of the open questions and areas where more investigation can yield useful insights for developing even better solutions. We have divided these possibilities into four categories: (i) environmentally friendly charge (i.e., utilizing renewable technology) and sustainability concerns related to EVs; (ii) the advancement and enhancement of the charging phases; (iii) the utilization of communication systems and machine intelligence and deep learning in EVs to enhance mobility and to increase the effective use of the charging network; and (iv) the usage of novel rechargeable battery innovations or production methods. Ultimately, this study serves to pave the road for future EV expansions that are more environmentally friendly [163–166].

Nomenclature

AFSMC: Adaptive fractional-order sliding mode control
ANN: Artificial neural network
ANFIS: Adaptive neuro-fuzzy inference system
BEV: Battery electric vehicle
BSS: Battery storage system
BMS: Battery management system
BS: Battery swapping
CV: Constant voltage
CC: Constant current
CIBC: Coupled inductor-based bidirectional converter
CARIMA: Controlled autoregressive integrated moving average
CPT: Capacitive power transfer
CSO: Chicken swarm optimization
DG: Distributed generation
DOE: Department of Energy
DC: Direct current
DSP: Digital signal processor
EV: Electric vehicle
EMS: Energy management system
FWA: Fireworks algorithm
FCEV: Fuel cell electric vehicle
FSPM: Flux switching permanent magnet
FEM: Finite element modelling
FSCM: Four-stage charging method
FC: Flyback converter
FLC: Fuzzy logic controller

FCs: Fuel cells
FFA-GBDT: Fertile field algorithm and gradient boost decision tree
GHGs: Greenhouse gasses
GPC: Generalized predictive control
HFT: High-frequency transformer
HEV: Hybrid electric vehicle
IEA: International Energy Agency
ICE: Internal combustion engine
IPT: Inductive power transfer
IoT: Internet of Things
MCS: Mobile charging station
MCM: Multistage charging method
OBD: On-board diagnosis
PFC: Power factor correction
PHEV: Plug-in hybrid electric vehicle
PMBLDC: Permanent magnet DC motor
PI: Proportional integral
PPC: Push-pull converter
PSO: Particle swarm optimization
QZBC: Quasi-Z-source bidirectional converter
RC: Resonant converter
RFBs: Redox flow batteries
SRM: Switched reluctance motor
SEV: Solar electric vehicle
SOH: State of health
SOF: State of function
SCs: Supercapacitors
SAE: Society of Automotive Engineers
SMC: Sliding mode control
VSI: Voltage source inverter
V2G: Vehicle to grid
VCM: Varying current method
WPT: Wireless power transfer
ZVS: Zero voltage switching
ZCS: Zero current switching.

Data Availability

The data used to support the findings of this study can be obtained from the corresponding author upon an e-mail request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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