Review of Electric Vehicles and Performance Analysis of its Battery Technology

A Project and Thesis submitted in partial fulfillment of the requirements for the Award of Degree of Bachelor of Science in Electrical and Electronic Engineering

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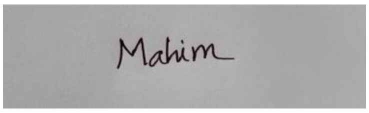
DECLARATION

We hereby declare that the work presented in this Thesis, is the outcome of the research work performed by us under the supervision of Jahedul Islam, Lecturer Department of Electrical & Electronic Engineering, Daffodil International University Bangladesh. We also declare that no part of this thesis and there of has been or is being submitted elsewhere for the award of any degree or Diploma Countersigned.

Signature



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This is to certify that the Thesis on **"Review of Electric vehicles and Performance Analysis of its Battery Technology"** by **Olid Hassan Mahim, ID: 182-33-724** has been completed in partial fulfillment of the criteria for the degree of Bachelor of Science (B.Sc.) in Electronics and Electrical Engineering in the year 2022, and its style and contents have been accepted.

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Thanks to the Almighty, the Creator and Sustainer who has given us strength and opportunity to complete the Thesis titled, **"Review of Electric vehicles and Performance Analysis of its Battery Technology"**

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ABSTRACT

The popularity, development, and widespread consumer use of electric vehicles are at a turning moment in history. Today's automotive industry is beginning to see a big role for battery-powered electric vehicles. At the moment, traditional gasoline-powered cars and hybrid electric cars, usually referred to as electrified cars since they mix gasoline cars with batteries to supply energy for movement, are the favored modes of transportation. Batteries for these devices might originate from conventional or plug-in hybrid vehicles (HEVs). However, we will be concentrating on Electric Vehicles and its battery in our thesis research, and we will show its operation and guiding principles in a manner that is understandable to all.

The charging stations for these BEVs have plugs that can be used for later use. We currently live in a time where fossil fuels are rapidly depleting, and our herbal oil reserves will be completely gone in just 33 years, or through the year 2051. In our research, we have finished a entire find out about on the specific parts of an electric vehicle. In the past, research was done on the various factors that can affect a car while it is moving down the road. Additionally, the various motor types and regulating techniques employed in an electric vehicle were investigated. It is obvious that a different method one that is more environmentally conscious as well as environmentally friendly is needed to power these vehicles. This transportation irritation may be resolved by altering how automobiles operate, and it seems that electric cars—as opposed to electrified vehicles are the answer. Utilizing electrically powered vehicles provides a variety of advantages, including reduced levels of noise pollution and no exhaust air pollution or carbon emissions as compared to standard autos.

In order to provide a comprehensive overview and perception of how an electric car operates, this paper explains how it functions. The modeling of an electric vehicle and the accompanying simulation results are also included. We have presented the significance and necessity of electric vehicles in the modern day through a comparison between the electric vehicle and the traditional vehicle. As a result, this thesis paper will cover the work and concepts of an electric powered car and their batteries in their entirety.

Dedicated to

Our Parents

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Abbreviations

IC	Internal Combustion
EV	Electric Vehicle
SOC	State of Charge
$LiFePO_4$	Lithium iron phosphate
BEV	Battery Electric Vehicle
UPS	Uninterrupted Power Supply
AEB	Automatic Emergency Braking
$LiCoO_2$	Lithium cobalt oxide
$LiMn_2O_4$	Lithium manganese-oxide
HEV	Hybrid Electric Vehicle
$LiPF_6$	Lithium hexafluorophosphate
EMF	Electromagnetic Force
BLDC	Brushless DC Motor
IM	Induction Motor
PMSM	Permanent Magnet Synchronous Motor
$LiNiO_2$	Lithium nickel-oxide
FOC	Field Oriented Control
DTC	Direct Torque Control
PWM	Pulse Width Modulation
PHEV	Plug-in Hybrid Electric Vehicle
PI	Proportional Integral

CHAPTER 1
Introduction

1.1 Introduction

The cars of the very near future are electric vehicles (EVs). They still need to be improved upon and mastered even if they are now used very regularly. They are undoubtedly a long way from the point where consumers would consider them to be preferable to other products on the market or a must-have. To start, compared to their typical internal combustion (IC) equivalents, battery electric vehicles' (BEVs') initial cost might be fairly expensive. However, it can be predicted rather accurately and with a high degree of certainty that this situation will continue to improve as a result of economies of scale. At the moment, it appears that lithium-ion batteries, which power many of our everyday gadgets like phones, laptops, and more devices, are the dominant battery technology. We should expect these batteries to become even more efficient and effective as their prices continue to decline because further enhancements to these batteries are now a popular topic of study. For instance, using these batteries in autos will increase demand for the batteries and push up the cost of production. The costs will certainly decrease until an equilibrium position is reached as there are an increasing number of businesses involved in the development and manufacturing of these batteries in large quantities, as a result of increased rivalry among them and more spectacular basic grant on the market. Long-term, we should expect the costs of these BEVs to decrease year after year as all the major automakers phase out their conventional internal combustion vehicles. This is inevitable given how quickly fossil fuels are leaving the scene. Zero air pollution and minimal noise are already popular buyer considerations and effective advertising and marketing strategies in the automotive sector. The current status of the automotive business may be compared to and seen as equivalent to the price-to-demand ratio of PCs in the early 1990s monitored up until 2010 and beyond in order to gain a clearer picture of where the PC industry stands. Although the computers' power and efficiency increased significantly more than they had at first, the price of these items rapidly decreased after they were initially quite expensive. Given that a change of this magnitude has not occurred in transportation for quite some time, it is very plausible for a comparable style to emerge in the vehicle industry. However, prior than that, the current scenario has been described. In part 1.2, we will look at a brief history of transportation and automobiles that occurred in the past and led to the place we are at now. Currently, there are three different types of electric vehicles: battery electric motors, plug-in hybrid electric vehicles, and hybrid electric vehicles (HEVs) (BEVs). This leaves the battery electric automobile as our only remaining choice (BEVs). This is the system that has to be used and elevated to the forefront of the automotive industry. This is due to the fact that combining all of the technologies that have been developed over the past few decades—including cutting-edge communication technologies, the internet, computerization, satellite tv for pc communication, and much more—along with a mode of operation that uses an electric interface and electric powered energy will create a breakthrough in transportation technology that is unlike anything that has ever been available before and is extremely efficient.

1.2 A Synopsis of Transportation History

If we look back in time, we can see that the concept of electric vehicles is not brand-new or modern; rather, it has been around since the middle of the 19th century. Electric vehicle prototypes of every form, including electric mannequin automobiles, were already in existence in the late 1820s [1]. The land speed record is acknowledged to have been held by electric vehicles up to the 20th century, before other sorts of engine technology seized control [2]. Between 1828 and 1835, the first scale models of electric vehicles were built, and shortly after, a flood of unrefined and unsuitable electric vehicles appeared. An electric vehicle with serious promise didn't exist until the year 1870 [3]. After the first electric car was created in the year 1900, these vehicles had begun to gain significant appeal among urban customers. They valued its simplicity and the absence of the black smoke pollution that was common at the time in cars. In their first ten years, these electric vehicles dominated US roadways by employing storm protection for one-third of the traffic. But at this period, none other than the wonderful Ferdinand Porsche invented the first gas-electric hybrid car. The Lohner-Porsche Mixte is the name given to this vehicle [4]. Henry Ford later contributed information regarding the internal combustion engine's revolution in the year 1912 [5]. It was more efficient than these early electric cars in terms of speed and range, making it an affordable and dependable vehicle for the general public. As the market soared, the internal combustion engine era was fully upon us, and we were beginning to use fossil fuels to power vehicles.

Electric Vehicles have totally disappeared from the boulevard by the year 1935. However, when the price of gasoline continued to rise in the second half of the 20th century, interest in electric cars increased once more [5]. The possibility of electric automobiles was once again examined in the 1990s. Once upon a time, research began to pick up steam at a rapid rate, and automakers took note. The General Motors EV1 and the Toyota Prius, two innovative automobiles that entered the market with electrically powered infrastructure—the former was a fully electric vehicle and the latter was formerly a full hybrid electric vehicle—were both entirely electric. However, it had made tremendous advancements in automobile engineering, and had they used Lithium-ion batteries instead of Nickel Metal Hydride batteries, even today these cars would have, pretty arguably, been the best in the market and all around. The well known motors EV1 had failed to secure profits using the nickel metallic hydride batteries for powering their automobiles, so by 1999 they shut down its meeting line. Unfortunately, battery technology had not yet been revolutionized by the amazing Tesla Motors. Nevertheless, GM has taught the world a tremendous amount, and they deserve kudos for making such an attempt at automotive engineering. They used the hybrid electric model approach, in which the IC engine would coexist with a different electric driven battery, and they have had great success with that concept. For instance, its production line has been operational since 1997.

Henry Ford made the beautiful discovery or creation of the internal combustion engine (IC engine), without which, in the early days of the development of electric vehicles, we would have had far less dependable means of transportation. Due to the massive amount of technical innovation that has occurred over the past century, modern electric vehicles will be considerably more empowering than ones from the past. All of those features may be integrated into one complete package in these electric automobiles. The potential for improvement in modern motors seems to be endless, in contrast to the early electric vehicles, where range and speed were the primary concerns and constraints. Satellite communication, the internet, self-driving cars, and motors communicating to one another are just a few examples. Henry Ford's vision of a future dominated by IC engine cars in such a broad range that the fossil fuels used to power these vehicles will eventually dwindle was unthinkable and unforeseen at the time, before both World Wars I and II. On the other hand, we are at a time and place when these fossil fuels will unavoidably deteriorate and disappear, thus a sustainable solution needs to be offered. In order to move forward, it is frequently essential to appear to be moving backward rather than dramatically develop something that is drastically different from what the natural order is. History has more than once laid out the next stages and suggested possible future courses of action

1.3 Inspiration

As was mentioned in 1.1, there are several benefits that electric vehicles may offer. For instance, charging batteries for electric vehicles will only need to happen at an electrical outlet. As a result, gas stations would become unnecessary and there would be no release of dangerous air pollutants due to the lack of gas. Additionally, by lowering the cost of operation, this makes these cars commercially viable. Additionally, electric motors may be made to work effectively with the right design and only need one gear for all speeds. Even after accounting for the CO2 and other harmful emissions released into the environment by the most powerful plants that are necessary to provide the energy required to power these cars, EVs still create roughly 40% less CO2 and O3 than regular automobiles. The fundamental and most urgent difficulty with regards to the feasibility of EVs is exceptionally their high costs and sub-par battery economy. Tesla Motors have made fantastic strides in this respect and hopes to make a difference. Their innovation has made batteries, in the recent year, not only cheaper, but additionally recharge extra quickly, and it’s with these low costs they hope to achieve extra than their opponents in the race to the next era of transportation which is that of Electric Vehicles.

Regarding the race to develop electric vehicles, many of the major automakers selected larger battery cells because fewer of them would be required, reducing complexity and cost as well. However, Tesla Motors has, in an unusual move, selected the very well-known Li-ion batteries as their base of battery development. Although the formers' packs had more strength overall, they also posed as being more lethal and hazardous due to their lower energy density. Therefore, less energy-dense battery materials that are more heat resistant might be employed. Automakers chose flat cells because they can be packed closely together to compensate for lower energy density, although these cells ultimately ended up costing more to produce [6].

Tesla also had more packaging options because to smaller cylindrical cells. The huge, flat cells may desire to deform in the event of a collision as well, which would cause a fire. This feature ensures that, even in the case of an accident, the battery will be kept safe. The passenger or cargo space is the only other location where such a fatality can be decreased. Tesla claims that, aside from their cells deforming or coolants leaking, its electric vehicles have passed crash testing with flying colors. On Tesla's stop, this type of engineering is fantastic and deserves praise [6].

Our thesis' driving objective is to compare batteries from various manufacturers, determine which cars are more battery-efficient, acquire insight into excellent engineering, and develop a deeper knowledge of the automotive industry via the use of graphs. In order to ensure that transportation is not only sustained but improved, safer, and cleaner following the depletion of fossil fuels, we are driven to educate more people on how electric vehicles as a whole operate. This will make life simpler for everyone.

1.4 Limitations with conventional IC cars

The typical IC motors have a wide range of problems. For instance, they mostly need fossil fuels to power them. On the other side, these fossil fuels have built up over hundreds of thousands of years, yet we are now closer than ever before in history to their depletion. The day when fossil fuels are no longer available draws closer and closer every day. Fossil fuel reserves are predicted to be depleted by 2051, or in around 30 years. But transportation has always existed, from the development of the wheel through the use of horse carriages, mechanized vehicles, and gasoline, among other things. With the exception of the need to consume fossil fuels, transportation has existed for endless millennia throughout history and has been continuously changing. Currently available vehicles should be produced, and technology should be dramatically advanced, so that dependence on fossil fuels ultimately declines and, ideally, ends altogether. The solution to this is using renewable sources of energy and utilizing the strength of nature to power our daily forms of mobility. Because of this, electric vehicles appear to be a common solution. Concerning IC engines, the issues include increased noise pollution, the release of hazardous chemicals into the environment as a result of the burning of fossil fuels, the need for large-scale fuel stations generally, greater maintenance costs for both short- and long-term use, and many more. The majority of these problems may be, at the absolute least, significantly alleviated by utilizing cleaner and more environmentally friendly electric vehicles.

1.5 Methodology

This thesis examines how electric vehicles function, including their battery, and explains its principles in a way that anybody can understand. In the very near future, electric cars, namely battery-electric vehicles employing lithium-ion battery modules and packs, will likely rule the streets. Here, we examine both the efficiency and the underlying concepts of these lithium-ion batteries. We collected the data from several firms for the battery for the electric car in an excel spreadsheet because the automotive industry is undergoing fast change right now and with each passing day. We are attempting to determine whether company's vehicle has a more effective battery. We are evaluating the battery offerings from several auto manufacturers. Therefore, it is crucial that we all understand how these vehicles work and the guiding principles that guide their operation.

1.6 Thesis Outline

The next chapter, Chapter, explores a few model-specific characteristics of current Electric Vehicle models. The construction and fundamental concepts of electric vehicles are then covered in Chapter 4 in detail. The construction of the well-known Li-ion batteries and the operation of the motor/controller of electric cars are then described in greater depth in chapters five and six, respectively. The dynamics of electric vehicles are then covered in detail in Chapter 7, including the forces at play and how to counter them. As a consequence of the previous chapter, we will witness a comparison of batteries from various manufacturers, learn which cars are more battery-efficient, get knowledge of excellent engineering, and develop a better understanding of the automotive sector via the use of graphs.

Chapter 2

Literature Reviews

2.1 Introduction

Electric Vehicles are at their most pivotal point in history in terms of popularity, development, and regular consumer usage. Battery powered Electric Vehicles are starting to play a significant role in today's automotive industry. Because of the increased demand for fossil fuels on international markets, as well as the worsening of environmental problems caused by an increase in the number of internal combustion engine vehicles, there is a greater interest in the research and development of batteries used in electric and hybrid vehicles. These vehicles represent a future solution in the field of road transportation, taking into account the desire to reduce greenhouse gas emissions as well as air and sound pollution. Electric vehicles powered by batteries are beginning to play an important role in today's automotive industry. There are numerous types of batteries used in the construction of today's electric vehicles, making it difficult to determine which one best meets all of the most important characteristics from various perspectives, such as energy storage efficiency, constructive characteristics, cost price, safety, and utilization life.

2.2Paper Review

1. Research paper on “Comparison of Various Battery Types for Electric Vehicles”

In this research paper, the authors proposed which battery is effective for electric vehicle. Electric vehicles powered by batteries are beginning to play an important role in today's automotive industry. This study examines the autonomy of an electric vehicle powered by four different types of batteries: Lithium Ion (Li-Ion), Molten Salt (Na-NiCl2), Nickel Metal Hydride (Ni-MH), and Lithium Sulphur (Li-S), all of which have the same amount of electric energy storage capacity. This paper's author shows the Comparison of Different Battery Types for Electric Vehicles. In terms of energy consumption (12.6 kWh/100 km), Na-NiCl2 batteries have proven to be the best choice. According to these studies, it has been demonstrated that Li-S batteries have the highest energy consumption (17.2 kWh/100 km). Despite having a reasonable energy consumption (15.7 kWh/100 km), Ni-MH batteries are inefficient due to increased energy density and power, heavy weight, and outdated technology.

But the last result is that Li-Ion batteries now have the largest market share in electric vehicle battery technology. Li-Ion batteries are an excellent choice in this field due to their moderate energy consumption (14.7 kWh/100 km), continuous price decrease, advanced manufacturing technology, increased cycle life, low weight, and high energy storage potential [7].

2. Research paper on “The Characteristics of Motor Drives used in Electric Vehicles: A Survey and Comparison”

In this research paper, the author survey and comparison of motor drive characteristics used in electric vehicles. The price of fuel has recently been rising on a global scale. One or more electric motors make up the electric motor drives, which are a crucial part of an electric vehicle. A thorough list of published references papers in the field of electric vehicles is also provided. In this essay, an effort has been made to compare various characteristics of motor drives used in electric vehicles. The author understands that the induction motor drive and the PM brushless motor drive are the two most commonly used motor drives. When comparing motor drives, induction motor drives are the most economical. The PM brushless motor drive is the most effective in terms of efficiency. Due to extensive research on them over the years, DC motor drives have one of the most developed technologies. The most dependable and low-maintenance technologies are switched reluctance drives and induction motor drives [8].

3. Research paper on "An Extensive Examination of the Key Elements, Technology, Problems, Consequences, and Projected Development Course of Electric Vehicles (EVs)"

The author was reviewing all pertinent data on EV designs, battery energy sources, electrical machines, charging processes, optimization approaches, impacts, trends, and possible future development paths is the major goal of this research. In order to encourage continuing research in this area, it aims to provide a thorough overview of existing EV technology as well as prospective areas for future development. EVs have a strong potential of replacing internal combustion engines as the preferred form of transportation in the future while averting imminent climate-related catastrophes. They provide a useful alternative to conventional automobiles, which are dependent on the limited supply of fossil fuels. The kinds, configurations, energy sources, motors, power conversion, and charging systems for EVs have all been thoroughly discussed in this study. The main technologies in each division have been looked at, and their features have been discussed. The effects EVs have on many industries have also been examined, in addition to the huge potential they offer to promote a better and more ecologically friendly energy system by collaborating with smart grid and easing the integration of renewable sources. An overview of the current EV market has been provided [9].

4. Research paper on "Review of the energy storage and management system for electric vehicles: requirements, problems, and challenges"

In this research paper the author presents Standards, problems, and challenges related to the energy storage and management system for electric vehicles. Long-term energy storage is possible with a variety of energy storage technologies, but one of the most potent and widely used is the lithium-ion battery. There are two different types of electrochemical batteries: primary battery and secondary battery. The battery is an electrochemical storage system that stores chemical energy and generates electricity. Higher specific energy and a power-based secondary battery are used in electric vehicles. Authors shows that in the Energy storage system, Li-ion batteries are becoming well known for EVs, practical devices, and utilities.

These batteries are a well-known choice for use in cell phones due to their lightweight characteristics. The retail price of Li-ion batteries has gradually decreased since their dispatch. By 2030, it is anticipated that further value declines will amount to about 75% of the market price. However, the cost is typically not excessive. In this study, there was some criticism of the ESS's environmental and safety problems [10].

5. Research paper on “Review of Electric Vehicle Technologies and Challenges”

In this paper, In terms of battery technological trends, charging methods, as well as fresh research obstacles and untapped prospects, this study evaluates the advancements of EVs. More precisely, a study is done on the prospects for and condition of the worldwide EV market. A thorough review of battery technologies, from lead-acid to lithium-ion, is included in the article because the battery is one of the essential elements of electric vehicles (EVs). The author also reviews suggestions for power control and battery energy management as well as alternative EV charging standards. Based on these qualities, the author investigated several battery kinds and talked about prospective future technologies, such as graphene, which is projected to be a tool for more powerful power storage and faster charging. [11].

6. Research paper on “A Study on the Many Principles, Interior Functioning, and Modeling of Electric Vehicles (EVs) Using Software Simulation”

In this study work, the author examined electric, hybrid, and internal combustion (IC) automobiles. A research on lithium-ion batteries was also addressed, and there was a thorough discussion of vehicle dynamics and motor control. The information presented here should help to improve the efficacy, interest, and engagement of future research into the topic of electric vehicles. The author presents thorough research on all of an electric vehicle's component parts. A study was conducted on the various forces that can affect a vehicle while it is moving down the road. Additionally, the various motor types and controlling techniques used in electric vehicles were investigated [12].

Chapter 3

Selected Popular Electric Vehicle Models

3.1 Introduction

Each significant automotive manufacturer has moved its focus as time has gone on to the mass production of electric vehicles. In order to give consumers a better experience, agencies have always worked to improve the overall performance of the motors and address any shortcomings. This has been made possible by increased customer demand and their overwhelmingly favorable response. Additionally, in order to contribute to the environment with the fewest poisonous emissions, firms that are responsible to nature are leaning toward the development of electric vehicles. A handful of the electric car models now being produced have been discussed. In the first decade of the 20th century, the majority of manufacturers of passenger automobiles chose gasoline-powered vehicles, although electric trucks had already found a niche market by the 1920s. The appeal of electric automobiles has waned as a result of many circumstances. The discovery of significant petroleum reserves in Texas, Oklahoma, and California resulted in the widespread availability of affordable gasoline/petrol, making internal combustion powered cars more cost-effective to operate over long distances. However, improved road infrastructure required a greater range than that provided by electric cars. There may have been a stigma associated with electric cars among male buyers because they were frequently advertised as luxury automobiles for women.

3.2 Nissan Leaf Electric Vehicle

Figure 3.1 Nissan Leaf Electric Vehicle [13]

The Nissan Leaf is an electric car that has achieved record sales among all current pure electric cars. Nissan Leaf sales in the world hit 300,000 in just over seven years. Sales of this first-generation 100% electric vehicle began in 2011, making this achievement all the more impressive.

The Nissan Leaf had an MSRP of $29,990 in 2018. Compared to earlier generations, this 2018 model is more polished. Compared to the first Nissan Leaf model, it is more powerful and has a greater battery range, and it also looks nicer on the inside and exterior. The comprehensive list of features for the 2018 Nissan LEAF's makeover is as follows:

- A 40-kWh Li-ion battery with improved capacity that now travels 150 miles as opposed to the previous model's 80 miles.
- The new e-faster powertrain's acceleration is made possible by an increase in horsepower and torque of 26% and 37%, respectively, giving it a maximum of 147 hp and 236 ft-lbs.
- 6.6-kW charger

- Cable for level 1/level 2 charging More safe and assured handling.
- A Nissan Connect SM with navigation option that supports Apple Car Play TM and Android Auto TM is available.
- All-new external and interior style, as well as improved Nissan Connect EV telematics
- Automatic Emergency Braking (AEB) is the default setting, whereas Automatic Emergency Braking with Pedestrian Detection is an option [14].

Pro PILOT Assist, e-Pedal, and Nissan Safety Shield are just a few of the new Nissan LEAF's Intelligent Driving features. Pro PILOT Assist is a single-lane driving assistance system that may be used "hands-on." When engaged, it may use the driver-specified speed and distance to automatically maintain the gap from the car in front. In order to keep the car centered in its lane, it can also help with steering. The Pro PILOT Assist system can automatically apply the brakes to help the car stop completely if the car in front of it comes to a complete stop. [14]

3.3 Tesla Model S Electric Vehicle

Figure 3.2 Tesla Model S Electric Vehicle [15]

The Tesla Model S, the world's first fully electric sedan [16], distinguishes apart from the competition because to a unique combination of power, security, and efficiency. This particular model has the greatest range of the electric cars that are currently being developed and has the highest safety ratings [16]. This vehicle has two motors, one in each of the front and back wheels, in contrast to previous production EVs. This controls the torque on an individual basis and, as a consequence, offers more traction than any other conventional cars, where increased traction is given up for fuel efficiency [16].

3.3.1 Tesla Model S Design

The three-phase, four-pole AC induction motor used in the Tesla Model S's first 2012 production delivered the vehicle 460 horsepower, or around 310 kw [17]. A copper-rotor 601 Nm motor is also included into the design and is housed on the backside of the vehicle [18]. The drag coefficient Cd of 0.24, the lowest of all production automobiles at the time, was a characteristic of the Tesla Model that was unsurpassed at the time of its debut [17]. Due to its extraordinarily low drag coefficient, the vehicle has always had a competitive edge over other vehicles of its sort and conventional cars. The two motors of the Tesla Model S P85D model allow it to accelerate from 0 to 97 km/h in less than 3.2 seconds [7].

3.3.2 Tesla Model S Battery

The Tesla Model S is reported to exceed the Nissan Leaf in terms of driving range, which is said to be longer by more than twice [19]. The Tesla Model S's battery is said to have an energy density that is up to double that of its major competitor, the Nissan Leaf. The value of the driving range is often impacted by a number of variables, such as the drag coefficient, the effectiveness of the engine, rolling resistance, and the weight of the vehicle. There are 7104 lithium ion battery cells distributed over 16 modules in the P85D variant of the Tesla S vehicle, which has an 85kwh battery and weighs roughly 540 kg [20].There are around 6 groups of 74 cells each in each module, and they are wired in parallel before being joined in series between one another [21]. A guarantee of eight years and unlimited miles is provided for the battery pack's performance [22]. To maintain the temperature of the motor, the controller, and the battery at their recommended operating temperatures, the Tesla Model S incorporates an internal heating or, alternately, cooling circuit [23]. The battery is kept heated in cold weather using the waste heat from the motor, which is used to keep it operating at its best capacity only at a specified temperature [24].

3.3.3 Drawbacks

Although the Tesla Model S appears to be the best car currently being produced, it also has a few flaws. An issue with the prior version's power dissipation, which lost around 4.5 kwh over the course of one night and presented a problem for the users, has been brought up [25]. In a couple of the model versions, there have also been complaints regarding power consumption exceeding estimated power consumption per km [26].

3.4 BMW i3 Electric Vehicle

Figure 3.3 Electric Vehicle Model of BMW i3 [27]

This car is distinctive in the pursuit of EVs since it is produced by a significant, renowned, and well-known automaker that started developing EVs in 2013 and began selling them in 2014. The BMW i3 is powered by a 33 kWh lithium-ion battery pack positioned beneath the passenger compartment and a 170-horsepower, 184-lb-ft of torque synchronous electric motor. The i3 can go from 0 to 60 mph in 7.2 seconds because to its single-speed transmission, which also transmits power to the rear wheels. The top speed is 93 mph [28].

The i3 doesn't have to operate totally on electricity: An optional 650cc, 34-horsepower, two-cylinder gasoline range extender that burns gasoline is available and works similarly to a generator [31]. The i3's drive wheels are not directly powered by the range extender; rather, it only activates when absolutely necessary [29].

The BMW i3 is a high-end EV that is perfect for city driving because to its 97-mile range. An accessory is a 650cc, 34-horsepower, two-cylinder gasoline that works like a generator and adds more charge to the battery. The range extender does not directly power the i3's drive wheels; instead, it only engages when it is actually necessary. Drivers of i3 vehicles can anticipate a range of closer to 180 miles with the range extender. When the automobile is connected to a home charger, a full charge is accessible in four and a half hours [28].

The BMW i3 weights about 1343 kg or 2961 lbs. The BMW i3's engine and fuel type are both electric, and it delivers 170 horsepower at 4800 revolutions per minute. The rear wheel drive system gives it the 184 lb-ft (250 Nm) of torque it produces. This vehicle has a 1-Speed automatic transmission, which is typical for EVs. The cost of this car is $44,450 [29].

This car's features have been praised by consumers and include:

- Strong, fluid acceleration
- low-speed agility
- Stylish, minimalist decor
- simple one-pedal maneuvers
- Range-extension potential [30]

Some dislike mentioned is:
The rear seat is compromised, there is a lack of BMW's customary energy, and the range is small compared to the newest competition, among other dislikes. [30]

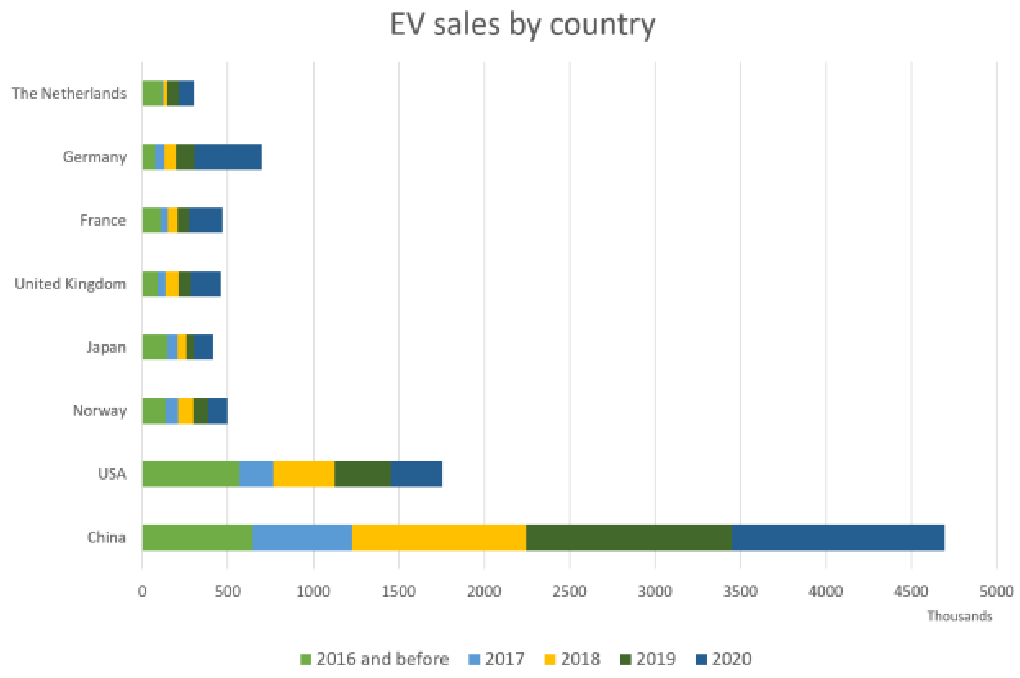


Figure 3.4 Global electric car sales have changed throughout time. [31]

Since some countries have stated their intention to ban internal combustion engine cars shortly, it is projected that these numbers will increase over the upcoming years. One nation that has declared that all vehicles and vans sold beginning in 2025 would have zero emissions is Norway. On the other side, all cars sold in India, Israel, and the Netherlands in 2030 will be electric. Germany and the United Kingdom postpone this deadline until 2040, the same year that California bans combustion-powered automobiles.

Despite the good sales figures worldwide, it is important to note that only 10 countries sold 95% of the world's electric vehicles. Finally, it should be underlined that a variety of BEV and PHEV vehicles are now on the market. According to sales data, some of the most popular models are the Tesla Model 3, Toyota Prius Prime, Nissan Leaf, Tesla Model S, Ford Fusion Energi, and BMW i3.

Chapter 4

Electric Vehicles Construction

4.1 Initial Thought

The three most crucial electrical components may help an electric vehicle (EV) be created and distinguishable from conventional motors, although the majority of other parts, such as the tires, windshields, aluminum body framework, taillights, seats, etc., are similar to those of conventional cars. The main distinction between these other components is that, in order to support higher speeds and accelerations, they need be made lighter while yet being stronger.

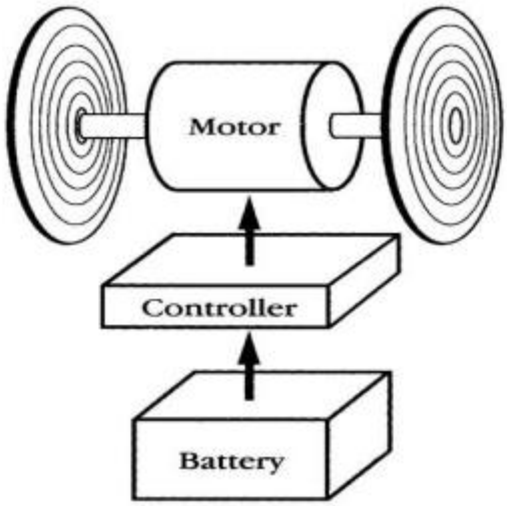


Figure 4.1 Simple Electric Car Block Diagram [32]

The following three elements, when combined, give motion its approval and set it apart from conventional automobiles.

- The automobile needs push to go forward, which the electric motor provides by converting electrical energy to mechanical energy.
- The Controller Unit transforms electrical energy from DC to AC. Additionally, this device contributes to the transfer of power from the battery to the motor .
- The Battery serves as an energy reserve that can take the place of a fuel tanks.

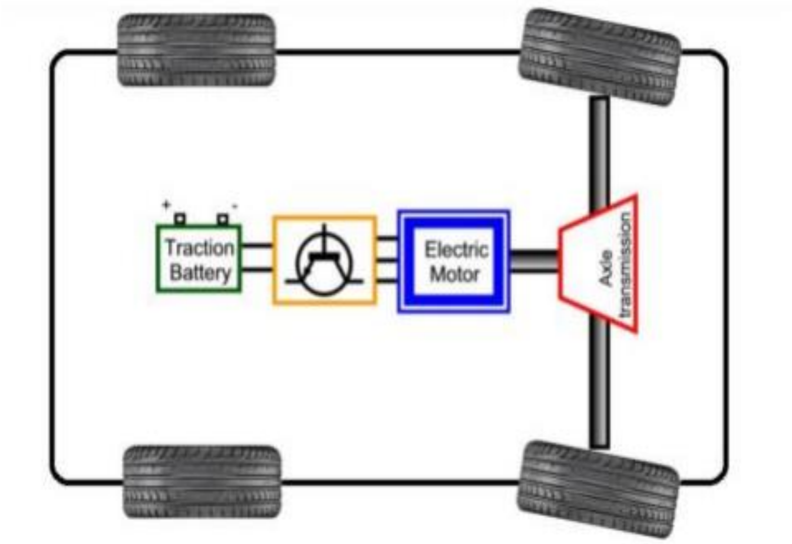


Figure 4.2 Drive Train for Electric Vehicles [32]

When the accelerator is pressed and in response to the force being delivered to the pedal, the manipulator unit, which functions as a brain, draws the appropriate power from the battery and delivers it to the electric motor, which converts the required electrical power into mechanical energy.

4.2 Various Electric Vehicle Types

A combination of an ICE and electric propulsion is also an option for EVs. The most basic type of electric vehicle (EV) uses simply batteries as its energy source, but there are many models that can use various types of power sources. These are hybrid electric vehicles (HEVs). Technical Committee Sixty-Nine (Electric Road Cars) of the International Electrotechnical Commission recommended that vehicles that use two or more forms of power source, storage, or converters can be classified as HEVs as long as at least one of them provides electrical strength [33]. Thanks to this standard, a wide range of HEV configurations, such as ICE and battery, battery and flywheel, battery and capacitor, battery and fuel cell, etc., are now practical. Consequently, vehicles with an ICE and an electric motor were first referred to as HEVs, vehicles with batteries and capacitors as ultracapacitor-assisted EVs, and vehicles with batteries and fuel cell technology as FCEVs. Following this criterion and the terminologies' general usage, EVs may be categorized as follows:

- Battery Electric Vehicle or BEV
- Hybrid Electric Vehicle or HEV
- Plug-in Hybrid Electric Vehicle or PHEV
- Fuel Cell Electric Vehicle or FCEV

4.2.1 Battery Electric Vehicle or BEV

BEVs are defined as EVs that rely only on their batteries to power the drivetrain. BEVs must completely rely on the energy stored in their battery packs, hence the range of these vehicles is directly correlated with the battery capacity. Typically, they can go between 100 and 250 miles on a single charge, although top-tier versions may travel up to 500 km. These levels take into account a variety of variables, such as driving styles, car configurations, weather, road conditions, and battery type. When the battery pack is empty, charging it requires more time than would be required to fuel an ICE vehicle. There are battery recharge techniques that can do the job in as little as 36 hours, but none of them come close to the speed at which a petrol tank can be filled. The charger's setup, configuration, and operational power level all have an impact on how long it takes to charge. BEVs' advantages include their straightforward design, ease of use, and functioning. These do no longer produce any greenhouse fuel (GHG), do not create any noise, and are therefore recommended to the environment. Electric propulsion provides instantaneous and high torques, even at low speeds [33]. These advantages, coupled with their obstacle of range, make them the best vehicle to use in city areas; as depicted in Figure 2, urban driving requires strolling at slow or medium speeds, and these ranges demand a lot of torque. Nissan Leaf and Tesla are some high-selling BEVs these days, along with some Chinese vehicles. The main layout for BEVs is shown in Figure 3, where the electric motor(s) that drive the wheels are powered by batteries via an energy converter circuit. To power the motor, the inverter converts the DC current from the battery to AC.

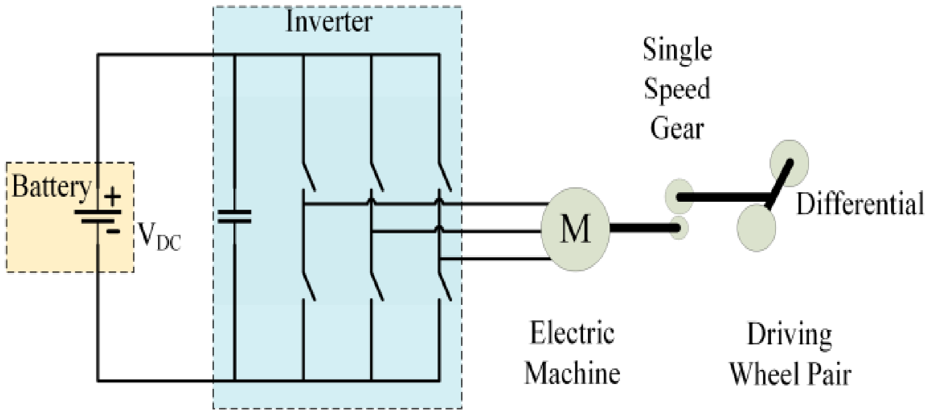
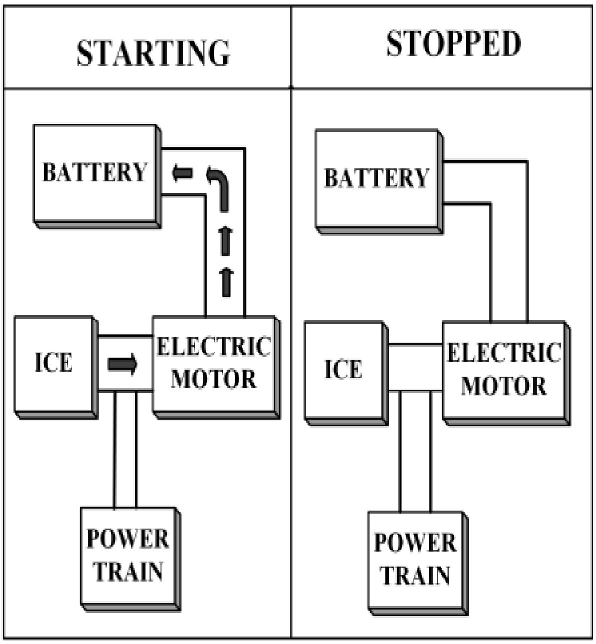


Figure 4.3 Setup for a BEV. [33]

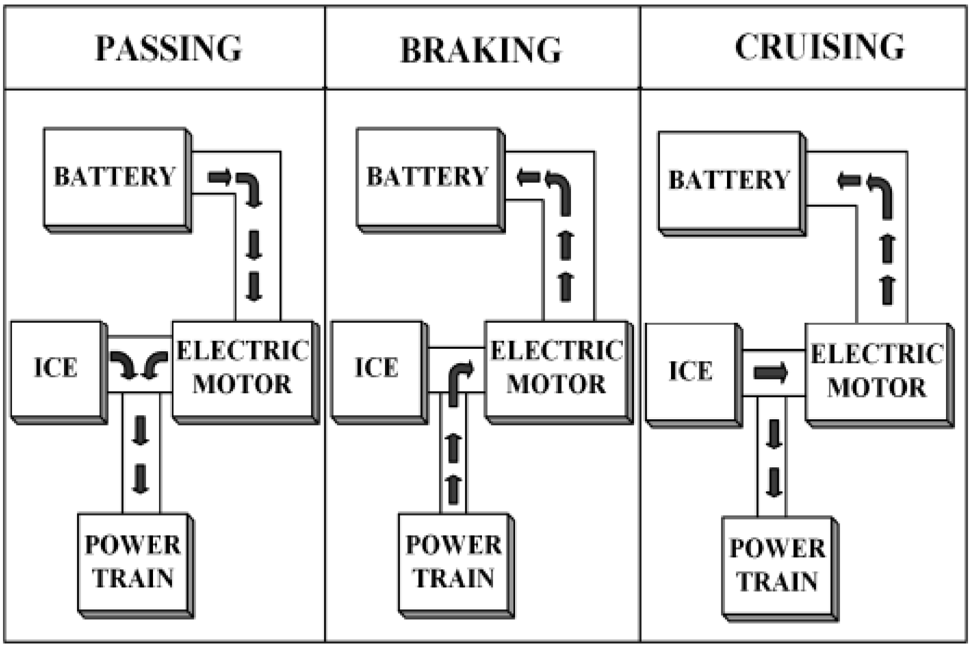
4.2.2 Hybrid Electric Vehicle or HEV

HEVs have a combined ICE and electrical engine that powers the vehicle. Together, these two components can assume unusual shapes that are discussed later. When there is little need for power, a HEV uses an electric propulsion mechanism. It is a huge benefit while traveling at modest speeds, as in cities, and it also lowers fuel consumption because the engine is completely shut off during times of inactivity, like when there are traffic jams. Additionally, this trait lowers GHG emissions. The HEV shifts to the ICE when a faster speed is required.

Additionally, the two drive trains can cooperate to enhance performance. In turbocharged vehicles like the Acura NSX, hybrid strength systems are heavily utilized to considerably reduce or completely eliminate turbo lag. By increasing speed when necessary and bridging the gaps between gear shifts, it also enhances performance. HEVs have the capability for regenerative braking, which enables them to recover power, whereas ICEs can recharge batteries. HEVs are therefore ICE-powered cars that have an electric powertrain to improve their overall performance or mileage. Automakers frequently employ HEV setups to implement these characteristics. The power flows in a primary HEV are depicted in Figure 3.2. In order to generate some power and store it in the battery while the car is being started, the ICE may also use the motor as a generator. Passing requires a speed increase, thus both the ICE and the motor exert pressure on the energy train. The power train uses regenerative braking when braking to use the motor as a generator and recharge the battery. During cruising, ICE uses the motor and the car as a generator, draining the battery. As soon as the vehicle comes to a halt, the energy drift ceases. A framework for managing strength that is employed in HEVs is seen in Figure 5. In order to achieve optimum fuel efficiency, the one shown above divides power between the ICE and the electric motor (EM) by taking into account the vehicle's speed, the driver's input, the battery's state of charge (SOC), and the motor speed.



1. The way power flows when it starts and stops.



(b) Direction of power flow during passing, braking and cruising.

Figure 4.4 Over several phases of the driving Cycle, power floats among the fundamental building parts of a HEV [34].

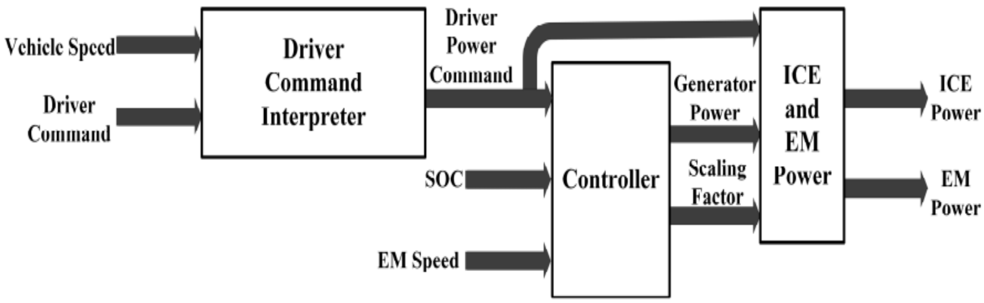


Figure 4.5 HEV usage as an illustration of an energy management strategy. The controller takes into account unique input characteristics to divide energy between the ICE and the motor. [34]

4.2.3 Plug-In Hybrid Electric Vehicle or PHEV

The all-electric HEV range was intended to be extended by the PHEV concept. Like a HEV, it uses both an ICE and an electrical powertrain. However, the difference between the two is that PHEVs employ electric propulsion as their primary form of propulsion, necessitating a larger battery capacity than HEVs. When the batteries are low on charge, PHEVs rely on the ICE to give a boost or to recharge the battery pack. PHEVs start off in "all electric" mode, which operates on electrical energy. Here, the range is extended using the ICE. PHEVs have the ability to use regenerative braking and can instantly charge their batteries from the grid, but HEVs cannot. The carbon footprint of PHEVs is lower than that of HEVs due to their ability to run exclusively on electricity for the most of the time. Additionally, they use a lot less petrol, which reduces the cost. Sales numbers for the Toyota Prius and Chevrolet Volt show how popular these are now that they are widely accessible on the automobile market [35–38].

4.2.4 Fuel Cell Electric Vehicle or FCEV

FCEVs are sometimes referred to as Fuel Cell Vehicles (FCV). Since fuel cells employ chemical processes to create energy, these cars got their name from having fuel cells as its central component. They are usually referred to as "hydrogen fuel cell vehicles" since hydrogen is the chosen fuel for FCVs to perform this reaction. FCVs transport hydrogen in recognizable high-pressure tanks for the energy production process, in addition to oxygen, which is acquired from the air pulled in from the environment. Electricity generated by the fuel cells drives a motor that moves the wheels. Supercapacitors or other battery-like storage devices are used to store extra power. In commercially accessible FCVs like the Toyota Mirai or Honda Clarity, batteries are utilized for this. As a byproduct of their electricity-generating technology, FCVs only create water, which is released from the vehicle through the tailpipes. Figure 3.4 illustrates how an FCV is configured. Such motors have the benefit of being able to generate their own energy without emitting any carbon, which allows them to reduce their carbon footprint in a manner comparable to other EVs. Another major benefit of these, and maybe the most significant one at the moment, is that filling up these motors takes about the same length of time as filling up a typical automobile at a gas station. This increases the likelihood that these cars will be adopted in the near future. The lack of hydrogen fueling stations is now a major barrier to adoption of this technology, although BEV or PHEV charging facilities weren't popular even a few years ago. The high cost of gas cells, which cost more than $200 per kW and are significantly more expensive than ICE (less than $50 per kW), was mentioned in a report to the U.S. Department of Energy (DOE). In the event that flammable hydrogen leaks from the tanks, there are extra security concerns. FCVs should essentially represent the automobiles of the future if these barriers were removed. Pininfarina's H2 Speed is used to demonstrate the viability of applying this technology in supercars. Figure 8 demonstrates that when BEVs and FCEVs were evaluated from different angles, FCEVs seemed to be superior to BEVs in several areas. This graph compares the unique costs and cost-related issues of BEV and FCEV for the 320 km and 480 km ranges. These issues include weight, necessary storage volume, preliminary GHG emission, required natural gas energy, required wind energy, additional expenses, fueling infrastructure cost per car, gasoline fee per kilometer, and incremental life cycle cost. The attribute ratio of BEV to FCEV is displayed on the horizontal axis. Any number greater than one on the horizontal axis will proclaim FCEVs better to BEVs in that characteristic since having a substantially lower cost in these qualities implies an advantage. In spite of this, BEVs only score higher in the categories of needed wind energy and gas cost per kilometer. Fuel cost still appears to be one of the most significant drawbacks of FCEVs because there is no affordable, environmentally friendly, and sustainable way to produce hydrogen and because the infrastructure for refueling FCEVs is inferior to that of BEVs. However, these issues won't persist for very long. [39]

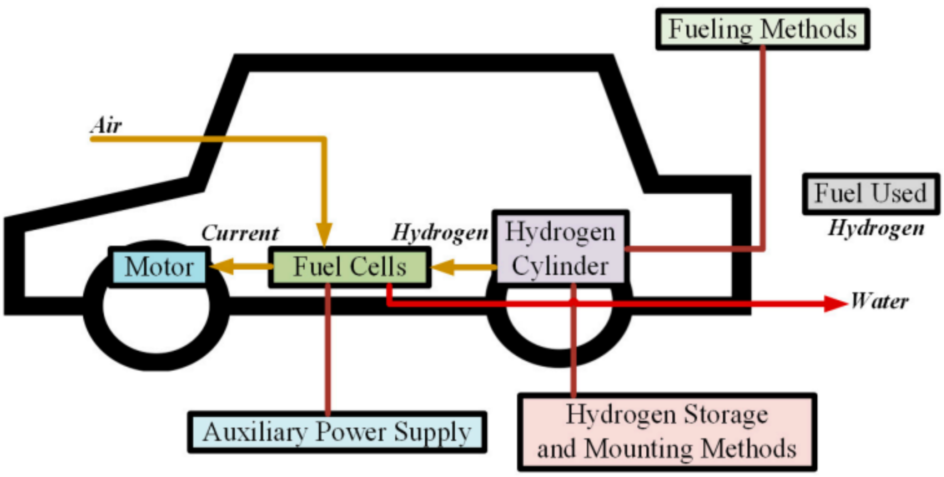


Figure 4.6 the FCEV setup. Fuel cells use a reaction between airborne oxygen and hydrogen from the cylinders to create the electricity needed to power the motor. The only derivative that is produced and released into the environment is water [39].

Figure 4.7 Supercar made by Pininfarina that uses hydrogen fuel cells [39] .

Table 4.1 Different vehicle models are compared [39]

EV Type	Driving Component	Energy Source	Features	Problems
BEV	• Electric motor	• Battery • Ultracapacitor	• No emission • Not dependent on oil • Range depends largely on the type of battery used • Available commercially	• Battery price and capacity • Range • Charging time • Availability of charging stations • High price
HEV	• Electric motor • ICE	• Battery • Ultracapacitor • ICE	• Very little emission • Long range • Can get power from both electric supply and fuel • Complex structure having both electrical and mechanical drivetrains • Available commercially	• Management of the energy sources • Battery and engine size optimization
FCEV	• Electric motor	• Fuel cell	• Very little or no emission • High efficiency • Not dependent on supply of electricity • High price • Available commercially	• Cost of fuel cell • Feasible way to produce fuel • Availability of fueling facilities

4.3 Configurations for EV

Electric cars are substantially more flexible than their ICE counterparts [4]. This is as a result of the absence of intricate mechanical systems required to run a regular vehicle. In an EV, the motor is the only thing that moves. It can be controlled using a variety of techniques and control schemes. The motor requires a power supply, which might originate from a number of areas, in order to function. The automobile may be parked wherever as long as these two components are connected by electrical cables; otherwise, it won't run. But although while an EV may operate solely on electricity, it also has the option of using both an ICE and an electric motor to power the wheels. Several layouts have developed as a result of this versatility and are utilized according to the kind of vehicle. A system that integrates the energy source, propulsion, and auxiliary components is what is known as an electric vehicle (EV) [4]. The source, its refueling system, and its energy management system make up the energy source subsystem. The electric motor, power converter, controller, transmission, and driving wheels make up the propulsion subsystem. The power steering unit, thermal management system, and auxiliary power supply make up the auxiliary systems. Figure 4.8 [33] depicts these subsystems.

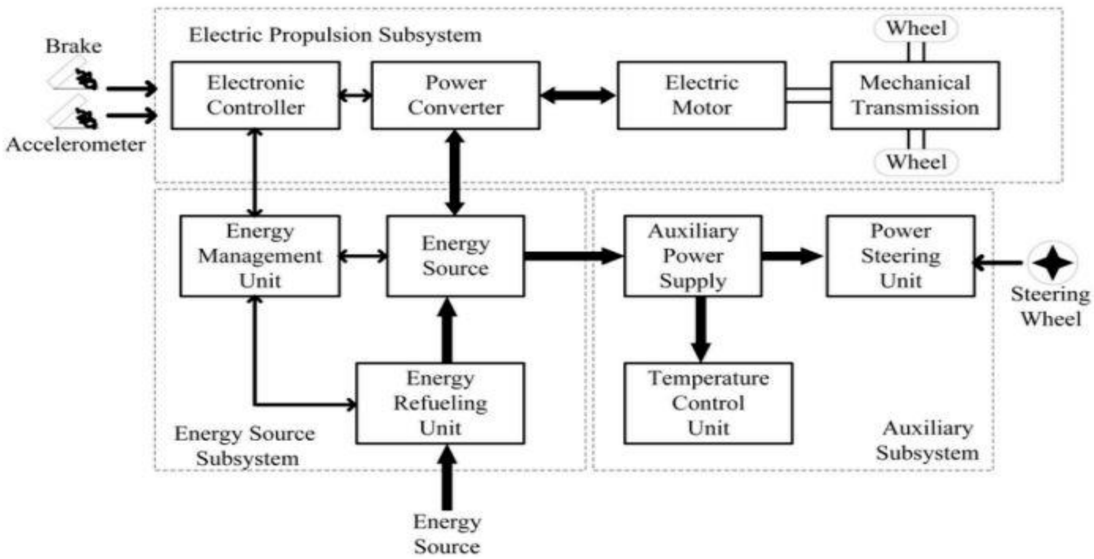


Figure 4.8 EV systems

The arrows represent the direction of the entities in question. Power can flow backward by utilizing regenerative methods like regenerative braking.

Chapter 5
Battery Technology

5.1 Introduction

Since the 1990s, numerous battery chemistries have been suggested as the energy source for electrical cars. In 1998 and 2003, respectively, California Zero Emission Vehicle legislated that 10% of all new cars sold must be zero emission vehicles. These battery chemistries included enhanced lead-acid, nickel-cadmium, nickel-zinc, NiMH, zinc-bromine, zinc-chlorine, zinc-air, sodium-sulfur, sodium-metal chloride, and later, Li-ion batteries, each of which had pros and cons of its own. The struggle between battery chemistries was settled around the end of the 20th century when General Motor decided to use NiMH for its EV-1 pure electrical vehicles. The technology of the HEV created by Toyota and Honda improved and gained popularity in the following decade thanks to its blend of fuel efficiency, reasonable price, and spotless safety record. The predominant battery chemistry in these HEVs as of 2011 is still NiMH. The development goal has changed from HEV to PHEV, with the ultimate ambition being a fully battery-powered EV, as worries about greenhouse gas emissions and the scarcity of fossil fuels have grown in recent years. Higher energy density requirements for PHEVs and EVs reignite the debate over automotive battery technology, providing Li-ion battery chemistry another chance to break into the market for electric car batteries. The fundamental ideas, the state of the market, and the potential future developments of NiMH and Li-ion batteries are covered in this part.

Given that so many of our everyday gadgets are powered by lithium-ion batteries nowadays, understanding their standards is crucial. This includes everything from our cellphones to our computers to UPSs and so many more devices. Tesla Motors has just started employing these lithium-ion batteries as a source of power to drive its vehicles forward, taking advantage of their high energy density and electrochemical properties while still being light and secure. The various car sectors will soon follow suit, and we, the customers, will start to see these batteries powering our vehicles as adequately in the very near future. This is definitely deserving of praise. Understanding the origins of Li-ion batteries, their production process, and how they work becomes even more important as a result. By doing this, the enigma surrounding the power-generating mechanism of electric vehicles may be understood. This chapter is fully devoted to and elaborates on lithium-ion batteries, including their characteristics and modes of operation.

5.2 Batteries types

Batteries come in two varieties: primary batteries and secondary batteries. These are the primary batteries that we use in clocks and remote controls. Once the zinc and manganese oxide needed to make these alkaline cells has been exhausted, they can no longer be utilized [36]. Secondary batteries that may be recharged are a unique form of battery. These Li-ion batteries fall under the category of secondary batteries. These cells have a high rate of rechargeability and discharge. When applying an electrical charge between the electrodes while powering the cell, the electrochemical response in secondary batteries is reversible and the unique chemical components may be recreated [40].

Figure 5.1 Lithium-Ion Battery [41]

In order to create a lithium-ion battery, two or more electrochemical cells that are each of which is electrically linked and has two electrodes and an electrolyte between the two. Redox process takes place. simultaneously at these electrodes, converting electrochemical energy in this way to produce electrical energy

In common parlance, a single cell can also be referred to as a "battery". The majority of the electrolytes in these batteries are liquid, although solid electrolytes are being considered as a way to improve on the present design. What facilitates the passage of ions from one electrode to any other electrode, cathode to anode and anode to cathode, are the electrolytes in the middle. Lithium is utilized in electrochemical cells because it is the lightest metal, with a density of 0.534 g/cm3, which is significantly lower than water's density of 1 g/cm3. This quality allows it to even float on water..

Because lithium only has 2 shells and a total of 3 electrons, it is incredibly reactive and has extraordinary electrochemical properties. This makes it possible for vigorous responses to occur. When we compare these houses to electric cars, we can see that they can provide lithium the capability to achieve extremely high power and energy densities in high-density battery applications for forces driving the car forward when the user chooses to drive.

As opposed to lithium-ion batteries, lithium batteries are primary batteries. In these batteries, the utilized lithium steel or lithium compound serves as an anode. Once their electrochemical capacity has been exhausted, these batteries cannot be recharged or used again. Depending on the materials used, a typical lithium mobile phone may produce voltages between 1.5 V and roughly 3 V. Lithium batteries are frequently used in pacemakers, digital cameras, watches, and other devices. Because they can be more expensive than alkaline batteries, they are used less frequently than those batteries when lengthy battery lives are preferred.

A pure lithium metallic substance is employed as the cathode in lithium-ion batteries. Due to reversible processes, the electrochemical characteristics of these rechargeable batteries can be recovered. Lithium-ion batteries are valued more than pure lithium-based batteries because they can power motors for a longer period of time thanks to their rechargeable characteristics [38].

5.3 Design lithium-ion battery

5.3.1 The anode and cathode

A positive cathode and a subpar anode make up Li-ion batteries, which are secondary cells connected in collection. These are the plus and negative terminals on a battery, which are located throughout the discharging part of the cell, or when power is extracted from a smartphone to use a device or equipment, or in our case, to power electric cars. The usual modern discharge path for a battery, for example, is from the flat end into the tiny round end; in other words, the flat end acts as the good cathode and the small round stop as the bad anode. However, these functions are switched around when the battery charges. The cathode, which is the beneficial terminal's little, rounded give-up, replaces the anode, which is the disadvantageous terminal's flat end. This serves the function of taking into account the conventional current flow. The tiny circle stop and the flat end serve as the cathode and anode, respectively, while the charging process progresses. The excellent conventional current flows from the small circular stop to the flat end. In essence, the positions have been switched. This is why the nomenclature of the cathode and anode has changed. Since words like cathode and anode in the context of rechargeable batteries might be misleading or confusing, the terminals will now be referred to as the high-quality and negative terminals. The good terminal is the flat bottom end, whereas the bad terminal is the round connector end.

5.3.2 Components Utilized in the Designed Battery

Lithium cobalt oxide ($LiCoO_2$) is used to make the positive terminal of standard lithium-ion batteries, whereas carbon or graphite, an allotrope of carbon, is used to make the negative terminal. Lithium-ion batteries have also been constructed using lithium iron phosphate ($LiFePO_4$), lithium manganese oxide ($LiMn_2O_4$), and lithium nickel oxide ($LiNiO_2$). Due to their ability to liberate lithium and the fact that they are formed of electroactive oxide materials, these particular types of chemicals and compounds also aid in oxidation and discount. The electrolyte and separator, which are made of lithium salt in a natural solution, are located between the two terminals. Lithium hexafluorophosphate ($LiPF_6$) is the lithium salt that is most frequently utilized, and the organic solution helps this chemical to be dissolved effectively throughout a wide range of temperatures. This electrolyte must work as an insulator between the two terminals when in a liquid state for the battery or cell to function properly.

5.3.4 Charge and Discharge of Battery

The lithium ions from the massive terminal cross the electrolyte from the little circular stop to the flat give up during the battery's charging phase. Since the electrons can't flow through the insulating barrier layer like the ions should when an external voltage is provided, they are forced to do so via an external circuit that is closer to the negative terminal. Instead, because of the difference in voltage between the terminals, these electrons go more toward the negative terminal. The negative terminal of the smartphone contains Li+ ions as the lithium ions go from the positive terminal to the negative terminal. The Li+ ions are then reached by the electrons, which combine with them once more to form the metallic lithium. The electrolyte in the middle serves as a separator and the insulating fabric prevents the electrons from doing this simultaneously. As a result, the path that offers the least amount of resistance—the external circuit—will require more time to complete. Lithium atoms are created at the negative terminal as a result of charging, and they remain there until discharged [43].

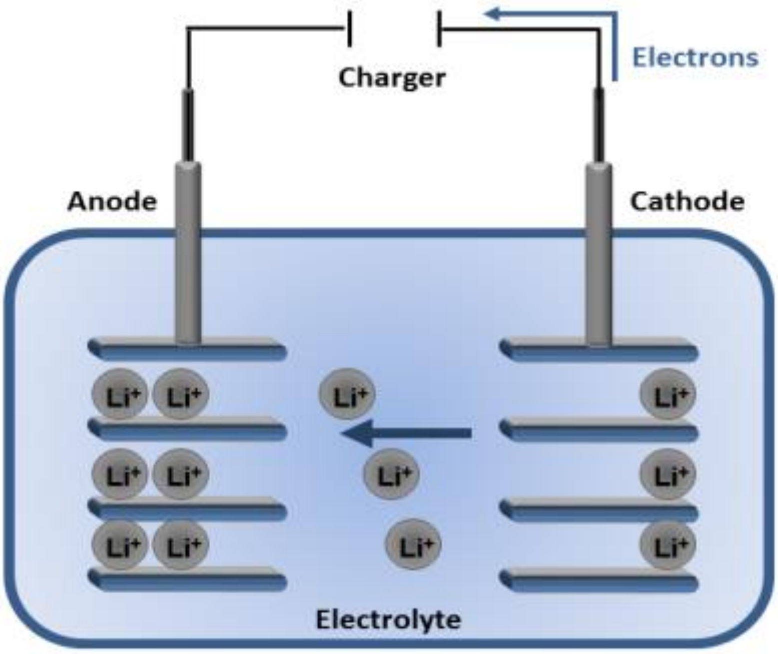


Figure 5.2 Charging of Lithium-Ion Batteries [44]

It should be noted that the flat end of the battery, which serves as the cathode in this example, Negative end, and the anode in this position is the fantastic end, the little spherical connector end. We use the electricity from depleted Li-ion batteries to restart electrical gadgets, or in our case, cars. In order for this to occur, charging is reversed. The lithium that was previously stored in the negative terminal subsequently transfers to the positive terminal across the electrolyte. Again, in order to recombine into lithium atoms, the electrons would be forced to flow through an external circuit and toward the fine terminal. We have our electrical equipment over there as these electrons now pass via the external circuit. Our gadget receives the required electricity to be powered up and used as these electrons pass through it.

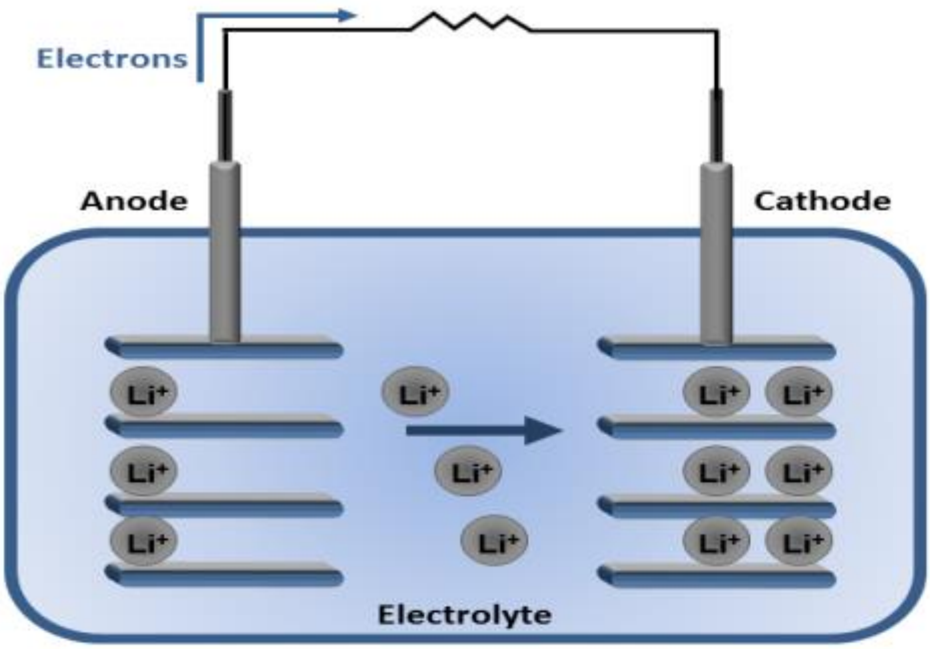


Figure 5.3 Lithium-Ion batteries discharge Process [40]

It should be noted that the anode in this instance is the little round connection end, the good end, and the cathode is represented by the flat stop of the battery, the negative end. Li-ion batteries may be charged and drained in this manner for a large number of cycles, if not more. The battery must not, however, be entirely depleted at this point. The battery would become useless if a complete discharge had place, which is when all of the lithium it received went to the positive terminal. The lithium-ion battery is employed in the device for this reason, which is why there are some kind of controls there. Although this increases the cost of using these lithium-ion batteries beyond what it currently is, it regulates both the charging and discharging cycles to maximize the lifetime and potential of these batteries. Due to lithium's high reactivity, which might result in explosions even after makers limit the strength of the battery, the voltages and current that these batteries can provide are additionally restricted by the manufacturers. It's also crucial to note that lithium-ion batteries self-discharge even after being completely charged, although this happens extremely slowly since it's dangerous to use them with a device. A Li-ion battery's capacity degrades with time as well. This is true for all types of batteries, however Li-ion battery capacity declines at a relatively low rate in comparison [45].

5.4 Electric vehicle use of lithium-ion batteries

The Tesla Model S, a standard electric vehicle, uses these lithium ion batteries exclusively and does not require an IC engine. This car is a prime illustration of an all battery-powered automobile. They employ 16 battery modules in the Tesla Model S that Tesla Motors created. These 16 modules each include 7,104 individual cells, and they are joined to one another in series. Each of these modules has cells that are parallel linked. As a result, the battery that powers the Tesla Model S can provide a total of 85 kWhs. The battery used in this device employs Panasonic 18650anca cells, which have an usual weight of 1200 lbs. (540 kg) [43]. This weight is quite excessive, thus making changes to the battery pack to reduce it while maintaining strength is essential and essential to enhancing the performance of electric vehicles. This is because weight affects acceleration and max speed since acceleration is inversely related to mass. The battery's modules each weigh around 33.75 kg. Given that the battery is charged using 120V with a current of 15A, the complete charge takes forty-eight hours. However, if they were to be charged using 240V and 90A, the charging time would be reduced to four hours. If the vehicle had been charged at a separate station created just for these BEVs, the situation might be easily wrapped up. The conventional gas stations and pumping stations should thereafter be obsolete due to the progressively declining oil supply.

Figure 5. 18650anca Panasonic Battery [46]

Maintaining a core temperature is necessary for these lithium-ion batteries to operate at their best. 0 to 45 degrees Celsius is the recommended range for charging, and -20 levels to 60 degrees Celsius is the recommended range for discharging. Lithium-ion batteries beat lead acid batteries even at lower temperatures. A battery heater was originally utilized externally on the Tesla Model S to maintain the batteries' ideal temperature, but in the more recent Model 3, the power train provided this temperature. This capacity means that even when the car is still parked, the software may send a request to the powertrain's inverter to turn on and send the motor the proper currents so that there is enough heat produced. This feature means that the Model 3's software may send a request to the powertrain's inverter to turn on and transmit the proper currents to the motor so that enough heat is created to warm the cells, even when the car is still parked. This removes the need for outside battery warmers and enables the battery pack to be generally considerably lighter.

The lithium-ion Panasonic 18650anca batteries feature large 3.4 Ah and 4.0 Ah capacity. These lithium-ion battery cells are somewhat larger than the common AA battery and are used in personal mobile phones as well as laptops. The motors that are pulling power from these battery modules are 380hp for the 60kWh form of the Tesla S [11]. The P85D model variation of the Tesla Model S includes two onboard motors that enable it to accelerate from 0 to 97 km/h in about 3.2 seconds [47].

5.5 Batteries' characteristics

a. Capacity: The difficulty and cost of storing electricity is one of its major problems. In order to increase the storage capacity of batteries, enormous sums of money are now spent on developing new batteries that are more dependable and effective. The battery capacity is a measure of the greatest amount of energy that can be extracted from the battery under a specific set of conditions. Both watt hours (Wh) and ampere hours (Ah) can be used to describe this unit, however the latter is more typically used in electric cars. Since the battery capacity of electric cars (EVs) is a significant component since it directly impacts the vehicles' autonomy, the development of new technologies that allow for the storage of more energy in the shortest length of time will be a key factor in the success of this kind of vehicles.

b. Charge condition: relates to how close to 100% of the battery's capacity the battery is.

c. Energy Density: Achieving the maximum energy density, which allows a battery to store more energy while remaining the same size and weight, is an important component in battery development. The energy density of a battery is measured as the amount of energy it can hold per unit volume (Wh/L).

d. Specific power: The amount of power a battery can deliver per kilogram of weight (W/kg).

e. Charge cycles: When the battery is fully utilized or loaded, a load cycle is finished.

f. Lifespan: The lifespan of the battery, which is determined by how many charging cycles it can withstand, is another factor to take into account. The objective is to acquire batteries that can withstand more loading and unloading cycles.

g. Internal resistance: The components of the battery have some resistance to the passage of electricity since they are not perfectly ideal conductors. The phrase "thermal loss" refers to the energy that is converted to heat during the charging process. Because the heat generated over a specific amount of time matches the power lost in the resistance, the internal resistance will be more apparent with high power charges [51]. Therefore, speedy charging will use more energy than gradual charging. Therefore, batteries need to be able to tolerate the increased temperatures and quick charging that internal resistance brings about. Reduced charge times for electric vehicles, which are now one of their main limitations, is another advantage of decreasing this resistance.

h. Efficacy : In relation to the energy charged, it is the amount of power that the battery offers [48].

5.6 Different Components and Battery Types

The increasing variety of EV models, different battery types, and a lack of standardization make the usage of BESs an impractical procedure, despite the fact that all of the cars supplied by a BES should utilize similar batteries. There are really many distinct battery kinds, some of which stand out despite the fact that lithium-ion batteries (Li-ion) are increasingly employed in electric vehicles (EVs).

- Lead-acid batteries or Pb-PbO2: These batteries were developed in 1859, making them the earliest form of rechargeable battery. This kind of battery is widely utilized in conventional automobiles despite having been used in electric vehicles. The ratios of specific energy and energy density are both quite small. The battery is composed of a layer of sulfuric acid and a number of lead plates. During the initial loading process in the negative plates, lead sulfate is transformed into metal, whereas lead oxide is produced in the positive plates (PbO2). Two examples of vehicles that used these batteries are the General Motors EV1 and the Toyota RAV4 EV.

- Nickel-cadmium batteries or Ni-Cd: In the 1990s, these batteries were employed because of their increased energy density. They do, however, have a strong memory effect, a brief lifetime, and the toxic and costly metal cadmium. Nickel-cadmium batteries are currently replaced with nickel-metal-hydride (NiMH) batteries due to these reasons.

- Nickel-metal-hydride batteries or Ni-MH: These batteries' negative electrodes are built of a hydrogen-storing alloy rather than cadmium (Cd) [67]. Despite having a higher amount of self discharge than nickel-cadmium batteries, these batteries are used in many hybrid vehicles, such as the Toyota Prius and the second-generation GM

EV1. The Toyota RAV4 EV was available in a nickel-metal hydride variant in addition to a lead-acid type.

- Zinc-bromine batteries or Zn-Br2: In these batteries, the positive electrode converts bromide to bromine in a zinc-bromine solution that is stored in two tanks. This technique was used in a 1993 prototype known as "T-Star" [68].
- Sodium chloride and nickel batteries or NA-NiCl: They are also referred to as Zebra and are quite similar to sodium sulfur batteries. Despite having a 260–300°C optimal working range, their benefit is that they can produce up to 30% more energy at lower temperatures. The employment of these battery types in electric vehicles is ideal [69]. They were employed at the now-defunct Modec firm in 2006.
- Sodium sulfur batteries or Na-S: which comprise liquid sodium (Na) and sulfur (S). A lengthy life cycle, high energy density, and good loading and unloading efficiency (89-92%) are all characteristics of this type of battery. Additionally, they profit from the low cost of these materials. Nevertheless, they may function between 300 and 350 C [70]. These batteries are used by the 1992–1993 model Ford Ecostar.
- Lithium-ion batteries or Li-Ion: The lithium salt employed in these batteries serves as the electrolyte and delivers the required ions for the reversible electrochemical process that happens between the cathode and anode. The small weight of their individual components, their high loading capacity, their low internal resistance, and their high loading and unloading cycles are all benefits of lithium-ion batteries. Additionally, they display a weaker memory effect [48].

Table 5.1 Common battery types, both benefits and drawbacks [48].

Battery Type	Advantage	Disadvantage
Lead-acid or Pb-PbO2	• Easily accessible in manufacturing quantity • Relatively affordable price • Modern technology that has been in use for more than 50 years	• Its discharge is limited to 20% of its maximum capacity. • If run at a deep rate of SOC, it has a finite lifespan. • Low power and energy densities • Weight is greater • Upkeep can be required
NiMH or Nickel Metal Hydride	• Lead-acid batteries' energy density has doubled. • Not detrimental to the environment • Recyclable • Safe high-voltage operation • Capable of storing energy and power in bulk • Longer cycle life •A wide operating temperature range • Not prone to overcharging or discharge	• A lifespan reduction of 200–300 cycles if drained quickly under peak load currents. •Memory effect results in decreased useable power
Lithium-Ion or Li-Ion	• Double the energy density of NiMH • Effective operation at high temperatures • Compostable • Memory impairment • Strong specific strength • High particular energy • Battery life is long, at 1000 cycles.	• Heavy price • Although slower than typical batteries, recharging still takes a while.

Nickel Zinc or Ni-Zn	• High kinetic energy • Increased power density • Uses inexpensive materials • Capable of deep cycle • Environmentally considerate • Usable from 10 °C to 50 °C	• Rapid dendritic development prevents usage in cars
Nickel Cadmium or Ni-Cd	• Extended lifespan • Can discharge entirely without being harmed • Compostable	•If cadmium is not disposed of appropriately, contamination may result. • Expensive for use in vehicles

5.7 Charging of Electric Vehicles

The duration and specifications of the battery charging process are equally important to autonomy. Without a doubt, for electric vehicles to succeed, users need to be able to charge their cars quickly and conveniently. To do this, it will be necessary to establish an infrastructure that makes rapid and simple charging possible. This recommends the creation of fast-charging electric charging stations for lengthy trips in addition to home charging. Below is a list of the several standards and rules created for the equipment used to charge electric vehicles. We go into detail about the connections and various charging methods as they are stated in the most recent standards.

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- AC Level 1. Standard electrical outlet that provides voltage in AC of 120 V offering a maximum intensity of 16 A, which serves a maximum power of 1.9 kW.
- AC Level 2. Standard electrical outlet with 240 V AC and a maximum intensity of 80 A, so it offers a maximum power of 19.2 kW.
- DC Level 1. External charger that by inserting a maximum voltage of 500 V DC with a maximum intensity of 80 A, it provides a maximum power of 40 kW.
- DC Level 2. External charger that, by inserting a maximum voltage of 500 V DC with a maximum intensity of 200 A, provides a maximum power of 100 kW.

Table 5.2 lists the SAE-charge J1772's ratings [49]

Charge Method	Volts	Maximum Current (Amps-Continuous)	Maximum Power
AC Level 1	120 V AC	16 A	1.9 kW
AC Level 2	240 V AC	80 A	19.2 kW
DC Level 1	200 to 500 V DC maximum	80 A	40 kW
DC Level 2	200 to 500 V DC maximum	200 A	100 kW

5.8 Charge Methods

The IEC-62196 standard was created in 2001 by the International Electrotechnical Commission (IEC) with the intention of facilitating the charging of electric cars in China and Europe. IEC-62196 establishes the fundamental characteristics of the charging procedure and the technique of energy delivery. Based on its nominal power and therefore the charging time, this standard, which derives from IEC-61851, gives a first categorization of the charging type [26]. Users have access to four charging options for their cars.

- Mode 1 for Slow charging : A conventional single-phase or three-phase power outlet with phase(s), neutral, and protective earth conductors with a maximum intensity of 16 A is used in this mode, which is referred to as home charging. This mode is most often used in our homes.

- Mode 2 for Semi-fast charging: With a predetermined maximum intensity of 32 A, this mode uses standard power outlets with phase(s), neutral, and protective earth wires. It may be used at home or in public settings.
- Mode 3 for Fast charging : It offers a 32 to 250 A intensity range. For this charging technique, an EV Supply Equipment (EVSE), a unique power source for charging electric vehicles, is required. This equipment (i.e., the EVSE) stops the energy flow when the connection to the car is not recognized. Additionally, it incorporates safety precautions and monitors the charging process [28].
- Mode 4 or Ultra-fast charging : A direct connection of the electric vehicle to the DC supply network is required, with a maximum voltage of 1000 V and a maximum power intensity of 400 A, resulting in a maximum charging power of up to 400 kW. This specification is found in the IEC-62196-3. Additionally, these modes require an additional charger that provides communication between the automobile and the charging outlet, as well as protection and control.

Table 5.3 IEC-62196 Charge Ratings [50]

Charge Method	Phase	Maximum Current	Voltage (max)	Maximum Power	Specific Connector
Mode 1	AC Single AC Three	16 A	230–240 V 480 V	3.8 kW 7.6 kW	No
Mode 2	AC Single AC Three	32 A	230–240 V 480 V	7.6 kW 15.3 kW	No
Mode 3	AC Single AC Three	32–250 A	230–240 V 480 V	60 kW 120 kW	Yes
Mode 4	DC	250–400 A	600–1000 V	400 kW	Yes

It's also crucial to take into account the Tesla Company, which, although not being an international standard itself, has its own rapid charging facilities known as Supercharger Stations. Tesla's superchargers work in DC and use a proprietary technique, the patents for which have mostly been made available to the public. A Model S battery may be charged 50% in roughly 20 minutes or 80% in 30 minutes even though they have a maximum charging power of 145 kWh [7]. Despite Tesla's claims that its superchargers are ultra-fast charging stations (see Table 5), these charging stations are really similar to Mode 3 stations under the IEC-62196 standard.

Table 5.4 The GB/T-20234 is classified as a charging standard [51]

Mode	Standard	Rated Voltage	Rated Current	Maximum Power
AC Charging	GB/T-20234.2-2015	250 V	10 A 16 A 32 A	27.7 kW
		440 V	16 A 32 A 63 A	
DC Charging	GB/T-20234.3-2015	750–1000 V	80 A 125 A 200 A 250 A	250 kW

5.9 Prospect in the future

The potential of lithium-ion batteries is limitless in the future. Since the need for rechargeable electricity is increasing tremendously right now, extensive research is being done. As an example, research on solid-state lithium-ion batteries is underway which takes use of strong electrolytes. Cost times for these lithium-ion batteries may often be completed in a few minutes [32]. Traditional lithium-ion batteries have a liquid electrolyte, however this has the drawback of requiring large separator gaps between each cell , in contrast to the solid-state lithium-ion battery, which only needs 3–4 micron. Furthermore, compared to their liquid counterparts, solid-state lithium-ion batteries can maintain a charge up to twice as long. They both weigh far less than their liquid electrolyte equivalents and, while being more robust, are less likely to catch fire, which might make them a crucial component of electric cars in the near future. As the batteries used in them need to be made secure even in the event of a collision, this gives them a highly important role in vehicle design. These solid-state lithium-ion batteries are still in the research and development stage, but given the potential these types of batteries provide, we can assume that over time and with a lot of study done, they will be polished for everyday consumer use.

5.10 Conclusion

As a result, it is far more practical to strengthen vehicles using a battery comprised of a large number of series-connected lithium-ion cells rather than a single, extremely powerful nickel-metal hydride battery. Battery packs are the best because they have a higher precise energy of 140Wh/kg in lithium comparing to 34Wh/kg in lead acid and 68Wh/kg. Additionally, the optimal discharge percentage is far lower than that of nickel metallic hydride batteries, which can lose up to 5% of their complete capacity per month, while lithium-ion batteries lose only 2% of their capacity annually. Lithium-ion batteries have an excessive amount of charging capacity. In conclusion, lithium-ion batteries are very practical for the future of powering motors and, of course, various electronics. The only drawback is that it is significantly more expensive than the alternatives. Despite this, research into developing solid-state lithium-ion batteries appears to be more promising than ever, which could more than make up for the disadvantage of having an expensive alternative to powering vehicles.

Chapter 6
Electric Motor

6.1 Introduction

An electric vehicle's powertrain control method serves as its main control system. Its main goal is to provide perfect control over acceleration, speed, and distance traveled in relation to charge. To enhance the system's performance in both dynamic and stable states, the control system should be built with good adaptability. The control of an EV is also crucial since it must be effective at managing the system's power. One of the main goals of the control system is to regulate the motor's torque. A system with quick response times and less ripple is preferred. An EV requires electric machinery with a wide variety of velocity guidelines. To provide such, a high torque output at low speed and low overload functionality is needed. At high-speed operation, a certain power output is also necessary. Torque may be produced by a variety of motor types to power electric vehicles. To maintain the necessary torque desired for an EV, these motors are regulated using remarkable manipulation techniques. Three different control techniques have been examined together with four different motor types in this research.

6.2 Several Motors

Different DC motor types

i. Brushed and
ii. Brushless DC Motor

Different DC motor types

a) Permanent Magnet Synchronous and
b) Induction Motor

6.2.1 DC Motor with Brushes

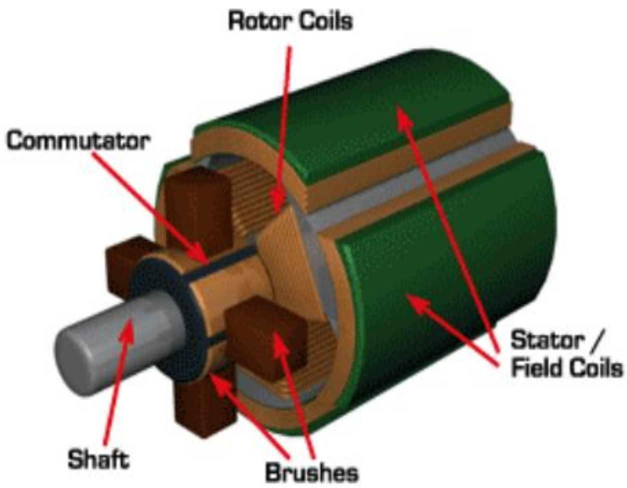

Figure 6.1 DC Motor with Brushes [52]

Since a DC motor's electricity supply is of the DC variety, operating one is simple. Three distinct types of DC motors exist. Shunt; series; individually excited copper coils; and shunt. The shunt motor might be challenging to control at times. Because a reduced magnetic field is caused by a little reduction in the grant voltage. This results in a decrease in the again EMF, which tends to improve speed. It's possible that a decrease in supply voltage won't have much of an effect on the speed. The independently stimulated motor enables impartial control of both the supply voltage and magnetic flux. This permits a great deal of freedom in positioning the necessary torque at any necessary angular speed. Series wound DC motors are also preferred for EVs due to their relatively higher starter torque and ease of operation [41]. As the brushes wear out and need to be changed more frequently, brushed DC motors have high maintenance costs. To get the torque of a brushed DC motor, apply the equation shown below.

Equation $\boldsymbol{T_e = 1/\ 2\pi\ k_b.\ I_a.\ \Phi}$

6.2.2 DC Motor with Brushless

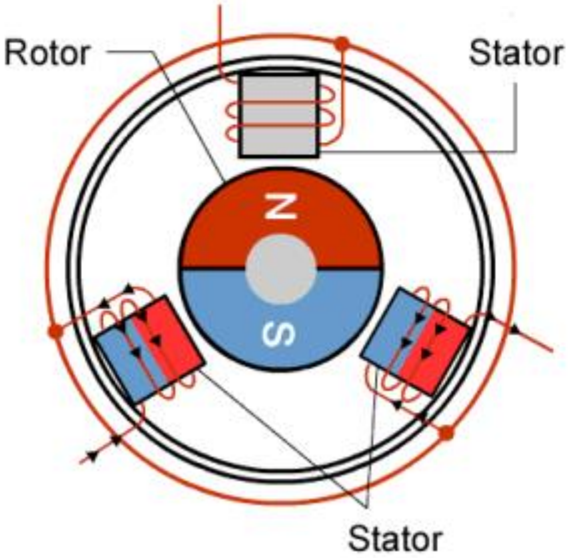

Figure 6.2 DC Motor with Brushless [53]

Brushless DC motors do longer contain brushes, as their names would suggest. Even more straightforward than brushed bldc motor, their mechanism. The rotor of a Brushless dc revolves and is made of a permanent magnet. The coils with permanent magnets are fixedly fastened to the stator. In this motor, the permanent magnets are rotated by changing the direction of magnetic fields produced by stationary coils encircling the stator. Therefore, the direction and magnitude of the contemporary in these stator coils are adjusted to regulate the rotation. As a measure of electromagnetic torque,

$$T_e = (e_a\, i_a + e_a\, i_b + e_c\, i_c) / \omega$$

6.2.3 PMSM or Synchronous Motor

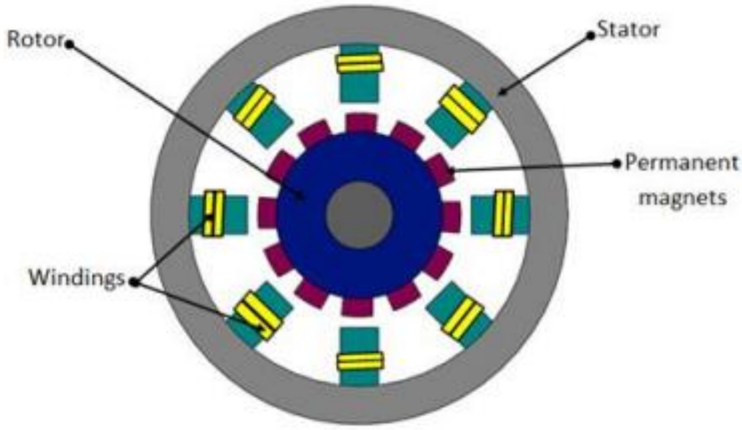

Figure 6.3 synchronous motor [54]

Everlasting magnets are included into the shaft of a synchronous permanent magnet motor to produce a steady magnetic field. Multiphase electromagnets in the stator produce a spinning magnetic region in time with pure sinusoidal oscillation. The interaction of the two magnetic fields causes pressure to transverse the rotor. The stator cutting edge may be managed so that, in most cases, it produces a stator vectors perpendicular to the rotors magnets, resulting in the greatest force. The formula may be used to determine the tension in a Permanent magnet synchronous motor.

$$T_m = 1.5p\ (\psi i_q + (L_q - L_d) i_d i_q)$$

6.2.4 Induction Motor

An induction motor is an AC electrical machine in which the blade receives its current from the stator winding's magnetism and uses electromagnetic induction to create torque. The stator coil generate a magnetic field that rotates when a 3 phase supply is applied to them. This induces a contemporary in the rotor conductors. This subsequent interaction causes the stator's revolving magnetic subject to interact with the current, which causes the rotor to rotate. Asynchronous motors and squirrel-cage motors are both examples of induction motors. Equation is

$$T = k \Phi I_r \cos \theta$$

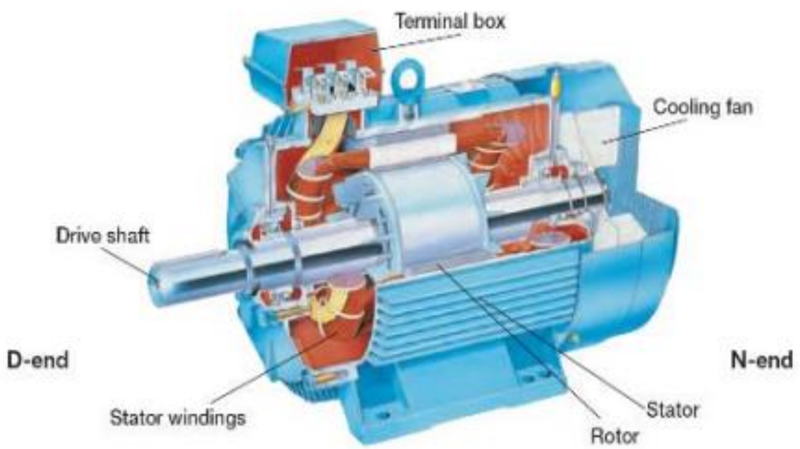

Figure 6.4 Induction Motor [55]

6.3 The motor's control techniques

An electric car's control mainly involves manipulating its motor. To manage the torque, several control systems are used to special motors. For two distinctive types of motors, three distinct control strategies have been used in this research.

- Dc modulation of pulse width
- Field-oriented controls and directly controlling torque for Permanent magnet synchronous motor

6.3.1 DC motor pulse width modulation

An Electric dc motor may be controlled relatively simply by using pulse-width modulation. The system is much more dynamic since either voltage or modern may be varied to modify the power (P=VI). Pulse Width Modulation fully benefits from this fact. A square wave is used in pulse-width modulation, with the pulse width being modified to change the waveform's average cost [65]. Here is given a Pulse width modulation signal example.

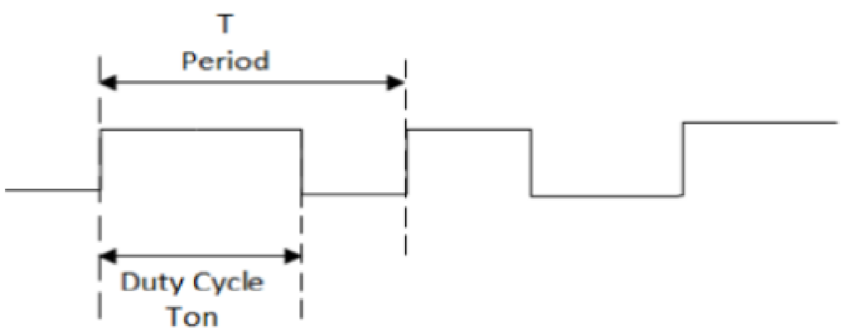

Figure 6.5 The Signal of Pulse Width Modulation [56]

The standard voltage that a DC motor receives

$$V_{avg} = (T_p / T_{on})\ V_{in}$$

One of the characteristics of each output waveform is the duty cycle. It is the on/off time ratio. By adjusting Ton, variable duty cycle % may be reached. The flowing power to the motor is turned on and off in the Pulse width modulation to vary the current to the motor. A PWM signal's duty cycle is varied to control the motor's speed. Therefore, by changing the obligation cycle, the motor's speed may be adjusted to the required level. A DC motor drive's accountability cycle is managed by a controller. The length of the wave is used to calculate the duty cycle of Pulse Width Modulation since the frequency is constant and the on-off period is variable [43].

To apply power to the load in various directions, a H bridges is employed. This establishes how the motor will rotate (forward or backward). Various modulation combinations can establish the vehicle's unusual operating modes. Additionally, power generation is possible here. The architecture of a H bridge is shown below, and it has been demonstrated that the operation mode is determined by unique switching states [43].

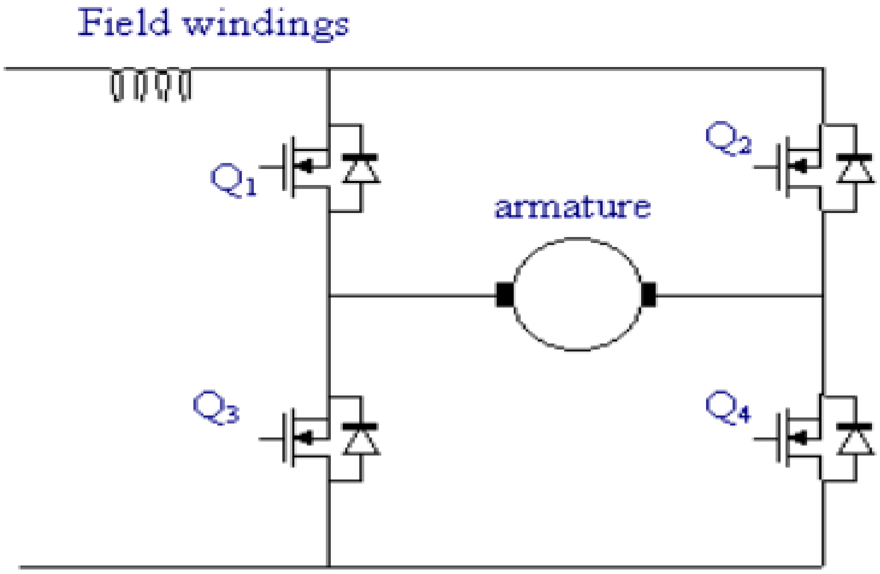

Figure 6.6 an H-bridge schematic [56]

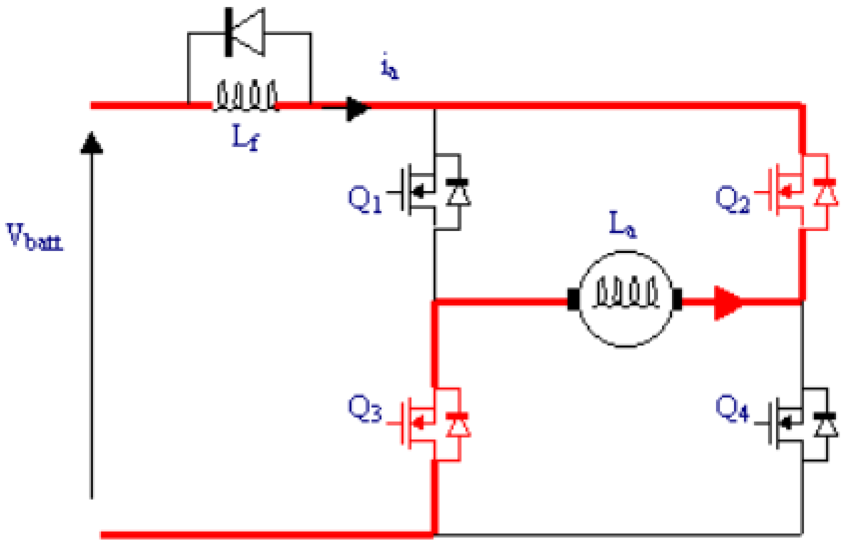

Figure 6.7 Autonomous braking [56]

Table. 6.1 Setup of H Bridge switches [56]

Q1	Q2	Q3	Q4	Operation Mode
1	0	0	1	Forward Drive
0	1	1	0	Reverse Drive
0	0	0	0	Free Running
1	0	1	0	Brakes
0	1	0	1	Brakes

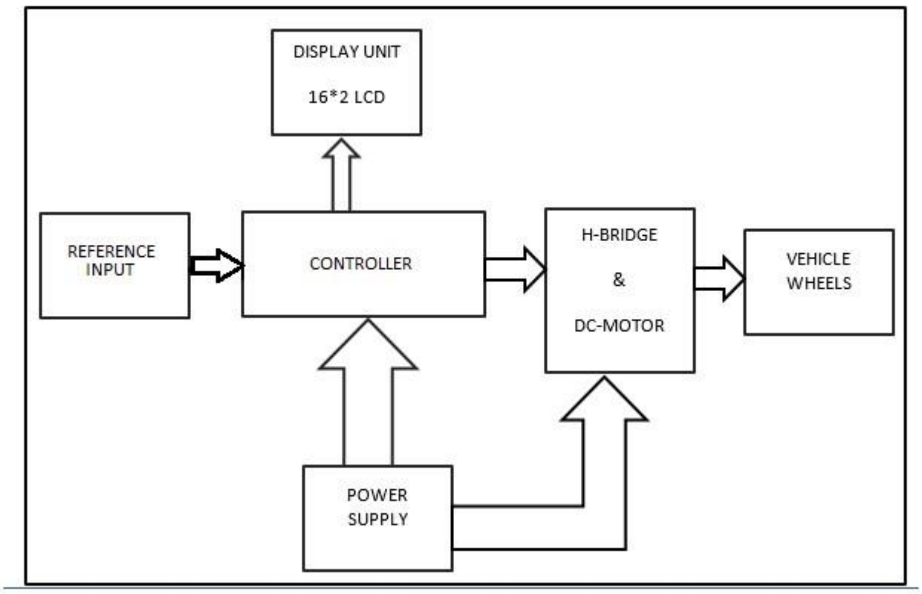

Figure 6.8 Schematic View for DC Motor Pulse Width Modulation Control [56]

6.3.2 Field-oriented control for Permanent magnet synchronous motor and Direct Torque Control

When creating a controller for an induction motor, there have been two control schemes available.

6.3.2.a Permanent magnet synchronous motor vector control Vector Control

For an electric motor's speed regulations, vector manipulation is frequently employed. The magnetism and energy are invariant under normal translation, which is the fundamental tenet of vector management.[57] The torque of a Permanent magnet synchronous motor is acquired with the help of the stator flux when the width of poles is fixed. Therefore, using the Clarke Translation, the stator area currents ia, ib, and ic are first collected and transformed to period latest estimates I and i.

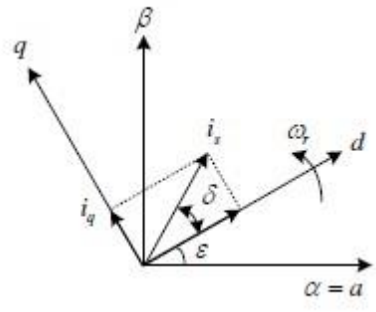

Figure 6.9 Current vector decomposition [35]

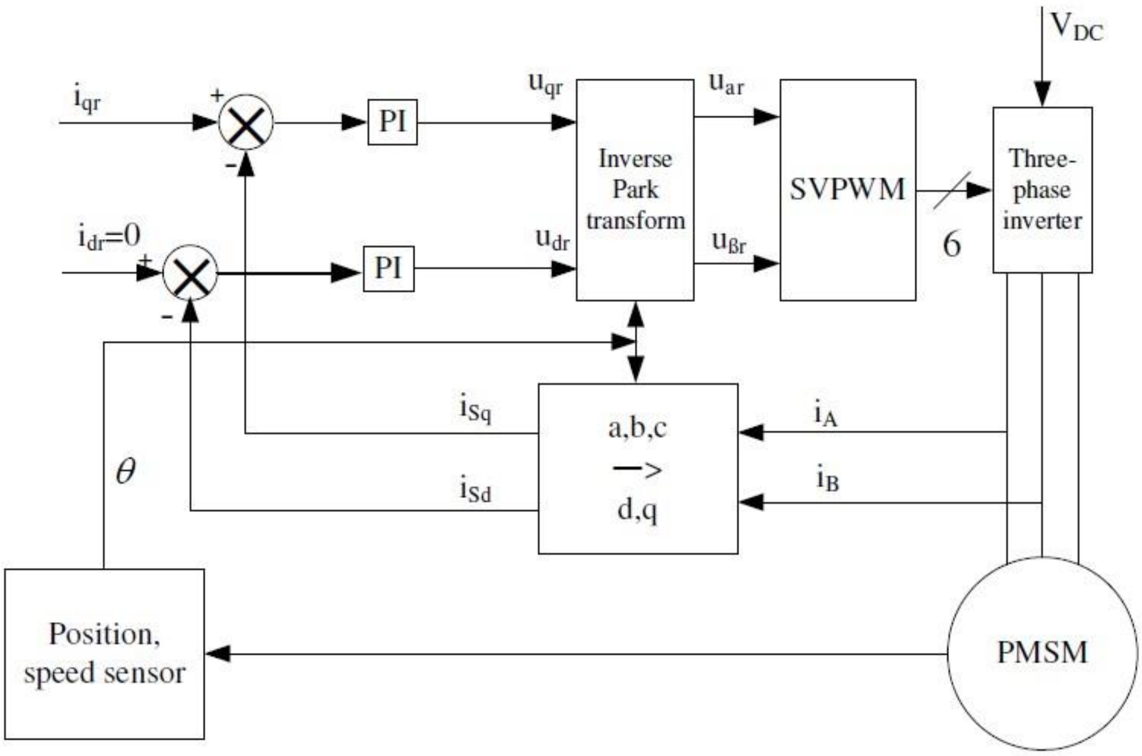

Figure 6.10 A block diagram for Permanent magnet synchronous motor vector control [35]

6.3.2.b Permanent magnet synchronous motor Direct Torque Control

There are several modulation techniques that variable frequency drives can use to manage AC induction motors. A set ratio between the voltage and frequency of the energy supplied to the motor is maintained via scalar control, also known as V/Hz or V/f control. As a result, the magnetic field's intensity remains consistent and torque output is steady. Although scalar control is a straightforward and affordable control technique, it does not allow for fine control of motor speed. The three variables that must be managed by the DTC approach include. There are .

a. Torque

b. the flow vector angle between the rotor and the stator

c. The stator flux linkage's amplitude

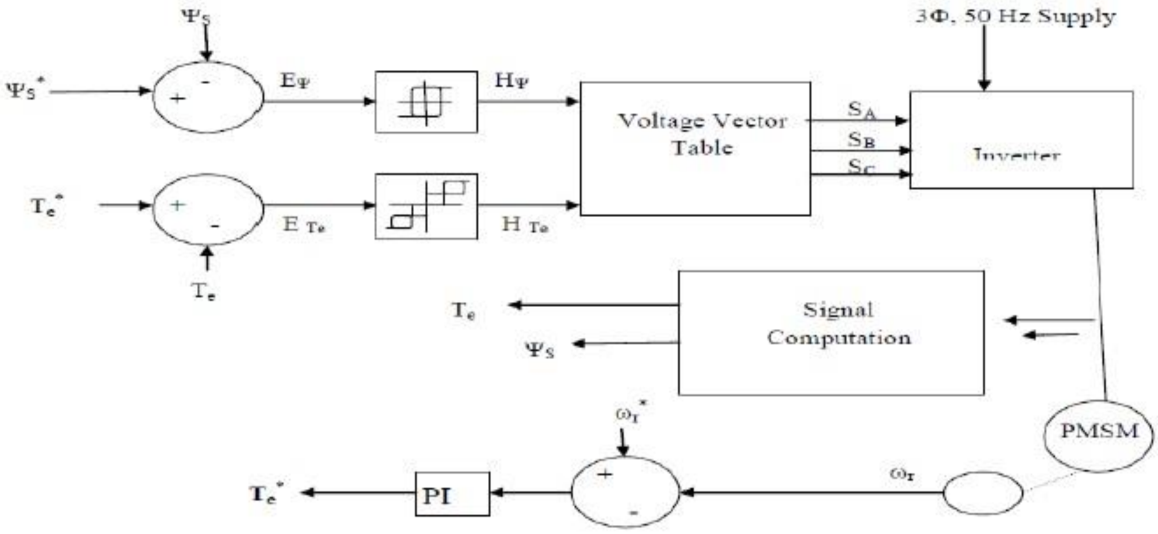

Figure 6.11 Block Diagram of Direct Torque Control for PMSM [39]

$$u_{set}\,(S_{abc}) = \sqrt{\frac{2}{3}}\frac{u_{dc}}{2}\left(S_a e^{0i} + S_b e^{\frac{2\pi i}{3}} + S_c\, e^{\frac{4\pi i}{3}}\right) - \sqrt{\frac{2}{3}}\left(u_a e^{0i} + u_b e^{\frac{2\pi i}{3}} + u_c\, e^{\frac{4\pi i}{3}}\right)$$

Table. 6.2 Section of flux connectivity and its location . [40]

Sector	θ1	θ2	θ3	θ4	θ5	θ6
Angle	-π/2, -π/6	-π/6, π/6	π/6, π/2	π/2, 5π/6	5π/6, 7π/6	7π/6, 3π/2

If the output is increased, the output is 1; if it is decreased, the output is -1; and if it is constant or the same, the output is 0.

Table. 6.3 Multiple switching states and related spaces [35]

Switching State [a b c]	Space Vector V_s (In polar form, in degree)
V_0 [0 0 0]	0<0
V_1[1 0 0]	V_s< 0°
V_2[1 1 0]	V_s< 60°
V_3[0 1 0]	V_s< 120°
V_4[0 1 1]	V_s< 180°
V_5[0 0 1]	V_s< 240°

Chapter 7

Analysis and Discussion

7.1 Introduction

The battery capacity of electric vehicles is the subject of this article, which focuses on how effectively they may be utilized. we find different data on electric vehicles. in this data, we find which vehicle is very efficient in its battery and reliable. we collect data from different types of articles and websites then we make a table to input this data, then we compare their battery capacities, mileage, and their efficiency. This data is very valuable for this thesis. The power source is a battery. In the modern automotive business, electric vehicles are beginning to have a big impact. The choice of a battery that best satisfies all the necessary requirements from different perspectives, including energy storage effectiveness, constructive characteristics, cost price, safety, and utilization life, can be challenging given the wide variety of battery types currently used in the construction of electric vehicles. Therefore, the data reveals which battery is safe and appropriate for use in electric vehicles at this time.

7.2 Analysis

The batteries are now the main impediment to EV adoption on a larger scale. Because of the improvement of better, more accessible, and greater capacity batteries, which will promote vehicle autonomy, users consider electric vehicles as a serious alternative to internal combustion engine vehicles.

On the electric vehicle, we gather some information. These numbers show their battery capacity between the 1980s and 2022. We create a graph for battery capacity using this data.

Data pertaining to the battery capacity of EVs are presented in Table 7.1 . As demonstrated, battery capacity is constantly increasing, and very soon, vehicles with batteries that are more than 100 kWh are anticipated.

Table 7.1 Different Electric Vehicle Battery Capacity by year

Vehicle	Year	Capacity (kWh)
Audi duo	1983	8
Volkswagen Jetta citySTROMer	1985	17.3
Volkswagen Golf	1987	8
Škoda Favorit	1988	10
Fiat Panda Elettra	1990	9
General Motors EV1	1996	16.5
Audi duo	1997	10
General Motors EV1	1999	18.7
General Motors EV1	2000	26.4
Tesla Roadster	2006	53
Smart ed	2007	13.2
Tesla Roadster	2007	53
BYD e6	2009	72
Mitsubishi i-MiEV	2009	16
Nissan Leaf	2009	24
Smart ed	2009	16.5
Tesla Roadster	2009	53
BYD e6	2010	48
Mercedes-Benz SLS AMG E-Drive	2010	60

Tata Indica Vista EV	2010	26.5
Tesla Roadster	2010	53
Volvo C30 EV	2010	24
Volvo V70 PHEV	2010	11.3
BMW ActiveE	2011	32
BMW i3	2011	16
BYD e6	2011	60
Ford Focus Electric	2011	23
Mia electric	2011	8, 12
Mitsubishi i-MiEV	2011	10.5
Renault Fluence Z.E	2011	22
Chevrolet Spark EV	2012	21.3
Ford Focus Electric	2012	23
Renault Zoe	2012	22
Tesla Model S	2012	40, 60, 85
BMW i3	2013	22
BYD e6	2013	64
Smart ed	2013	17.6
Volkswagen e-Golf	2013	26.5
Renault Fluence Z.E	2014	22
Tesla Roadster	2014	80
Chevrolet Spark EV	2015	19
Mercedes Clase B ED	2015	28
Tesla Model S	2015	70, 90
BYD e6	2016	82
Chevrolet Volt	2016	18.4
Kia Soul EV	2016	27

Vehicle	Year	Capacity (kWh)
Jaguar I-Pace	2017	90
Nissan Leaf	2017	40
Tesla Model S	2017	75, 100
Volkswagen e-Golf	2017	35.8
Audi e-tron	2018	95
Kia Soul EV	2018	30
Nissan Leaf	2018	60
Renault ZOE 2	2018	60
Renault ZOE 2 rs	2018	100
Tesla Model 3	2018	70, 90
Mercedes-Benz EQ	2019	70
Nissan Leaf	2019	60
Volvo 40 series	2019	100
Audi e-tron	2020	95
BMW i3	2020	42
Hyundai Kona e	2020	64
Mercedes EQC	2020	93
Mini Cooper SE	2020	32.6
Peugeot e-208	2020	50
Volkswagen ID.3	2021	77
Ford Mustang Mach-E	2021	99
Tesla Roaster	2022	200

One of the most significant challenges with electric power is the complexity and high cost of storage. As a result, significant quantities of money are presently being spent on developing new batteries that are more dependable and efficient, hence boosting battery storage capacity.

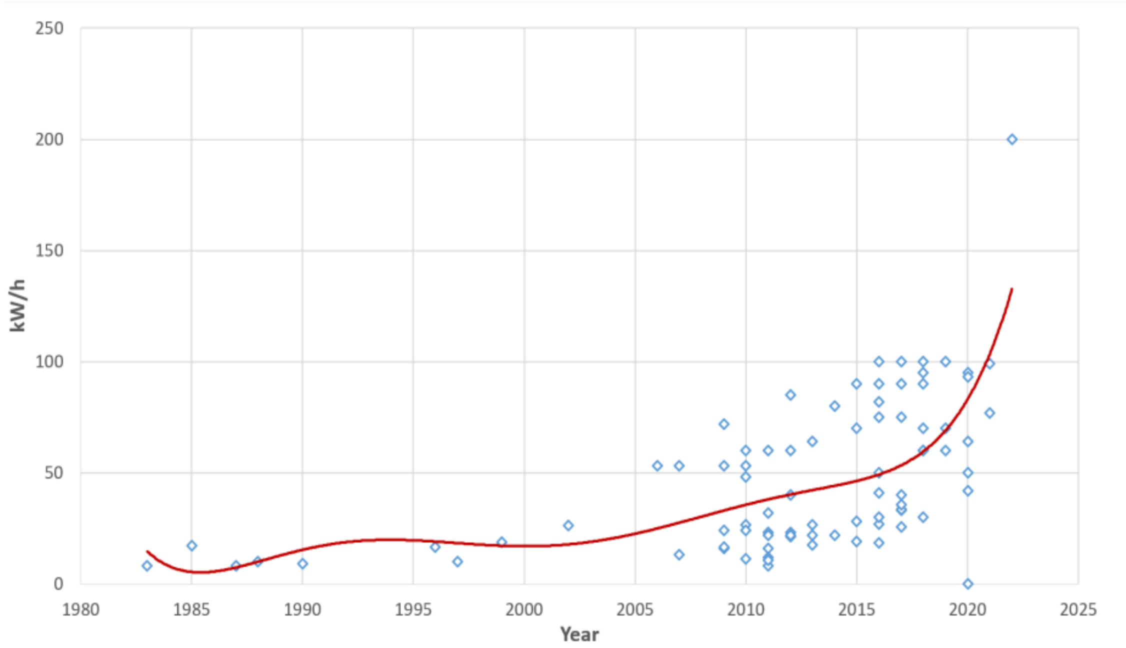

Figure 7.1 Battery capacity evolution from the mid-1980s to the present

This figure shows that battery capacity between the 1980s and 2022 increased constantly. At present battery capacity rise up to 200 kWh from the 80s. The battery's capacity is a representation of the greatest quantity of energy that may be drawn from it under particular predetermined circumstances. This measure can be represented in watt hours (Wh) or ampere hours (Ah), although electric vehicles more frequently utilize the latter.

Table 7.2 EV Battery Capacity, Travel range and efficiency

Brand	Battery	Battery capacity (Kwh)	Travel range (mile)	Efficiency (kWh/mile)
Tesla Model S	Lithium-Ion	100	396	0.25
Nissan Leaf	Lithium-Ion	40	168	0.23
BMW i3	Lithium-Ion	70.3	327	0.21
KIA Soul EV	Lithium-Polymer	30.5	111	0.27
Jagur i-pace	Lithum-ion	90	292	0.30
Hyundai Ioniq Electric	Lithum-polymer	28	124	0.23
Renault Zoe	Lithum-ion	41	250	0.26
Tesla Model x	Lithium-ion	100	337	0.37
Audi e-tron	Lithium-ion	71	211	0.33
Mercedes EQB	Lithium-ion	66.5	216	0.30

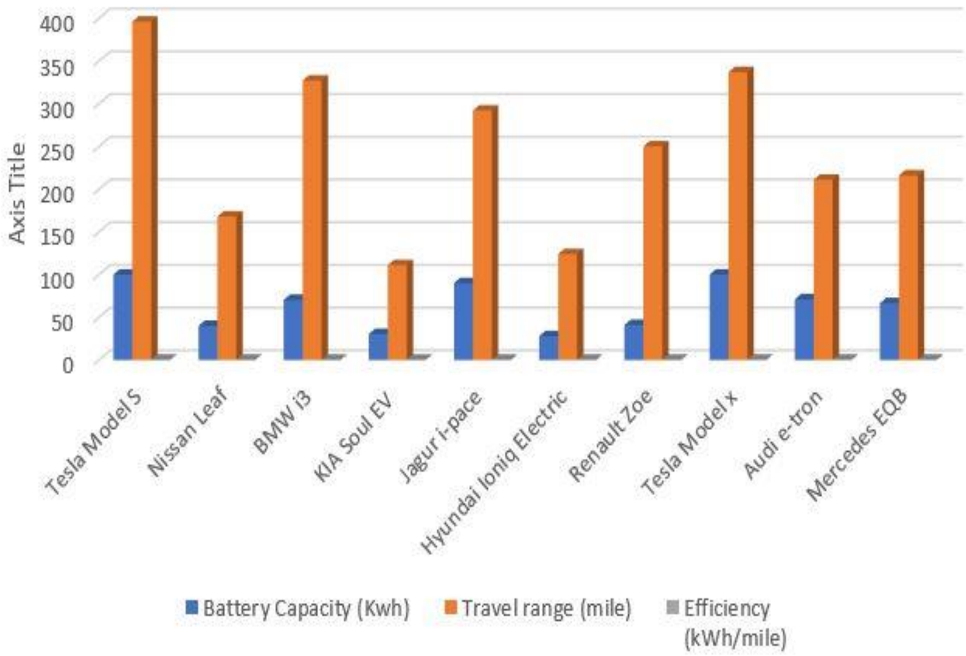

Figure 7.2 EV Battery Capacity, Travel range and efficiency

Temperature and voltage windows, which serve as limits for lithium-ion battery operation, must be safe and dependable. Overstepping these limits would significantly degrade battery performance and may even represent a security issue, since electrolytes begin to self-destruct at 150 degrees Celsius. This type of battery is now used in the great majority of EVs and PHEVs.

Table7.3 and Figure 7.2 compare the most critical properties of the various available technologies. When comparing technologies, it is critical to examine their operating temperatures because they may limit their acceptance. In this regard, lead-acid and lithium batteries perform well since they can endure loading temperatures of up to 20 °C, but Li-Ion batteries suffer significant capacity loss in low temperatures owing to self-discharge. Actually, the recommended working temperature for this type of battery is 40 degrees Celsius. As we can see, sodium batteries (Na-Ni Cl or Na-S) operate better at higher temperatures. In terms of specific energy and energy density, lead-acid ($Pb-PbO_2$) and nickel

(Ni-Cd, Ni-MH) batteries perform poorly, but lithium-ion batteries are significantly more helpful.

Table 7.3 EV battery characteristics

	$Pb\text{-}PbO_2$	Ni-Cd	Ni-MH	$Zn\text{-}Br_2$	Na-NiCl	Na-S	Li-Ion
Working Temperature (°C)	−20–45	0–50	0–50	20–40	300–350	300–350	−20–60
Specific Energy (Wh/kg)	30–60	60–80	60–120	75–140	160	130	100–275
Energy Density (Wh/L)	60–100	60–150	100–300	60–70	110–120	120–130	200–735
Specific Power (W/kg)	75–100	120–150	250–1000	80–100	150–200	150–290	350–3000
Cell Voltage (V)	2.1	1.35	1.35	1.79	2.58	2.08	3.6
Cycle Durability	500–800	2000	500	>2000	1500–2000	2500–4500	400–3000

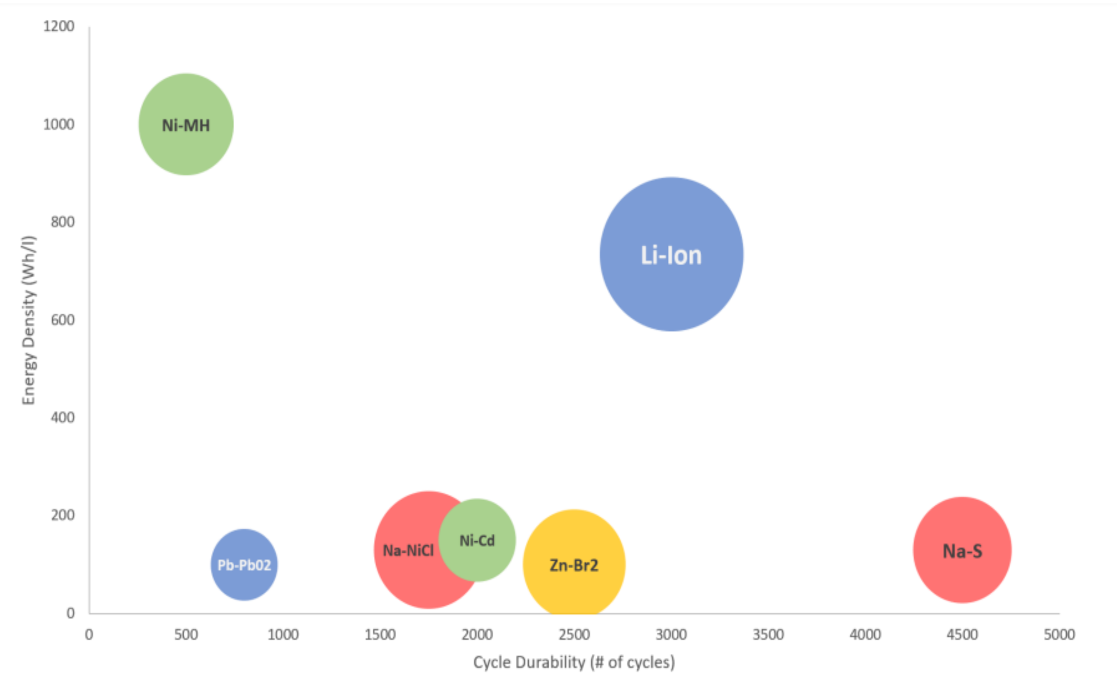

Figure 7.2 A study of battery technologies based on their operating temperature, lifetimes, power density, and specific energy. Higher operating temperatures are indicated by warmer colours.

In terms of specific power, lead and zinc batteries perform poorly (up to 100 W/kg), whereas Ni-MH and Li-ion batteries perform best (up to 1000 W/kg and 3000 W/kg, respectively). In terms of cell voltage, lithium-ion batteries and sodium batteries (Na-S and Na-NiCl) need a higher voltage than batteries made of nickel and zinc. Lead-acid and Ni-MH batteries, on the other hand, provide the worst performance in terms of life cycles. Finally, whereas lithium batteries can sustain up to 3000 cycles, Na-S batteries perform better and can support up to 4500 cycles.

7.3 Discussion

The battery capacity reveals the maximum amount of energy that can be extracted from the battery under specific circumstances. Although electric vehicles frequently utilize ampere hours (Ah), this measurement can also be stated in watt hours (Wh). The success of this kind of vehicle will depend heavily on the development of new technologies that make it possible to store more energy in the shortest amount of time. This is especially true given that the battery capacity of EVs is an important factor because it directly affects the cars' autonomy.

When all of the aforementioned considerations are taken into consideration, current electric cars rely on lithium ion technology for their batteries, which gives the greatest performance across virtually all of the analyzed qualities. Li-Ion batteries are now the most widely utilized type of battery technology in electric cars because of its high energy density and improved power per mass battery unit. As a result, a number of battery types with lower costs and smaller sizes and weights have been developed. In comparison to Ni-MH batteries, Li-Ion batteries, which are used in the electric car sector, have been demonstrated in studies to have higher power and specific energy.

Studies reveal that this technology provides the best "charge to weight" solution, fulfilling one of the most important specifications for a battery used in the electric vehicle sector and making it possible to swap Ni-MH batteries out for them easily. Another advantage is the lack of memory effect, which results in a longer life cycle.

One of the drawbacks of Li-Ion batteries is their high operating temperature, short lifespan, and lack of safety while usage. This method requires a single management battery system to control and monitor internal cell temperature. High production costs, battery recycling capabilities, and recharging infrastructure are problems, in addition to the negatives imposed on by high operating temperatures.

Chapter 8
Conclusion

8.1 Conclusion

We examined the various EV models, the technology used, the advantages over internal combustion engines, the rise in EV sales over the past few years, as well as the numerous charging options and potential future advancements. We also discussed the main research roadblocks and prospects. EVs stand a good possibility of replacing internal combustion engines as the preferred form of transportation in the future while averting imminent climate-related catastrophes. They provide a useful alternative to conventional automobiles, which are dependent on the limited supply of fossil fuels.

We also examined several battery types in light of these qualities. We also talked about prospective future technologies, such as graphene, which is thought to be a tool for storing more energy and facilitating faster charging. Additionally, this kind of technology might increase the range of EVs, which might persuade more users and drivers to adopt them.

At the moment, Li-Ion batteries are the most popular market segment for electric vehicle components. Because of their low weight, high energy storage capacity, moderate energy consumption (14.7 kWh/100 km), steady cost price decline, advanced production technology, longer cycle life, and moderate energy consumption, Li-Ion batteries are the best alternative in this sector. The fact that they function at high temperatures might be detrimental to their life cycles and energy capacities. All of these present risks to the vehicle's ability to operate safely. The use of the fastest, most potent charging methods as well as more sophisticated wireless charging systems will be encouraged by higher capacity batteries. The creation of a unique universal connection is another element that may aid in the expansion of electric cars. Future Smart Cities will depend significantly on electric vehicles, thus it will be especially important to provide a choice of charging options that can be tailored to the requirements of the users.

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