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TOPICAL REVIEW

A Comprehensive Review on Electric Vehicle: Battery Management System, Charging Station, Traction Motors

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ABSTRACT Electric vehicles (EVs) are widespread, and their usage is increasing as a result of air pollution and rising fuel costs. EVs are quickly gaining popularity as a green means of transportation. By 2030, most cars will probably be battery-powered EVs. However, the development of EV power transmission is packed with important challenges and is an active topic of research. In EVs, the battery serves to store electrical energy. The DC-DC converter provides a direct current (DC) link between the battery and the inverter. A motor provides the transmission for the vehicle's motion. Hence, this state-of-the-art provides exhaustive information about battery management systems (BMS), power electronics converters, and motors. Lithium-ion batteries are more efficient for EV applications, and boost converters and full bridge converters are commonly used in EVs. EVs use permanent magnet synchronous motors (PMSM) and induction motors (IM). The renewable energy-based charging station and the fast charging specifications are also clearly addressed for EV applications.

INDEX TERMS Electric vehicle, BMS, power converters, motors, charging station, cyber security.

NOMENCLATURE

ABBREVIATION

BLDC	Brushless DC Motor.
BMS	Battery Management Systems.
CO	Carbon monoxide.
CO_2	Carbon dioxide.
DC	Direct Current.
EVs	Electric Vehicles.
EIS	Electro-chemical impedance spectroscopy.
ESS	Energy storage systems.
FC	Fuel cell.
HEVs	Hybrid Electric Vehicles.
IM	Induction Motor.
ICEVs	Internal Combustion Engines.
IWM	In-Wheel Motor.
LNO	Lithium nickel oxide.
LTO	Lithium titanium oxide.
LFP	Lithium iron phosphate.
LMO	Lithium manganese oxide.
LCO	Lithium cobalt oxide.
NCA	Lithium nickel cobalt aluminum oxide.
NOx	Nitrogen oxides.
NMC	Lithium nickel manganese cobalt oxide.
SOC	State of Charge.
PI	Proportional Integral.
PMSM	Permanent Magnet Synchronous Motor.
PV	Photovoltaic.
SRM	Switched Reluctance Motor.
SOH	State of Health.
SOE	State of Energy.

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SOP State of Power.
SMES Superconducting magnetic energy storage.

I. INTRODUCTION

A. BACKGROUND

EV is a term for a car that is driven by electric motors. The energy from the battery is used by the motor. The battery stores energy that comes from the charging station or sources of clean energy. A DC-DC converter is needed to recharge the battery and maintain the photovoltaic (PV) cell's supply going, and an electric motor is needed to move things [1]. A self-contained electric vehicle can be powered by solar panels, a battery, a battery-powered generator that turns gasoline into electricity, or a collector system and electric motor that collects energy from sources outside of the vehicle. Figure 1. shows the three different kinds of electric vehicles [2]. In the past 150 years, EV technology and development have come a long way. As shown in Figure 2, the development of EVs from simple cars that couldn't be charged to cars with modern control systems can be broken down into three stages: the beginning in 1832, the middle in 1960, and the present. If the vehicle is powered by renewable energy sources, it is possible to have zero emissions [3].

World's population growth, economic expansion, expanding car usage, and urbanization are all contributing to an increased vehicle and E-motor vehicle [10]. EVs provide advantages including being more cost-effective to operate and maintain, as well as better for the environment and human health [11]. The goal of thestudy is to understand, using a survey of real-world electric vehicles, the optimal way to use batteries, DC-DC converters, and motors from the perspective of an application for EVs [12]. Additionally, a thorough presentation of the renewable energy source-based charging station's emission control methods is made [13].

In Norway, where EV sales are high, annual sales of electric and hybrid vehicles climbed from 0.6% to 4% in the United States to 86% in 2022. Table 1, displays the total new automobile sales for selected nations in percentage. Figure 3. shows that EV sales doubled in 2021 [14]. Table 2. Comparison between the Internal Combustion Engine in vehicle emissions [7].

The majority of governments throughout the world had already started paying attention and showing they are ready to reduce greenhouse gas emissions and improve air quality everywhere [8]. However, it is predicted that 10.2 billion electric vehicles would be available on the market by 2023, accounting for roughly 1.5% of all inventors worldwide. Because of this, EV adoption still has a way to go. The utilization of EVs has grown since 2011 [9].

B. MOTIVATION FOR RESEARCH

In [15] article discusses the importance of EVs while coming on the road and facing many challenges of charging time, range covers, and energy storage system issues. All these

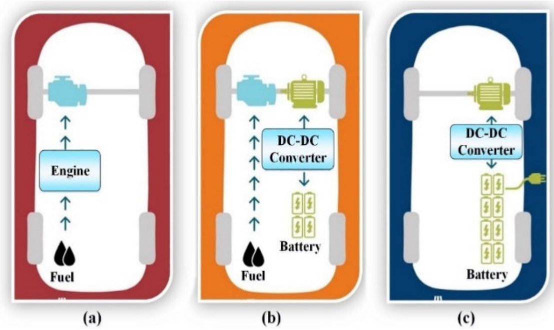


FIGURE 1. Transformation of vehicle [4].

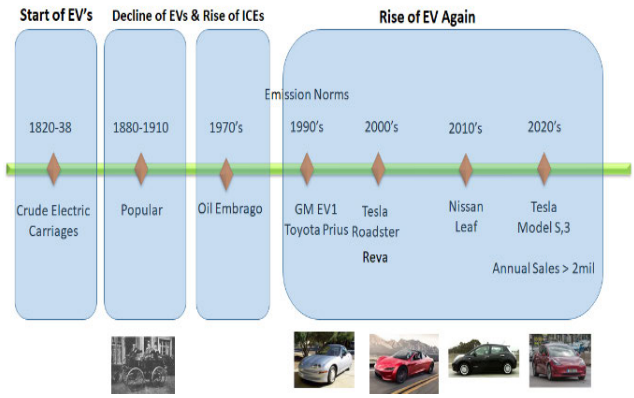


FIGURE 2. Generation of electric vehicles [5].

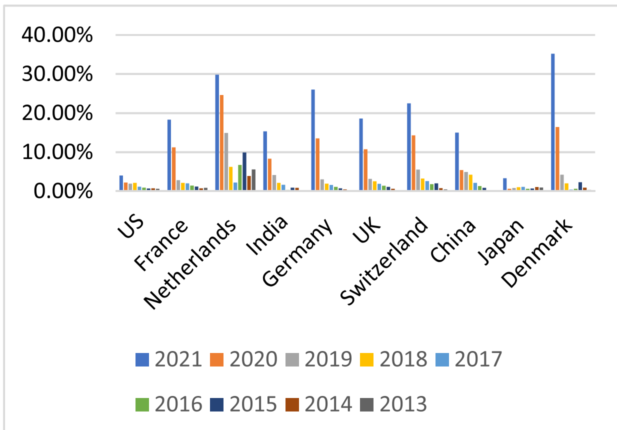


FIGURE 3. Statistical analysis of EV by country [6].

issues can be overcome by improving the technological development of BMS in terms of various parameters, including battery sizing, the life cycle of the battery, and battery capacity demand with proper calculations and examples. In [16] BMS, most important, to improve the performance of cell balancing, state of health, state of charge, charging/ discharging control, and increase the battery's life span. Further, discuss the thermal management issue and alternative energy storage systems such as electro-chemical (battery), chemical (fuel cell) hydrogen storage, mechanical (flywheels), electrical

TABLE 1. Since 2013, total new automobile sales for selected nations [6].

Country	2021	2020	2019	2018	2017	2016	2015	2014	2013
US	4.0%	2.2%	1.9%	2.1%	1.13%	0.90%	0.66%	0.72%	0.60%
France	18.3%	11.2%	2.8%	2.11%	1.98%	1.4%	1.19%	0.70%	0.83%
Netherlands	29.8%	24.6%	14.9%	6.2%	2.2%	6.7%	9.9%	3.87%	5.55%
India	15.3%	8.3%	4.1%	2.1%	1.6%	0.3%	0.9%	0.84%	0.21%
Germany	26.0%	13.5%	3.0%	1.9%	1.58%	1.1%	0.73%	0.43%	0.25%
UK	18.6%	10.7%	3.15%	2.53%	1.86%	1.37%	1.07%	0.59%	0.16%
Switzerland	22.5%	14.3%	5.5%	3.2%	2.55%	1.8%	1.98%	0.75%	0.44%
China	15%	5.4%	4.9%	4.2%	2.1%	1.31%	0.84%	0.23%	0.08%
Japan	3.3%	0.6%	0.8%	1.0%	1.1%	0.59%	0.68%	1.06%	0.91%
Denmark	35.2%	16.4%	4.2%	2%	0.4%	0.6%	2.29%	0.88%	0.29%

TABLE 2. Comparison between the internal combustion engine vehicle and E-motor vehicle [24].

Characteristic	ICE	HEV	EV
Moving parts	More	More	Less
Vibrations	Medium	Medium	Low
Bidirectional	No, turn in one way	Rotate both ways by Electric.	Rotate both ways
Emission of gasses	More	More while consuming gas	Less
Reliability	Low	Very high	High
Efficiency	30% to 40%	30% to 40% by the engine. More than 90% as EV.	More than 90 %
Regeneration	Not possible	Possible as EV	Possible
Torque at zero speed	0	Maximum as EV	Maximum torque

(ultra-capacitors or supercapacitor), Superconducting magnetic energy storage, and thermal energy storage. Moreover, from the charging point to ESS, multiple challenges affect the EVs subsystem parts: motor, controller, converter, and grid integration. In a few automotive industries, they introduced alternative ESS-based EVs, such as the Fuel cell-based Toyota Mirai Sedan in 2014. CAPABUS is a capacitor vehicle (developed in China) and a German company; MAN's model is a developed ultra-capacitor that can store only 5% of that of lithium-ion-based EVs. The VOLVO in 2013, PARRY PEOPLE MOVER, and Oxford Bus Company in 2014 is powered flywheel. The Bosch, in collaboration with PSAP Citroen, developed SMES-based EVs with a reduction of 45% in fuel consumption. In [16] EVs, technology demand fast charging to reduce the charging time and improve range anxiety. Also, discuss the system for the fast charging of EVs, which provide continuous feedback to the dc-dc converter considering the battery SOC by using a battery pack control module and tuning the PI controller. In article [17], EV charging classification and methodology, isolation, unidirectional and bidirectional chargers, and safety standards in EVs chargers. Further, examine the advanced converter topologies and charging methods, including unidirectional full-bridge series resonant charger and bidirectional isolated dual active bridge charger. Also [18] comparative criticism of the EV charging technologies, control strategies, and power levels include various fast charging topologies in power electronic DC-DC converter topologies, AC-DC bridgeless boost converter, AC-DC matrix converter topologies, Vienna rectifier, Quasi Z source, and modular multilevel converter for EVs [19]. To develop a high-performance bidirectional converter and control system to handle the power flow between the energy storage and the grid automatically and efficiently. Additionally, [20] battery swapping technology improved in EV charging facilities to reduce the time consumption, power transmitted through different levels of distribution lines (33 kV, 11 kV, 400 V) is analyzed and increased the power flow capability such as up to 118.3% capacity improvement in the case of 400 V line improves the great economic efficiency with the availability of DC sources such as battery storage plant to the grid. In [21] the advanced EV technology moving towards intelligent transportation system needs smart cities to know the level of EV charging. The autonomous EV development can resolve the charging issues of the future by communicating the relevant transportation information with other receivers through Vehicle-to-anything (V2V or V2G) communication. In the [22] article, reduce the EVs subsystem cost by replacing magnet motors with magnetless motors. The present EV magnet motor is BLDC, PMSM producing high efficiency but using high-cost rare earth material and demagnetization effect [23]. The future Magnetless motor, such as induction motor and switched reluctance motor comes with low-cost material. The main issues of the above motors are torque ripple, noises for SRM, and losses in IM for EV applications [11].

According to the following, Section II of this article analyses the problems and effects of conventional automobiles. Section III serves as an illustration of the BMS for electric vehicles. The review of power electronics converters for electric vehicles is covered in section IV. Section V is a detailed review of electric motors for EVs. Section VI reviews charging stations that use renewable energy. Cyber security for EVs is described in section VII. Future research direction briefs in section VIII. The ninth section, which serves as the paper's conclusion is clearly explained in the Survey organization chart shown in Figure 4.

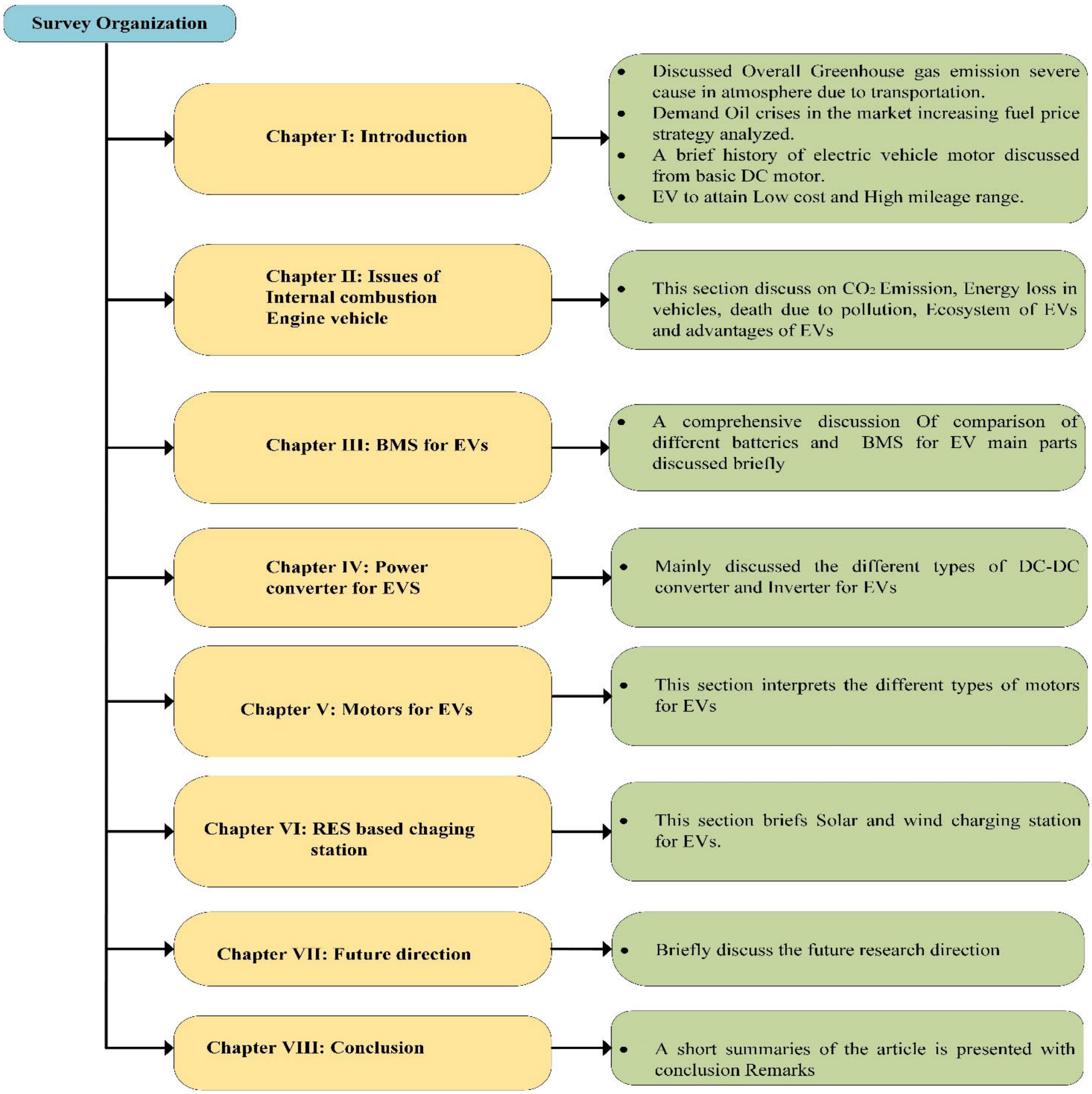


FIGURE 4. Survey organization chart.

II. ISSUES AND IMPACT OF CONVENTIONAL VEHICLES

A. CO_2 EMISSIONS OF DIFFERENT VEHICLE

One of the biggest sources of greenhouse gases is a car's engine, which is responsible for 30–50% of carbon dioxide (CO_2) emissions from roads. The world's population is growing, the economy is getting better, more people are using cars, and more cities are being built. Most governments around the world have started to pay attention and show that they are ready to cut down on greenhouse gas emissions and raise the standard of the air everywhere. Compared to vehicles with internal combustion engines (ICEVs), EVs produce no emissions and have a significant potential to cut CO_2 emissions. when combined with a reduced carbon power sector, as depicted in Fig.5. Gas and diesel cars put out almost 3 times more CO_2 than electric cars [25].

The energy requirements are based on a 55 percent city to 45 percent highway driving scenario in fuel cars, the engine is where the majority of the energy is wasted, mostly as air pollution, rising gas prices, and global warming mean that we need other ways to get around. To preserve the environment for future generations, IC engines must be maintained regularly due to their low efficiency. IC Engine automobiles have a lower well-to-wheel efficiency. EVs don't release any harmful gases like carbon monoxide (CO) and nitrogen

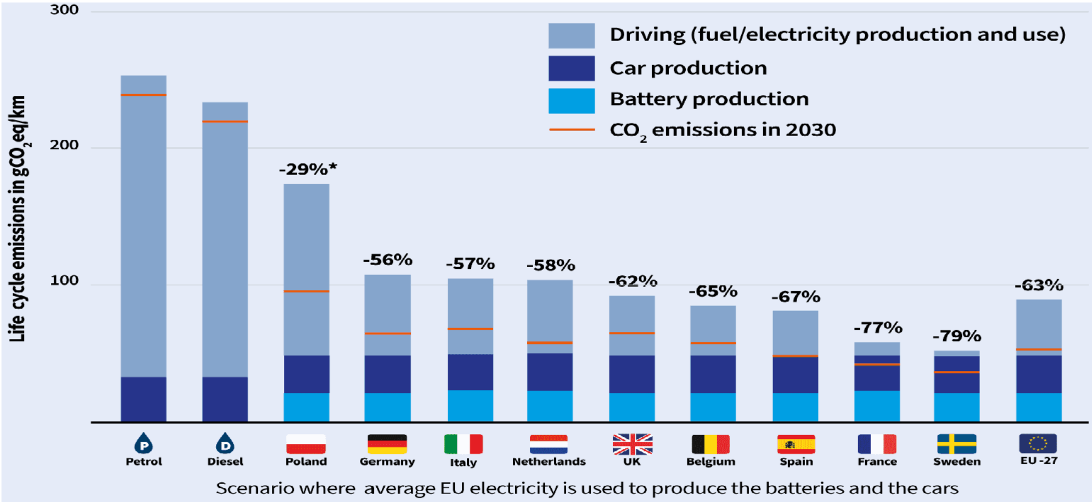


FIGURE 5. CO2 emissions of different vehicles.

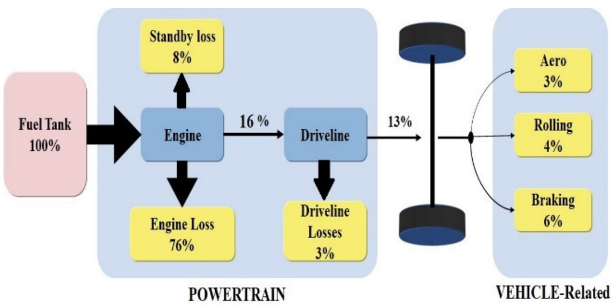


FIGURE 6. Energy loss in an ICE vehicle.

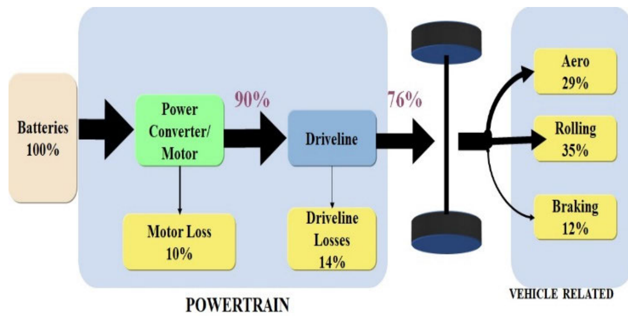


FIGURE 7. Energy loss in E-vehicles.

oxides (NOx) (NO). So, the alternative vehicle is an electric car [26].

B. ENERGY LOSS COMPARISON OF ICE VEHICLE AND E-VEHICLE

Only about 13% of the energy is contained in conventional automobiles Depending on the drive cycle, gasoline may be utilized to move the car along the road. The remaining part is either wasted owing to the rear driveshaft and motor inefficiency or utilized to power accessories. As a result, the potential for fuel efficiency improvement through modern techniques is enormous temperature. Engine friction, air pumped into and out of the engine, and other smaller energy loss factors and heating low efficiency [27]. Figure 6 Energy Loss in ICE vehicle and Figure 7 Energy Loss in EVs.

Braking losses: When the brakes of a conventional vehicle are used, the energy utilized Due to braking system friction, the energy used to resolve the vehicle's rigidity and get it moving is lost as heat. So little energy is needed to move a vehicle that is not too heavy. Because of this, it takes less energy to break a lighter vehicle. Using lighter materials and technology is one way to cut down on weight. Regenerative braking is used by hybrids, plug-in hybrids, and electric cars to get back some of the electricity that would have been lost when stopping [28].

Resistance to the wind: As a car moves along the road, it requires electricity to blow air away from the way. It uses less energy at slower speeds and more energy even as the speed goes up. This resistance is directly related to the shape and frontal area of the vehicle. Smoother vehicle shapes have already made a big difference in how much drag they cause, but 20%–30% more decreases are feasible [29].

Resistance to Rolling: Rolling resistance is a resistive force created when a tire deforms while rolling on a flat surface. Rolling resistance can be reduced with new tire designs and materials. For automobiles, a 4% reduction in rolling resistance results in a 1% increase in fuel efficiency, but these gains must be matched against locomotion, reliability, and vibration [30].

C. NUMBER OF DEATHS DUE TO POLLUTION

India has a substantially greater rate of pollution-related fatalities than other emerging or developed nations. According to statistics, India has an 8 times greater death rate from

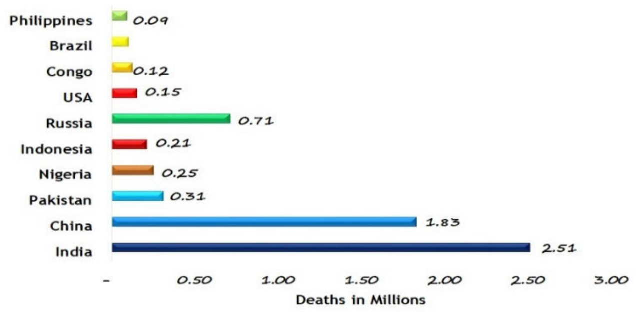


FIGURE 8. The death rate due to pollution in different countries [31].

pollution than Pakistan, its neighbor, and the United States. India has the highest death rate of any nation due to its dense population. Pollution can be reduced in terms of many factors, like avoiding ICE vehicles, and using EVs also reduces pollution widely. As a result, the death rate will be lower than it is now. Figure 8. shows the death rate due to pollution in different countries [31].

D. ADVANTAGES OF EVs

1) EVs ARE FAR LESS HARMFUL TO THE ENVIRONMENT

The average Internal Combustion Engine is just 40% efficient, with 60% of its energy being lost to heat and friction during operation. As a result, when traveling the same distance, internal combustion engines waste substantially more energy.

2) EVs ARE MORE COMFORTABLE TO DRIVE

EVs are so well for functioning properly and quietly. Because they function with an electric engine rather of an exhaust system, they naturally produce less noise pollution and have a smoother acceleration and deceleration. Furthermore, because of their reduced center of gravity, they have improved handling, comfort, and reactivity. In addition, EVs tend to consume less power in stop-and-go busy traffic [32].

3) EVs OFFER LOWER MAINTENANCE EXPENSES THAN CONVENTIONAL VEHICLES

Even though electric vehicles have a somewhat large initial investment cost, savings in other sectors like maintenance. EVs have significantly fewer moving components, which means they are less expensive to maintain and endure less wear and tear. Having said that, EVs do require some maintenance. Brakes, tires, and other components should be inspected regularly by the manufacturer's recommendations. Due to the effect of regenerative braking, EVs have lower maintenance requirements than conventional vehicles. As a result, these inspection schedules are less frequent than those for conventional vehicles. The majority of EVs may be supported by major automobile dealerships. Independent service centers that can service EVs, on the other hand, are few and far between at the moment.

4) ELECTRICITY IS LESS EXPENSIVE THAN PETROLEUM

In the United Kingdom, it is significantly less expensive to power your car electrically rather than petroleum. Not least because you can charge your vehicle at home – and even install solar panels to create your own electrical if you so desire. Due to the ability to regeneratively brake, electric automobiles can potentially transform into generators and generate their energy [33].

5) LESS EXPENSIVE TO REFUEL

When compared to other fuels such as petrol and diesel, refueling a car electrically is more economical. Assuming that the average electric vehicle drives approximately 3.5 miles per kWh, 100 miles would cost approximately 5p each mile. However, with gasoline currently priced at approximately £1.24 per liter, driving a car fuelled by gasoline would cost approximately 11p each mile.

6) LESS MAINTENANCE COST

As previously stated, Electric cars are easier to maintain because they have fewer moving parts than cars with combustion engines. According to estimates, yearly tax and maintenance for ICE models will be 49 percent lower than for ICE vehicles.

E. DISADVANTAGES OF EVs

(i) Electric vehicles can be costly to purchase.
(ii) An electric vehicle cannot travel as far.
(iii) There are not enough charging stations.
(iv) increased charging time.

III. BMS FOR EVs

Researchers are most concerned about green environments and environmental hazards. Green House Gas (GHG) emissions and global warming are getting worse because so many people use gasoline and diesel to run their cars, which makes a lot of carbon dioxide every year [34].

EVs are the best way to cut down on these carbon emissions. EV development creates a lot of jobs in many different areas, like making batteries, modeling powertrains, constructing highly efficient motors, etc. Small and medium-sized electricity storage systems have been using batteries a lot due to their high energy density, making little noise, and being easy to maintain. In many EVs, Li-ion and Ni-MH batteries are often used. Table 3 compares the batteries used in EVs to those used in Table 4. Getting a better idea of how different electric cars with Li-Ion batteries compare [35]. Li-ion is very important because it has many benefits, as shown in Table 3, such as long life, high efficiency, and high energy density. The type of lithium-ion battery is largely determined by the materials used for the positive and negative electrodes [36]. Various EV applications frequently use lithium-ion batteries. Lithium-ion batteries have a significant impact thanks to additional advantages Table 3 illustrates these characteristics, together with long life, excellent efficiency, and energy

TABLE 3. Comparison between batteries used in EVs [34], [35], [36], [37], [38].

Parameter	Lead Acid Battery [35]	Ni-Cd Battery [36], [37]	Li-Ion Battery [38], [39]
Cost	Less	Less	More
Life cycle	200-300	1500	500-1000
Nominal Voltage	2V	1.25V	3.6V
Energy Density (Wh/kg)	30-50	45-80	110-160
Self-Discharge	Less	Medium	Very less
Overcharge Tolerance	High	Moderate	Very Low
Operating Temperature	-20ºC to 60ºC	-40ºC to 60ºC	-20ºC to 60ºC
Toxicity	The sulphuric acid in the battery is very dangerous.	contains a deadly metal	Non-Toxic (Electrolyte may be toxic)
Thermal Stability	Less stability	Less stability	More stability
Efficiency	85% - 90%	95%	98%-100%
Power density	180	150	1800

TABLE 4. Comparative analysis of various electric cars using Li-Ion batteries [34], [35], [36], [37], [38], [39].

EVs	Battery	Power	Capacity
Renault Twizzy	Li-Ion	4kW / 5CP	6.1 kWh
Tesla Model S	Li-Ion	193kW / 259CP	100 kWh
VW E-Golf	Li-Ion	100kW / 136CP	24.2 kWh
Nissan Leaf	Li-Ion	80kW / 107CP	30 kWh
Hyundai Ioniq	Li-Ion	88kW / 118CP	28 kWh

density. According to the kind of lithium-ion battery, the materials used for the positive and negative electrodes have a big impact on how accurate SOC measurements are. For EV applications, the most common Li-ion battery types are lithium nickel cobalt aluminum oxide (NCA), lithium cobalt oxide (LCO), lithium titanium oxide (LTO), lithium manganese oxide (LMO), lithium nickel oxide (LNO), lithium iron phosphate (LFP), and lithium nickel manganese cobalt oxide (NMC). The comparison of the features of various Li-ion batteries is shown in Table 5. The performance of different Li-ion battery types is compared in Table 6.

A good BMS is capable of safe and reliable operation. To update data, regulate a battery's voltage balance, and detect defects all of which have a big impact on SOC precision it is also necessary. A BMS's SOC is taken into account alongside significant issues that have recently been reviewed. A gasoline-powered vehicle's SOC of the battery controls a similar function to the fuel indicator, which indicates how much energy is still in the battery. The reliable and secure functioning of the EV is ensured by a detailed assessment of the charge states, which also provides information about the battery's current and available performance. The most challenging task for the development of EVs is estimating battery SOC, though [40].

A. THE FRAMEWORK OF BMS

At the moment, a BMS is used by many car companies, universities, and colleges BMS products have been offered for sale by EV Power Australia, the British REAP group, American Edition Company, Beijing Significant Power Technology, and Harbin Guantuo Power Equipment Company [29]. Since its beginnings, BMS has always been employed in EVs. The primary argument is that there are 100 times more batteries in EVs than that in portable devices [37]. The expected range of EVs is also currents, voltages, and powers. This step makes a BMS harder to use than portable electronics. A BMS is made up of different types of actuators, sensors, signal lines, and controllers, all of which work together to make the system work. The survey circuit determines the temperature, voltage, and current which the controller circuit uses to get the gating sign. The controller circuit's most important job is to estimate the state of charge (SOC), state of health (SOH), state of energy (SOE), and state of power (SOP) of the batteries using a series of algorithms as well as analog signals. The voltage, temperature, and current measurement systems of the power supply are changed. After that, the information will be sent to the vehicle controller, which will have to make important decisions about the vehicle and power distribution. The BMS checks for problems with the EV's power distribution and energy storage. Researchers have come up with many different models for batteries. Figure 9, demonstrates how well the BMS section is split into software and hardware assemblies [41].

1) BMS HARDWARE

BMS uses various sensor systems to track and manage the battery's current, temperature, and voltage. Various researchers think that electrochemical impedance

TABLE 5. **Comparison of the features of various Li-ion batteries [34], [35], [36], [37], [38], [39], [40].**

EV Model	Battery capacity (KWh)	Battery Voltage (V)	Energy Consumption (Wh/mile)	Distance Range (miles)	Charging Time for 50kW (min)	Connector type	Charging power AC 1P-phase (KW)/ AC 3P-phase (KW)/DC fast (KW)
Honda e 2020	35.5	-	275	138	40	CCS, Type 2	6.6 / 6.6 /56
Volkswagen e-Glof	35.8	323	245	144	60	CCS, Type 2	6.6 / 6.6 /100
Nissan Leaf	40	350	330	168	60	CHAdeMO, Type 2	3.6 / 3.6 /50
BMW 13	42.2	352	245	191	50	CCS, Type 2	7.4 / 11 /155
Renault Zoe R110 ZE50	52	400	280	245	50	CCS, Type 2	7.4/ 22 /46
Lexus UX 300e	54.3	-	270	196	40	CHAdeMO, Type 2	6.6 / 6.6 /50
Tesla Model 3	55-82	350	225-265	278-360	40-60	Supercharger	7.4 / 11 /250
SKODA Enyaq Iv	62	-	252	256	50	CCS, Type 2	7.2/ 11 /100
Kia Niro EV	64	327	255	283	75	CCS, Type 2	7.2/ 7.2 /77
Nissan Leaf Plus	64	350	285	239	45	CHAdeMO, Type 2	6.6 / 6.6 /100
Mercedes EQA	66.5	405	355	263	50	CCS, Type 2	7.4 / 16.5 /100
Tesla Model S	75-100	350	305-310	283-388	60	Supercharger	7.4 / 11 /100-200
Ford Mustang Mach-E	75.7	450	275	273	60	CCS, Type 2	7.4 / 11 /115
Volvo XC40 Recharger	78	-	380	257	60	CCS, Type 2	7.4 / 11 /150
Polestar 2	78	400	305	292	60	CCS, Type 2	7.4 / 11 /150
Porsche Taycan	79.2	800	335	254	50	CCS, Type 2	7.4 / 11/ 225
Volkswagen ID.4	82	365	290	310	60	CCS, Type 2	7.4 / 11/ 125
Jaguar I-PACE	90	390	354	292	55	CCS, Type 2	7.4 / 11/ 100
Audi E-Tron	95	400	426	249	60	CCS, Type 2	7.4 / 11/ 115
Tesla Model X	100	350	360-365	233-315	60	Supercharger	7.4 / 16.5/100-200

TABLE 6. **Comparison of the features of various Li-ion batteries [40].**

Battery Name	Nominal Voltage (V)	Discharge (c)	Lifespan (hrs)	Charge (c)	Specific Energy (Wh/kg)
LFP	3.2~3.3	1	1000~2000	1	90~130
LNO	3.6~3.7	1	>300	0.7~1	150~200
LMO	3.7~4.0	1	300~700	0.7~1	100~150
NMC	3.8~4.0	1	1000~2000	0.7~1	150~220
LTO	2.3~2.5	10	3000~7000	1	70~85
NCA	3.6~3.65	1	500	0.7	200~260
LCO	3.7~3.9	1	500~1000	0.7~1	150~200

spectroscopy (EIS) could be used to test the impedance of battery cells. Accurate information is hard to get outside of the lab because it costs a lot and there isn't enough room. A protection system needs to be made to stop the battery from overheating, charging, and discharging. To charge batteries, you need a constant voltage or current, and you may need a galvanostat and a potentiostat. Balance cells may also need a rheostat that can be changed. Balancing the cells is a key way to make a battery pack more stable and estimate how long it will last. Cell balance, performance, and reliability

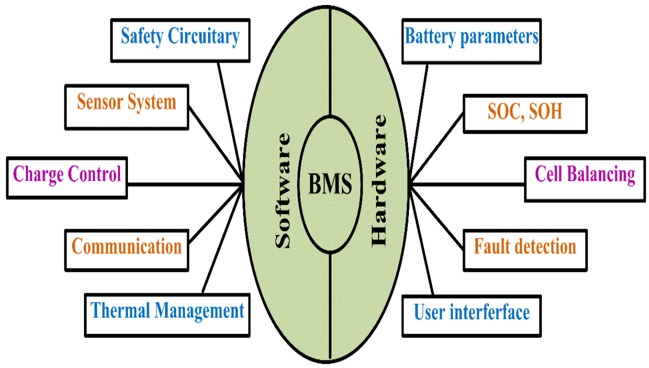


FIGURE 9. The basic plan of a BMS in an EV [45].

are all affected by temperature. So, some authors [42] have agreed that lowering the temperature difference between cells is essential and must be watched and worked on. After data or information is transferred, a BMS unit works on its own. For data to be sent inside the BMS, it needs to go through a controlled transceiver. With wireless communication and smart batteries, the charger and battery can share a lot of information.

2) BMS SOFTWARE

The BMS software is the middle point of the arrangement. It uses information from sensors and how the hardware works to make decisions and guess the state. BMS software needs a sample rate, switch authority trying to check in the cell trying to balance the controller, a detector scheme, and a uniform armed guard circuit strategy. Online research and preparation are needed to find out about controlling how batteries work. Because the study is about figuring out what Total cell voltage, current, separate cell voltage measurement, temperature, impedance, and smoke detection are battery parameters. Estimating the state of a battery involves SOH and SOC, which seem to be groups of State–space representations, neural networks, and symbolic/fuzzy logic support working circumstances., etc. The best way to get the most out of a battery is to balance the cells without overcharging or draining them. It fits with the stages of SOC cells. Based on the SOC of each cell, the controller can control charging. So, to enhance cell balancing, an accurate estimate of each cell's SOC is needed. When sensitive issues are handled online, they will be exposed. Data analysis is needed to find battery faults and situations that are outside of the acceptable range. Before problems happen, important information will be written down [43]. The BMS interface has to show important information. The battery SOC shows the range on the control panel. Also, the operators of the battery estimate and calculation need unusual, disturbing, and extra ideas. Figure 10. shows the block diagram of the BMS. The details of how it works are broken down. At every moment, the measuring device block of the battery changes the current, temperature, and voltage into digital signals [44]. These restrictions are utilized to determine the SOH and SOC of the battery. The maximum charging and discharging current are governed by a capability assessment block. The cell balancing block uses the findings of the is wrong and how to fix it, it may be important to have a reliable and robust automated information analysis system. The operator will see this information on an easy-to-use interface. Roles that are specific to BMS are listed below. capability estimation to restrict over-discharge or over-irregularities. Ground fault set of appropriate systems safer. The thermal control module monitors the temperature of the battery to ensure its safety. A transceiver with input and output control is utilized. For high-volume data transmission and reception, a high-speed, regulated transmitter is required [45].

IV. POWER ELECTRONICS CONVERTERS (PEC) FOR ELECTRIC VEHICLES

Power Electronics Converters (PEC) play a major role while the manufacturing of electric vehicles which performs the power conversion operation for EVs such as DC-DC converters and Inverters which is shown in Figure 11.

A. DC-DC CONVERTER FOR ELECTRIC VEHICLE

For the electric motor to get a constant voltage supply while driving, each EV has a battery that is connected to the DC-DC converter. Modern EVs are impossible without this converter circuit. The function of the circuit is unaffected by the circuit's architecture [47]. The battery's output voltage is several hundred volts of direct current (DC), and the EV's internal electrical systems, including the motor, audio, and video systems, heating, ventilation, and air conditioning (HVAC), lights, displays, etc., all require various voltage levels. The DC-DC Converter performs step-up or step-down operations depending on the voltage requirements [48], [49]. There are primarily two types of DC-DC converters.

(i) Isolated DC-DC Converter
(ii) Non-Isolated DC-DC Converter

For the design of a DC-DC converter, the following factors are taken into account: (i) high efficiency (ii) low electromagnetic interference (EMI) and current ripple from the fuel cell or battery; (iii) lightweight and small volume; and (iv) the DC/DC converter's Boost mode, which regulates power flow in response to a range of voltage fluctuations at the converter input [50], [51]. Applications involving low- and medium-power electric vehicles use isolated DC-DC converters [52], [53]. There are five distinct topologies for isolated DC-DC converters that are routinely used.

(i) Full Bridge Converters [54]
(ii) Half Bridge Converter [55]
(iii) Z – Source Converters [56]
(iv) Sinusoidal Amplitude High Voltage converter [19]
(v) Multiport converter [57]

Among the converter topologies typically used in electric vehicles are isolated DC-DC converters, complete bridge converters, sinusoidal amplitude high voltage converters, and multiport converters. In isolated DC-DC converters, there are three stages of operation: DC-AC-DC. AC volt-

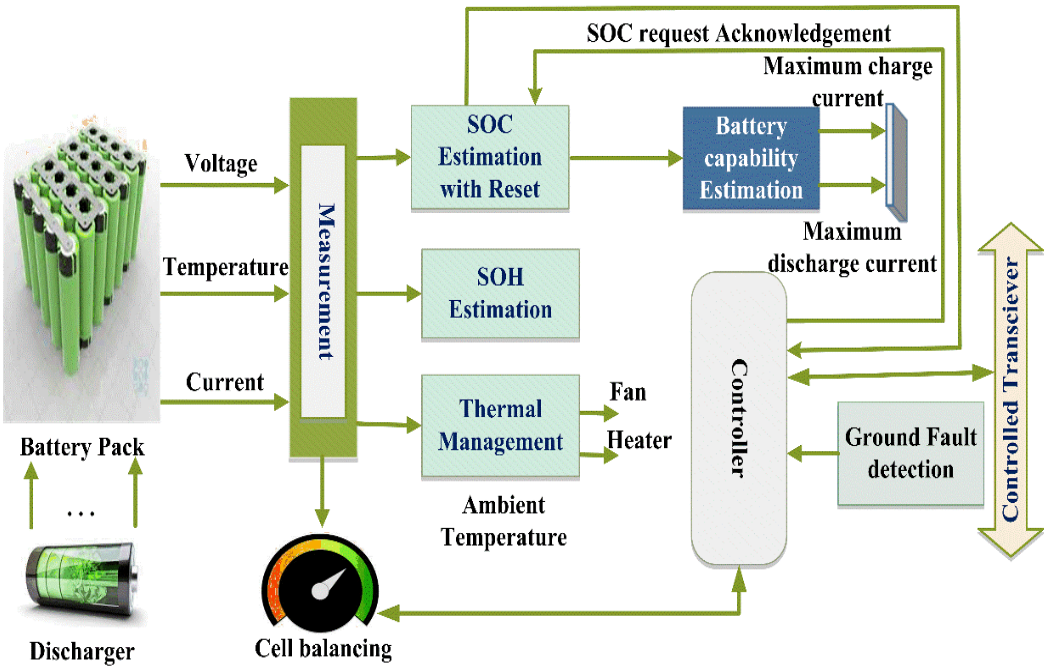


FIGURE 10. Block diagram of the BMS [45].

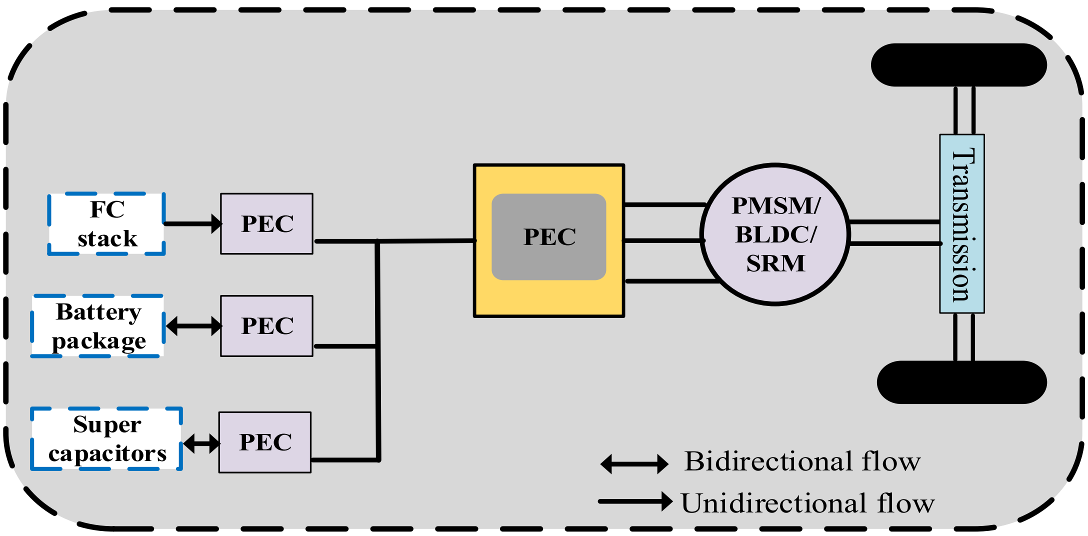


FIGURE 11. The different energy sources for EVs [46].

age is used as the high-frequency transformers' input [58]. Table 6. Shows the summary of DC-DC Converters. The transformer increases the size and weight of the isolated converter used in EVs. The issue with electric vehicles has been addressed by the use of non-isolated DC-DC converters. Non-isolated DC-DC converters are often used in uninterruptible power supplies and electric vehicles (UPS). Non-isolated DC-DC converters are used in EVs for medium- and high-power applications [59]. Table 7 Comparative Analysis of DC-DC Converter Topologies. A battery or supercapacitor serves as the converter's input [60]. The following types of non-isolated DC-DC converters are further divided into categories [60]:

1) SEPIC DC-DC Converter
2) Multi-Device port DC-DC Converter
3) Interleaved DC-DC Converter
4) Boost DC-DC Converter
5) Buck-Boost DC-DC Converter
6) 6) Cuk DC-DC Converter

Electric vehicles typically employ boost DC-DC, multi-device port DC-DC, and interleaved DC-DC converters. For

TABLE 7. Summary of DC-DC converters [62], [63], [64].

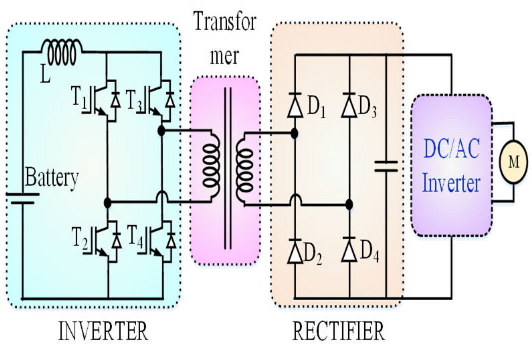
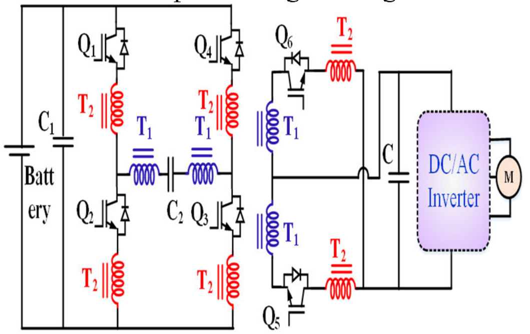
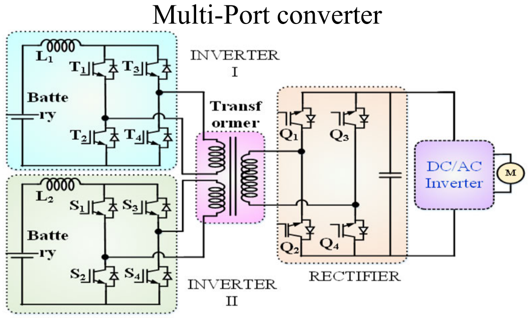
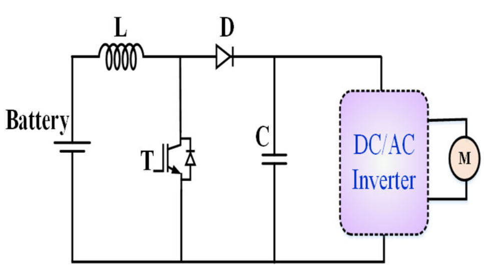
Topology	Advantages	Disadvantages	Components list with quantity
Full Bridge Converter 	• Possibility of High voltage step-up and Galvanic isolation • The efficiency at full load is 91.5% • Reduced voltage stress in switching circuits	• A clamping circuit is required because of HFT. • Switching circuits are characterized by high current tensions • Large capacitors are required.	-4 Diodes -1 Inductor -2 Capacitors -4 MOSFETs -1 HFT
Sinusoidal Amplitude High Voltage converter 	• extremely effective • Lower output impedance • Up to 1MHz output impedance • Noiseless operation	• Complicated gate switching and Control approach • Not suitable for converting to high power	-6 MOSFETs -3 Capacitors -6 Diodes -1 HFT
Multi-Port converter 	• High voltage gains and Low output voltage ripples • Galvanic isolation and Bidirectional power flow are possible	• Synchronization is difficult due to the use of more components • Complicated analysis during steady state and transient state	-2 Electric sources -1 HFT -12 Diodes -12 MOSFETs -1 Capacitor
Boost DC-DC Converter 	• Simple to Meet EMI Requirements • Low Cost • Simple to Manage	• Needed large capacitor • Voltage gains • <4:1 Parallel devices are necessary for high-power levels. • The ripple rate is extremely high.	-1 Inductor -1 MOSFET -1 Capacitor -1 Diode

TABLE 7. ***(Continued.)*** **Summary of DC-DC converters [62], [63], [64].**

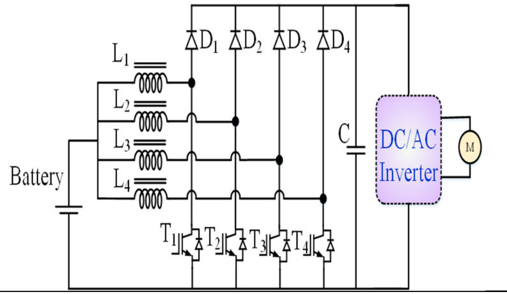
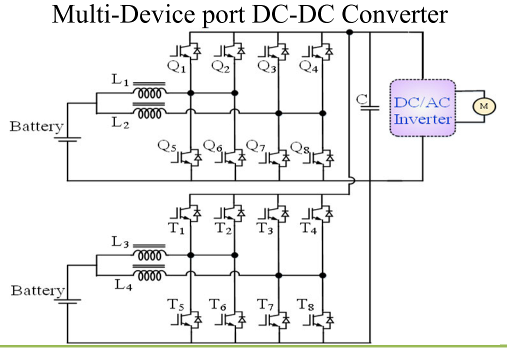
Interleaved DC-DC Converter 	• Minimize input current ripples and the bulk of passive elements. • High voltage gain. Easy to control.	• Greater number of components and large switching loss. • Duty cycle sensitivity.	-4 Inductors -4 MOSFETs -1 Capacitor -4 Diodes
Multi-Device port DC-DC Converter 	• 97% efficiency • Switches with low current stress • Reduce the size of the heat sink and passive components • Bidirectional & easy control	• At the load stage, the duty cycle is sensitive to modify • A high component counts • Challenging steady-state and transient analyses	-2 sources -1 Capacitor -16 MOSFETs - 4 Inductors -16 Diodes

TABLE 8. **Switching operation for scalar control for BLDC motor [68].**

Step	Rotor Position Signal	Reference Currents			Hall Sensor output			ON	OFF	Controlled Switch
	θ_r	i_a*	i_b*	i_c*	H_a	H_b	H_c			
1	0°-60°	1	0	-1	1	0	0	T_1	T_3, T_4, T_5, T_6	T_2
2	60°-120°	0	1	-1	1	1	0	T_2	T_1, T_4, T_5, T_6	T_3
3	120°-180°	-1	1	0	0	1	0	T_3	T_1, T_2, T_5, T_6	T_4
4	180°-240°	-1	0	1	0	1	1	T_4	T_1, T_2, T_3, T_6	T_5
5	240°-300°	0	-1	1	0	0	1	T_5	T_1, T_2, T_3, T_4	T_6
6	300°-360°	1	1	0	1	0	1	T_6	T_2, T_3, T_4, T_5	T_1

high-power automotive applications, these Converters are suitable options [61].

B. INVERTER FOR EV

The PMSM, as well as BLDC motors, operate with quasi-sinusoidal phase current as well as trapezoidal back EMF supplied by the rotor switching table in Table 7; Figure 12 displays the power circuit for scalar control of the magnet motor. PWM signals are used to control the power switches [65]. Many researchers have designed and constructed magnet motors with various rotor and stator parameters. Based on the history of the development of magnet motors, a variety of technical issues that must be considered during the design and construction of magnet motors are discussed. The most commonly used SRM converter is the asymmetric bridge converter as depicted in Figure 13. Each Phase winding excitation independently. Both magnetization and demagnetization require the highest DC voltage [66]. With a bigger number of semiconductor elements, and an asymmetric half-bridge topology. The advantages of this traditional converter topology include:

•Each phase control is completely autonomous from the others.

•The voltage rating of all switching devices and diodes is V_{dc}, which is a low voltage.

•During the chopping time, the converter can freewheel at low speeds, thereby reducing the switching frequency and, consequently, the switching losses.

•The energy from the previous step is returned to its source so that it can be utilized.

C. ARCHITECTURE OF EV CHARGING STATION

In DC rapid charging stations, an ac-dc rectifier and dc-dc power converter are positioned outside and connected to

TABLE 9. EV Market has last Two decades including their Power, Speed, Model, E-Motor, and Year.

Electrification model	Power (kW)	Max. speed(rpm)	e-motor	Passengers	Year
Tesla Model X	193-375	170000	IM	5	2015
NIO ES6	320	16500	PMSM	4	2020
NIO EC6	320	9000	PMSM	4	2020
Camry	270	14000	PMSM	5	2013
Tesla Model S	225	14800	IM	5	2012
Tesla Model 3	192	18000	PMSM	6	2020
Roadster	215	14000	IM	5	2008
BJEV EU5	160	11000	PMSM	8	2018
BYD E6	160	5000	BLDC	5	2014
Bolt	150	8810	PMSM	4	2017
BMW i3	125	11400	PMSM	5	2016
Accord	124	14000	PMSM	5	2014
Volt	111	12000	PMSM	4	2016
Hyundai Kona	88-150	3600	PMSM	6	2018
Lexus	110	7000	PMSM	5	2008
Spark	105	4500	PMSM	5	2014
Toyota Prius	82	6000	PMSM	5	2004
Nissan Leaf	80	10390	PMSM	4	2012
Land Rover	70	6000	SRM	5	2013
Morgan Plus E	70	10000	BLDC	2	2011
Volkswagen	60	12000	PMSM	5	2019
Prius	53	17000	PMSM	5	2017
Mitsubishi	47	9000	BLDC	4	2009
My car	30	4000	BLDC	2	2003
Smart	30	5000	BLDC	2	2009
Kinetic Green, Volta Automotive	3.3	2000	BLDC	2	2017
Renault Twizy Electric	13	5800	IM	2	2012
Renault kwid	50	5500	PMSM	5	2020
DS-Cross back E-Tense	100	300-3670	PMSM	5	2020
Audi e-tron	370	16000	PMSM	5	2021
Mercedes Benz EQC	300	10000	IM	5	2016
Kia Niro EV	150	3800	PMSM	5	2022
Honda e	100	5500	BLDC	4	2020
Chevrolet Bolt	149	8810	PMSM	5	2017
FORD Mustang Mach-E	248	13500	PMSM	5	2019
22 Motors, NDS Eco Motors	2.1,1.5	2300	BLDC	2	2015
Genkan Electric Motors	1	2000	BLDC	2	2013

the EV through electric vehicle supply equipment (EVSE). According to the design of EV battery packs, PCS must be able to produce 100–800 V of regulated DC output voltage. The state of charge (SoC) must reach 80% in less than 30 minutes for a 20 kWh–40 kWh battery by the PCS, and modular converters that can be stacked to give high power are

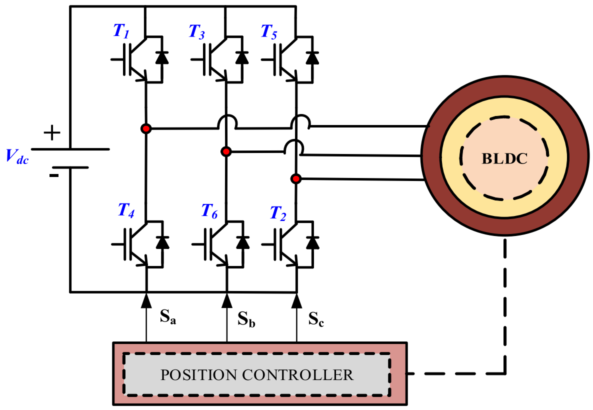


FIGURE 12. Inverter with motor [67].

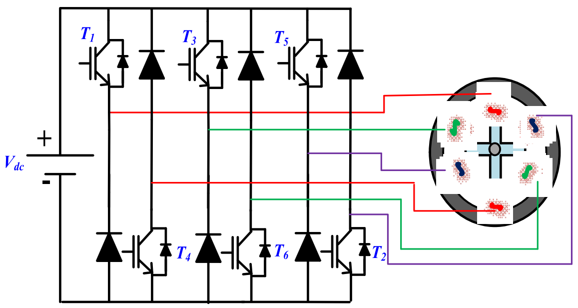


FIGURE 13. SRM asymmetric inverter.

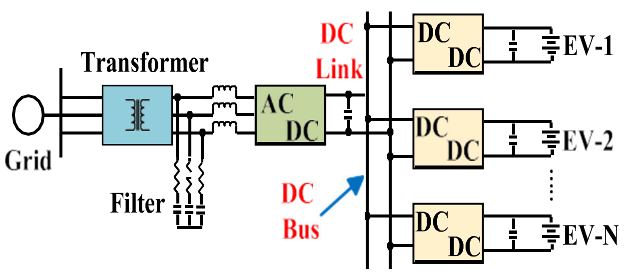


FIGURE 14. DC-connected EV charging station.

preferred. Bidirectional power converters are attractive owing to the development of vehicle-to-grid (V2G) technologies. The dc-dc power stage's output voltage ripple should be less than 5% of the maximum output voltage, and the battery pack's current ripple should be less than 1% of the minimum current profile to ensure battery durability. For safety, the grid and EV battery must be galvanically isolated. There are two forms of galvanic isolation based on location: the low-frequency transformer linked to the grid in front of the input filter and the high-frequency transformer associated with the dc-dc converter. The first kind has substantial magnetic components that make the system bulky. When charging power is high, a high-frequency transformer incorporated into the dc-dc converter is preferred. The DC connected EV charging station is shown in Figure 14.

In an AC-connected system, the line-to-line voltage of a three-phase AC bus is between 250 and 480 volts. Each charger unit has an ac-dc rectifier and a dc-dc converter. This means that there are more power stages, which raises the cost and makes the system harder to understand. On the other hand, most fast and ultra-fast charging stations use ac-connected systems because power electronics and ac power distribution systems are well-equipped and have been used for a long time. In dc-bus setups, there is a central ac-dc rectifier that is connected to the low-frequency transformer on the input side. The dc-dc converter connects PV sources, energy storage devices, and EVs to the dc bus. This structure gives the system more flexible, and any problems on the grid side are easy to avoid. When there are fewer ac-dc rectifiers, the dc bus structure works better, and the control method is easier to put in place. When there are fewer ac-dc rectifiers, the DC bus structure works better, and the control method is easier to put into place. In the United States, CCS combo 1, CHAdeMo, and the Tesla supercharger are considered for Level-3 dc charger connectors, although in Europe, CCS is used. Combination 3, CHAdeMo, and the Tesla supercharger are all options. To alleviate EV drivers' range anxiety even further and to be competitive with the IC engine-based refueling procedure, dc ultra-fast charging has emerged as a feasible option in which EV batteries are fully charged within 10 minutes at a rate of 400 kW or more. A significant volume of power transfer between the grid and the EV, on the other hand, increases issues and research requirements in the EV battery, charging cable, charging infrastructure, and dependability. CHAdeMO just came out with a new standard for charging electric vehicles quickly. It will be able to charge at 500 kW. The most current it can handle is 600 A, and it can handle voltages up to 1500 V. This will be a big step forward for both regular EV chargers and heavy-duty ones. It was made by the China Electricity Board together with Japan, and it has caused a big fight over how to make EVs go faster between the associations of China and Japan and manufacturers in Europe and the US who follow the CCS standards.

Some of the things it has are:

- A thin wire with a connection that is light and small.
- A new plug like the old one that follows GB/T rules
- DC charging requires more than 500 kW of power (maximum current is 600 A).
- The use of systems that use liquid to cool
- The interface has a way to unlock and lock it.
- Compatible with the current standards for DC fast charging (CHAdeMO, GB/T, and maybe CCS) for CHAdeMO 3.0-certified cars. Adapters for Tesla cars are probably on their way.

CHAdeMO was meant to work in both directions. The CCS protocol is behind when it comes to being able to go both ways. Bi-directional charging would improve how EVs are charged as well as how energy is used in homes and by grid utilities. It can charge battery packs and send energy back to the grid when it has too much power.

V. MOTOR FOR EV

The biggest problem faced in EV adoption is apprehension about long mileage and high cost. The EVs compared to ICEVs are less subjective about the mileage concern because at every point fuel station is available. In the case of EVs, the driver needs a charging station to administer mileage at every limit. However, the higher cost of purchasing an EV limits their acceptance. When policy subsidies are considered, the overall price of EVs slightly comes down to ICEVs. Most countries' directorial incentives encourage the purchase of electric vehicles. Subsidies will be phased out until revenues reach a certain level. The current development of EV technology uses modern technical manufacturing size and the price of EVs becomes high. The key factors preventing the widespread of EVs adoption include less mileage range and high cost. These issues are intertwined with the motor system's efficiency and cost. The motor performance and power-torque density have a direct impact on mileage, and secondly on the EVs battery cost. The increased growth of EVs in the market is more than 40% to 50% every year. The invention and development of electric vehicles over the past 150 years have a lengthy history. The early stage, middle stage, and current stage describe the evolution of EVs from the invention and development of electric vehicles over the past 150 years has a lengthy history. The early stage, middle stage, and current stage describe the evolution of EVs from simple non-chargeable conditions to modern control techniques. In the 1900 century, the EV was developed and compared with the gasoline engine which produced a good performance in mileage and cost than EV.

Later in 1930 gasoline vehicles emerged into mass production in the market with less cost and surpassed the EV in both cost and mileage. Due to the lack of battery station charging infrastructure, EVs face difficulties in traveling over long distances. The limitation in electric transmission reliability is also considered a big issue in EVs. In the later 1930 to 1970 increase gasoline vehicles created more climatic changes in the atmosphere and due to the increased fuel cost, the market needed to switch over to alternate transportation to provide the basic requirement of changing conditions and demand for fuel, the adoption of EVs worldwide has started to begin [69]. The development of power electronics converters, semiconductor-controlled devices, and battery technologies EV in late 1997. In the automobile industry, the revolutionary improvement strategy combined to produce a new model started when Toyota Prius launched the first hybrid electric vehicle in the market with a brushless DC motor for drive and lead-acid battery technology. In the last two decades, many automobiles industry started their EV with a different model. The Automobile industry such as Honda, Toyota, and Ford introduced their new hybrid electric vehicle (HEV) in 2009. It features to further improve HEV while incorporating renewable energy sources into EVs, setting up battery charging stations for a long drives comes with Plug-in and fuel cell EVs to develop required transportation facilities [70]. The different types of EVs are the only transportation growth for the future automobile sector The propulsion process is also important in electric motor (e-motor) traction. The automotive industry in the last decade is shown in Figure 15. The conversion of battery chemical energy into electromechanical energy is processed to start the motor to get the EV driving. The e-motor selection needs basic requirements in the electrical machines industry such as high torque, power density, a wide speed range, robustness, low cost, high dependability, low vibration, minimum noise, and smaller size. The selected e-motor is based on vehicle performance parameters such as power, maximum speed, acceleration time, maximum climb age gradient, and endurance mileage [71].

The e-motor designed with different power ratings can be chosen based on the vehicle parameters corresponding to the road curb weight, gross weight, wheelbase, wheel rolling radius, frontal area, transmission efficiency, drag coefficient, and rolling resistance coefficient. This parameter undergoes differential equations to get vehicle dynamics e-motor design and optimize finite element analysis. The e-motor was developed initially with a brushed DC motor with low efficiency, the brush creates maintenance, the spark brings reliability issues, and bulky in structure size. Within the industry, they are primarily utilized for low-speed drives such as shuttle buses and cargo with limited range. While an EV is running, the e-motor creates regenerative braking (RBS) which returns energy to the input source to maximize charging is one of the main benefits [72]. The power semiconductor devices with fast switching operation and minimum switching loss devices like SiC, MOSFET, Si-based insulated gate bipolar transistor (IGBTs), silicon carbide (SiC), gallium nitride (GaN) are developed significantly in a power converter with maximum efficiency and mileage per charge for increasing the drive. The IGBT packaging module technology is imported to vehicle standard with high performance, reliability, and large-scale application used in automotive. The new generation silicon power devices have a wide bandgap (WPG) with SiC and GaN having strong advantages in high switching frequency, minimum switching loss, high operating temperature, and maximum voltage. They are suitable for EV inverters motor operation with high power density. The power devices are used in EVs for greater than 25kW/L power density, they can be operated at low conduction loss and high switching frequency. WPG switching devices increase the switching frequency by 50-100kHz with minimum conduction loss. Hence, their material properties having high thermal conductivity, wide bandgap, and high electron drift velocity were considered most suitable for EV inverters. The efficient thermal management technology improves the cooling techniques using soil, water, and oil to reduce heat in the traction motor and improve the power density [73]. The power semiconductor devices with fast switching operation and minimum switching loss devices like SiC MOSFET, Si-based insulated gate bipolar transistor (IGBTs), silicon carbide (SiC), gallium nitride (GaN) are developed significantly in

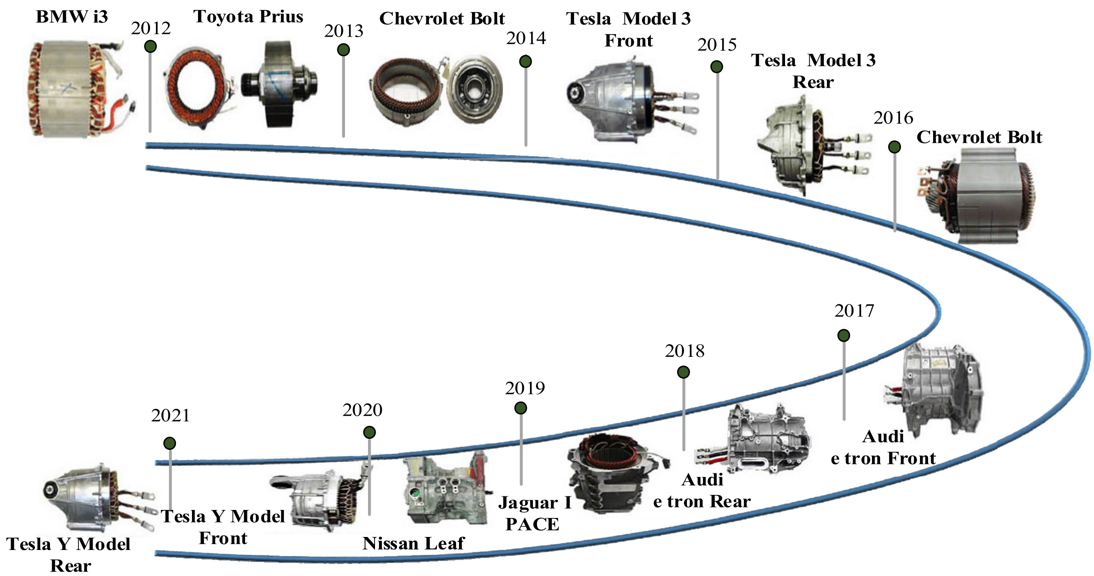


FIGURE 15. e-motor development last decade [73].

a power converter with maximum efficiency and mileage per charge for increasing the drive. The IGBT packaging module technology is imported to vehicle standard with high performance, reliability, and large-scale application used in automotive. The new generation silicon power devices have a wide bandgap (WPG) with SiC and GaN having strong advantages in high switching frequency, minimum switching loss, high operating temperature, and maximum voltage. They are suitable for EV inverters motor operation with high power density. The power devices are used in EVs for greater than 25kW/L power density, they can be operated at low conduction loss and high switching frequency [74]. WPG switching devices increase the switching frequency by 50-100kHz with minimum conduction loss. Hence, their material properties having high thermal conductivity, wide bandgap, and high electron drift velocity were considered most suitable for EV inverters. The efficient thermal management technology improves the cooling techniques using soil, water, and oil to reduce heat in the traction motor and improve the power density. As depicted in Figure 16, the e-motor approach has both advantages and disadvantages for driving powertrain motors over a lengthy period of development. During the previous century, several automotive industries began modifying their motor structures and control techniques to improve the performance of electric vehicles (EVs) at a cost. The bulk of electric vehicle (EV) motors that use rare earth magnet material are expensive, but their high torque density and power density are their primary advantage. Permanent magnets in brushed dc motors provide superior heat dissipation, small motor size, reduced weight, and great dependability. The range of power is constant for a brief period, after which torque declines with increasing speed due to back electromagnetic force in the stator winding, a control issue in field weakening ability, and the expensive cost of PM material. Toyota Prius train launched in 2005 started with a brushless permanent magnet DC motor with high-cost material, low speed, and mileage issues. Since, changing the permanent magnet position in the rotor with different modifications in the operating range and speed is suitable for EV drive systems particularly in-wheel motor structures having features such as compact size, more efficiency, and the ability to achieve high torque at very low speeds [75]. The drawback of this motor is the material cost of rare earth permanent magnet which is too high and the demagnetization problem. To meet the desired EV, the Tesla model used a non-permanent magnet Induction motor drive for different commutators and fewer systems. Both stator and rotor material losses are substantial, which decreases the motor's efficiency and is the primary disadvantage of this EV drive system. Double salient switching reluctance motor aligned with minimal reluctance nonpermanent magnet material is appropriate for EV drive with simple construction, ruggedness, high power density, long constant power range, and improved fault-tolerance capability. The controllability, power density, and power factor of reluctance motor efficiency pose the greatest challenge. Other motors, such as the synchronous reluctance motor (SynRM), were also appropriate for EV drive systems due to their fault tolerance, durability, high efficiency, and small size. The main issues with the reluctance motor are its controllability, power density, and power factor [76]. The EVs technology resulted in the development of numerous types of e-motors with optimally balanced solutions for multiple factors, including cost, power density, torque density, top speed, efficiency, and simplicity. Current e-motors include the permanent magnet synchronous motor, the brushless DC motor, the induction motor, and the switching reluctance motor, each of which has its own set of benefits and drawbacks. This article mainly focuses on

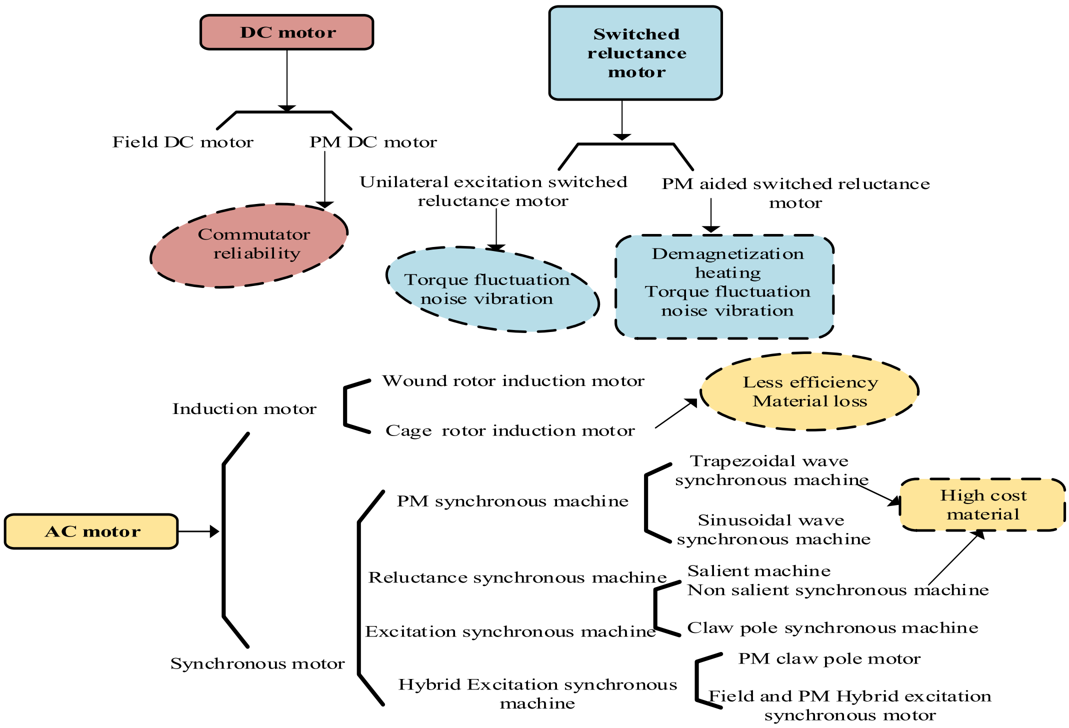


FIGURE 16. Type of e- motors limitation [76].

e-motors challenges, how to mitigate the challenges from design and different control techniques for each motor individually. This study will help to understand the importance of different e-motor design aspects with a clear knowledge of control techniques and challenges. In today's electric vehicle propulsion systems, BLDC, IPMSM, IM, and SRM motors are the most prevalent. Incorporating an inner permanent magnet in the rotor enables the BLDC motor to operate at a high speed, with improved heat dissipation and great efficiency. This motor has produced less efficiency over a wide range of speeds at a constant power range. Rare earth alloy magnets with high remanence and corrective force Neodymium Ferrite boron (NdFeB), High density and temperature withstand Samarium cobalt (SmCo) is commonly used for EV driving. The BLDC Motor is divided into outer and inner runner rotors, and its core configurations are distinct. The inner run rotor is unfit for propulsion due to magnetization stress. The switching operation for scalar control for BLDC motor is elaborated in Table 8. Ferrite in the outer run rotor has a minimum flux density for a given volume to facilitate the development of future cars; it is also prevalent in the low-power motors of EVs. Due to the high power and torque density permitted by high-energy-density PMs, the PMSM (NdFeB and SmCo) has become the preferred alternative among EV makers. High-speed internal PMSM and low-speed surface PMSM are two types of PMSM. Since the internal PMSM has a higher overload potential for the same size, it is common in EV train drives. Since maximum energy density interior PM has a low yield, non-renewable material, and the cost is very high compared to other electric motor raw materials [77]. As a result, weight reduction techniques use low-cost materials that can bring lower PM prices without compromising efficiency characteristics and demand for the EV industry. Low-cost PM motor solutions include the different interior permanent magnet-supported spoke-type motors and synchronous reluctance motors.

Electric motors used in some EV drive trains from 2000 to 2020 are listed in Table 8. PMBLDC, IPMSM, ACIM, and SRM are now the most prevalent motors utilized in electric vehicle propulsion systems. The BLDC motor can operate at high speed in operation, with better heat dissipation and high efficiency by incorporating an interior permanent magnet in the rotor. This motor has produced less efficiency over a wide range of speeds at a constant power range. Rare earth alloy magnets with high remanence and corrective force Neodymium Ferrite boron (NdFeB), High density, and temperature withstand Samarium cobalt (SmCo) are commonly used for EV drive. The BLDC Motor is divided into outer and inner runner rotors, each of which has a unique core structure [82]. The inner run rotor is not suitable for propulsion due to overloading magnetization. Ferrite in the outer run rotor has a minimum flux density for a given volume to facilitate the development of future cars; it is also prevalent in the low-power motors of EVs. Due to the high power and torque density permitted by high-energy-density PMs, the PMSM (NdFeB and SmCo) has become the preferred alternative among EV makers.

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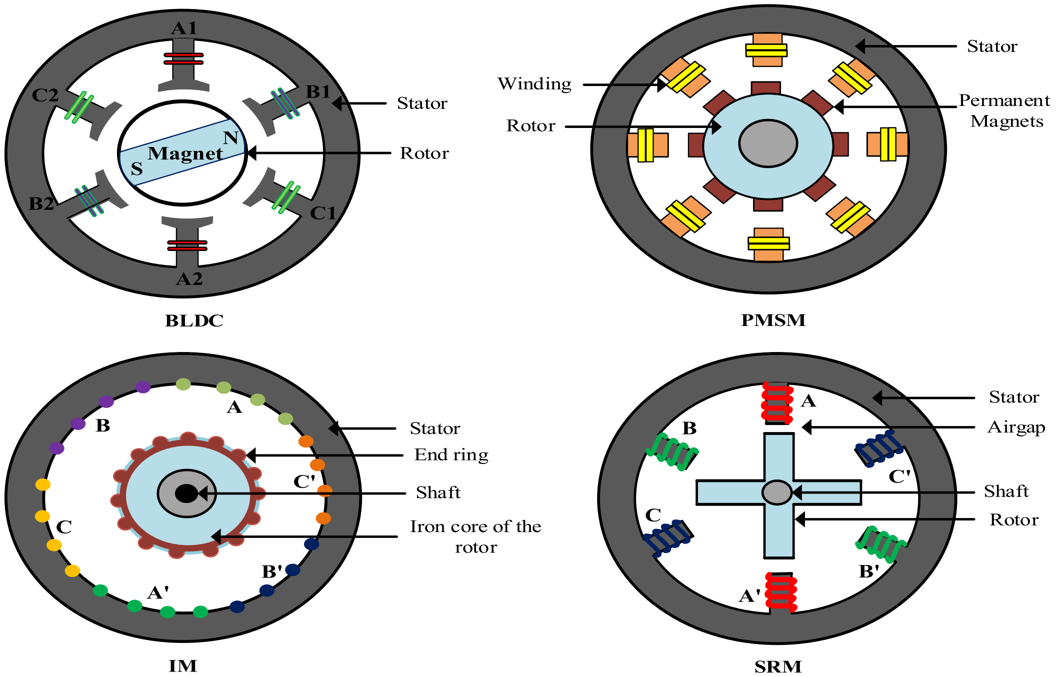


FIGURE 17. Different types of motors for EVs [77].

TABLE 10. Properties and price of PM materials [82].

Material parameters	SmCo	NdFeB	Alnico	Fe
Max energy product $(bh)_{max}$, kj/m^3	130-240	220-336	10.7-71.6	8.35-31.8
Remanence (br), t	0.83-1.16	1.00-1.41	0.7-1.28	0.23-0.41
Corrective force (hc), ka/m	480-840	760-1030	37-143	50-290
Density (d), g/cm^3	8.4	7.4	6.8-7.3	4.9
Electric resistivity (ρ), Ω cm	(53-86) $*10^{-6}$	$160*10^{-6}$	(50-70) $*10^{-6}$	10^{-6}
Price usd/kg	100	75	58	7.1

in EV train drives. Since maximum energy density interior PM has a low yield, non-renewable material, and the cost is very high compared to other electric motor raw materials. As a result, weight reduction techniques use low-cost materials that can bring lower PM prices without compromising efficiency characteristics and demand for the EV industry. Low-cost PM motor solutions include different interior permanent magnet-supported spoke-type motors and synchronous reluctance motors [9]. High-priced PM material, speed range, low efficiency, and torque ripple are the most significant constraints of BLDCM. Four distinct earth materials can be used to classify the manufacturing of permanent magnet motors: Alnico, ferrite, NdFeB, and SmCo. Currently, the high energy density, high remanence, high demagnetization, and corrective force PM material is generally mixed with other substances, such as Neodymium magnet alloys and Samarium alloys [84]. EV Market has last Two decades including their Power, Speed, Model, E-Motor, and Year is shown in Table 9.The other PM material influences demagnetization ability and torque density due to its lower coercivity, low remanence, high-temperature capability, and energy products, which are detailed in Table 10. In [85] low-cost magnetless motors are induction motors (IM) and switched reluctance motor (SRM) is perfectly suited for EV drives. The above drawbacks can be mitigated by optimized design topology and advanced control techniques. The motor configuration is detailed in Table 12, and the comparison is shown in Table 12, shows the different types of Electric Motors used in Automotive Industry [86]. Different control methods for EV traction motors are depicted in Figure.18. These controller techniques are used to minimize the torque ripple, cogging torque, noise, vibration, speed, and other control parameters of EV motors. Each controller has its advantages and drawbacks based on the selection of motor controller signal parameters [93].

VI. RENEWABLE ENERGY SOURCES (RES) FOR EV

In this section, a general overview of RES for EV is presented. In the context of electric mobility, two types of plug-in

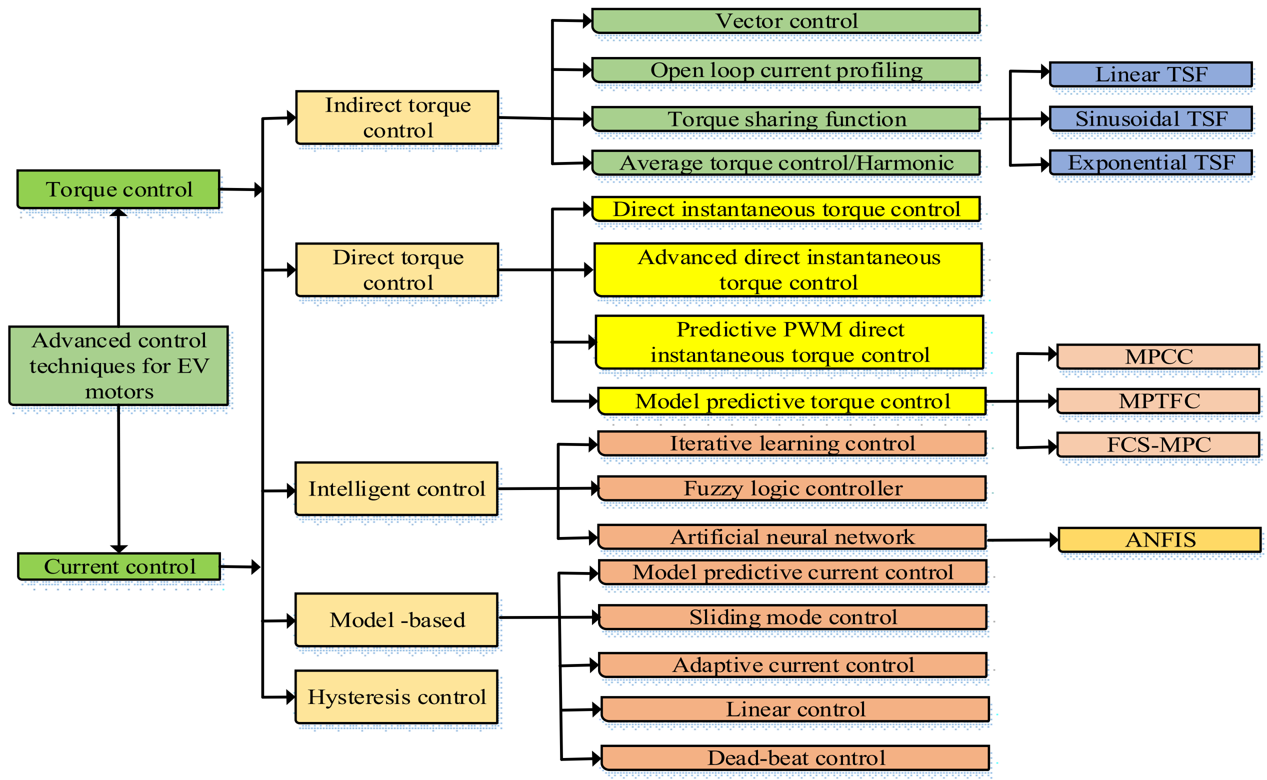


FIGURE 18. Control techniques for EV motors [93].

electric vehicles (PEVs) and their corresponding battery packs are now available. Wind and solar energy have been studied the most, as have the models used to predict electricity output. To make the world greener, people are looking for fresh and interesting solutions. If we implement wind and solar charging infrastructure widely across our nation, there is a guarantee of zero emissions. Figure 19. Green Environment, along with traditional power production ideas, this section introduces renewable options. The two categories of sources of renewable energy shown in Figure 20 are those that are most frequently used to charge EVs [94]. As a renewable energy source, wind power is gaining prominence. According to the Global Wind Energy Council, wind energy capacity rose by around 840,9 gigawatts worldwide in 2022. By 2030, the European

FIGURE 19. Green environment.

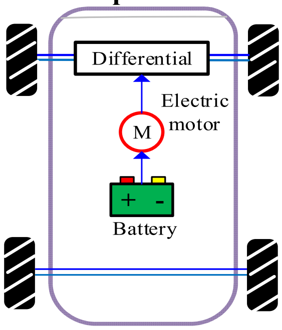
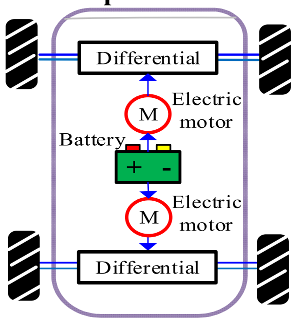
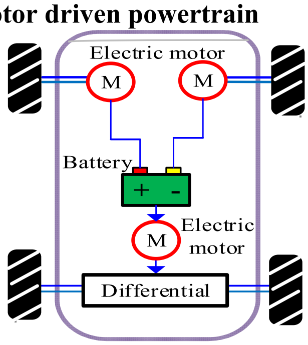
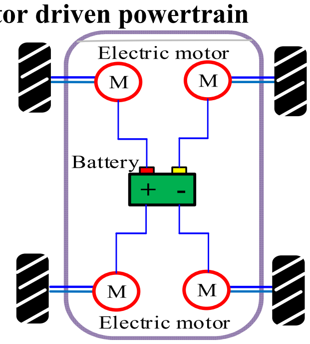
A. WIND ENERGY FOR EV CHARGING STATION

Wind Energy Association intends to supply 23% of Europe's electricity demand using wind energy. It is essential to choose suitable locations for wind turbines to maximize the amount of energy generated by wind power. Due to the relationship between wind speed and the amount and kind of available wind energy, the first step entails determining the quantity and type of available wind energy. One way of assessing wind speed (for example, 15 m) is to use a measuring instrument to take air pressure measurements at a height that is frequently much less than the initial height of the turbine [95]. Peterson and Hennessey recommend using the 1/7 airflow power law to determine the air velocity at a specific height (for example, 90 m) for a wind turbine.

$$\left(\frac{V}{V_r}\right) = \left(\frac{h}{h_r}\right)^a \tag{1}$$

where V_r represents the air velocity at a known reference height h_r, V is the air velocity at height h, and a has a usual value between 0.1 and 0.4. The amount of usable power produced by energy is estimated to be significantly influenced

TABLE 11. Motor configurations [87].

Single motor driven powertrain  	▪ Small unit with high efficiency. ▪ Fewer components are required, cheaper to construct. ▪ Tesla Polestar 2, electric range 425 kilometers, top speed 160 kilometers per hour ▪ Less effective than other motors ▪ Not appropriate for high power.
Dual motor driven powertrain  	▪ Increased horsepower (HP), acceleration, fuel economy, and speed. ▪ The increased degree of vehicular freedom improves traction and stability control. ▪ The enhanced performance of the total traction system. ▪ Tesla Model 3, electric range 575km, 260kmph. ▪ More costly lack of standard transmission. ▪ Complex control
Triple motor driven powertrain  	▪ More HP, high acceleration, efficiency, and speed. ▪ Effective coupling and regulation of torque in a moving drive. ▪ All-wheel drive stability handling group. ▪ Audi-etron-S, Tesla model S, and Tesla model X. ▪ More costly. ▪ There is no standard transmission. ▪ Control more complex
Four motor driven powertrain  	▪ Greater horsepower, acceleration, efficiency, and velocity. ▪ All-wheel drive stability handling group. ▪ A wheel with four miniature motors, often known as an in-wheel or hub motor. ▪ Positive and negative torque is controlled independently in each motor. ▪ The complexity of torque vectoring control in each in-wheel motor has increased.

by climatic factors like the velocity and density of the air [96].

$$P = \frac{1}{2}\alpha\rho A V^3 \quad (2)$$

where ρ is the air density in kilograms per cubic meter, A is the wind turbine's surface area, and V is the air velocity in meters per second.

B. SOLAR ENERGY FOR EV CHARGING STATION

Solar energy can be converted into electrical energy using photovoltaic cells or concentrated solar power (CSP) systems. Solar PV panels use a solid-state semiconductor to convert direct sunlight into electricity, whereas CSP installations concentrate solar radiation via mirrors or lenses to generate sufficient heat to run conventional steam engines.

TABLE 12. Different types of electric motors are used in automotive industry [87].

	BLDC	IPMSM	ACIM	SRM
EV Motors				
EV Company	Toyota Prius Ather Energy Scooters Yamaha EC-03 Upcoming TVS	Soul EV Nissan Leaf Toyota Prius	GM EV1 Toyota RAV4 Tesla Model X Tesla Model S	Chloride Lucas Land Rover
Advantages	High torque density. No rotor copper loss. Small size and lighter. Better heat dissipation. High reliability. Specific power is high.	Efficiency is high. Specific torque. Density is high. High power density.	Ruggedness. Maximum peak torque. Dynamic response is good. Less maintenance.	High power density. Simple and robust. Fault tolerant. Construction cost less. High speed. Robust and efficient.
Disadvantages	PM rare earth material cost is high. Constant power range less. High Cogging and reluctancet torque ripple. Decreased with increase in drive speed.	Iron loss maximizes at high speed through in wheel operation. Demagnetization. High cost material.	Less efficiency. Copper loss.	High noisy. High torque ripple. Low torque density. Large vibration.

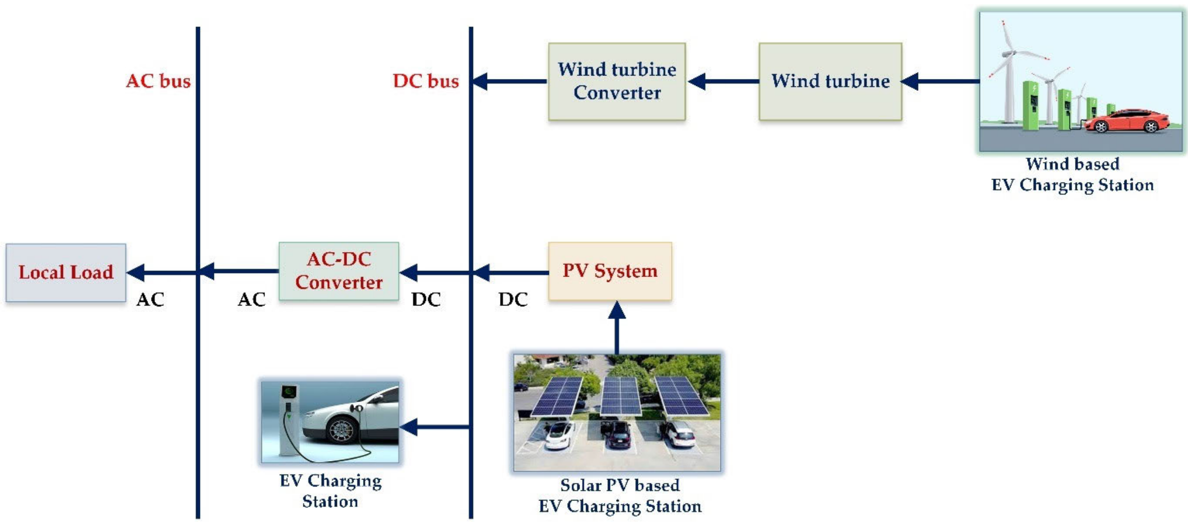


FIGURE 20. RES-based EV charging station [97].

In recent years, PV solar technology advancement has outpaced CSP. According to the Solar Energy Industry Association, the renewable energy industry in the United States installed 4,751 MW of new PV solar panels in 2013. Even at low temperatures, the solar cell, which is the most critical component of PV solar panels, performs properly. The energy efficiency of the solar cell (solar) scarcely changes when the temperature rises. The sunlight decreasing rate is 0:2-0:5% for a 1°C rise in temperature. In reality, solar cell producers often employ a heat insulation strategy to prevent extreme temperature changes [97]. Because of this, the variance in sunlight is quite little as the outside temperature varies. Setting up recharging at home: If the grid is down, a modest solar panel with BSS might be installed in the home to power the home and charging cars throughout the day. This system can run as a centralized light of the fact system or as a distributed system that connects to the grid sporadically [98]. A PV system, which would be viewed as a comprehensive system, is made up of various components that are especially involved in converting solar radiation into energy (photovoltaic panels, battery bank, voltage regulator, and adapter). There are numerous photovoltaic systems available on the market, including vehicle-to-grid (V2G) and vehicle-to-home (V2H) applications [99]. In either approach, an electric vehicle battery or battery state sensor can provide additional energy to the grid or a home load (BSS). In contrast to the use of DC to recharge a battery from a variety of sources, the PV system was initially developed in response to expanding residential energy demands [100]. The solar parking space has a centralized architecture and operation capability and is a decentralized platform. A BSS is often used in the charging station when the grid is at peak demand, which raises the load on EVs. The government must construct more Photovoltaic public charging stations, and EV owners should improve the residential charging points that already exist [101].

VII. FUTURE RESEARCH DIRECTION

To improve the unpredictability of the model's assumptions, the EVs model must have a greater range of inputs. For instance, if many maximum values of charging power, charging places, and battery size were represented with the same effort, a more effective technique would be established to reflect the changing needs of various EVs. The majority of V2G research has focused on the technical aspects of V2G, particularly how V2G networks may aid in job scheduling or minimize power costs by integrating environmental and economic objectives as constraints for specific situations. There is also a need for an energy coordination policy for V2G, which presents prospects for more research. In the literature, the significance of client acceptance and driving behaviors in V2G systems is examined in detail. Due to the rapid growth of RES and EVs in the energy industry, additional study is required. There should be additional research on how automobile owners respond to the expectations of grid operators, as well as benchmarking studies that examine the costs of power generation and charging. During a grid failure condition, the V2G controller can stop giving power to the grid. Otherwise, the controller needs to overcome unexpected fault conditions with the help of advanced AI technologies. Every element of the electric vehicle (EV) charging infrastructure, including the charging stations, the energy storage systems (ESS), and the numerous EV parts, has had to overcome several obstacles. Controlling the speed of a motor, integrating power electronics into the grid, developing efficient power trains, and developing ESSs are some examples. On the other hand, the specifics of ESSs for Vehicle applications have been discussed in this work. After covering a variety of ESS-related topics, the following issues and potential future approaches are discussed. EVs are a rising component of the automotive industry, so raw material supply is important. Traceability and transparency in raw material distribution networks are vital to address raw material supply concerns and promote sustainable mining. For multilateral collaboration to effectively address these difficulties, binding regulatory frameworks must be developed. It's also necessary to reduce the number of raw materials needed for batteries and minimize the danger of shortages by managing battery end-of-life, including second-life applications for automotive batteries, guidelines for battery waste disposal, and environmental aspects of lithium batteries. To achieve supply chain sustainability, you must anticipate and predict demand. Cobalt, lithium, manganese, nickel, aluminum, graphite, and copper are in high demand, providing problems.

•Production ramp-up, access to raw materials, potential price spikes due to demand/supply imbalance, and geographic challenges of mining and/or decontaminating.

•Production ramp-up, access to raw materials, potential price spikes due to demand/supply imbalance, and based on geography challenges of mineral extraction and/or decontaminating.

EVs and HEVs use the battery as a main energy source, hence its performance in all conditions will affect EV sales. Manufacturers want to improve battery technologies and BMSs. Chemical changes inside the battery depend on operation conditions, hence battery degradation might vary. Developing a mature and wide BMS is crucial for firms that want to grow their market share. Critical difficulties in BMSs technologies include accurate calculation of battery modeling and cell balancing, with battery condition evaluation as a key concern. Battery SOC, SOH, and SOL need further attention.

Highly automated vehicles may have longer daily travel lengths because of higher efficiency levels, resulting in larger, more costly battery packs or more regular recharging (and downtime). The onboard electronics in self-driving cars may consume a lot of power; this must be handled. It is in the hands of the researchers to determine whether the number of EV charging stations should be increased and the battery charging time shortened in the future.

VIII. CONCLUSION

This article looks at all the current developments in EVs around the world. For many countries, the most popular systems have already been looked at for numerical analysis of quantitative data. There is talk about the different kinds of batteries. Based on the detailed analysis, lithium-ion batteries are the best choice for EVs. This shows that the assessment of batteries being used in EVs is clear. Different types of converters have been evaluated based on whether or not they are isolated. Based on comparisons and testing, the Full Bridge converters in Isolated DC-DC and the Boost converters in Non-Isolated DC-DC appear to be efficient and reliable for use in electric cars. The many types of electric motors utilized in the automotive industry are examined, and a comparison table is created. A PMSM is the greatest option for low power ratings (below 5kW) while an induction motor is the best option for high power ratings, according to the full analysis (above 5kW). There is also a basic summary and analysis of the RES-based charging techniques. It is possible to have zero emissions if the vehicle is powered by renewable energy. EVs still have certain drawbacks, such as high costs, the inability to drive as far, a longer charging time, and a lack of charging stations. Researchers are working hard to overcome the barriers to EV usage. EVs have numerous advantages, such as being significantly less detrimental to the environment, being more comfortable to drive, requiring less maintenance, and being less expensive than petroleum. EVs have the potential to safeguard the environment for future generations.

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