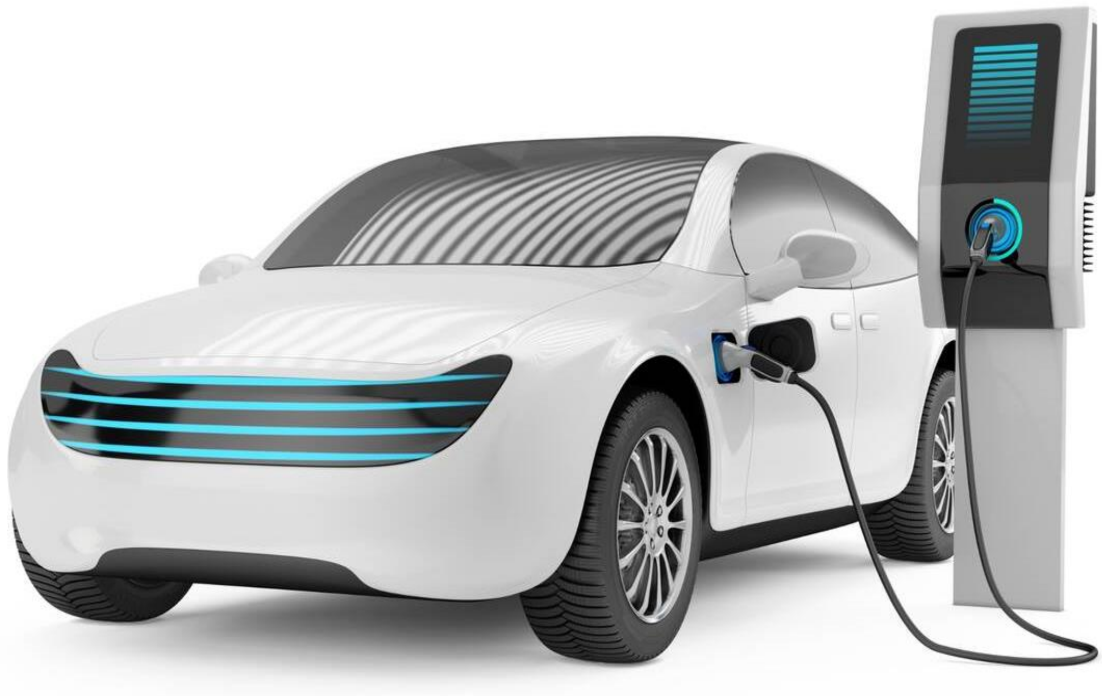
Automotive Electricity and Electronics

Level –V

Based on December 2024, Curriculum Version II



Module Title: Servicing and Maintaining Electric Vehicles

Module Code: EIS AEE5 M03 1224

Nominal Duration:80 Hours

Prepared by: Ministry of Labor and Skill

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Addis Ababa, Ethiopia

Table of Contents

Acronyms

EV	Electric Vehicles
CO	internal combustion engine vehicle (ICEV),
BEV	Diagnostic Trouble Codes
ECM	Electronic control Module
HC	Hydrocarbon
Sox	Sulfur dioxides
CO	Carbon monoxide
VOCs	Volatile organic compounds
Carbon	CO2 dioxide
EVB	Electric vehicle battery
PCU	Power Electronics and Control (PCU)
BMS	Battery Management System
O3	Ozone
AC	Alternative Current
PHEV	Plug-In Hybrid Electric Vehicle
FCEV	Fuel Cell Electric Vehicles
NiMH	Nickel-Metal Hydride
NiCad	Nickel-cadmium
Li-Ion	Lithium-Ion
SOH	State of Health
GPIO	General Purpose Input Output
CAN bus	Controller Area Network
BUS	Binary Unit System
PMBLDC	Permanent Magnet Brushless DC Motor
PMSM	Permanent Magnet Synchronous Motor Drives
HEPM	Hybrid-excited permanent magnet
FMPM	Flux-mnemonic permanent magnet

Acknowledgment

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Introduction to Module

The Electric Vehicle Servicing and Maintenance competencies provide comprehensive training on the technical aspects of EV repair and upkeep. Trainees will gain hands-on experience with EV components, diagnostics, battery management, and safety protocols. This competence equips individuals with the necessary skills to excel in the growing EV industry.

This module is designed to meet the industry requirement under the Automotive Electricity and Electronics level V occupational standard, particularly for the unit of competence: Servicing and Maintaining Electric Vehicles

This module covers the units:

- Introduction to Electric Vehicles
- EV Battery Systems
- Electric Motors and Power Electronics
- EV Drivetrain and Chassis Systems
- EV Maintenance and Repair

Learning Objective of the Module

- Realize Electric Vehicles
- Recognize EV Battery Systems
- Grasp Electric Motors and Power Electronics
- Comprehend EV Drivetrain and Chassis Systems
- Maintain and Repair EV

Module Instruction

For effective use these modules trainees are expected to follow the following module instruction:

1. Read the information written in each unit.
2. Accomplish the Self-checks at the end of each unit.
3. Perform Operation Sheets which were provided at the end of units.
4. Do the “LAP test” giver at the end of each unit and
5. Read the identified reference book for Examples and exercise

Unit one: Introduction to Electric Vehicles

This unit is developed to provide you the necessary information regarding the following content coverage and topics:

- Comparison of Electric Vehicles to Combustion Engine
- Reasons for EV development
- Basic Components of an EV
- Types of Electric Vehicles
- Electric Vehicle Safety

This unit will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this learning guide, you will be able to:

- Compare Electric Vehicles to Combustion Engine
- Comprehend the reasons for EV development
- Identify Basic Components of an EV
- Differentiate Types of Electric Vehicles
- Figure out Electric Vehicle Safety

1.1 Comparison of Electric Vehicles to Combustion Engine

To move and operate, all vehicles must have a way to store energy, a way to control the input and output of energy, and a way to change the energy into a rotary motion to rotate the drive wheels. In an electric vehicle, the battery serves the same purpose as the fuel tank in an internal combustion engine vehicle (ICEV), storing energy until it is needed. To regulate the speed and acceleration of the vehicle, an ICEV uses a fuel injection system to control the flow of energy. In a BEV, the flow of energy is regulated by a controller. The controller provides electrical energy to the motor at the required rate. Like in an ICEV, the rate is adjusted according to the position of the accelerator pedal. In both types of vehicles, the power output is used to rotate the drive wheels.

Table 1- 1 Comparison of Electric Vehicles to Combustion Engine

Major Components of an ICE	Purpose of the Component	Major Components of an EV
Gasoline tank	Stores the energy to run the vehicle	Battery
Gasoline pump	Replaces the energy to run the vehicle	Battery charger
Gasoline engine	Provides the force to move the vehicle	Electric motor
Fuel injection system	Controls acceleration and speed	Controller
Generator/alternator	Converts AC to DC to charge the battery and run the accessories	Inverter and DC/DC converter
Not needed	Convert DC to AC to power traction motor	Inverter
Emissions	Reduces pollutants from the exhaust	No needed

An EV can look like a conventional car without an exhaust pipe or have a very distinctive look. Internally, however, a BEV is quite a bit different. In many EVs, there is no transmission because the rotary motion of the motor can be applied directly to the differential gears. A motor can provide enough torque throughout its speed range to move the vehicle without torque multiplication from transmission gears. The motor can be positioned to provide front-wheel or rear-wheel. An engine loses a lot of energy through heat. Much of the energy produced during combustion merely heats up the engine or goes out of the exhaust, rather than serving as energy to power the vehicle. Also, some of the energy from the engine is used to drive accessories; this also decreases the efficiency of the engine. BEVs generate much less heat and, therefore, much less energy is wasted. BEVs can also reclaim or capture energy through regenerative braking.

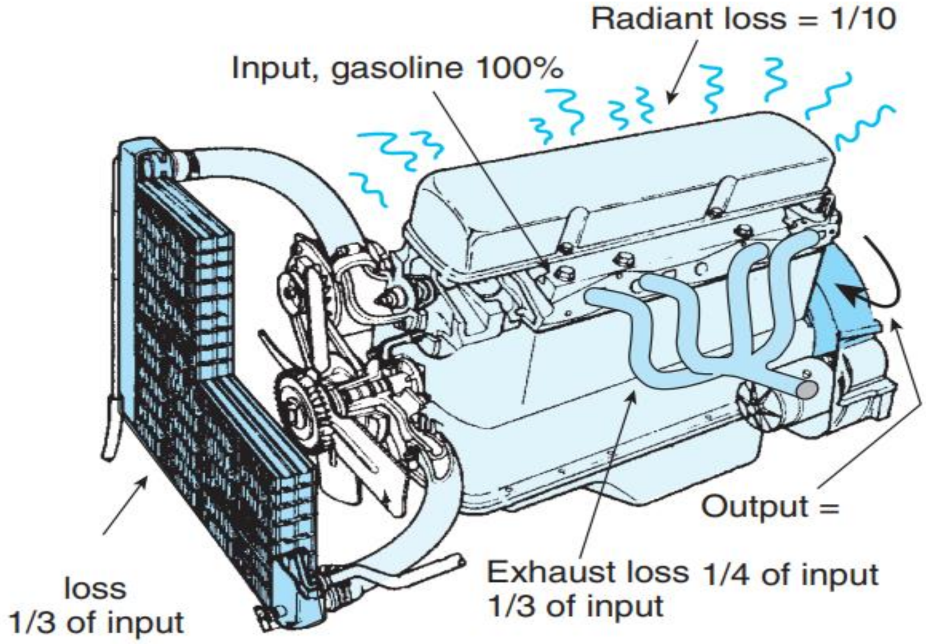


Figure 1- 1 Power loss of engine

In BEVs, most accessories are driven by power from the battery and not by the motor, further increasing efficiency. The power source for an EV has few moving parts. The armature or rotor of the motor is the only moving part in the powerplant system. An engine has hundreds of moving parts, each requiring clean lubrication and each subject to wear. The rotor in a motor is normally mounted on sealed bearings and requires little, if any, additional lubrication throughout its life. The controller and battery charger are electronic units with no moving parts, and they require little or no maintenance. The batteries are sealed and maintenance-free. In summary, an EV requires less periodic maintenance and is more reliable than an ICE.

1.2 Reasons for EV development

Although these days people talk more about EVs, which have become very popular, their underlying features torque and emission.

1.2.1 Torque

An ICE does not develop peak torque until it has reached a particular rpm. Then once the peak torque is reached, it starts to decrease quickly. This is why ICEs are coupled with multispeed transmissions. The various available gear ratios allow the engine to run at speeds where it is most effective for the conditions. With an electric motor, instant torque is available at any speed.

The entire rotational force of the motor is available the instant the accelerator pedal is pressed. Peak torque stays constant to nearly 6,000 rpm, and then it begins to slowly decrease. The wide torque band, especially the available torque at low speeds, eliminates the need for multispeed transmissions. There is no need for a reverse gear, either, since switching the polarity of the stator will cause the rotor to turn in reverse. The absence of a typical transmission saves weight and makes the powertrain much less complex.

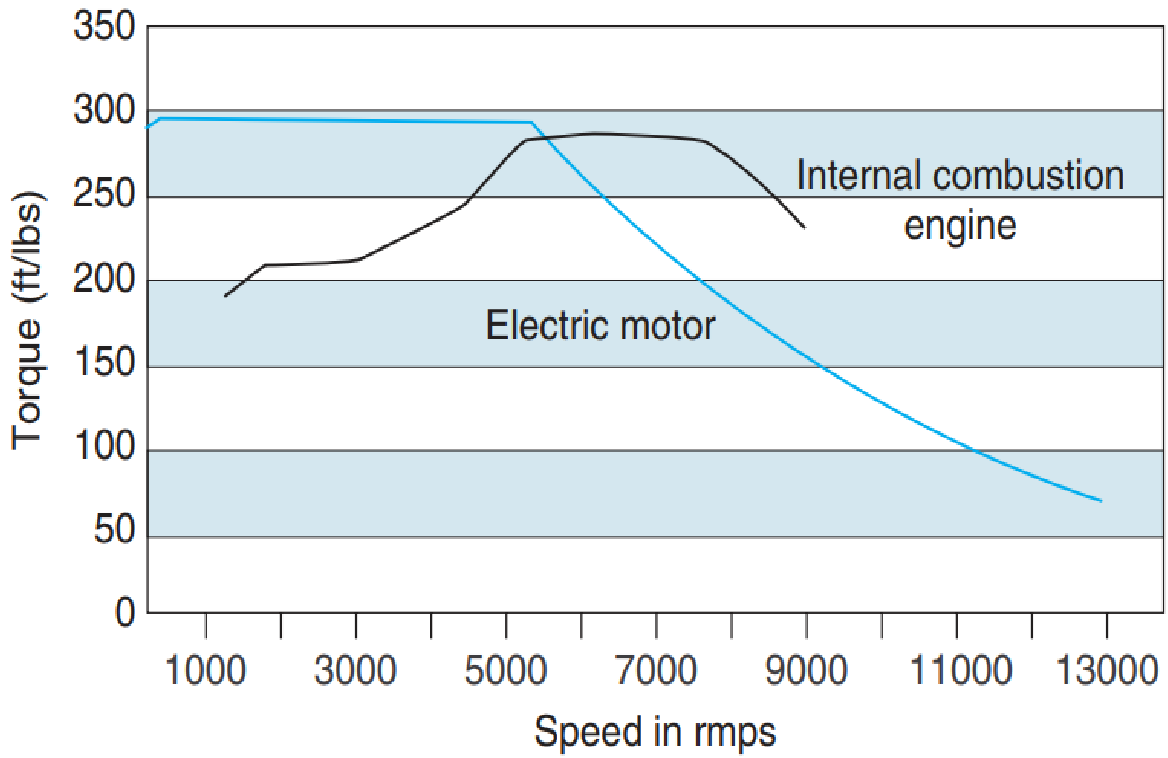


Figure 1- 2 Electric motor vs ICE

1.2.2 Emissions

EVs produce zero emissions. The only emissions related to a EV are released when coal, oil, or natural gas are used in power plants to generate the electrical energy required to recharge the batteries. The use of hydroelectric, wind, sunlight, or other renewable sources to generate electricity would eliminate all emissions associated with EVs. It is impossible to have zero emissions from the ICE. Other than operating cost advantages, zero emissions is a primary justification for having a EV. There are many chemicals and substances related to the emissions of an ICE, none of which are emitted by an electric vehicle:

- Carbon monoxide (CO) is a by-product of combustion and is a deadly gas.
- Sulfur dioxides (Sox) are produced by combustion of coal, fuel oil, and gasoline, because these fuels contain sulfur. SOx combined with water vapor in the air becomes a major contributor to acid rain.

- An ICE releases hydrocarbons (HCs) through its exhaust and its fuel storage system. HCs are best thought of as unburned fuel. These fumes contribute to the formation of ozone layers, and HCs can cause cancer or irritate mucous membranes.
- Nitrogen oxides (NOx) are released from an ICE's exhaust and the burning of coal, oil, or natural gas. When nitrous oxides combine with the oxygen in the air, a poisonous gas is formed that can damage lung tissue.
- Volatile organic compounds (VOCs) contribute to ozone and smog formation. VOCs are emitted by ICE exhaust, gasoline/oil storage and transfer, chemical manufacturing, dry cleaners, paint shops, and other facilities using solvents.
- Ozone (O3) is a toxic gas and is seen as a white haze (smog) over many cities. Ground-level ozone is formed by a chemical reaction between VOCs and NO x, in the presence of sunlight.
- Carbon dioxide (CO2) is a product of combustion. Some CO2 is needed because vegetation needs it to survive. However, a high concentration of CO2 traps heat and warms the atmosphere, which causes the ''greenhouse effect' and global warming.

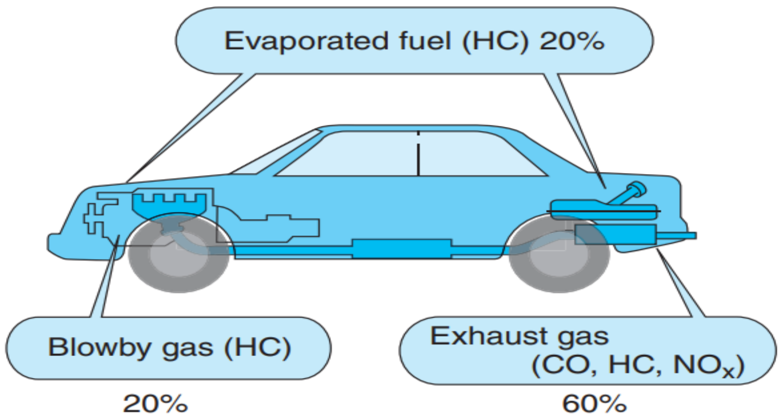


Figure 1- 3 Emission rate of ICE

1.3 Basic Components of an EV

Despite the differences in layout and efficiency, electric cars of all generations have much in common in terms of design: they are equipped with almost identical sets of main components and units. Let us look at each of them.

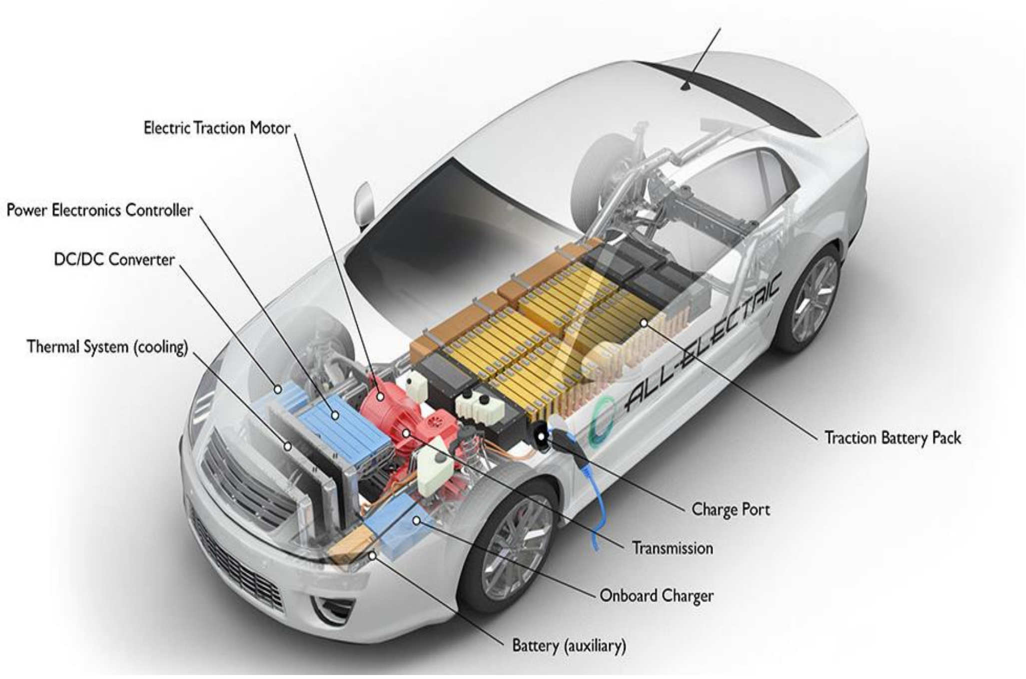


Figure 1- 4 Basic Components of an EV

1.3.1 Electric Motor

It is the main unit of any BEV. The electric motor operates on the following principle: a mechanical force acts on a current conductor placed in the magnetic field, which, in turn, rotates its shaft due to electromagnetic interaction of the moving component (rotor) with the stationary housing (stator). This can be achieved by different methods, so electric motors also differ in design.

Brushless motors are used for actuating electric cars. A synchronous AC generator with permanent magnets used as a rotor is the most efficient example. The drawbacks include price (rare metals are used to produce magnets) and difficult steerability due to the constant magnetic field. Therefore, these engines are used in expensive and powerful electric vehicles.

Figure 1- 5 EV Electric Motor

Electric motors with induction coils replacing magnets, which also operate under alternating current, are used more often due to their lower price. They can be synchronous, but more often the rotor rotates slower than the magnetic field created by the stator coils. Because of this, such engines are called asynchronous. They have lower efficiency, but they are easier to operate.

1.3.2 Gearbox

All motors used in electric cars develop very high torque - they can spin up to very high speeds literally from the start and change the direction of rotation. That is why electric cars do not need complex multi-speed gearboxes and heavy transmission like cars with ICE. A simple and reliable reduction gearbox connected directly to the engine would be enough. Powerful and fast cars can additionally be equipped with a two-range gearbox combining powerful traction at low speed and a high maximum speed.

1.3.3 Traction Battery Pack

A traction battery pack is also known as an Electric vehicle battery (EVB). It powers the electric motors of an electric vehicle. The battery acts as an electrical storage system. It stores energy in the form of DC current. The range will be higher with increasing kW of the battery. The life and operation of the battery depends on its design. The lifetime of a traction battery pack is estimated to be 200,000 miles.

1.3.4 Power Electronics and Control (PCU) systems

Power electronics and control systems manage the flow of electricity between the battery, motor, and other vehicle components. The PCU manages and controls braking, acceleration, and regenerative braking. Electric cars that have advanced power control systems have optimal energy usage and enhanced safety and operational features.

A. Charge Port

The charge port connects the electric vehicle to an external supply. It charges the battery pack. The charge port is sometimes located in the front or rear part of the vehicle.

Primarily, there are six types of connectors used in EVs worldwide - Type 1, Type 2, CHAdeMo, CCS, GB/T, and IEC 60309.

Figure 1- 6 Charge Port

B. Onboard charger

Though the battery present in the vehicle gets charged by using DC or direct current, the current output from the charging station or a charger is in form of AC or alternating current. The function of the onboard charger is to convert alternating current (AC) from the charging source into direct current (DC) to charge the battery. The charging speed and compatibility is independent of the onboard charger and depends on the source charger's capacity and BMS.

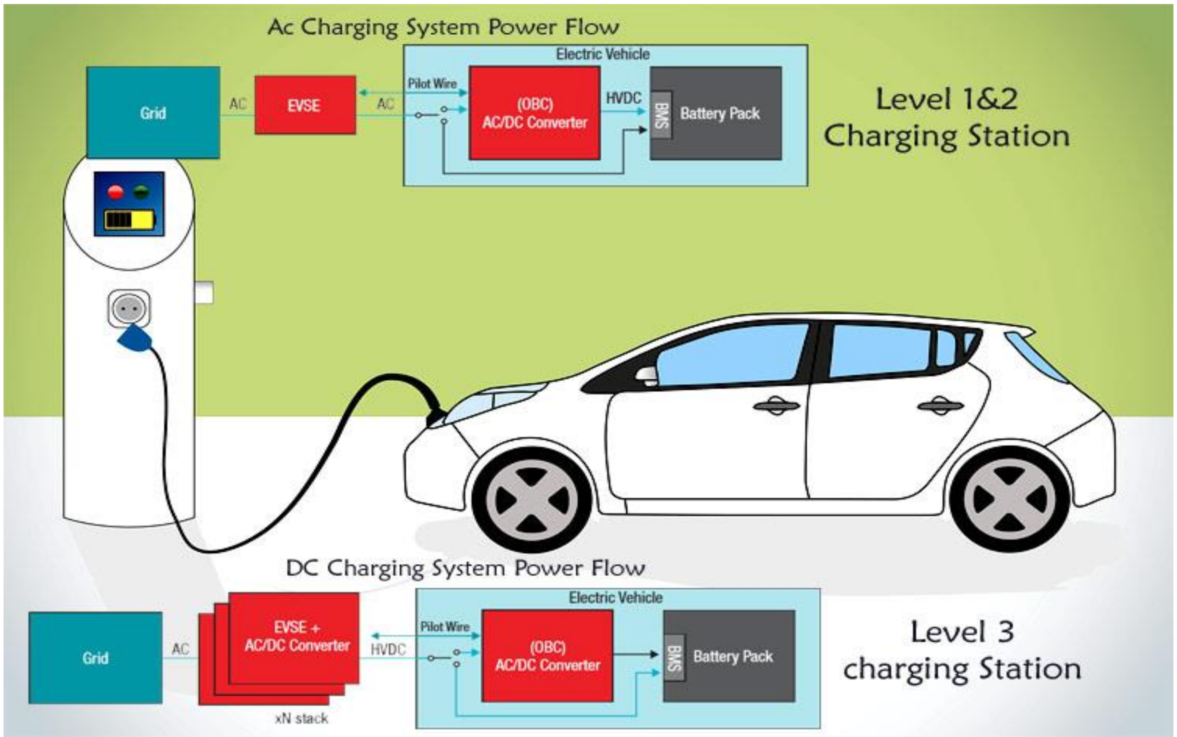


Figure 1- 7 Onboard Charger

C. DC-DC Converter

The traction battery pack delivers a constant voltage. But different components of the vehicle have different requirements.

The DC-DC converter distributes the output power that is coming from the battery to a required level. This module converts high-voltage DC power from the battery into lower-voltage DC power, which is necessary for various vehicle systems, including lighting, entertainment, and air conditioning.

1.3.5 Vehicle Control Unit

The vehicle controller or electronic control unit (ECU) is an integrated circuit/chip which is regarded as the brain of the vehicle. In addition to essential functions like engine performance and power steering, it controls safety and comfort features, such as parking assistance, memory seats and airbag deployment. The vehicle control unit is responsible for all internal communications between various systems deployed in the vehicle and enabling them whenever required.

- **Battery Management System (BMS):** The BMS monitors the state of charge (SoC), state of health (SoH), and overall health of the battery pack. The BMS ensures that the battery performs within safe limits. To protect the battery from the thermal runway and overcharging, BMS stops the input current to the battery and disconnects it from charger or load. The BMS is also responsible for managing key battery aspects like thermal management, cell balancing, and communication and reporting.
- **User interface and display**: Electric cars have user interfaces and displays that provide information to the driver and passengers, including battery status, range estimation, and charging information.
- **Safety systems**: Like traditional ICE vehicles, EVs incorporate safety features like airbags, anti-lock brakes, stability control, and collision avoidance systems.

1.3.6 Auxiliary Batteries

Auxiliary batteries are the source of electrical energy for the accessories in electric vehicles. Without the main battery, the auxiliary batteries will continue to charge the car. It prevents the voltage drop, produced during engines start from affecting the electrical system.

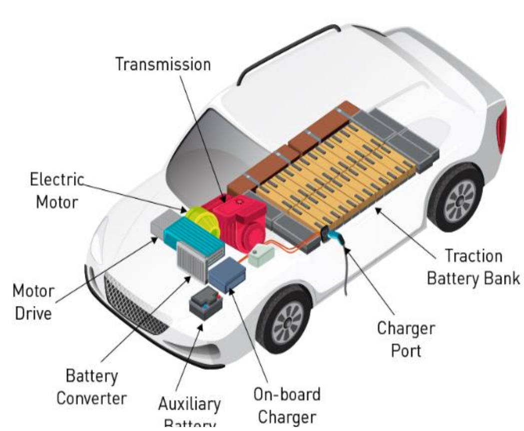


Figure 1- 8 Auxiliary Batteries

1.4 Types of Electric Vehicles

Electric vehicles, or EVs, are revolutionizing the automotive industry, promising a cleaner, more sustainable future. With advancements in technology and increasing environmental awareness, various types of EVs have emerged, each offering unique benefits and addressing different aspects of sustainable transportation. There are four primary types of electric vehicles:

1.4.1 Battery Electric Vehicles

A battery-operated electric vehicle, sometimes referred to as a battery-electric vehicle (BEV), uses one or more electric motors to turn its drive wheels. The electricity for the motors is stored in a battery that must be recharged from an external electrical power source. This technology is used for passenger cars, forklifts, urban buses, airport ground support equipment, and off-the-road industrial equipment. BEVs are zero-emission vehicles because they do not directly pollute the air. The only pollution associated with them is the result of creating electricity to charge their batteries. Even when those emissions are included, BEVs are significantly cleaner than the cleanest ICE vehicle.

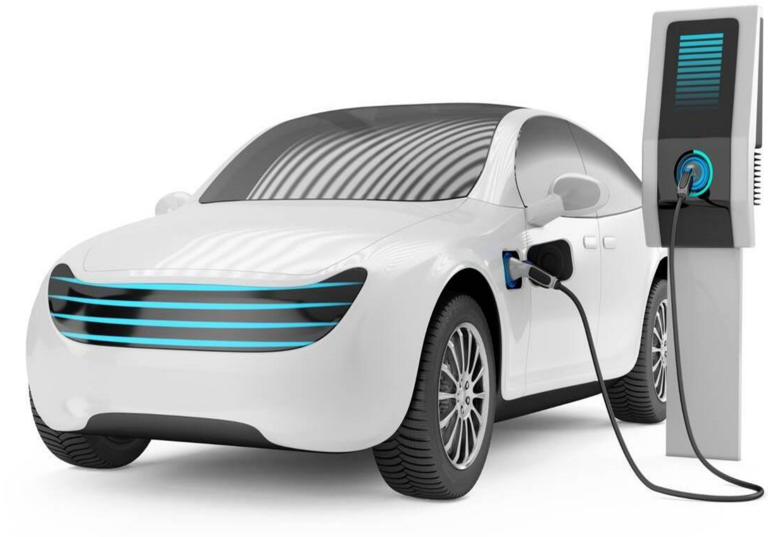


Figure 1- 9 Battery Electric Vehicles

Normally, a battery-operated vehicle drives the same as any other, but it is quiet and carries no fossil fuel. However, rather than filling a tank with fuel, you need to recharge the batteries. The batteries are recharged by plugging them into a recharging outlet at home or at other locations.

The recharging time varies with the type of charger, the size and type of battery, and other factors. Normal recharge time is four to eight hours.

After several years of BEVs not being available, manufacturers are now offering or planning to offer them to the public. Sold as commuter cars, BEVs are not practical for everyone because of their limited range and relatively high cost. Most have less than a 100-mile range before the batteries need to be recharged. Also, many find it hard to justify the higher purchase or lease costs, despite the advantages.

Whether battery-operated electric vehicles will have good sales numbers in the future depends on the development of new batteries. To be practical, electric vehicles need to have much longer driving ranges between recharges and must be able to sustain highway speeds for great distances. Although BEVs were not accepted in the past, many lessons were learned by building them. Manufacturers can use those lessons to again build BEVs and use that same technology to build hybrid electric and fuel cell electric vehicles. (For more information watch the following video https://www.youtube.com/watch?v=tJfERzrG-D8)

1.4.2 Hybrid Electric Vehicles

A hybrid electric vehicle (HEV) has more than one available power source to propel the vehicle—it uses one or more electric motors and an ICE. Depending on the design of the system, the ICE may propel the vehicle by itself, act together with the electric motor to propel the vehicle or drive a generator to charge the vehicle's batteries. The electric motor may propel the vehicle by itself or assist the ICE while it is propelling the vehicle. Some hybrids rely exclusively on the electric motor(s) during slow-speed operation, on the ICE alone at higher speeds, and on both during some driving conditions. A hybrid's electric motor is powered by batteries, which are continuously recharged by a generator that is driven by the ICE. The battery is also recharged through regenerative braking.

Complex electronic controls monitor the operation of the vehicle. Based on the current operating conditions, electronics control the ICE, electric motor, and generator. The system recharges the batteries while driving; therefore, plug-in charging is not required. The engines used in hybrids are specially designed for vehicles and for electrical assistance. Therefore, they can operate more efficiently, resulting in a very good fuel economy and very low tailpipe emissions.

Hybrids will never be true zero-emission vehicles, however, because they have an ICE. HEVs have an extended range, going farther than a BEV can on just the charge in its batteries. They also have a longer driving range than a comparable ICE equipped vehicle. HEVs also provide the same performance as the same vehicle equipped with a larger ICE, if not better. The delivery of power to the wheels is smooth and very responsive.

There are three major types of hybrids: parallel, series and series parallel designs.

- **Parallel HEV**: A *parallel HEV* uses either the electric motor or the gas engine or both to propel the vehicle.

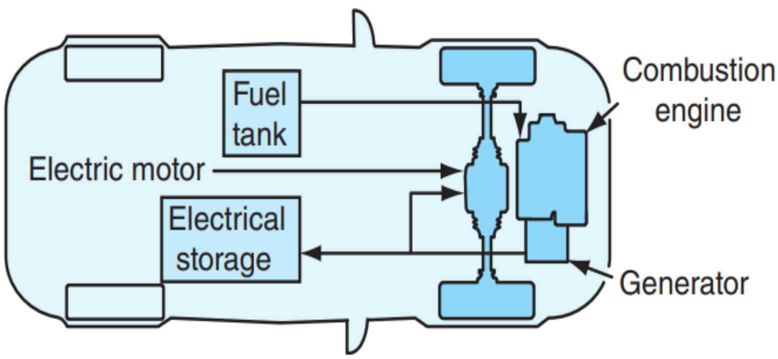


Figure 1- 10 Parallel HEV

- **Series HEV**: only uses the ICE to power the generator to keep the batteries charged. The vehicle is powered only by electric motors.

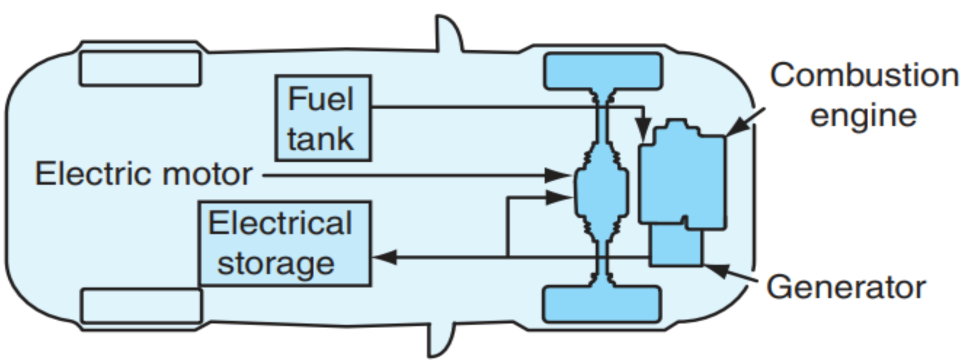


Figure 1- 11 Series HEV

- **Series-parallel hybrids**: Most of today's hybrids rely on a series/parallel configuration because they have the features of both designs. As of early 2012, there was one mostly series hybrid, the Chevrolet Volt. This car is called an extended range electric vehicle because the ICE starts when the batteries are low. By charging the batteries with the ICE, the operating range of the car is extended. However, the engine never directly drives the car's wheels. There are several hybrid cars on the market today, with more planned for the near future. Although most current hybrids are focused on fuel economy, the same construction is used to create high-performance vehicles. Hybrid technology has also influenced off-the-road performance. With the use of individual motors at the front and rear drive axles, additional power can be applied to certain drive wheels when needed. (Refer https://www.youtube.com/watch?v=h5ysddrlXLw)

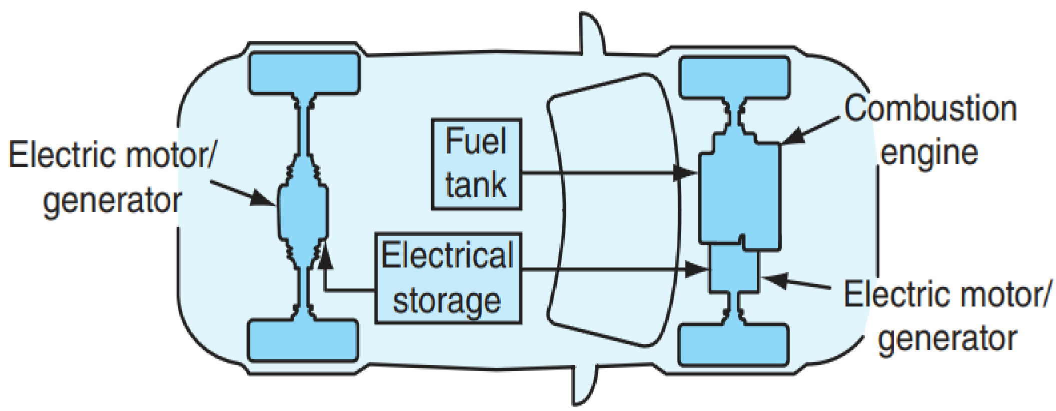


Figure 1- 12 Series-parallel hybrids

1.4.3 Plug-In Hybrid Electric Vehicle (PHEV)

PHEV, as the name suggests, differs from HEV only by the fact that it allows one to plug in a cable running from the vehicle to a household utility wall socket at home or elsewhere to charge the vehicle's battery.

To extend the flexibility of the system, it is also possible in principle to use the engine and/or the battery system in the vehicle to generate AC power and feed it back to the utility grid. Since plug-in allow a fair amount of external utility system energy to drive the vehicle, it is helpful to use a larger battery than in a regular HEV.

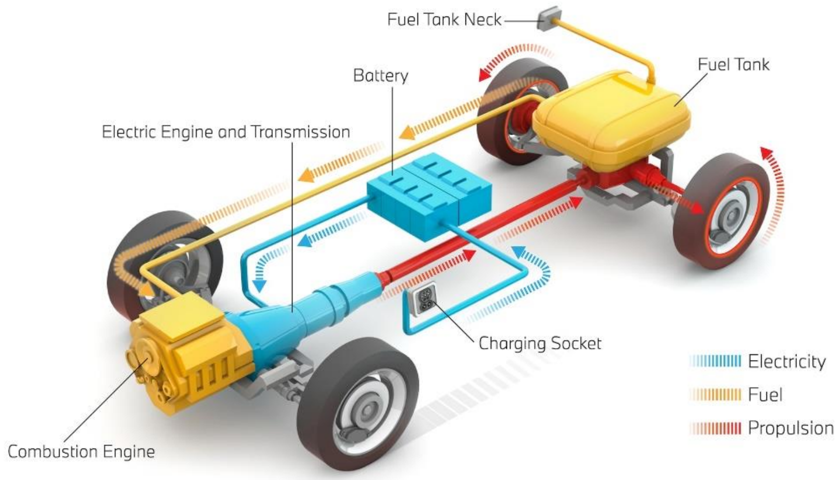


Figure 1- 13 Plug-In Hybrid Electric Vehicle

A larger battery is not a required part of the PHEV but has one benefits fuel economy and increases the range of the vehicle when fully charged. In HEV, using a much larger battery may not necessarily be the optimal choice in terms of design, since the ICE is always capable of kicking in, when the battery needs to be charged. People sometimes think that a large battery is mandatory for PHEV, which may not be the case. How large the battery can be depending on the packaging space available in the vehicle. If the battery size is small, then the benefits from the PHEV will be merely incremental, whereas if it is too big then it can be very expensive and will take longer to recharge from the utility system. Note also that the household utility system may have some limitations on how much it can sustain in charging a battery system, hence some safeguards are necessary for the plug-in. Since the cost of utility energy at present is much lower than the price of gasoline, it makes sense to use the PHEV, where possible.

Refer https://www.youtube.com/watch?v=IEarYZ6ffoU

1.4.4 Fuel Cell Electric Vehicles

A possible alternative fuel for the future is hydrogen, which is the fuel for fuel cells. Basically, a fuel cell generates electrical power through a chemical reaction. A fuel cell electric vehicle (FCEV) uses the electricity produced by the fuel cell to power motors that drive the vehicle's wheels. FCEVs operate like most EVs, but their batteries do not need to be charged by an external source. FCEVs emit few, if any, pollutants. Fuel cell technology may also be used to provide energy for homes and businesses. Fuel cells convert chemical energy to electrical energy by combining hydrogen with oxygen from the air. Refer https://www.youtube.com/watch?v=NTwHD2n-vRI

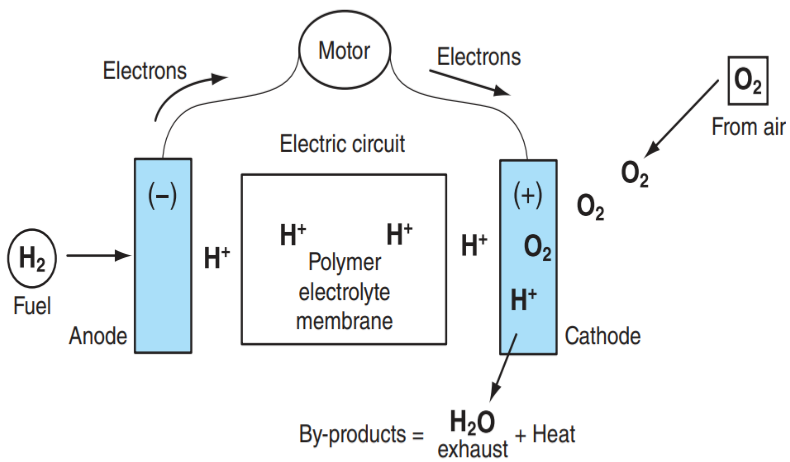


Figure 1- 14 Fuel Cell chemistry
Refer: https://www.youtube.com/watch?v=a4pXAmljdUA

Hydrogen can be supplied directly as pure hydrogen gas or through a ''fuel reformer' that pulls hydrogen from hydrocarbon fuels such as methanol, natural gas, or gasoline. A fuel cell is made up of two electrodes (the anode and the cathode) located on either side of an electrolyte. As hydrogen enters the fuel cell, the hydrogen atoms give up electrons at the anode and become hydrogen ions in the electrolyte. The electrons that were released at the anode move through an external circuit to the cathode. As the electrons are moving toward the cathode, they can be diverted and used to power the electric motors to move the vehicle.

When the hydrogen ions combine with oxygen molecules at the cathode, water and heat producing or greenhouse gases are generated and only water is emitted from the tailpipe of the fuel cell. A fuel cell power system has many other parts, but central to them all is the fuel cell stack. The stack is made of many thin, flat fuel cells layered together. Each cell produces electricity, and the total output of all the cells is used to power the vehicle. The entire stack of fuel cells is often referred to as a fuel cell, although that is not technically correct. A fuel cell is one cell, whereas the stack is many cells.

Vehicles that run on pure hydrogen are true zero emission vehicles. FCEVs that have reformers will emit some pollutants, but far less than an ICE vehicle. Without a reformer, FCEVs do not consume fossil fuels nor contribute to global warming.

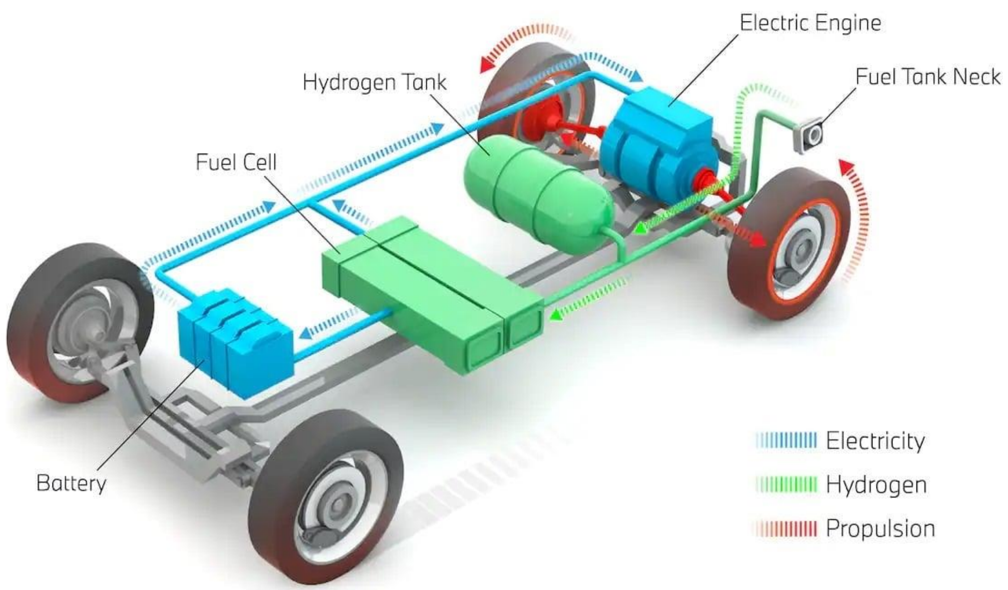


Figure 1- 15 Fuel Cell Electric Vehicles

However, there may be some emissions related to the production of hydrogen. This is an area that must be addressed before Many obstacles need to be overcome before FCEVs become a truly viable option for personal transportation. These include:

- Storage: Because hydrogen is a gas, a large volume of it is needed to travel the same distance as a tank of gasoline.
- Weight and size: Current fuel cells are quite large and heavy; both need to be reduced to make FCEVs more practical.
- Cost: The cost of a fuel cell is high, and this must also be reduced.
- Startup time: Fuel cells operate best at a fixed moderate temperature.
- FCEVs must have systems that allow for quick reactions to changing operating temperatures and conditions.
- Hydrogen sources: Because fuel cells debenture to supply hydrogen and/or clean operating reformers.

Most auto manufacturers are actively researching fuel cell transportation technologies and testing prototype passenger vehicles. Many cities are testing fuel cell–powered transit buses. The advances made by hybrid vehicle technology will benefit fuel cell vehicle development.

1.5 Electric Vehicle Safety

1.5.1 Safety Precautions of Electric Vehicles

Electric drive vehicles have high-voltage electrical systems (from 42 volts to 650 volts). These high voltages and their high amperages can kill you! Fortunately, most high voltage circuits are identifiable by size and color. The cables have thicker insulation and are typically colored orange. The connectors are also colored orange. On some vehicles, the high-voltage cables are enclosed in an orange shielding or casing; again, orange indicates high voltage. Be careful not to touch these wires when they are connected to their power source. The battery pack and most high-voltage components also have ‘‘High Voltage’’ caution labels. Be careful when working around these parts. There are other safety precautions that should always be adhered to when working on an electric drive vehicle:

- Always adhere to the safety guidelines given by the manufacturer.
- If a repair operation is incorrectly performed on an EV, a dangerous situation can result; always perform each repair operation correctly.

- Disable or disconnect the high-voltage system before working on or near the system. Always follow the procedures for doing this given by the manufacturer.
- Some systems have a high-voltage capacitor that must be discharged after the high-voltage system is isolated. Make sure to wait the prescribed amount of time (normally about 10 minutes) before working on or around the high-voltage system.
- After removing a high-voltage cable, cover the terminal with vinyl electrical tape.
- Always use insulated tools.
- Always follow the test procedures defined by the equipment manufacturer.
- Alert other technicians that you are working on high-voltage systems with a warning sign such as ''HIGH-VOLTAGE WORK: DO NOT TOUCH.'
- Follow the manufacturer's instructions for removing the battery packs.
- When disconnecting electrical connectors, don't pull on the wires. When reconnecting the specifications.
- Do not wear metallic objects such as rings and necklaces while working around these systems.
- Do not carry metal objects, such as a mechanical pencil or a measuring tape, that could fall and cause a short circuit
- Wear insulating gloves, commonly called' 'lineman's gloves,' when working on or around the high-voltage system. Make sure the gloves have no tears, holes, or cracks and that they are dry. The integrity of the gloves should be checked before using them.
- Always install the correct type of circuit protection device into a high-voltage circuit.
- Use only the tools, test equipment, and service procedures specified by the manufacturer.
- Many electric motors contain a strong permanent magnet; individuals with pacemakers should not handle these parts.
- Before doing any service to an electric drive vehicle, make sure the power from the battery is disconnected or disabled.

- Any time the engine is running in a hybrid vehicle, the generator produces high voltage, and care must be taken to prevent shocks.
- When an electric drive vehicle needs to be towed into the shop for repairs, make sure it is not towed by its drive wheels. Doing this will drive the generator(s), which can overcharge the batteries and cause them to explode. Always tow these vehicles with the drive wheels off the ground or move them on a flatbed.
- In the case of a fire, use a Class ABC powder type extinguisher or very large quantities of water.

1.5.2 Electric Vehicle Battery Precautions

Because the electrical power for an electric drive vehicle is stored in a battery pack, special handling precautions must be followed when working with or near batteries. Make sure to wear safety glasses (preferably a face shield) and protective clothing when working around and with batteries.

- Keep all flames, sparks, and excessive heat away from the battery at all times, especially when it is being charged.
- Remove wristwatches and rings before servicing
- any part of the electrical system. This helps prevent the possibility of electrical arcing and burns.
- Never lay metal tools or other objects on the battery.
- All batteries have an electrolyte, which is very corrosive. It can cause severe injuries if it meets your skin or eyes. If the electrolyte gets on you, immediately wash with baking soda and water. If the acid gets in your eyes, immediately flush them with cool water for a minimum of 15 minutes and get immediate medical attention.
- When removing a battery from a vehicle, always disconnect the battery ground cable first. When installing a battery, connect the ground cable last.
- Always use a battery carrier or lifting strap to make moving and handling batteries easier and safer.

- Always disconnect the battery's ground cable when working on the electrical system or engine. This prevents sparks from short circuits and prevents accidental starting of the engine. Always charge a battery in well-ventilated areas.
- Never connect or disconnect the charger leads to a battery when the charger is turned on.
- Never recharge the battery when the system is on.
- Turn off all accessories before charging the battery and correct any parasitic drain problems.
- Always disconnect the battery ground cable before fast charging the battery on the vehicle.

1.5.3 Personal Protective Equipment (PPE)

When working on electric and hybrid vehicles, it is important that technicians are supplied with reliable protective equipment to safely carry out work. Personal Protective Equipment (PPE) is impelled as a final measure for suitable safety precautions when working on EHVs. The purpose of this equipment is to protect individuals who work near an installation that presents an electrical hazard. The equipment used should be appropriate for the type of operation and voltage level of the installation. The use of improper PPE for a specific hazard can cause significant danger to the user.

- Electrical Safety Gloves – these are the first line of defense for contact with energized components. Most EV manufacturers recommend that insulated rubber gloves should be worn when working near all high-voltage components, not just the vehicle batteries. Ordinary latex gloves are not thick enough and do not provide sufficient protection from the shock hazard.
- Cotton Under gloves – to be worn underneath electrical safety gloves and leather gloves, our cotton under gloves not only reduce sweating, they give added comfort and protection to the PPE user in warm and humid conditions.
- Leather Over gloves – these are worn over insulating gloves to protect against mechanical hazards and electrical arcing.

- Face Shield – this part of equipment is extremely important when working on high voltage as it protects the eyes from any 'flash over' that can occur if an electrical spark is produced. The face shield provides forehead protection and a full 180° field of vision.
- Dielectric Over boots – to be worn over existing footwear, the dielectric over boot provides additional protection of insulation, preventing electric shocks should a vehicle technician encounter contact with a live electric source.
- Insulating Rubber Apron – Manufactured from 1mm thick orange neoprene with nylon insert for added strength, this apron is to protect technicians working with live voltages up to 1000V.

It is important to maintain PPE and perform regular examinations before and after use to ensure the equipment continues to provide the degree of protection for which it is designed. This may include checking for defaults (e.g. if there are any tears in gloves) and cleaning items. If there are any uncertainties, the items should not be worn and replaced.

1.5.4 Emergency Response for EV incidents

Emergency response protocols for electric vehicle (EV) incidents are crucial to ensure the safety of both responders and the public. There are key guidelines to follow:

- **Prioritize Safety**: Always prioritize the safety of responders and the public.
- **Understand EV Technology**: Gain a basic understanding of EV technology, including the high-voltage (HV) system and battery components.
- **Follow Manufacturer Guidelines**: Adhere to the specific emergency response guidelines provided by the EV manufacturer.
- **Utilize Appropriate PPE**: Wear appropriate personal protective equipment (PPE), including insulating gloves, boots, and eye protection.
- **Communicate Effectively**: Establish clear communication channels among all responders.

A. Incident Arrival

- Assess the Scene: Conduct a thorough size-up of the incident, including the extent of damage, potential hazards, and the number of occupants.
- Immobilize the Vehicle: Secure the vehicle to prevent unintended movement.
- Identify the EV Type: Determine the specific make and model of the EV to access relevant emergency response information.
- Deactivate the HV System: Follow manufacturer guidelines to safely deactivate the HV system. This may involve using specialized tools or procedures.

B. Extrication

- Coordinate with Medical Personnel: Work closely with medical personnel to prioritize patient care and minimize exposure to hazards.
- Use Appropriate Tools: Utilize specialized tools designed for EV extrication, such as insulated cutters and spreaders.
- Minimize Battery Exposure: Avoid unnecessary cutting or piercing of the HV battery pack.
- Cool the Battery: If possible, use water to cool the battery pack to reduce the risk of thermal runaway.

C. Fire Suppression

- Large Quantities of Water: Use large quantities of water to cool the battery pack and suppress the fire.
- Foam Suppression: In some cases, foam may be used to suppress the fire, but consult manufacturer guidelines for specific recommendations.
- Avoid Direct Water Contact with Battery: Direct water contact with the battery may lead to electric shock or increased fire intensity.
- Extended Cooling Period: Allow the battery pack to cool for an extended period after the fire is extinguished to prevent reignition.

D. Post-Incident Procedures

- Document the Incident: Document the incident, including details about the response actions taken and any challenges encountered.
- Clean Up and Disposal: Follow proper procedures for cleaning up the scene and disposing of hazardous materials.
- Debriefing: Conduct a debriefing session to identify lessons learned and improve future response efforts.

By following these guidelines and staying updated on the latest information, emergency responders can effectively manage EV incidents and minimize risks.

Self-check 1.1

Directions: Answer all the questions listed below.

Part I: Say True or False

1. A hybrid vehicle can operate solely on electric power for short distances.
2. Range anxiety is a major concern for owners of plug-in hybrid vehicles.
3. Fuel cell vehicles produce water as their primary byproduct.
4. Regenerative breaking is a feature unique to electric vehicles.
5. All electric vehicles are eligible for any roads.

Part-II: Choose the appropriate answer from the given alternatives

Choose the Best Answer

1. Which component in an EV is responsible for converting DC power from the battery to AC power for the motor?
   a) Inverter
   b) Controller
   c) Charger
   d) Regenerator
2. Which of the following is the most significant factor limiting the range of a battery electric vehicle (BEV)?
   a) Motor efficiency
   b) Tire pressure
   c) Battery capacity
   d) Driving speed
3. Which type of EV typically offers the longest all-electric range?
   a) Mild hybrid
   b) Plug-in hybrid
   c) Battery electric vehicle
   d) Fuel cell electric vehicle
4. What is the primary environmental concern associated with the widespread adoption of electric vehicles?
   a) Battery disposal
   b) Noise pollution
   c) Emissions from electricity generation
   d) Tire wear
5. Which of the following is NOT a typical benefit of hybrid vehicles compared to conventional gasoline-powered vehicles?

a) Zero tailpipe emissions

b) Improved fuel economy

c) Reduced reliance on gasoline

d) Reduced noise pollution

Part-III: Answer the following questions accordingly.

1. Explain the key difference between a parallel hybrid and a series hybrid vehicle.
2. Describe the primary functions of the battery management system (BMS) in an electric vehicle.
3. List at least three major challenges that currently hinder the widespread adoption of fuel cell electric vehicles.
4. How does regenerative braking improve the efficiency of an electric vehicle?

Unit Two: EV Battery Systems

This unit is developed to provide you with the necessary information regarding the following content coverage and topics:

- Introduction to EV Battery
- Basic Battery Theory
- Types of EV Batteries
- Battery Management System (BMS)
- EV Battery charging

This guide will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this learning guide, you will be able to:

- Introducing the EV Battery
- Recall the Basics of Battery Theory
- Differentiate types of EV Batteries
- Infer Battery Management System (BMS)
- Perform EV Battery charging

2.1 Introduction to EV Battery

The battery in an electric drive vehicle serves a different purpose than a battery in a conventional vehicle. In an internal combustion engine (ICE)-powered vehicle, the battery's primary purpose is to provide a short, powerful burst of power to start the engine. This type of battery is typically called a starting battery. In electric drive vehicles, however, the batteries provide continuous current to power electric motors for a long period of time. A starting battery is also found in hybrids, in addition to a high-voltage (HV) battery. The starting battery is used to start the engine or to close the contractors to allow the HV battery to start the ICE and to power the electric motors. The HV system may also be used to power some accessories. In these vehicles, the starting battery is also used as the power source for normal accessories, such as lights.

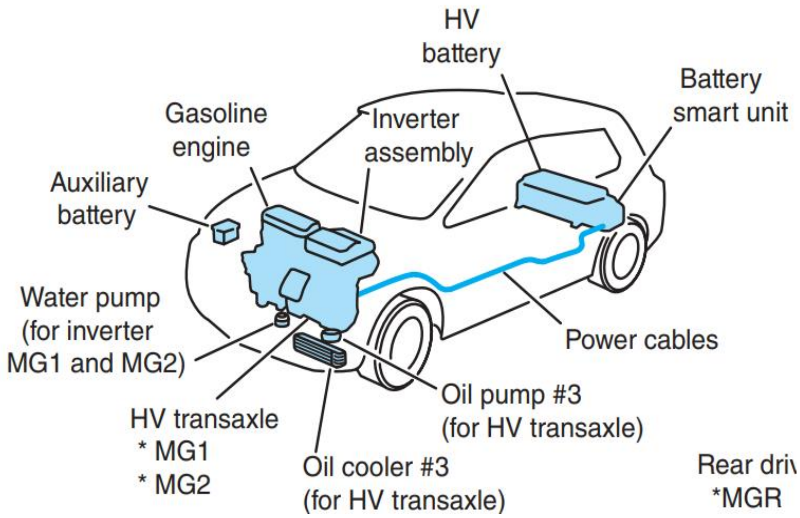


Figure 2- 1 EV Powered systems

Obviously, in a battery electric vehicle (BEV) and a fuel cell electric vehicle (FCEV), there is no need for a starting battery. These vehicles have driven, or traction batteries constructed in the same way as those used in hybrids. The primary downfall of the BEV has been short driving range and long recharge times. The range limitations of BEVs were due to battery technology. Perhaps one day batteries will be developed to make BEVs a practical alternative to ICE-powered vehicles. Electric drive vehicles not only need high-power, high-voltage batteries, they also need batteries that can be totally discharged and recharged often. This is a requirement called deep cycling, and a battery designed to do this is called a deep cycle battery.

These batteries tend to have less instant power than a starting battery but can deliver electrical energy for longer periods of time, as well as go through many deep cycles.

Electric drive vehicles typically run on 100 to 600 volts. The batteries may be 6- or 12-volt batteries connected in series. If the electric motor requires 240 volts, the vehicle needs forty 6-volt batteries or twenty 12-volt batteries. In many cases, hundreds of individual battery cells, each about the size of a flashlight battery, are connected to store and provide the needed power. Many different types of batteries are available and under development to exceed the needs of electric drive vehicles. In addition to batteries, some electric drive vehicles are equipped with ultra-capacitors, which also store and provide electrical energy. Most high-voltage battery packs have a control unit designed specifically to control the temperature of the battery. Some batteries work best when they are warm. For these, the battery box also has a heater. Remember, each battery design has its own optimal temperature range.

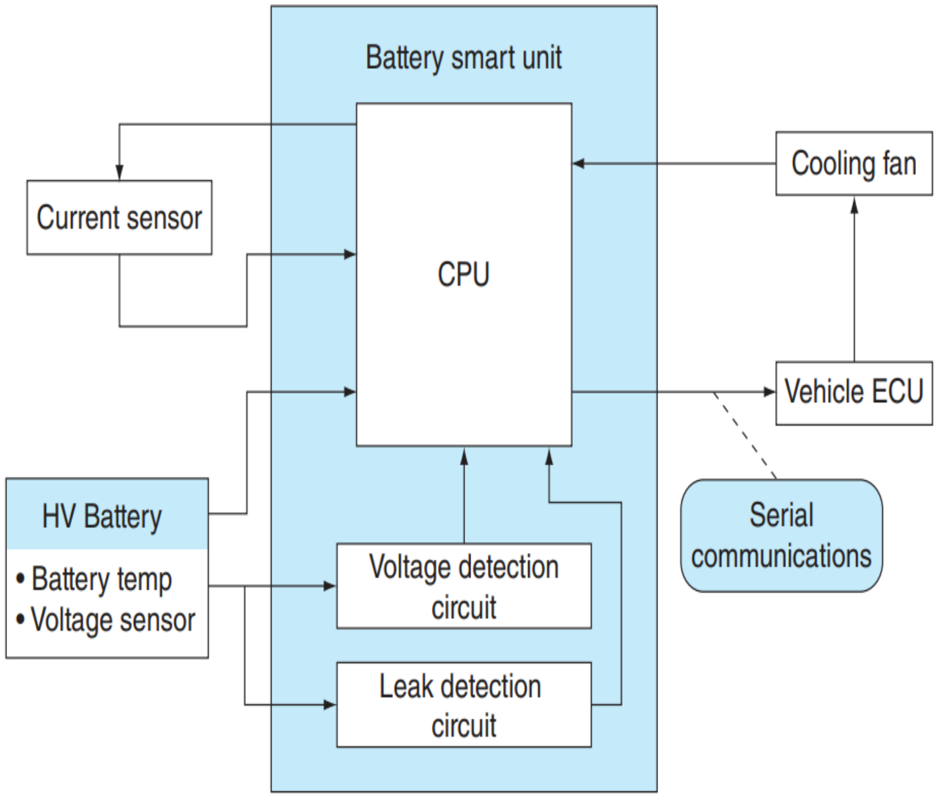


Figure 2- 2 EV battery system layout

2.1 Basic Battery Theory

Electrical current is caused by the movement of electrons from something negative to something positive. The strength of the attraction of the electrons (negative) to the protons (positive) determines the amount of voltage present. When a path is not present for the electrons to travel through, voltage is still present but there is no current flow. When there is a path, the electrons move and there is current. This is the basic operation of batteries.

A battery stores DC voltage and releases it when it is connected to a circuit. Inside the battery are two different types of electrodes or plates. One of the plates has an abundance of electrons (negative plate) and the other has a lack of electrons (positive plate). The electrons want to move to the positive plate and do so when a circuit connects the two plates. Batteries have two terminals and a negative connected to the negative plate. The plates are surrounded by an electrolyte. Electrolytes are chemical solutions that react with the metals used to construct the plates. These chemical reactions cause a lack of electrons on the positive electrode and an excess on the negative electrode. When connected into a circuit, the electrons move out of the negative terminal and the chemical reactions begin. The reactions continue to provide electrons for current flow until the circuit is opened or the chemicals inside the battery become weak. At that time, either the battery has run out of electrons, or all the protons are matched with an electron. Recharging simply reverses the chemical reaction and restores the battery to its original chemical state.

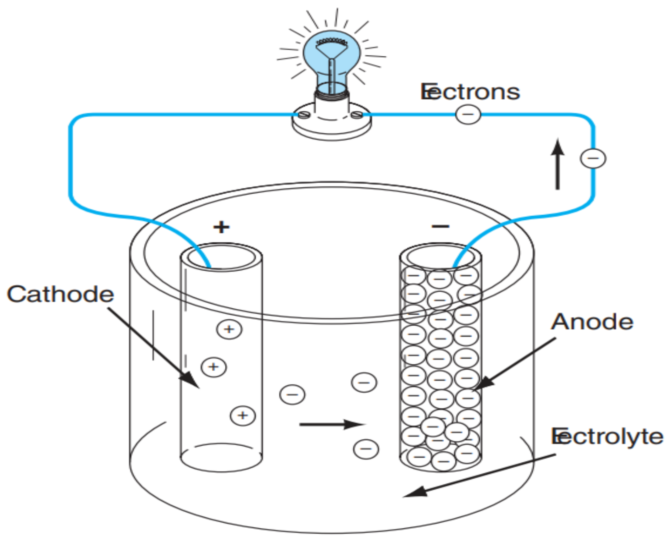


Figure 2- 3 Electrolysis Process

2.2 Types of EV Batteries

The following battery types can be or are being used in electric drive vehicles. There are many other types available, but they are not relevant to the topic of this book. Some of the batteries in the list that follows will be discussed in more detail later.

2.2.1 Lead-Acid

Lead-acid batteries are the most used starting batteries. This type of battery is rechargeable. In some electric vehicles, several lead acid cells are connected in series to provide high voltage. There are many variations to the basic design, but all work and are constructed in the same way. Lead-acid batteries are the kind of 12-volt batteries used in gasoline-powered cars to start the motor. They have been around for a long time and are inexpensive and safe to use. However, lead-acid batteries have a relatively short life, and don't perform well in cold weather. This sort of battery is only used in EVs to power supplemental auxiliary features, providing backup power to power steering, brake boosting, and to power the safety features in EVs. They cannot power the electric motors themselves.

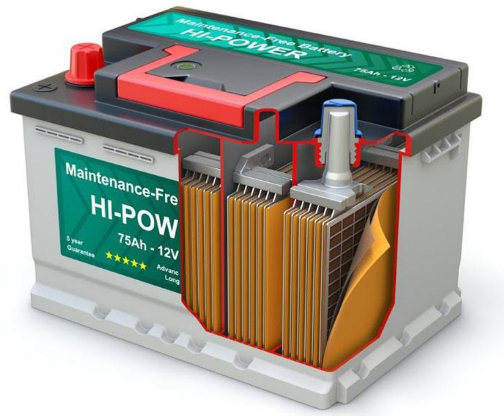


Figure 2- 4 Lead Acid Battery

2.2.2 Nickel Based Batteries

Two designs of nickel-based rechargeable batteries are commonly used: the nickel-metal hydride (NiMH) and nickel-cadmium (NiCad). Except for the materials used as the anode, a NiMH cell is constructed in the same way as a NiCad cell. Both designs are found in the same types of equipment such as laptop computers, digital cameras, and electric vehicles. The cell voltage from both designs is 1.2 volts, which makes them potentially interchangeable. Most of today's hybrid vehicles use NiMH batteries.

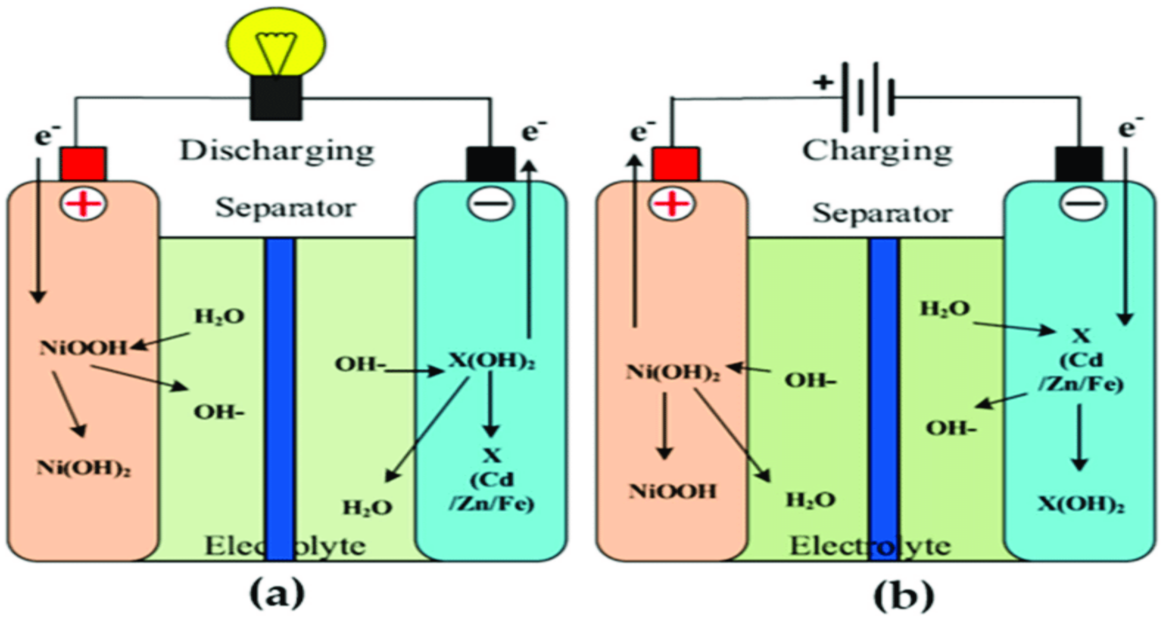


Figure 2- 5 Chemistry of nickel-based battery, (a) during discharging, (b) during charging

The chemical reaction happening at the positive electrode is comparable to that of the nickel–cadmium cell (NiCd), as both use nickel oxide hydroxide (NiOOH). The negative electrodes, on the other hand, are made of a hydrogen-absorbing alloy rather than cadmium. NiMH batteries can have two to three times the capacity of NiCd batteries of the same size, as well as a substantially better energy density than lithium-ion batteries, but at a lower cost.

2.2.3 Sodium-Based Batteries

Sodium-ion batteries are emerging as a potential alternative to lithium-ion batteries for electric vehicles (EVs). While lithium-ion batteries have dominated the EV market, their reliance on lithium and other scarce materials has raised concerns about supply chain stability and cost. Sodium, on the other hand, is abundant and widely available, making sodium-ion batteries a more affordable and sustainable option. Basically, there are two types of Sodium ion-based batteries:

a) Sodium-Sulfur (NaS)

The electrodes in a sodium sulfur battery cell are composed of molten sodium (negative electrode) and liquid sulfur (positive electrode). The plates are separated by a solid ceramic electrolyte, made from aluminum. The battery must be kept at about 5708F (3008C) to discharge and recharge. This battery design is very efficient and is currently being researched for possible use in electric drive vehicles.

b) Sodium-Nickel-Chloride

The electrodes in a sodium nickel-chloride cell are made with nickel and iron powders and sodium chloride (table salt). The electrodes are separated by a ceramic electrolyte. Sodium nickel-chloride batteries are also known as ‘‘ZEBRA’’ batteries. These batteries have nearly five times the energy density of a lead-acid battery and are totally recyclable. However, they must operate at high temperatures, and the required thermal management batteries were designed to be used in electric drive vehicles, including automobiles and trains.

2.2.4 Lithium-Based Batteries

Lithium-based batteries are very similar in construction to nickel-based batteries and cells. They have high energy density, do not suffer much from memory effect, and are environmentally friendlier. Lithium-ion batteries are used in EVs because they:

- They have high energy density: They can store a relatively large amount of electrical energy into a smaller and more lightweight package than other battery technologies.
- Perform well at high temperatures and can withstand low temperatures without being damaged.
- Have a low self-discharge rate, meaning that the battery holds its energy well even if it’s not used for days or weeks.
- Can withstand many charge cycles while retaining almost all of their original capacity.

There are two major types of lithium-based cells: lithium-ion and lithium-polymer. Lithium is the lightest known metal and provides the highest energy density of all known metals.

a) Lithium-Ion (Li-Ion)

Battery cells do not use lithium metal due to safety issues; instead, they use lithium compounds. The term lithium-ion (Li-Ion) applies to all batteries that use lithium regardless of the materials mixed with lithium. These compounds are the focus of much research. Recently, a manganese lithium-ion battery has been developed that may last twice as long as a NiMH battery.

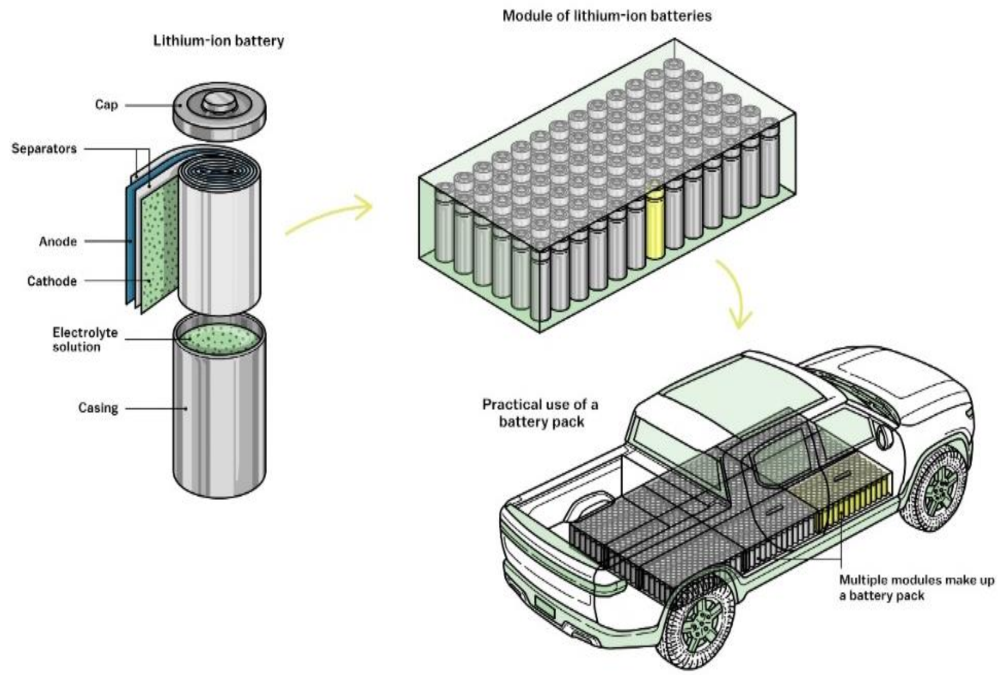


Figure 2- 6 Lithium-ion battery

Li-Ion cells have a voltage output of 3.6 volts. The compounds used in the cell determine the energy density of the cell. However, the higher-density designs are more dangerous than many other batteries. Safety issues also surface when connecting Li-Ion cells, in series or in parallel, to form a battery pack. Not all lithium-ion cells are designed to be used in a battery pack; only cells that meet tight voltage and capacity tolerances should be used. If the connected cells do not have the same output and capacity, the battery pack can be overcharged and cause a fire. Lithium-ion batteries are expensive to produce. This Because lithium metal is very reactive and can explode, the cycling of the battery must be monitored. A protection circuit limits the peak voltage of each cell during charging and prevents the voltage from dropping too low during discharge. The temperature of the battery pack is also monitored, and charge and discharge activity is controlled to prevent high temperatures. The circuit also contains electronics and/or fuses to prevent polarity reversal.

i. Chemical Reactions Lithium-Ion (Li-Ion)

As with other cells, ions move from the anode to the cathode when the cell provides electrical energy, and during recharging, the ions are moved back from the cathode to the anode. The anode is made of graphite, a form of carbon. The cathode is mostly comprised of graphite and lithium alloy oxide. The construction of the cathode is one of the areas that researchers are working on to produce a safer and stronger Li-Ion battery. Electrolytes are also the target of much research. The basic electrolyte is a lithium salt mixed in a liquid. Polyethylene membranes are used to separate the plates inside the cells and, in effect, separate the ion small pores that allow the ions to move within the cell.

ii. Charging Lithium-Ion (Li-Ion)

Li-Ion cells have a nominal voltage of 3.6 volts and a typical charging voltage of 4.2 volts. The cells should be charged with constant voltage, and the charging current should change in resp voltage of the cell. In other words, as the cell’s voltage increases, the charging current should decrease. Lithium-ion batteries should not be fast charged.

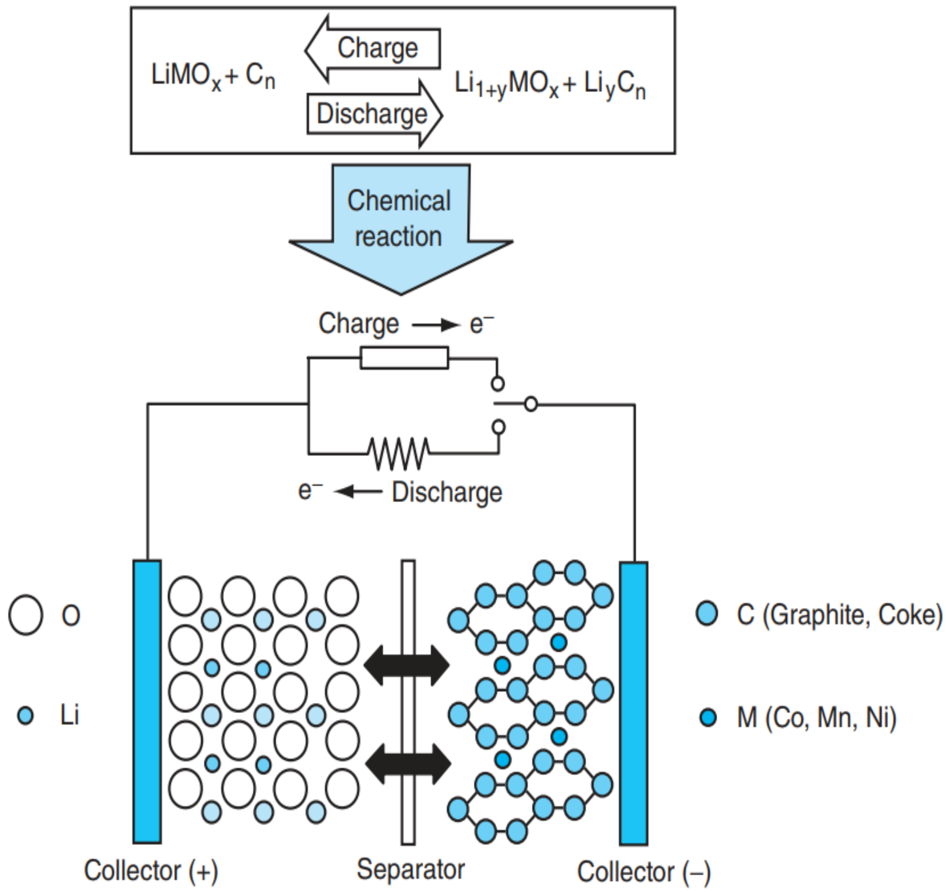


Figure 2- 7 Charging and discharging process of Li-ion Battery

Due to the explosive nature of lithium, certain precautions must be followed to safely discharge and charge Li-Ion batteries:

- Never connect cells in parallel and/or series if they do not have identical output voltages.
- Never charge or discharge the battery if it is not connected to its protection circuit.
- If the protection circuit does not have a temperature sensor, carefully monitor the battery's temperature while charging and discharging.
- Never charge a Li-Ion battery that is physically damaged.

b) Lithium-Polymer (Li-Poly)

Lithium-Polymer was developed through continuous research on the Li-Ion battery. The electrolyte used in Li-Poly cells is not a liquid; rather, the lithium salt is held in a solid polymer composite (such as polyacrylonitrile). The polymer electrolyte is not flammable, and these batteries are less hazardous than Li-Ion batteries. The dry polymer electrolyte does not conduct electricity. Instead, it allows ions to move between the anode and cathode.

The polymer electrolyte also serves as the separator between the plates. The dry electrode has very high resistance and therefore cannot provide bursts of current for heavy loads. The voltage of a Li-Poly cell is about 4.23 volts when fully charged. The cells must be protected to prevent overcharge. However, these cells are more resistant to overcharging than Li-Ion cells, and there is much less chance for electrolyte leakage.

Li-Poly cells are expensive to manufacture and have a much higher cost-to-energy ratio than lithium-ion cells. However, since Li-Poly cells do not use a metal case, they are lighter and can be packaged in many ways. As a result, Li-Poly cells have a much higher energy density than Li-Ion, NiMH, and NiCad batteries. In some Li-Poly cells, a gelled electrolyte has been lithium-ion-polymer cells.

2.2.5 Ultracapacitors

Ultracapacitors store energy in the interface between an electrode and an electrolyte when voltage is applied. Energy storage capacity increases as the electrolyte-electrode surface area increases. Although ultracapacitors have low energy density, they have very high-power density, which means they can deliver high amounts of power in a short time. Ultracapacitors can provide vehicles additional power during acceleration and hill climbing and help recover braking energy. They may also be useful as secondary energy-storage devices in electric-drive vehicles because they help electrochemical batteries level load power.

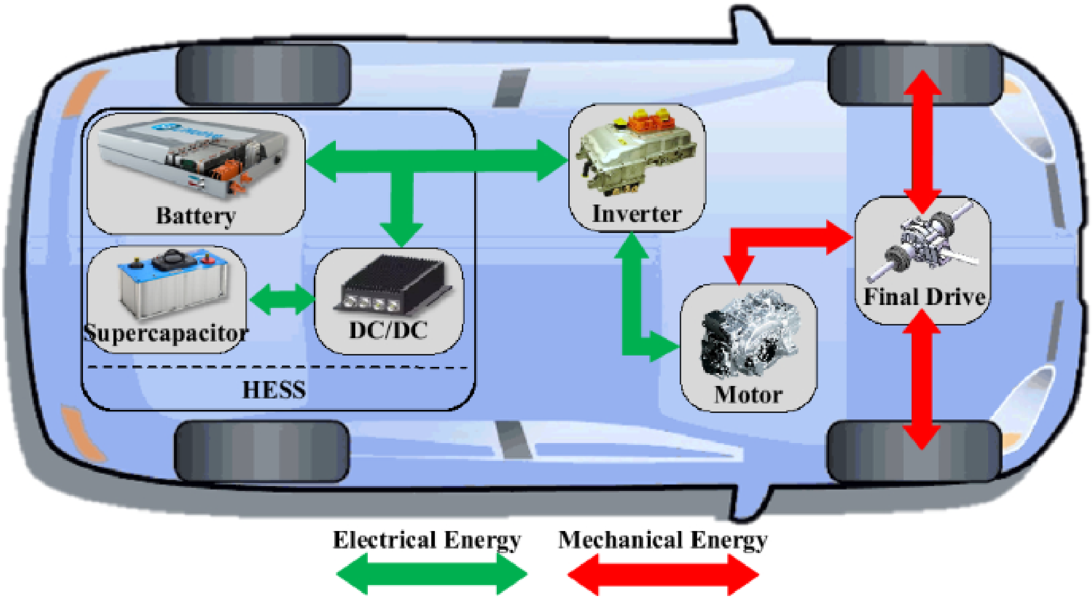


Figure 2- 8 Ultracapacitors battery layout

2.2.6 Zinc-Air

The zinc-air cell is commonly used in hearing aids but has been tested and modified for possible use in electric drive vehicles. The interesting characteristic of this battery is that oxygen from the outside air is used as the cathode.

The anode is a replaceable cassette made of zinc particles in an electrolyte solution of potassium hydroxide. Within the cell, a chemical reaction produces electrical energy, and the cells are not electrically rechargeable. They can, however, be recharged by replacing the anode cassette. This type of battery is lightweight and has very high energy density.

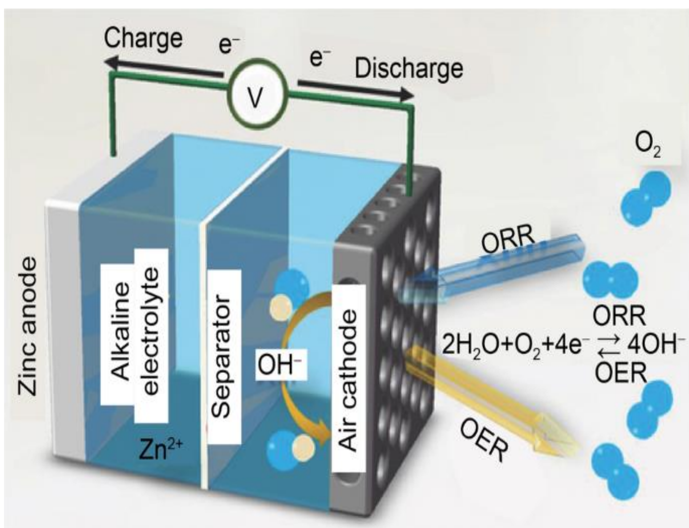


Figure 2- 9 Zinc-Air Battery

2.2.7 Solid-State Batteries for Electric Cars

In the next few years, solid-state batteries may well be the battery of choice for electric cars. They can reduce the carbon footprint of EV batteries by nearly 40 percent. Solid-state technology uses solid ceramic material instead of liquid electrolytes to carry the electric current, making the batteries cheaper, lighter, and faster to charge. BMW and Ford are testing the batteries now for use in 2025 vehicles. Solid-state batteries are also capable of having a driving range of 500 miles, eliminating "range anxiety."

2.3 Battery Management System (BMS)

A Battery Management System (BMS), which manages the electronics of a rechargeable battery, whether a cell or a battery pack, thus becomes a crucial factor in ensuring electric vehicle safety. It safeguards both the user and the battery by ensuring that the cell operates within its safe operating parameters. BMS monitors the State of Health (SOH) of the battery, collects data, controls environmental factors that affect the cell, and balances them to ensure the same voltage across cells.

A battery pack with a BMS connected to an external communication data transfer system or a data bus is referred to as a smart battery pack. It may include additional features and functions such as fuel gauge integration, smart bus communication protocols, General Purpose Input Output (GPIO) options, cell balancing, wireless charging, embedded battery chargers, and protection circuitry, all aimed at providing information about the battery's power status. This information can help the device conserve power intelligently.

A smart battery pack can manage its own charging, generate error reports, detect and notify the device of any low-charge condition, and predict how long the battery will last or its remaining run-time. It also provides information about the current, voltage, and temperature of the cell and continuously self-corrects any errors to maintain its prediction accuracy. Smart battery packs are usually designed for use in portable devices such as laptops and have embedded electronics that improve the battery's reliability, safety, lifespan, and functionality.

These features enable the development of end products that are user-friendly and more reliable. For instance, with embedded chargers, batteries can have longer life cycles as the chargers charge the batteries to optimal, ideal specifications within the temperature limits. Accurate fuel gauges allow users to confidently discharge batteries to their limits and not worry about damaging the cell. GPIO, which stands for General Purpose Input/Output (GPIO), is an interface used to connect electronic devices and microcontrollers such as diodes, sensors, displays, and so on.

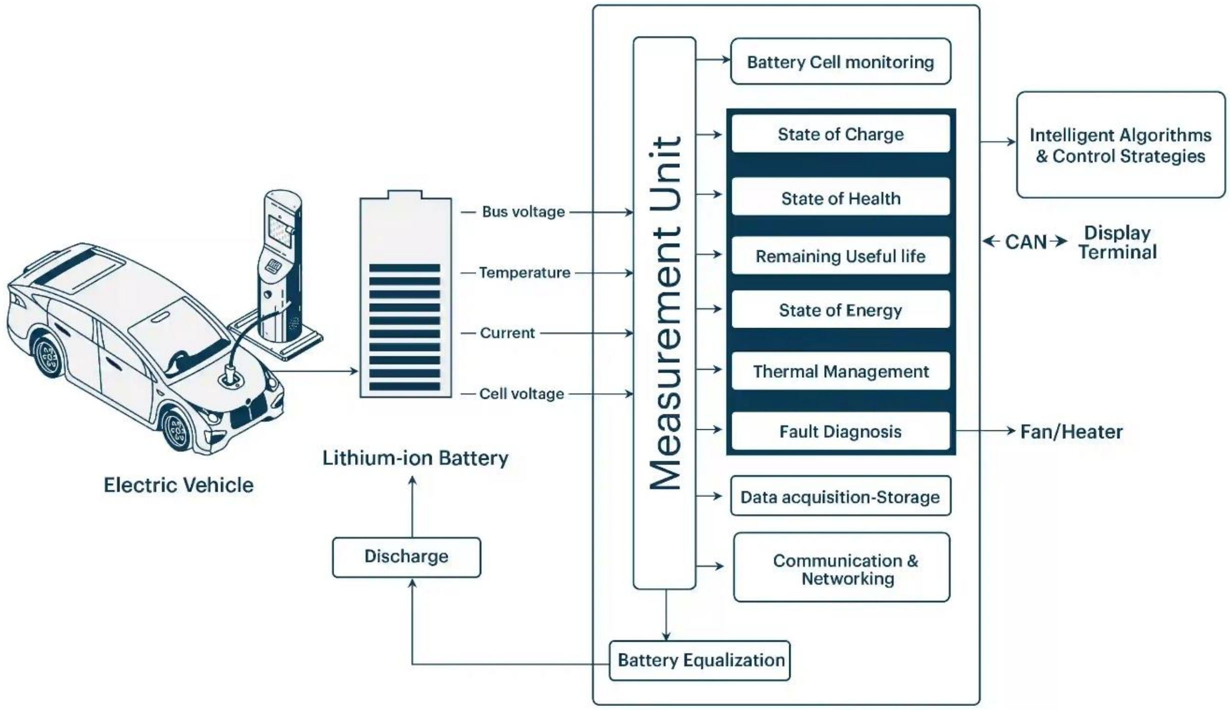


Figure 2- 10 Battery Management System Layout

2.3.1 Functions of the BMS

Fitting an EV with a BMS can improve safety. The battery management system performs the following four functions:

1. Monitoring battery parameters

This is the primary function of a BMS. It monitors the state of a cell as represented by parameters such as:

- Voltage—indicates a cell's total voltage, the battery's combined voltage, maximum and minimum cell voltages, and so on.

- Temperature—displays the average cell temperature, coolant intake and output temperatures, and the overall battery temperature.
- The state of charge of the cell shows the battery's charge level.
- The cell's state of health—shows the remaining battery capacity as a percentage of the original capacity.
- The cell's state of power——shows the amount of power available for a certain duration given the current usage, temperature, and other factors.
- The cell's state of safety——determined by keeping a collective eye on all the parameters and determining if using the cell poses any danger.
- The flow of coolant and its speed.
- The flow of current into and out of the cell.

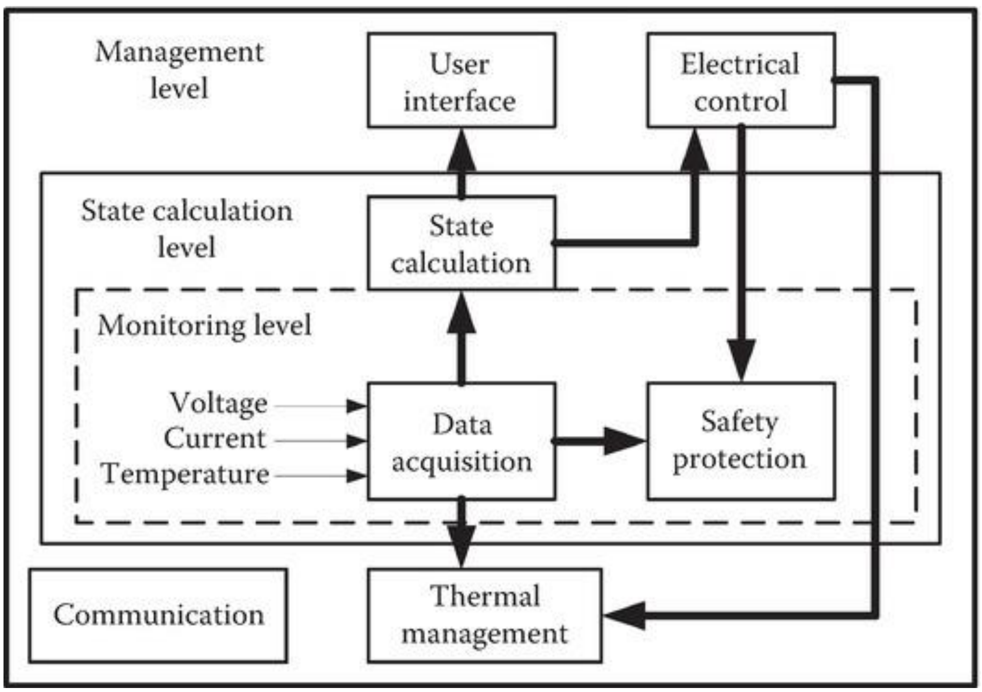


Figure 2- 11 Monitoring battery parameters

2. Managing thermal temperatures

Temperature is the biggest factor affecting the battery. The battery's thermal management system keeps an eye on and controls the temperature of the battery. These systems can either be passive or active, and the cooling medium can either be a non-corrosive liquid, air, or some form of phase change. Using air as a coolant is the simplest way to control battery temperatures.

Air cooling systems are often passive as they rely on the convection of the surrounding air or use a fan to induce airflow. However, the main drawback is the system's inefficiency. Significant power is used to run the cooling system as compared to a liquid-based one. Also, in larger systems such as batteries, the additional components needed for air-based systems such as filters can increase the weight of the car, further affecting the battery's efficiency.

Liquid-cooled systems have a higher cooling potential than air because they are more thermally conductive. The batteries are submerged in coolant, or the coolant can freely flow into the BMS without affecting the battery. However, this indirect form of thermal cooling can create large temperature differences across the BMS due to the length of the cooling channels. But they can be reduced by pumping the coolant faster, so a tradeoff is created between the pumping speed and thermal consistency.

3. Making key calculations

A BMS calculates various battery values based on parameters such as maximum charge and discharge current to determine the cell's charge and the discharge current limits. These include:

- The energy in kilowatt-hour(s) (kWh) delivered since the last charge cycle
- The internal impedance of a battery to measure the cell's open-circuit voltage
- Charge in Ampere per hour (Ah) delivered or contained in a cell (called the Coulomb counter), to determine the cell's efficiency
- Total energy delivered and operating time since the battery started being used
- Total number of charging-discharging cycles the battery has gone through

4. Facilitating internal and external communication

A BMS has controllers that communicate internally with the hardware at a cellular level and externally with connected devices. These external communications differ in complexity, depending on the connected device. This communication is often through a centralized controller, and it can be done using several methods, including:

- Different types of serial communications

- CAN bus communicators, often used in vehicles
- DC-BUS communications, which are serial communications over power lines
- Various types of wireless communication including radio, pagers, cellphones, and so on.

Only a high-level voltage BMS has internal communication; low-level centralized ones simply measure cell voltage by resistance divide. A distributed or modular BMS must utilize a low-level internal cell controller for modular architecture or implement controller-to-controller communication for distributed architecture. However, communication is difficult, especially in high voltage systems, due to the voltage shift between cells. What this means is that the ground signal in one cell may be hundreds of volts higher than that of the next cell.

This issue can be addressed using software protocols or using hardware communication for volt-shifting systems. There are two methods of hardware communication, using an optical-isolator or wireless communication. Another factor hampering internal communication is the restriction of the maximum number of cells that can be used in a specific BMS architectural layout. For instance, for modular hardware, the maximum number of nodes is 255. Another restriction affecting high voltage systems is the seeking time (for reading voltage/current) of all cells, which limits bus speeds and causes loss of some hardware options.

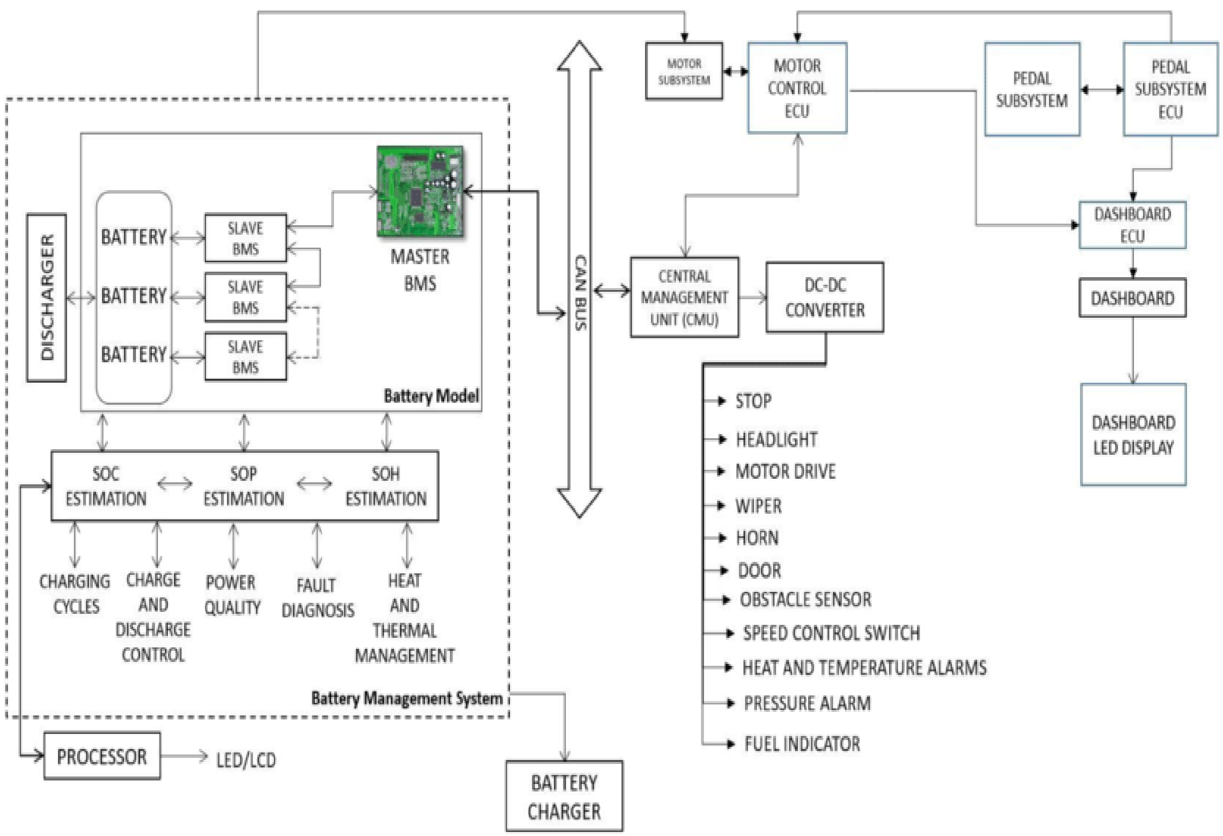


Figure 2- 12 BMS CAN BUS communication

2.4 EV Battery charging

Refueling a BEV simply means charging the batteries. Recharging involves connecting a battery charger to a source of electricity and connecting the charger to the battery pack. Battery chargers may be internal or on-board (in the vehicle) or external or off-board (at a fixed location). There are advantages and disadvantages to both. An on-board charger allows the batteries to be recharged wherever there is an electrical outlet. The disadvantage of on-board chargers is their added weight and bulk. To minimize this, manufacturers normally equip vehicles with low power chargers that require long charge times. Offboard chargers, however, force the driver to charge the decrease the time required to charge the batteries. Some manufactured EVs with off-board chargers also have a convenience charger. These on-board chargers plug into standard 110-volt outlets and allow the driver to recharge batteries wherever there is electricity available.

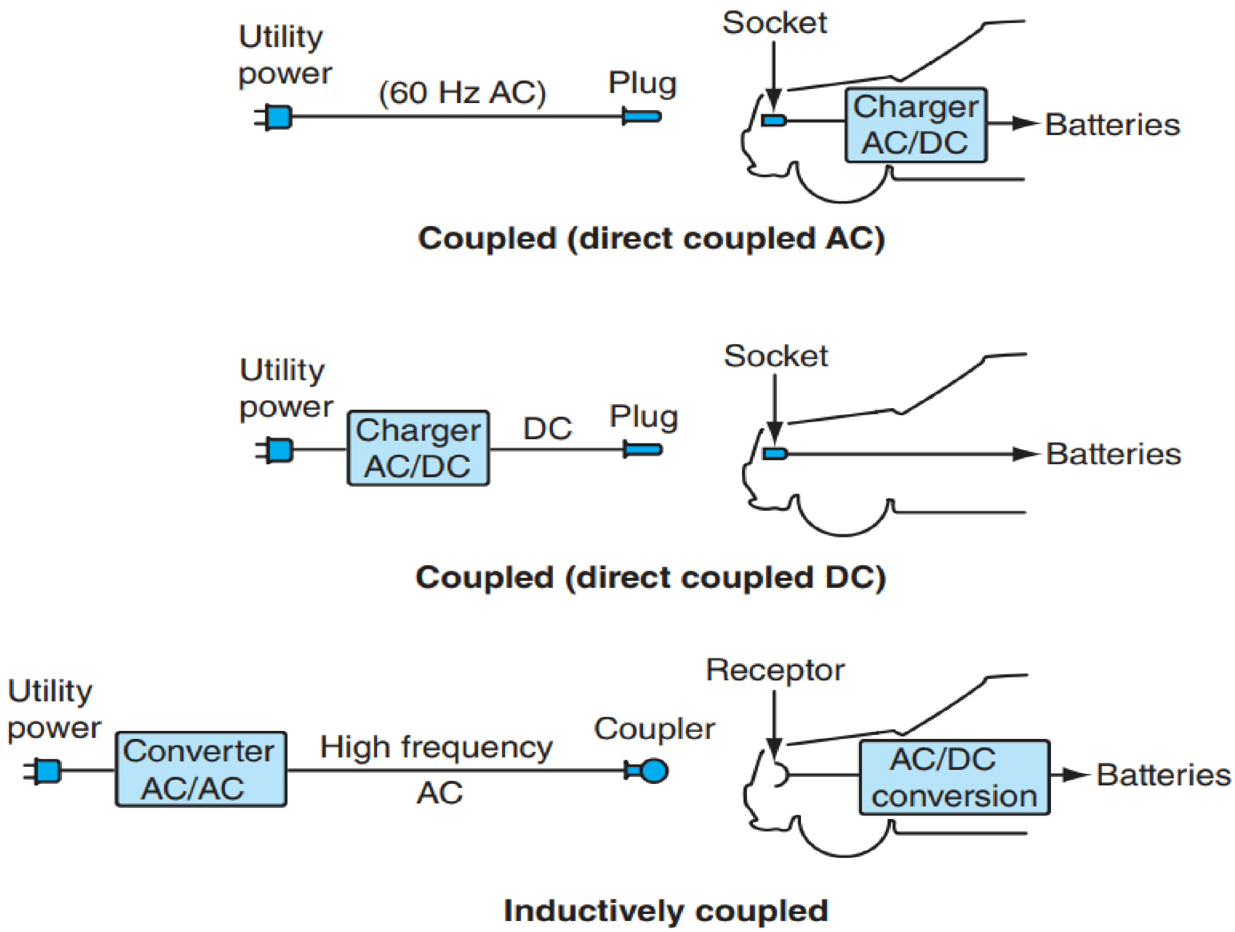


Figure 2- 13 EV Battery charging type

It normally takes several hours to recharge the battery pack. The required time varies with the size and type of battery pack and battery charger. New designs for chargers have been able to recharge a battery pack in less than 20 minutes. These chargers use sophisticated electronics to monitor the cells and regulate the charging voltage and current. Being able to quickly charge the batteries would certainly make an electric vehicle more practical.

The connections between the battery charger and the power outlet can be an ordinary plug (as used for golf cars) or a specialized connector to improve safety (as used for electric automobiles). These specialized connections contain ground-fault interrupters that break the circuit if any electrical current leakage to the ground is detected, such as when charging the vehicle when it is wet.

2.4.1 Types of EV charger connection

There are two basic ways EV is connected to an external source of electricity for charging. One is the traditional coupling is plugged into a receptacle on the vehicle, in the other type of coupling is called an inductive coupling. This coupling uses a paddle that fits into a socket on the vehicle. Let's discuss independently:

A. Conductive Charging

Conductive charging is a 110 or 220V recharging method. AC electricity from the local utility or other source is transformed to the voltage required for the battery pack, converted into DC, and fed to the batteries via conductive, metal-to-metal contact. With a conductive charger, a connector, it safely makes the link between the power supply and the vehicle's charge port. The connector section to the vehicle's internal charge port. This type of charging is used with most on-board chargers. Some off-board chargers also use conductive coupling.

Figure 2- 14 Conductive Type Charging

B. Inductive Charging

Inductive charging is a 220 VAC recharging system that transfers electricity from a charger to the vehicle using magnetic principles. To charge the batteries, a weatherproof paddle is inserted into the vehicle's charge port. The paddle and charge port form a magnetic coupling. The external charging unit sends current through the primary wind inside the paddle. The resulting magnetic flux induces an alternating current in the secondary winding, which is in the charge port. The connection is basically a transformer with the primary winding in the paddle and the secondary winding in the vehicle.

The induced AC is then converted to DC (within the vehicle) to recharge the batteries. There is no metal-to-metal contact between the charge paddle and the charge port of the vehicle. This system provides a safe and easy-to-use way to recharge the batteries. Inserting the paddle begins the charging process. The insertion of the paddle completes a communication link between the charger and the vehicle. The charger displays what percentage of charge remains in the batteries and an estimate of the time needed to fully charge the batteries. This link also allows the charging unit to enter self-diagnostics and prevents the vehicle from being driven while the paddle is inserted in its port. If the charging cable becomes damaged or cut, power will shut off within milliseconds. The charging process ends immediately after the paddle is removed from the port.

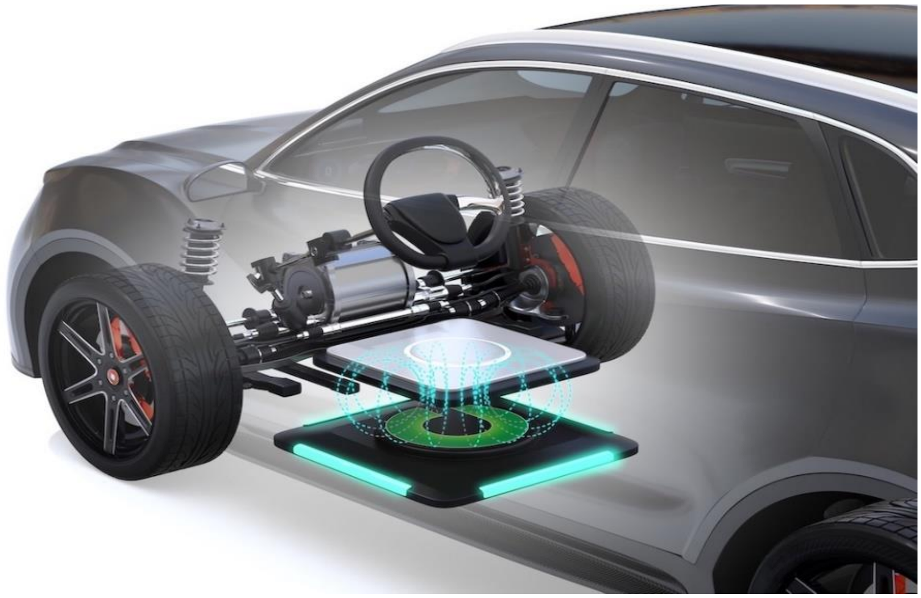


Figure 2- 15 Inductive type charging

2.4.2 Charge Levels

Battery chargers are classified by the level of power they can provide to the battery pack:

- Level 1—Level 1 chargers use the standard household three-prong electrical plug. They are usually portable and have ratings of up to 120 VAC and 15 amps.
- Level 2—Typically, an on-board charger with ratings of up to 240 VAC and 60 amps. Greater than 240 VAC and 60 amps.

- Fast chargers are rated as Level 3 chargers. However, not all Level 3 chargers are fast chargers. A charger can be considered a fast charger if it can charge an average battery pack in 30 minutes or less.

2.4.3 EV Charging Connector Types

There are regional and model-specific variations in the standard for EV charging connectors or EV charging plugs. Whereas there is debate about universal plug technology, the Combined Charging System (CCS) is supported by a significant number of international manufacturers in the United States and Europe, while Japan and its manufacturers utilize CHAdeMO, and China, which is the largest market for electric vehicles, employs GB/T. There are also several power levels accessible in each location, depending on the type of EV charging connector.

A. J1772 connector Type

The SAE J1772 connector, commonly referred to as a Type 1 connector, is a charging standard for electric vehicles prevalent in North America and Japan. It boasts of five pins and has the capacity to charge up to 80 amps using 240 volts input, with a maximum power output of an impressive rate. This charging solution is suitable for Level 1 and Level 2 EV chargers that rely on single-phase AC charging. However, the Type 1 connector lacks an automatic locking mechanism, which makes it less secure than the Type 2 connector used in Europe.

B. Mennekes Connector Type 2

The Mennekes connector, also referred to as the Type 2 connector, is a popular charging standard in Europe. This connector has seven pins and can charge up to 32 amps with 400 volts input, providing a maximum power output of 22 kW. It is capable of supporting both single-phase and three-phase AC charging for Level 2 chargers. One of its distinguishing features is the automatic locking mechanism, whereby the connector locks into place automatically when connected to the EV for charging. This feature ensures that the charging cable is not accidentally disconnected during the charging process, improving safety and convenience.

C. CCS Connector Type 1

output of 360 kW, making it one of the fastest charging options available. The CCS Type 1 connector is an improvement of the J1772 standard, as it adds two high-speed DC charging pins to the J1772 Type 1 plug, allowing for faster charging. This connector is commonly used in North America and is compatible with most Level 2 and DC fast charging stations. With the ability to deliver high power at a fast rate, the CCS Type 1 connector is a popular choice for EV owners looking to charge their vehicles quickly and efficiently.

D. CCS Connector Type 2

The CCS Type 2 connector is the primary DC fast charging standard used in Europe, and it's rapidly gaining popularity in other regions as well. This connector combines the Mennekes Type 2 plug with two additional high-speed charging pins, allowing for faster charging times and greater convenience. With the ability to provide up to 500 amps and 1000 volts DC, a CCS 2 charger can deliver a maximum power output of 360 kW, making it one of the most powerful and efficient charging options available for electric vehicles. The CCS Type 2 connector is designed for use with Level 2 and Level 3 chargers, making it suitable for a wide range of electric vehicle models.

E. CHAdeMO Connector

The CHAdeMO connector is a DC fast-charging standard that was initially developed by Japanese automakers and released before CCS. It can charge EVs up to 400 amps, providing a maximum power output of 400 kW. The CHAdeMO protocol is not as universal or widespread as CCS, but ongoing development is taking place to enable even faster charging. However, with Japanese automakers adapting models to CCS connectors for North American and European markets, we may see fewer CHAdeMO chargers in markets outside of Japan in the future.

F. GB/T Connectors

The GB/T connectors are the national standards for EV charging in China, with separate versions for AC and DC charging. The AC connector can deliver up to 7.4 kW of power output, while the DC connector can deliver up to 237.5 kW. The GB/T DC connector is currently the only fast charging protocol used in China, with plans to develop a next-generation connector in partnership with CHAdeMO to achieve 900 kW output power. Despite the incompatibility with the European Mennekes plug, the GB/T AC connector's appearance is similar.

G. TESLA Connectors

Tesla connectors vary depending on the region and model. In North America, Tesla uses its proprietary NACS connector, which can deliver up to 250 kW and is only compatible with Tesla's. In Europe and most parts of the world, Tesla Model 3 and Y use a CCS Type 2 connector, while Model S and X use a modified Type 2 plug with notches to prevent non-Tesla sockets. However, Tesla recently made its EV charging connector available to other EV manufacturers to promote EV adoption and charging infrastructure development.

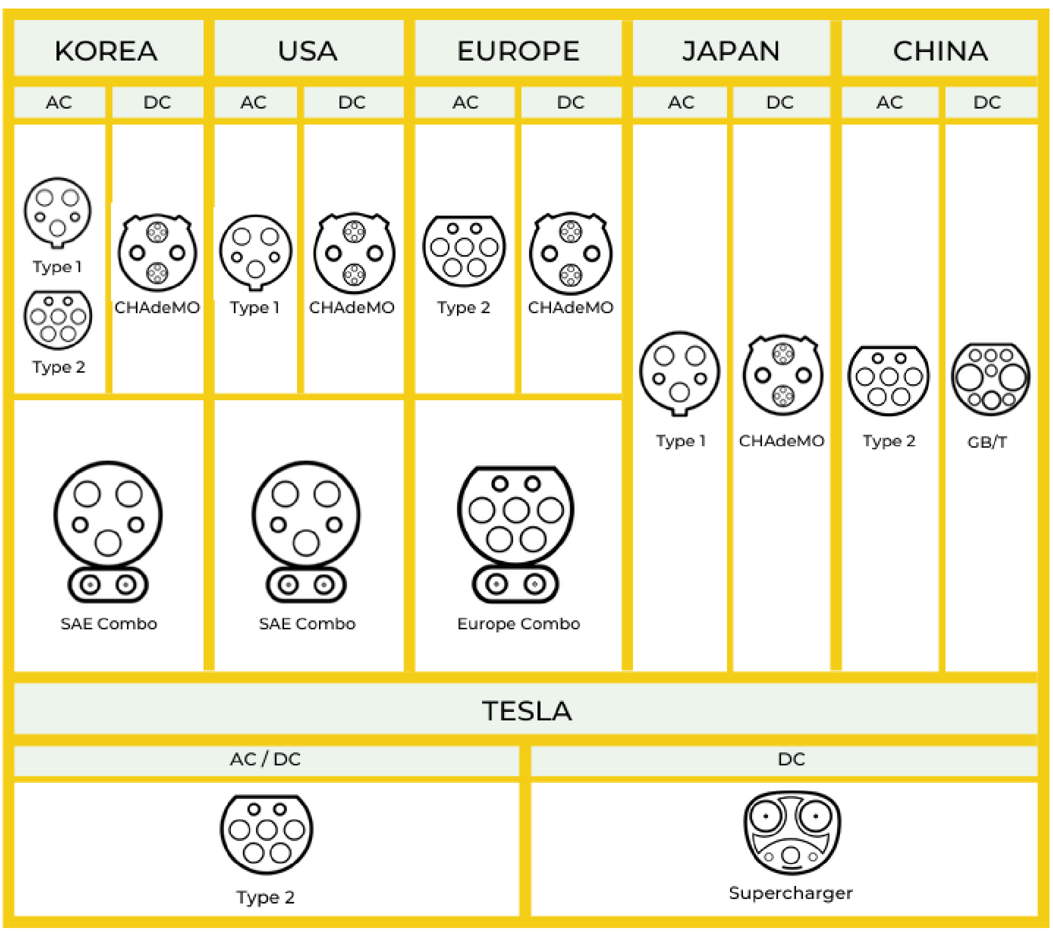


Figure 2- 16 EV Charger Connector types

Self-check 2.1

Directions: Answer all the questions listed below.

Part I: Say True or False

1. Electrolytes are responsible for maintaining chemical reactions within a battery.
2. Recharging a battery involves reversing the chemical reactions within it.
3. Lead-acid batteries are the primary power source for most modern electric vehicles.
4. Nickel-metal hydride (NiMH) batteries offer significantly higher energy density than lead-acid batteries.
5. Sodium-sulfur batteries require high operating temperatures.
6. Lithium-ion batteries are known for their low energy density compared to other battery types.
7. Lithium-polymer batteries are considered safer than traditional lithium-ion batteries due to their solid-state electrolyte.
8. Ultracapacitors are ideal for applications requiring high power output for short durations.
9. Zinc-air batteries are rechargeable in the same way as traditional lead-acid batteries.
10. Solid-state batteries are a promising technology for future electric vehicles due to their potential for higher energy density and faster charging times.

Part-II: Choose the appropriate answer from the given alternatives

1.Which power electronics device is primarily responsible for converting DC power from the battery into AC power for the electric motor?

a) Rectifier c) Charger
b) Inverter d) Controller

2. During regenerative breaking, which power electronics device converts the AC power generated by the motor back into DC power for the battery?

a) Inverter c) Charger
b) Rectifier d) Controller

3. Which of the following is NOT a key function of power electronics in EV charging systems?

a) Converting AC mains power to DC for battery charging

b) Regulating charging current and voltage

c) Protecting the battery from overcharging

d) Directly powering the electric motor

4.Wide-bandgap materials like SiC and GaN are used in power electronics to:

a) Increase energy consumption

b) Reduce efficiency

c) Increase size and weight

d) Improve efficiency and reduce size

5.What is the primary function of a DC-DC converter in an EV?

a) Convert DC power to AC power

b) Step up the high battery voltage to lower voltages for accessories

c) Step down the low-voltage AC power from the grid

d) Control the speed of the electric motor

Part-III: Give a short answer for the following questions

1. Explain the role of Pulse Width Modulation (PWM) in power electronics for EV inverters.
2. Describe the significance of bidirectional charging (V2G) and the role of power electronics in enabling this technology.
3. Discuss the importance of thermal management for power electronics components in EVs.
4. Explain the difference between a step-up and a step-down converter.
5. How do power electronics contribute to the overall efficiency and performance of an electric vehicle?

Operation Sheet 2.1

Operation Title: Charging Electrical Vehicle

Instruction:

- The charging equipment is a high voltage electrical device. Minors are prohibited from charging or touching the charging equipment. In addition, keep minors away from the vehicle when charging.
- Charging may affect medical or implanted electronic devices. Consult the device manufacturer before charging.
- Charge the vehicle in a relatively safe environment, and avoid charging in damp areas, or areas with fine or heat sources.
- Protect the charging equipment against water contact on rainy days.

Purpose: To perform charge Electric Vehicle

Required Tools and Equipment: EV Charger with compatible connector

Precautions:

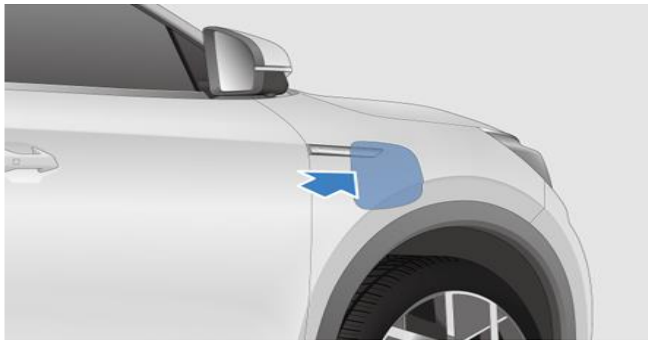
- Make sure that power supply equipment, charging connector, charging port, and charging
- connection devices are free of defects, such as cable wear, rusted ports, cracked casings, or foreign objects in the ports.
- When the charging connector, port, power plug or socket is visibly stained or damp, wipe them with a dry and clean cloth to ensure the connection is dry and clean.
- Use charging equipment that complies with local standards.
- Do not modify, disassemble or repair the charging equipment and related ports to avoid charging failure or fire.

Quality Criteria: - Observing attentively

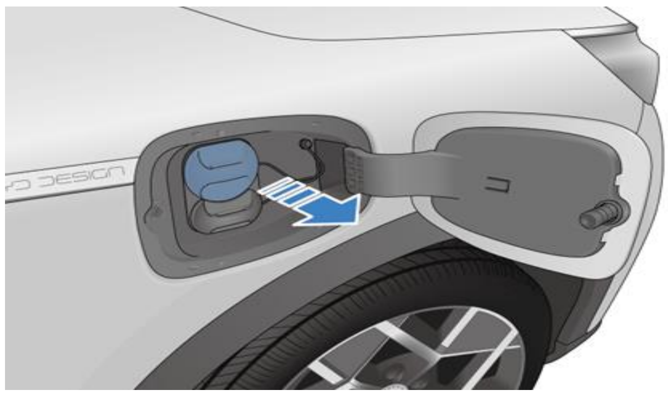
Procedures:

1. Charging

- Power off the vehicle.
- With the doors unlocked, press the charge port hatch to open.



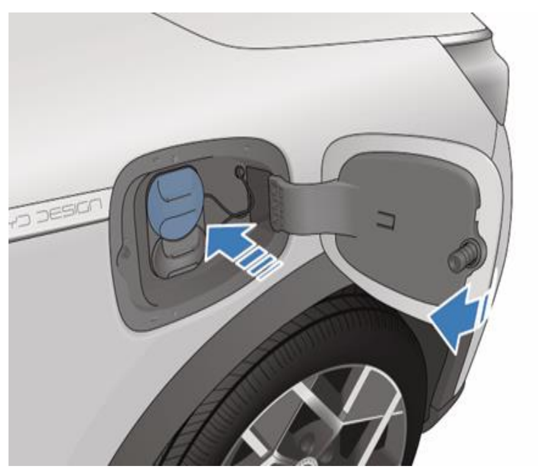
- Open the hatch and remove the charge port cap. Make sure the port is not obstructed in any way.



- Insert the Mode 2 plug into the household socket.
- Insert the charging coupler into the charging port.
- The connecting indicator on the instrument cluster or infotainment system lights up.

2. Stopping charging

- Charging will stop when the battery is fully charged.
- To stop earlier, first disconnect the charging port by pressing the door handle microswitch while carrying the smart key and pulling out the charging coupler.



- Disconnect the power plug.
- Reinsert the charge port cap and close
- The charge port hatch.
- Store the charging equipment properly.

Unit Three: Electric Motors and Power Electronics

This unit is developed to provide you with the necessary information regarding the following content coverage and topics:

- Governing Principles of Electric Motors
- Basic Motor Operation
- Types of Electric motors
- Power Electronics

This guide will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this learning guide, you will be able to:

- Grasp the governing principles of electric motors
- Understand the basic motor operation
- Differentiate electric motor types
- Comprehension of Power Electronics

3.1 Governing Principles of Electric Motors

When electrical current passes through a wire, a magnetic field is formed around that wire. The flux lines of the magnetic field form in concentric circles around the wire. The direction of the magnetic field can be determined by the left-hand rule.

This rules the direction of the current flow, your fingers will point in the direction of the magnetic

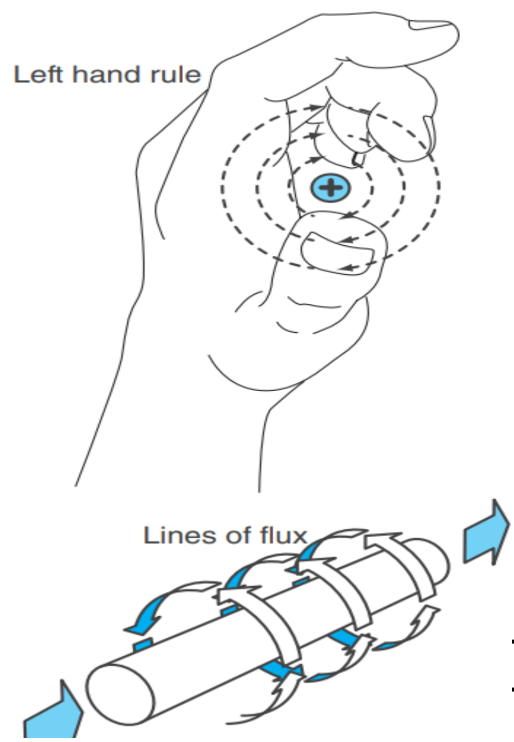


Figure 3- 1 Principles of Electric Motors

field. Remember, the attraction of poles is from north to south. When the wire is shaped into a coil or winding, the individual flux lines are produced by each section of wire join to form one large magnetic field around the total coil. The magnetic field around the coil can be strengthened by placing a core of iron or similar metal in the center of the coil. The iron core presents less resistance to the lines of flux than air, and the magnetic field's strength increases.

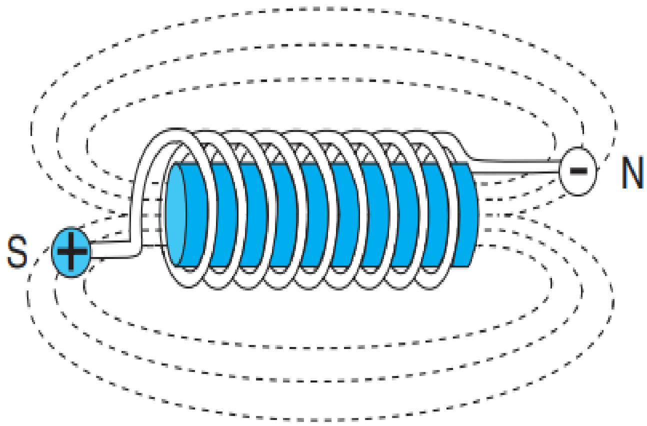


Figure 3- 2 Magnetic flux around a magnetic core

The basic components of a motor are the stator or field windings that are the stationary part of the motor and the rotor or armature that is the rotating part. The stator is comprised of slotted cores copper wire to form one or more pairs of magnetic poles. Some motors have field windings wound around iron anchors, called pole shoes. The rotor is comprised of loops of current-carrying wire, or it can be a series of permanent magnets. The magnetic fields in the rotor are pushed away by the magnetic field in the stator, causing the rotor to rotate away from the stator field. The use of an electromagnet in a motor makes it easy to change polarity in a magnetic field and keep a motor spinning. By changing the direction of current flow, the magnetic polarities are changed.

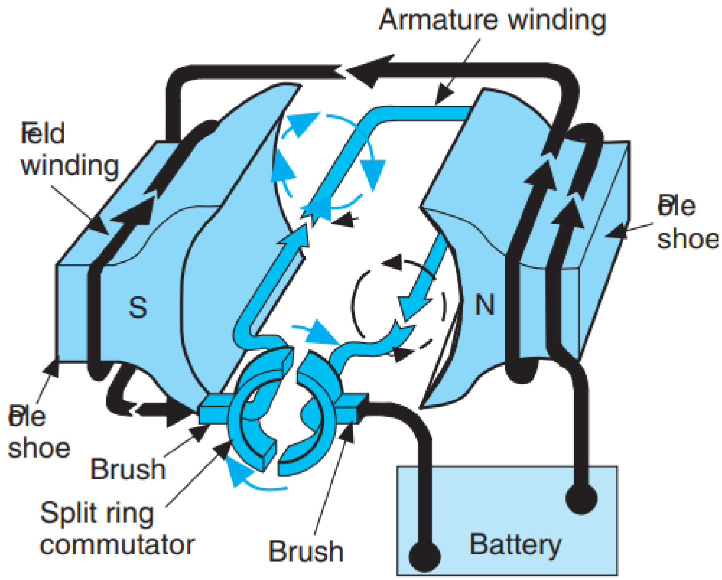


Figure 3- 3 Magnetic effect of motor

3.2 Basic Motor Operation

An electric motor converts electric energy into mechanical energy. Through the years, electric motors have changed substantially in design; however, the basic operational principles have remained the same. That principle is easily observed by taking two bar magnets and placing them end-to-end with each other. If the ends have the same polarity, they will push away from each other. If the ends have the opposite polarity, they will move toward each other and form one magnet. If we put a pivot through the center of one of the magnets to allow it to spin, and move the other magnet toward it, the first magnet will either rotate away from the second or move toward it.

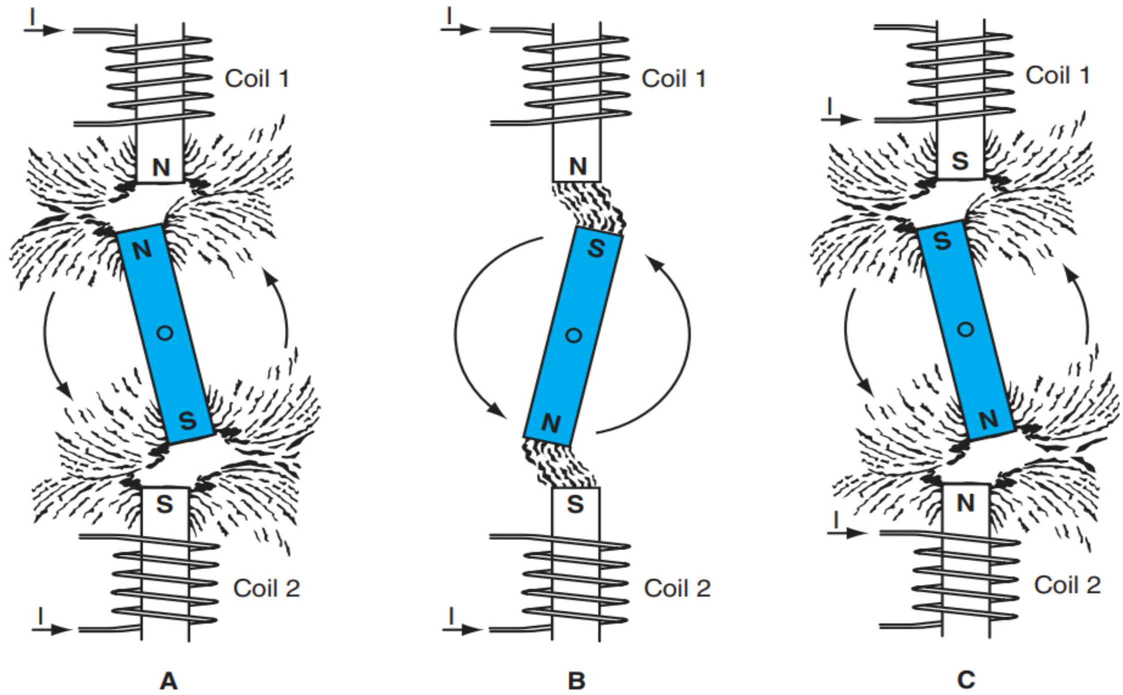


Figure 3- 4 Magnetic effects(A) Like poles repel, (B) unlike poles are attracted to each other, and if we change the polarity of the coils, (C) the like poles again repel.

This is basically how a motor works. Although we do not observe a complete rotation, we do see part of one, perhaps half turn. If we could change the polarity of the second magnet, we would get another half turn. So, to keep the first magnet spinning, we need to change the polarity immediately after it moves halfway. If we continued to do this, we would have a motor. In a real motor, an electromagnet is fitted on a shaft. The shaft is supported by bearings or bushings to allow motor. Surrounding, but not touching, this inner magnet is a stationary permanent magnet or an electromagnet.

There is more than one magnet or magnetic field in both components. The polarity of these magnetic fields is quickly switched, and we have constant opposition and attraction of magnetic fields. Therefore, we have a constantly rotating inner magnetic field, the shaft of which can do work due to the forces causing it to rotate. This force is called torque. The torque of a motor varies with rotational speed, motor design, and the amount of current drawer the motor has. The speed of the rotation depends on several factors, such as the current draw of the motor, the design of the motor, and the load on the motor's rotating shaft.

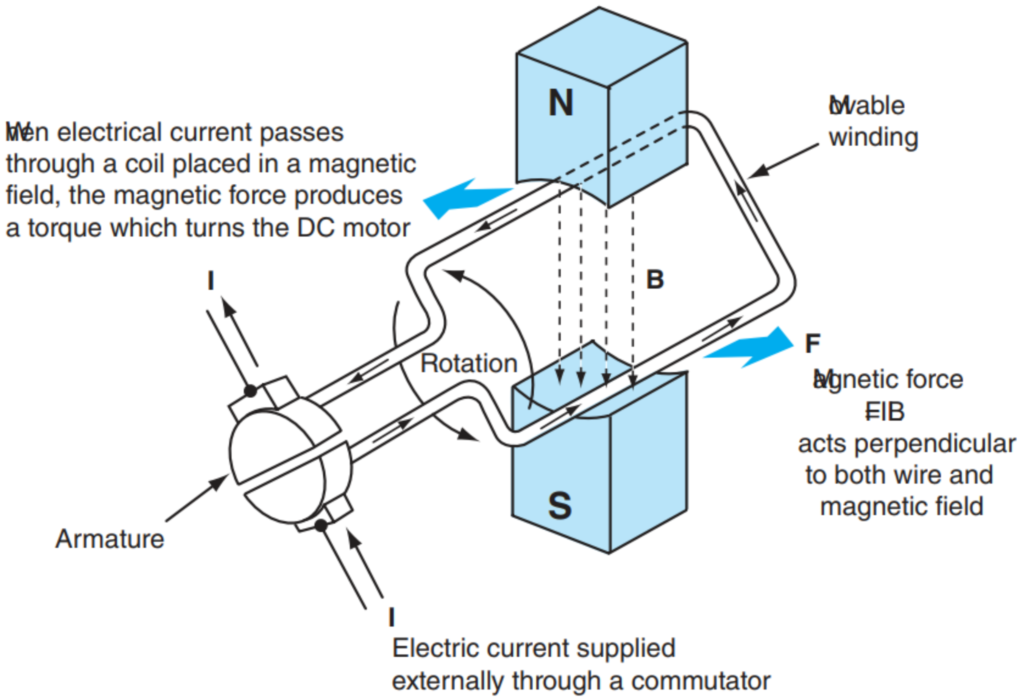


Figure 3- 5 Effect of magnetic on motor operation

3.3 Types of Electric motors

3.3.1 Dc Motors

The design of a DC motor is quite simple. It has housing, field coils (windings), an armature, a commutator and brushes, bearings, brush supports, and end frames. The motor has a stationary magnetic field and a rotating magnetic field. The stationary field is created by permanent magnets or electromagnetic windings. When the current flows through the armature (rotating) windings, a magnetic field is present around the armature windings.

Because the armature windings are formed in loops or coils, the current flows outward in one direction and returns in the opposite direction. Because of this, the magnetic lines of force are oriented in opposite directions in each of the two sides of the loop. When placed into the field coils, one part of the armature coil is pushed in one direction and the other is pushed in the opposite direction. This causes the coil and its shaft to rotate.

A. Parts of DC Motor

I. Motor Housing

The motor housing or frame encloses the internal components and protects them from damage, moisture, and foreign materials. The housing also holds field coils. The housing and end frames are usually made of steel, aluminum, or magnesium. The armature is mounted on a steel shaft supported by two bushings or bearings in the end frames. The shaft's bushings and bearings are typically lubricated by grease or oil. An end frame is a metal plate that bolts to the end of the motor housing.

II. Field Windings

The field windings or coils are normally made of copper wire and are insulated from but wrapped around metal plates, called pole shoes. The field coils and of the housing. The field coils are designed to produce strong stationary electromagnetic fields as current is passed through them. These magnetic fields are concentrated at the pole shoes. Fields have a north or south magnetic polarity depending on the direction of current flow. The coils are wound around respective pole shoes in opposite directions to generate opposing magnetic fields.

III. Armatures

The armature is made by coiling wire around two or more poles of the metal core fixed to a shaft. Armature is the only rotating component of a motor. It is in the center of the motor housing. One factor that determines the power output of a motor is the number of loops or windings in the armature. The armature is made up of two main components: the armature windings and the commutator.

IV. Commutator

To keep the armature of a motor rotating, the polarity of its magnetic field must change. To do this, the armature of DC motors fits with a commutator, which has plates connected to each of the armature loops. Electrical current enters and leaves the armature through a set of brushes that slide over the commutator's pass from one segment of the commutator to another, current flow through a loop of the armature is established. As the armature rotates, the brushes connect with a different segment of the commutator, and a magnetic field is set up in another loop or the field in the previously excited loop is reversed.

B. Field Winding Designs

The number of armature coils and brushes vary with the design and purpose of the motor, as does how the armature and field coils are wired together.

I. Series Windings

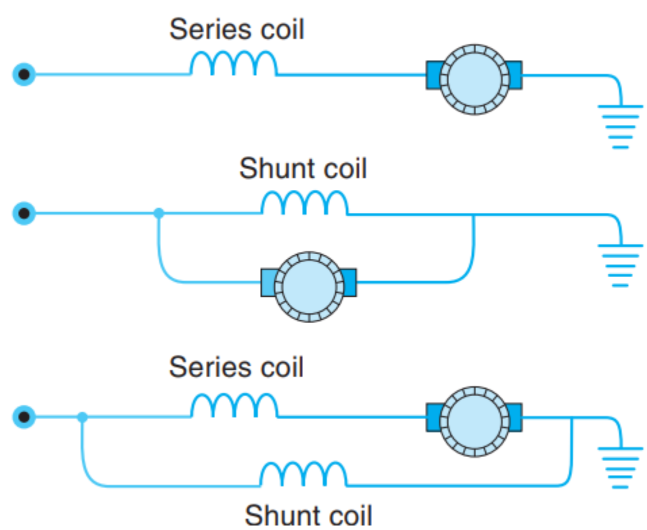
When the windings are connected in series with the armature, all current that passes through the field windings also passes through the armature windings. This type of winding allows the motor to develop maximum torque output at the time of initial start and when it is overloaded. As the speed of the motor increases, however, its torque output decreases. This is due to the CEMF created by self-induction. The speed of a series-wound motor changes greatly with a change in load. A series motor is often used in applications where there are heavy starting loads.

II. Shunt Windings

Shunt motors have field windings wired in parallel with the armature. A shunt winding usually consists of many turns of thin wire, but fewer turns than the series winding. A shunt motor does not decrease in its torque output as speeds increase. This is because the CEMF produced in the armature does not decrease the field coil strength. Shunt motors develop considerably less startup torque but maintain a constant speed at all operating loads.

III. Compound Windings

This type of winding has shunt winding and a series winding. This type of winding has good starting and constant-speed torque. The compound design is used where heavy loads are suddenly applied.



In a compound motor, some of the field coils are connected to the armature in series, and the rest are connected in parallel with the battery and the armature.

Figure 3- 6 The various ways the field windings may be connected to the brushes in DC motors.

C. Working Principle

By controlling the voltage to the armature, the speed of a DC motor is controlled. The higher the voltage to the armature, the faster it will rotate. Likewise, the torque output of a DC motor is controlled by the current to the windings and armature. Counter-EMF also affects the torque output of a motor. It limits the current flow based on the load on the motor. When the load increases, the rotation of the armature will slow down. This drop in rotational speed causes a decrease in CEMF, which allows for an increase in current flow. As a result, the motor turns with more torque. The reverse is also true; if the load on the motor is decreased, the armature speed inflows through the motor. There is less torque from the motor because less is needed.

3.3.2 Brushless DC Motors

A brushless DC motor is like a brushed DC motor, but the purposes of the rotor and field windings (stator) are reversed. The rotor is made up of a set of permanent magnets and the stator has controlled electromagnets. Obviously, a brushless motor has no brushes and no commutator. The electrical arcing that takes place between the brushes and commutator is also eliminated with the brushless design. This arcing not only decreased the usable life of the motor but also created electromagnetic interference that is detrimental to advanced electronic systems. In place of brushes, an electronic circuit switches current flow to the different stator windings as needed to keep the rotor turning. The reversing of current flow through the windings is done by power transistors that switch according to the position of the rotor.

3.3.3 AC Motors

With AC voltage, the direction of current flow changes but does not change immediately. Rather, as the current is getting ready to change directions, it decreases until it reaches zero and then gradually builds up in the other direction. Therefore, the amount of current in an AC circuit always varies. When AC is given as a value, it is referred to as a ‘‘root mean square (RMS) value. In other words, the value of AC voltage is not stated according to its positive and negative voltage peaks. The RMS value expresses the effective value of the AC voltage or current and is determined by multiplying the peak voltage by 70.7 percent.

1. Basic Construction

An AC motor has two basic electrical parts: a stator and a rotor. The Stator, the stationary field, is comprised of individual electromagnets electrically connected to each other or connected in groups. The rotor is the rotating magnetic field and can be an electromagnet or a permanent magnet. The rotor is located within the stator fields. Like in a DC motor, the rotor will rotate because of the repulsion and attraction of the magnetic poles. The way this works is quite different from how a DC motor works.

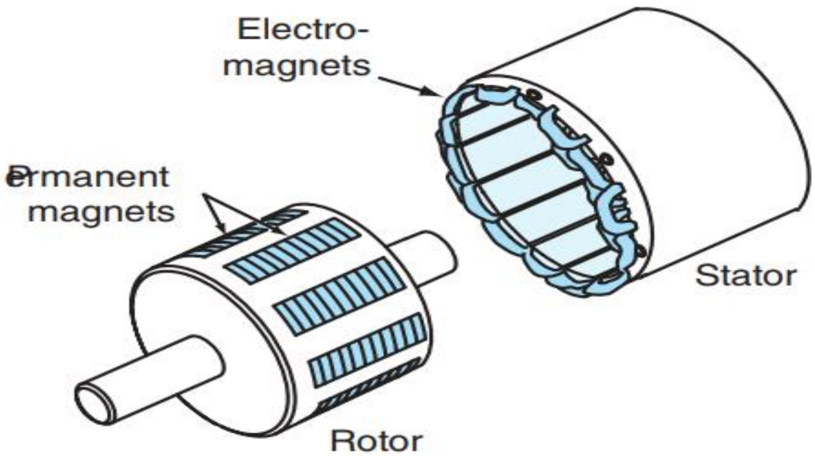


Figure 3- 7 The construction of the rotor and stator of an AC motor

2. Basic Operation

A current passes through the stator and rotor, causing the rotor to spin. Because of the current alternating, the polarity in the windings constantly changes. A synchronous AC motor will run at the frequency of the AC voltage. Many AC motors are induction types. In these motors, electrical current is induced in the rotor as it rotates, rather than having current delivered to it from an external source. Obviously, this type of motor needs to begin spinning before the rotor induces current, so these motors are equipped with a variety of starting aids.

The rotor in an AC motor rotates because it is pulled along by a rotating magnetic field in the stator. The stator does not physically move. The magnetic field does. If the windings of the stator are wired in series, current passes through them one at a time and because it is AC, the polarity and strength of the field around them is constantly changing . The magnetic field of the rotor reacts and moves along with the ‘‘rotating magnetic field’’ of the stator.

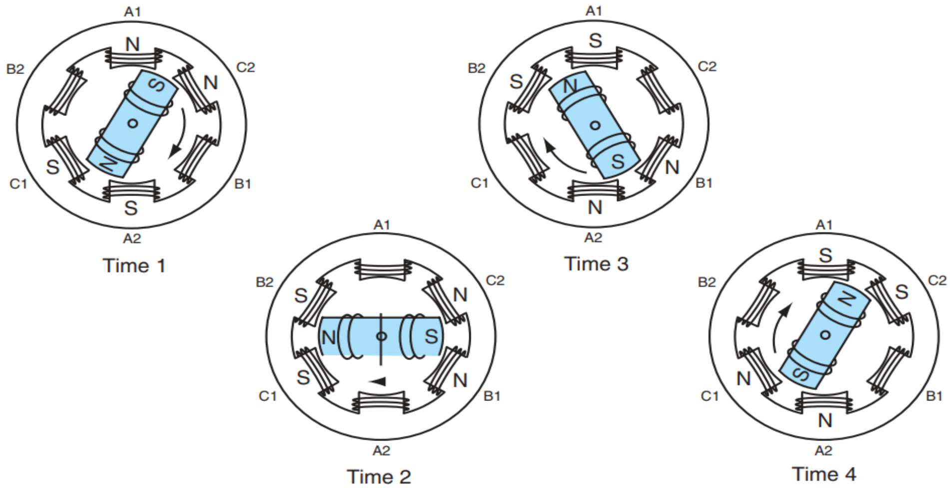


Figure 3- 8 The polarity of the stator and rotor changes over time.

To better understand this concept, let us look at a three-phase motor. Three-phase AC voltage is commonly used in motors because it provides a smoother and more constant supply of power. Three-phase AC voltage is much like having three independent AC power sources, which have the same amplitude and frequency but are 120 degrees out of phase with each other.

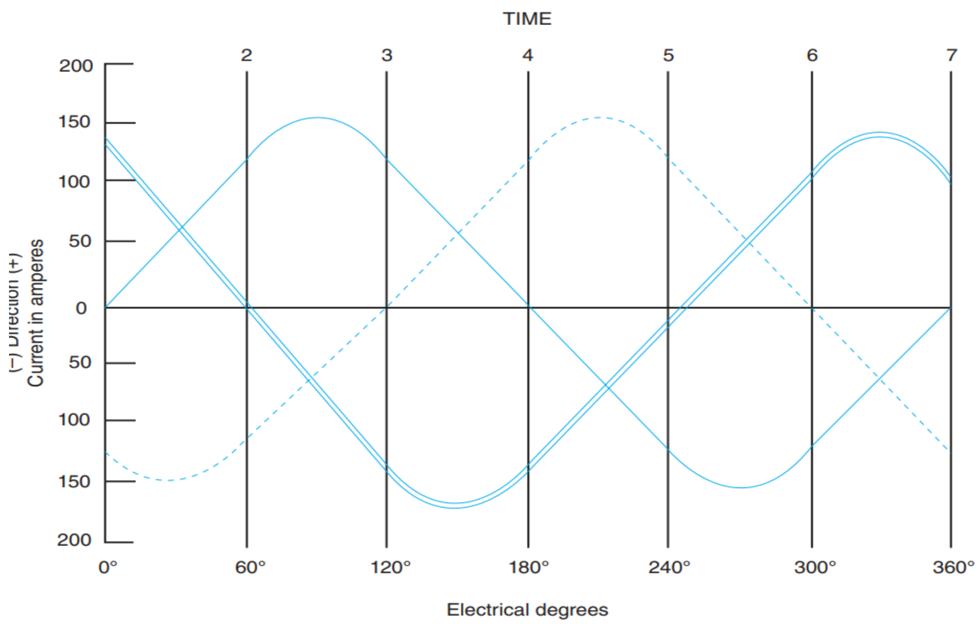


Figure 3- 9 Graphical representation of AC Current

To produce a rotating magnetic field in the stator of a three-phase AC motor, each phase of the three-phase power source is connected to separate stator windings. Because each phase reaches its peak at successively later times, the magnetic field is at its strongest point in each winding in succession as well. This creates the effect of the magnetic field continually moving around the stator. This rotating magnetic field will rotate around the stator once for every cycle of the voltage in each phase. This means the field is rotating at the frequency of the source voltage. Remember that as the magnetic field moves, new magnetic polarities are present. As each polarity change is made, the poles of the rotor are attracted by the opposite poles on the stator. Therefore, as the magnetic field of the stator rotates, the rotor rotates with it. In most cases, the speed of an AC motor depends on:1. The number of windings and poles built into themotor.2. The frequency of the AC supply voltage. Controllers are used to change this frequency and allow for a change in motor speed.3. The load on the rotor's shaft.

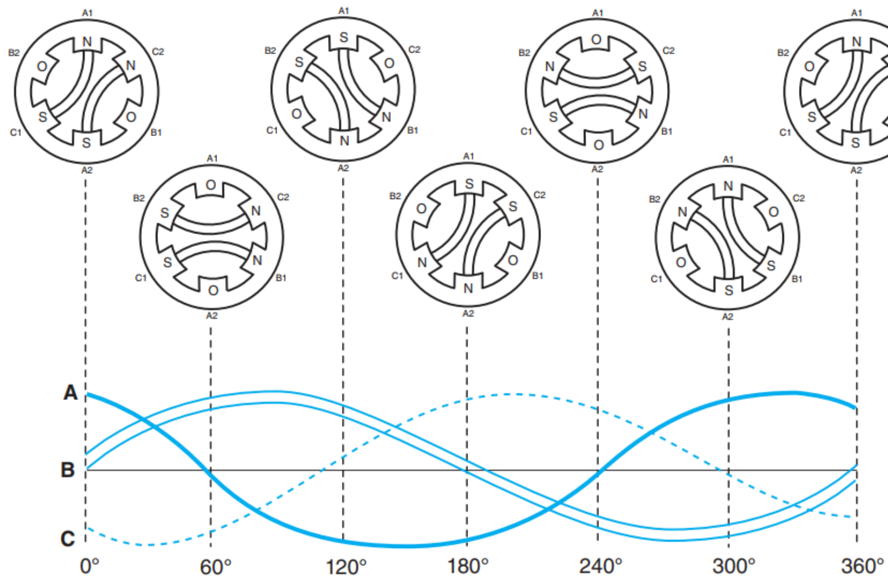


Figure 3- 10 A look at the three separate phases of the three-phase AC.

3.3.4 Synchronous Motor

A synchronous motor operates at a constant speed regardless of load. Rotor speed is equal to the speed of the stator's rotating magnetic field. A synchronous motor is used when the exact speed of a motor must be maintained. Often, synchronous motors have magnets built into the rotor assembly. These magnets allow the rotor to easily align itself with the rotating magnetic field of the stator. When three-phase AC is fed to the three sets of windings in the stator coil, a rotating magnetic field is present around the stator. The rotor simply rotates with that rotating magnetic field. The torque output of the rotor, therefore, is dependent on the strength of the magnetic field around the stator.

The speed of the rotor is determined by the frequency of the AC input to the stator. Synchronous motors are available with outputs up to thousands of horsepower. One of the disadvantages of most synchronous motors is that they cannot be started by merely applying three-phase AC power to the stator. When AC is applied to the stator, a high-speed rotating magnetic field is present immediately. This field rushes past the rotor so quickly that the rotor cannot get started. The rotor is first repelled in one direction and then, very quickly, in another. There are many ways of addressing this issue, but for hybrid and electric vehicles the problem is solved by complex electronics that begin rotating the magnetic field in such a way and at such speed that the rotor simply follows the field. Once the rotor is spinning, normal synchronous operation begins.

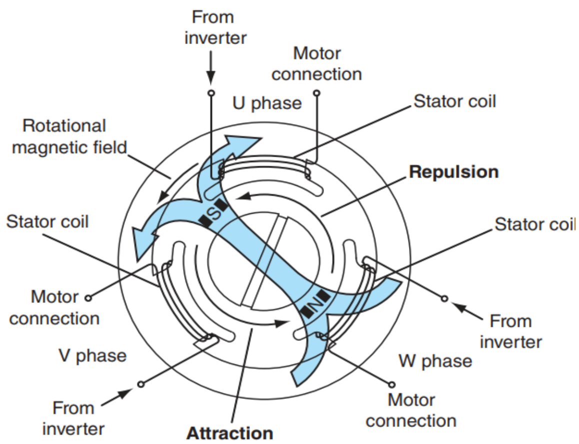


Figure 3- 11 Synchronous Motor

3.3.5 Induction Motor

The most common industrial motor is the three phase AC induction motor. This motor has a low cost and a simple design. The motor works on the principle of rotating magnetic fields in the stator windings. The stator has three windings separated by 120 degrees. A magnetic stator and around in the stator windings. The stator is connected to the power source and the rotor. The three-phase AC sets up a rotating magnetic field around the stator. The rotor has permanent magnets and is the output shaft of the motor. The rotor rotates and follows the rotating magnetic field in the stator. An induction motor generates its own rotor current. The current is induced in the rotor windings as the rotor cuts through the magnetic flux lines of the rotating stator field.

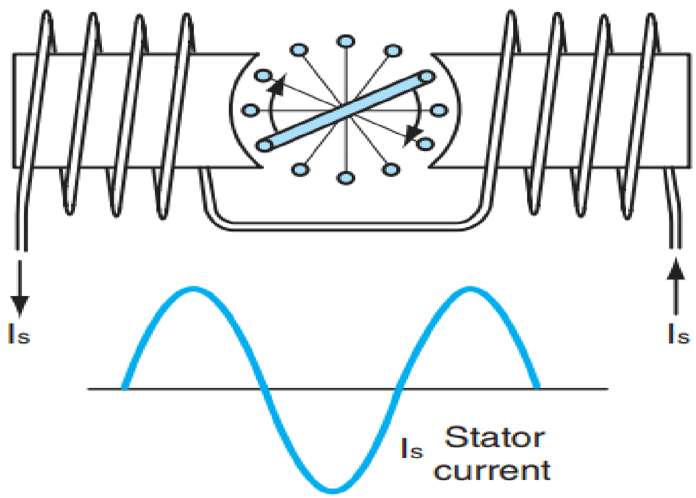


Figure 3- 12 Induction Motor

The induced current causes each magnetic field of the stator to rotate; the magnetic field of the rotor follows the rotating magnetic field of the stator. It should be obvious that this type of motor needs some forced rotation of the rotor before it can rotate on its own. Various methods are used to start these motors, including capacitors and separate starting windings.

It is impossible for the rotor of an induction motor to rotate at synchronous speed. If the rotor were to turn at the same speed as the rotating field, there would be no relative motion between the stator and rotor fields. As a result, no lines of force would be cut by the rotor's conductors, and there would be no induced voltage in the rotor. In an induction motor, the rotor must rotate at a speed slower than that of the rotating magnetic field. The difference between the synchronous speed and actual rotor speed is called slip. Slip is directly proportional to the load on the motor. When loads are onthe rotor's shaft, the rotor tends to slow and slip increases. The slip then induces more current in the rotor and the rotor turns with more torque, but at a slower speed and therefore produces less CEMF.

Other AC induction motors rely on a rotor position sensor to begin and maintain rotor rotation. The sensor tells a control unit precisely where the rotor is inside the stator. The control unit then energizes the appropriate circuits to begin sending AC voltage at the correct stator winding. Once the rotor begins to spin, the sensor keeps track of the position of the rotor and continuously sends signals to the control unit. The control unit, in turn, energizes the next winding to maintain rotor torque.

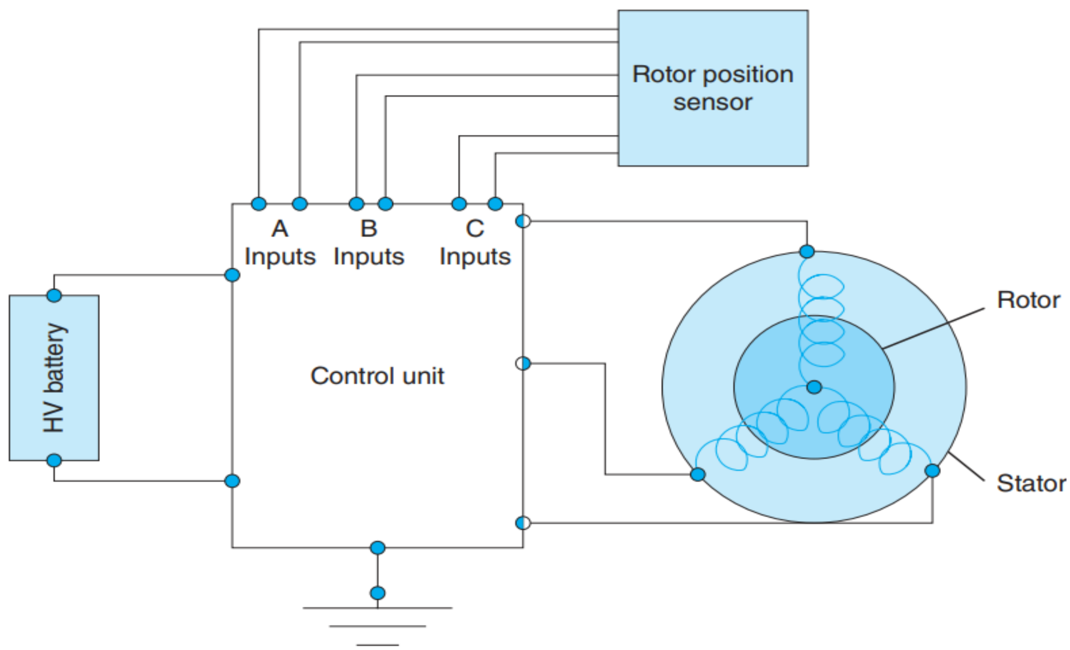


Figure 3- 13 An electric diagram for an induction motor with a rotor position sensor.

3.3.6 Reluctance Motors

A variable switched reluctance motor can be powered by AC or DC. Like other motors, it has a rotor and a coil winding in the stator. The toothed rotor has no coil windings or permanent magnets. The stator typically has slots containing a series of coil windings. The energizing of the stator is done by an electronic controller. The controller establishes a rotating magnetic field around the stator as it activates one coil set in the stator at one time. The timing of this activation is based on rotor angle; therefore, sensors monitoring the position of the rotor are used. When one coil winding is energized, a magnetic field is formed around it. The metal rotor tooth that is closest to the magnetic field moves toward that field. When the tooth is close, the current is switched to another winding in the stator and the tooth moves to it. As the current is sent to the consecutively placed windings, the rotor rotates. By controlling the current and timing through the stator windings, the rotor can be forced to rotate at any desired speed and torque.

3.4 Power Electronics

3.4.1 Overview of Power Electronics in EVs

As we pivot towards a more sustainable energy landscape, electric vehicles (EVs) have emerged as a cornerstone of modern transportation. The role of power electronics in this revolution is paramount. With its ability to efficiently and swiftly control and convert electricity, power electronics provide the essential technological infrastructure that facilitates the widespread adoption and operation of EVs.

Figure 3- 14 Power Electronics in EV's

In an EV, the core function of power electronics is the effective conversion and control of electrical energy. With the primary power source being the battery pack, a high-voltage direct current (DC) power source, power electronics devices are employed to convert this DC power into the alternating current (AC) the electric motor requires for propulsion. This conversion is achieved using an inverter, a critical power electronics device.

Conversely, during regenerative breaking, the motor turns into a generator, producing AC power that needs to be converted back to DC to recharge the battery. Power electronics converters known as rectifiers perform this task.

Power electronics are also indispensable in battery management systems (BMS). These systems oversee the battery pack's health, safety, and optimal usage, ensuring its long lifespan and efficient energy utilization. Sophisticated charging systems regulated by power electronics enable rapid and efficient charging of EV batteries while maintaining their safe operating limits.

Other auxiliary systems in vehicles, like HVAC systems, lighting, and infotainment, also utilize power electronics for the required voltage and current levels. DC-DC converters are used extensively to step down the high battery voltage to lower levels suitable for these systems.

As power electronics technology continues to advance, so does the performance and efficiency of EVs. Advancements in semiconductor materials, like Silicon Carbide (SiC) and Gallium Nitride (GaN), have led to the development of power electronics devices with higher efficiencies, smaller sizes, and better thermal properties.

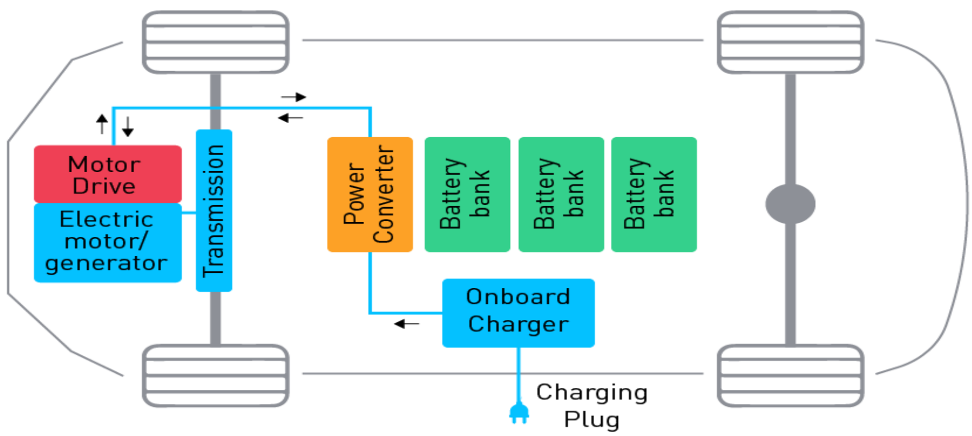


Figure 3- 15 Power Electronics architecture in EVs

3.4.2 Role of Power Electronics in Electric Vehicles

In electric vehicle (EV) drive systems, power electronics serve as a critical component in efficiently delivering and controlling electrical energy from the battery to the propulsion unit. In essence, power electronics devices control and convert power, making it available in the appropriate form and quantity when and where it is needed.

EV drive systems typically comprise a battery pack, power electronics converters (including the inverter and DC-DC converter), an electric motor, and control units. The high-voltage DC power from the battery pack needs to be converted into three-phase AC power suitable for the electric motor. This process is facilitated by a key power electronics device, the inverter.

The inverter utilizes pulse width modulation (PWM) techniques to create an AC output waveform from the DC input. Modern inverters also incorporate intelligent control algorithms that allow for variable frequency drive, improving the efficiency and performance of the electric motor.

Conversely, during regenerative breaking, the motor functions as a generator. The generated AC power must be converted back to DC power for battery charging. This process of conversion is again facilitated by a power electronics device known as a rectifier.

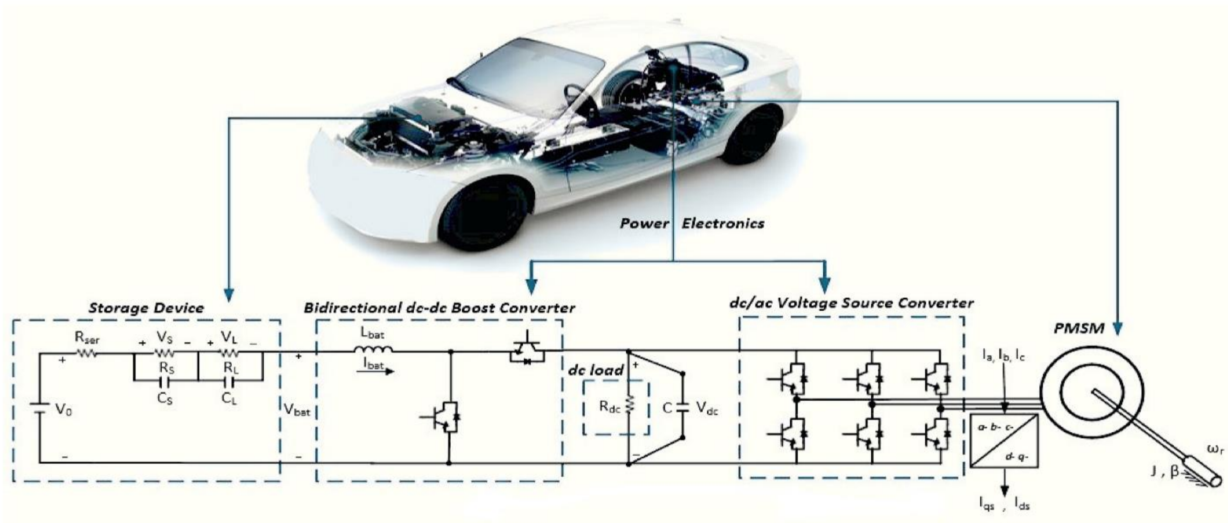


Figure 3- 16 Power Electronics components

In addition to the primary power conversion function, power electronics in the EV drive system also enhance efficiency, power factor correction, and reduce harmonics in the electrical system. Advanced power electronics devices built using wide-bandgap materials like Silicon Carbide (SiC) or Gallium Nitride (GaN) enables higher efficiencies, compactness, and better thermal characteristics, improving overall vehicle performance.

3.4.3 Battery Charging Systems and Power Electronics

The efficient and safe charging of the electric vehicle's battery is a central concern in the design and operation of EVs. This process is primarily governed by power electronics systems, which offer control, conversion, and management of electrical energy during the charging process.

Power electronics play a critical role in onboard and off-board EVs' charging systems. In an onboard charger, power electronic converters, including AC-DC converters, are used to convert the AC voltage from the mains to a DC voltage suitable for charging the vehicle's battery. This involves a rectification process followed by a DC-DC conversion stage to provide the required voltage level and control the current flow to the battery. It is essential to ensure that the charging process adheres to the battery's charge profile, which typically involves constant current and constant voltage phases, to preserve the battery's health and longevity.

Off-board charging systems, such as DC fast-charging stations, rely heavily on power electronics. The power electronic converters in these systems convert the AC supply into a high-voltage DC output, which can directly charge the vehicle's battery, by passing the onboard charger. Advanced control strategies are implemented via power electronics to regulate the charge rate and protect the battery from potential harm.

The advent of bidirectional charging or Vehicle-to-Grid (V2G) technologies has added another layer of complexity and capability to the role of power electronics in EV battery charging. In these systems, power electronics facilitate vehicle charging and the supply of power from the vehicle battery back to the grid or home during peak demand or outages. Bidirectional DC-DC converters are crucial to enabling this two-way power flow, ensuring that power can be efficiently transferred while maintaining the safety and integrity of the grid and vehicle systems.

In wireless charging systems for EVs, power electronics are used to manage the power transfer process between the grid, the primary coil (transmitter), the secondary coil (receiver), and the vehicle's battery. This involves rectification, inversion, and control processes to facilitate efficient power transfer while ensuring safety and standards adherence.

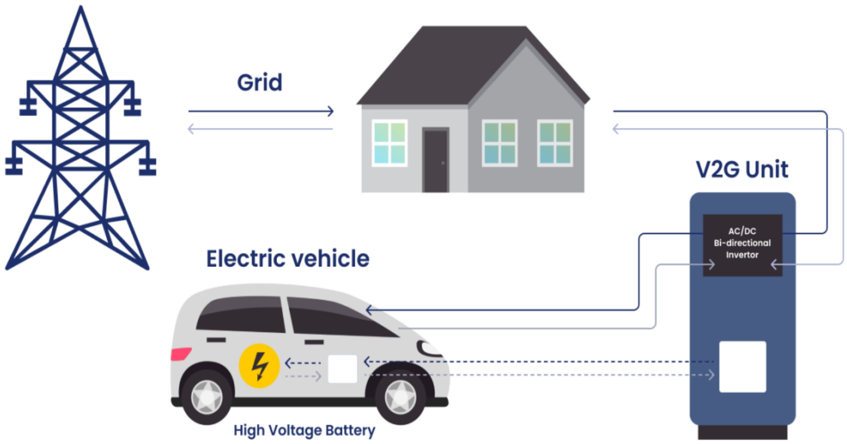


Figure 3- 17 Vehicle-to-Grid

3.4.4 Power Electronics Components

A. Controllers

A controller is used to manage the flow of electricity from the batteries and thereby to control the speed of the electric motor. A sensor located by or connected to the throttle pedal (also called gas pedal or the accelerator) sends the driver's input to the controller. The controller then sends the appropriate amount of voltage to the motor.

A simple controller is a variable resistor or potentiometer connected to the accelerator. When there is no pressure on the accelerator, resistance of the potentiometer is too high to allow voltage to the motor. When the accelerator is fully opened, the resistance is very low, and full battery voltage is delivered to the motor. The positions of the accelerator between closed and wide open allow corresponding amounts of voltage to the motor. This type of system does not provide smooth control of the motor.

Using electronics, the same principle can be used but with more positive results. A sensor monitors the accelerator and sends information to a control unit. The control unit monitors that signal plus other inputs regarding the operating conditions of the vehicle. In this way, the voltage is pulsed, and more precise motor speed control is possible. Most controllers pulse the voltage more than 15,000 times per second. Pulsing the voltage causes the motor to vibrate at the frequency of the voltage. If the frequency is faster than 15,000 cycles per second, it cannot be heard.

Figure 3- 18 Controller

3.4.5 Inverters and Converters

An inverter may be part of the controller, or it may be a separate unit. The inverter converts the DC voltage from the batteries into three phase AC voltage for the motor(s). DC voltage from the battery is fed to the primary winding of a transformer in the inverter. The direction of the current is controlled by an electronic switch (generally a set of insulated gate bipolar transistors primary winding and then is quickly stopped and reversed its direction. This change of direction induces an AC voltage in the transformer's secondary winding. The AC is then used to power the traction motors and other AC devices. The electronic switch responds to inputs from a variety of sensors, such as vehicle speed and throttle position. These inputs are used to determine the required amount of current and the frequency of the AC voltage.

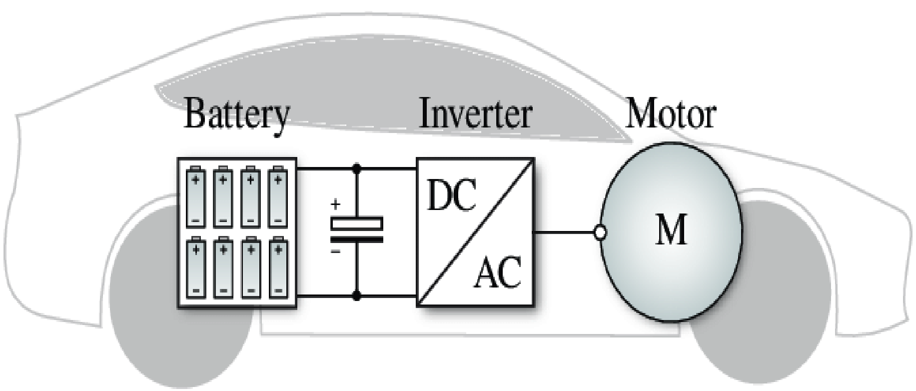


Figure 3- 19 Inverters

When the conversion of AC to DC is required, current is sent through diodes that effectively change AC to DC by allowing only half of the AC's sine wave to flow past the diodes. The diodes are normally called rectifiers. Rectifiers are also found in AC generators.

Most inverter housing also contains a converter, although this could be contained in separate housing. A converter changes the amount of voltage from a power source. There are two types of converters, one that increases voltage, called a step-up converter, and one that decreases the voltage, called a step-down converter. A common application of a converter in electric drive vehicles is one that drops some of the high DC voltage to the low voltage required to power accessories such as sound systems, lights, blower fans, and the controller. A converter is also used to step down (reduce) high AC voltage to power accessories such as the air-conditioning compressor. During the operation of the inverter and converter, a great amount of heat is generated. This heat must be controlled to protect their components, especially the transistors. To provide the necessary cooling and ventilation, inverter/converter housings have dedicated cooling systems that are independent of the engine's cooling system.

Self-check 3.1

Directions: Answer all the questions listed below.

Part I: Say True or False

1. The direction of the magnetic field around a current-carrying wire can be determined using the left-hand rule.
2. An iron core within a coil will weaken the magnetic field.
3. The stator of a motor is the rotating part.
4. Like magnetic poles attract each other.
5. The speed of a motor is directly proportional to the current drawn by the motor.

Part-II: Choose the appropriate answer from the given alternatives

1. In a DC motor, the direction of rotation is primarily determined by:

a) The strength of the magnetic field.
b) The polarity of the armature current.
c) The speed of the motor.
d) The type of bearings used.

2. Which type of DC motor provides the highest starting torque?

a) Shunt motor
b) Series motor
c) Compound motor
d) Permanent magnet motor

3. The commutator in a DC motor serves to:

a) Increase the voltage applied to the armature.
b) Reduce the speed of the motor.
c) Continuously reverse the current flow through the armature coils.
d) Provide mechanical support to the rotor shaft.

4. Brushless DC motors offer several advantages over brushed DC motors. Which of the following is NOT a key advantage?

a) Higher efficiency
b) Reduced maintenance
c) Lower cost
d) Improved reliability

5. In an AC induction motor, the rotor speed is:

a) Always equal to the synchronous speed.
b) Slightly less than the synchronous speed.

c) Always greater than the synchronous speed.

d) Independent of the supply frequency.

Part-III: Give a short answer for the following questions

1. What is the primary function of power electronics in an electric vehicle?
2. Explain the role of the inverter in an EV drive system.
3. How do power electronics contribute to the efficient charging of EV batteries?
4. Describe the significance of wide-bandgap semiconductors (like SiC and GaN) in the development of advanced power electronics for EVs.

Unit Four: EV Drivetrain and Chassis Systems

This unit is developed to provide you with the necessary information regarding the following content coverage and topics:

- Configuration of Electric Vehicle
- Electric Propulsion Unit
- Transmission System
- Electric Vehicles Brake System

This guide will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this learning guide, you will be able to:

- Realize the configuration of Electric Vehicle
- Complete Electric Propulsion Unit
- Comprehend Transmission System
- Know Electric Vehicles Brake System

4.1 Configuration of Electric Vehicle

Electric vehicle configuration refers to the layout of the energy source and the drive train components of an electric vehicle, an architecture of the EV is flexible when compared with compared with conventional internal combustion engine powered vehicles due to the absence of complex engine setup, no clutch, zero requirement of manual transmission system, no requirement of exhaust pipe, etc. The energy flow in EVs is made with flexible electrical wires with no mechanical linkage, different EV drive systems have different system architecture and different energy sources have different characteristics and different charging systems.

Battery electric vehicles powered by one or more electric engine have the most straight forward architecture as the motor itself can acquired the required power. The detailed foundation of an electric vehicle system along with its interconnection with different components. The fundamental components of an electric vehicle system are the motor, controller, power source, and the transmission system.

In the general configuration of the EV is shown. The EV has three major subsystems:

1. **Electric Propulsion**
   - The electronic controller
   - Power converter
   - Electric Motor
   - Mechanical Transmission
   - Driving Wheels
2. **Energy Source Subsystem**
   - The energy source
   - Energy Management Unit
   - Energy Refueling Unit
3. **Auxiliary System**
   - Power steering unit
   - Temperature control unit
   - Auxiliary Power unit

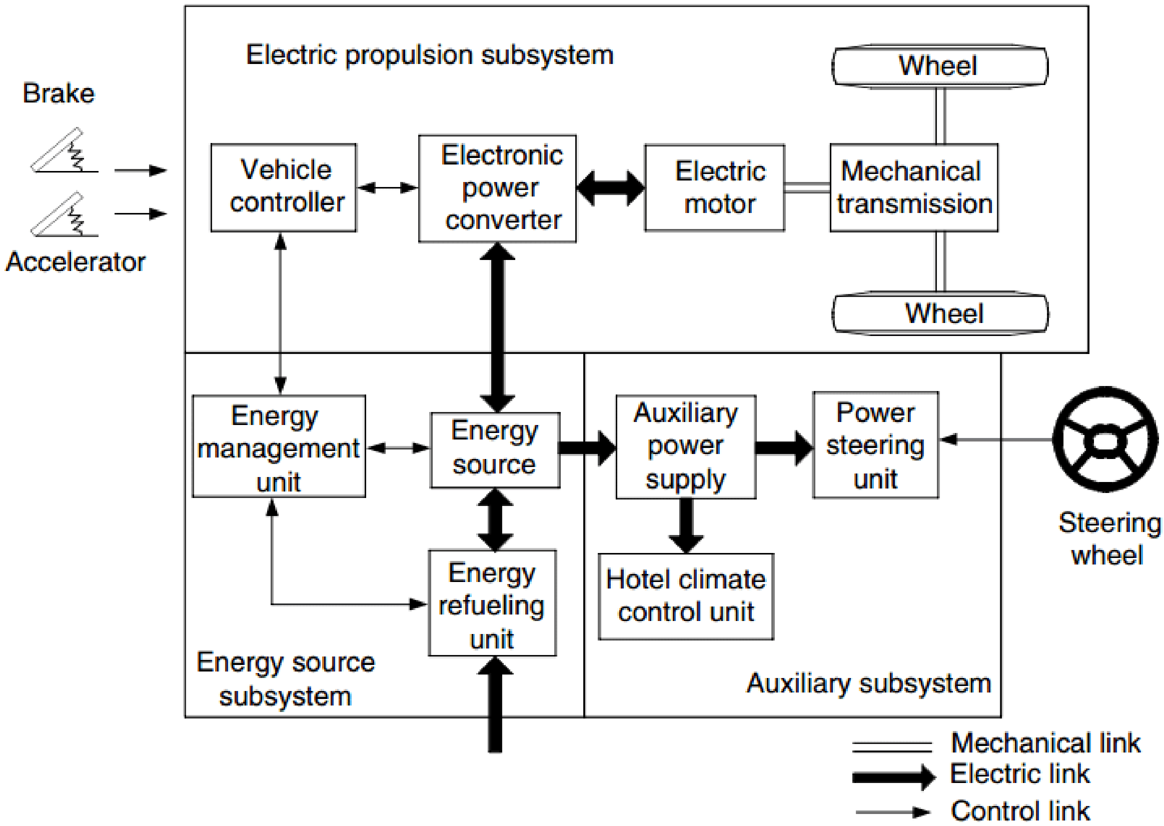


Figure 4- 1 Configuration of Electric Vehicle

The black line represents the mechanical link, the green line represents the electrical link, and the blue line represents the control of information communication. Based on the control inputs from the brake and accelerator pedals, the electronic controller provides proper control signals to switch on or off the power converter which in turn regulates the power flow between the electric motor and the energy source.

The backward power flow is due to regenerative braking of the EV and this regenerative energy can be stored provided the energy source is receptive. The energy management unit cooperates with the electronic controller to control regenerative breaking and its energy recovery. It also works with the energy refueling unit to control refueling and to monitor the usability of the energy source. The auxiliary power supply provides the necessary power with different voltage levels for all EV auxiliaries, especially the temperature control and power steering units.

4.1.1 Drive train Alternatives Based on Drive train Configuration

There are many possible EV configurations due to the variations in electric propulsion and energy sources. Based on these variations, six alternatives are possible. These six alternatives are:

A. **Single motor with Gearbox and Clutch**

In this electric motor architecture system, which has an electric motor, a clutch (C), a gearbox, and a differential (D). The clutch engages or disengages the power flow from electric motor to wheels like it does in internal combustion engine powered vehicles. The wheels have low speed with high torque in the lower gears and low torque with high speed in the higher gears. This architecture setup was mostly used in conversion of ICE powered vehicles to EVs utilizing the existing components.

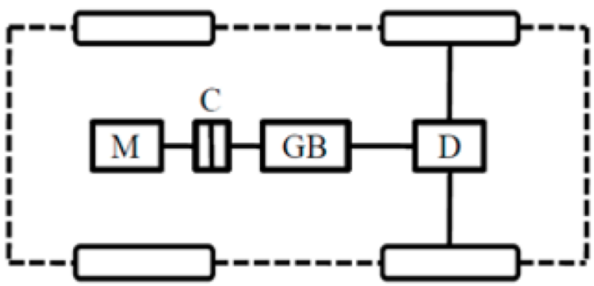


Figure 4- 2 Single motor with Gearbox and Clutch

B. **Single Electric Motor Architecture with Fixed Gear**

The advantage of this architecture is that the transmission weight is reduced as transmission and clutch have been omitted. Some vehicle conversion using electric machines without transmission system utilize this configuration.

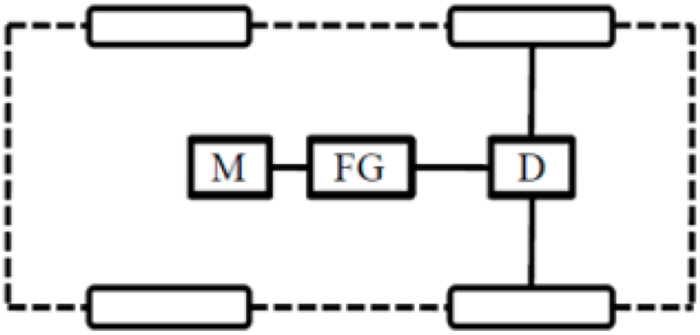


Figure 4- 3 Single Electric Motor Architecture with Fixed Gear

C. **Single Electric Motor Architecture with Fixed Gear and Differential**

It is an EM with rear-wheel-drive architecture with fixed gearing and differential integrated into a single assembly and has been preferred by most of the electric vehicle manufacturers at present scenario.

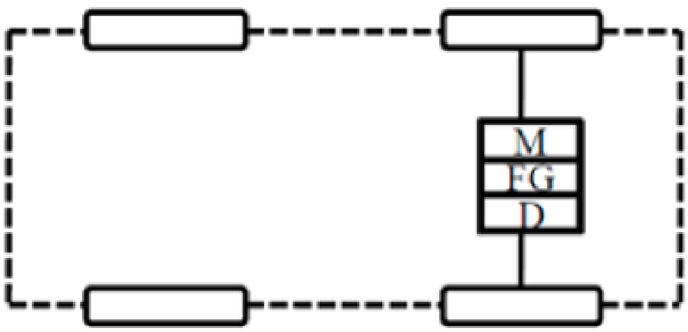


Figure 4- 4 Single Electric Motor Architecture with Fixed Gear and Differential

D. **Double Electric Motor attached to Two Wheel Fixed Gear**

In this configuration, the differential action can be electronically controlled by two electric motors that operate at different speeds. In this dual-motor architecture, the driving wheels are derived separately by two separate electric motors separately via fixed gearing.

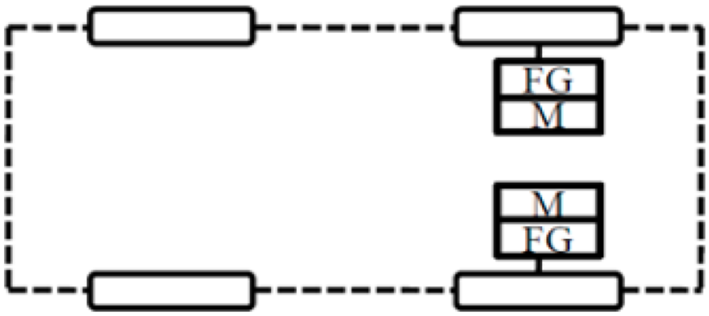


Figure 4- 5 Double Electric Motor attached to Two Wheel Fixed Gear

E. **Double Electric Motor in Wheel Fixed Gear**

An architecture with a fixed planetary gearing system employed to reduce the motor speed to the desired wheel speed. This architecture is called an in-wheel drive system and the planetary gearing in this system offers the advantages of a high-speed reduction ratio along with an inline arrangement of input and output shafts.

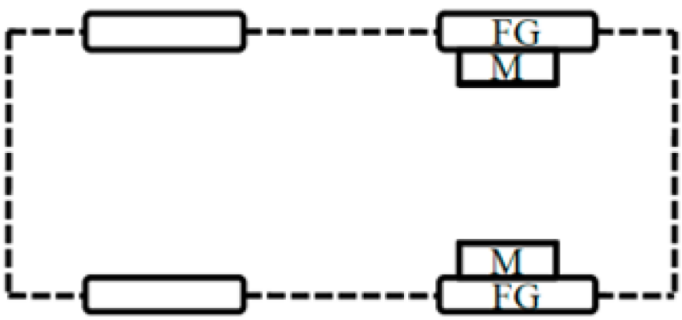


Figure 4- 6 Double Electric Motor in Wheel Fixed Gear

F. **Double Electric Motor in Wheel without Fixed Gear**

It presents EV architecture without a mechanical gear system. A low-speed outer-rotor electric motor has been installed inside the wheels. The gearless arrangement with outer rotor mounted directly on the wheel rim makes equivalent speed control of the electric motor with the wheel speed and, hence, speed of the vehicle.

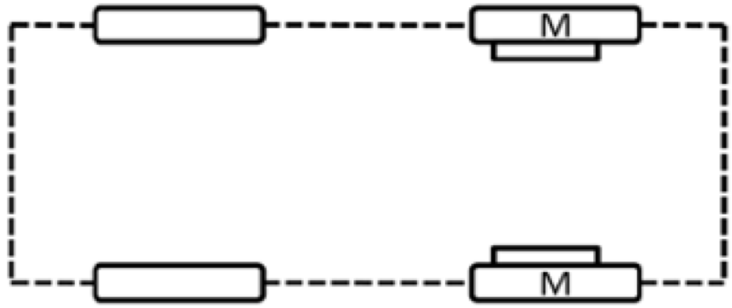


Figure 4- 7 Double Electric Motor in Wheel without Fixed Gear

4.1.2 Drive train Alternatives Based on Power Source Configuration

Electric Vehicle (EV) Drive train Alternatives Based on Power Source Configuration Besides the variations in electric propulsion, there are other EV configurations due to variations in energy sources. There are five possible configurations, and they are:

A. EV Configuration with battery source

It is a simple battery powered configuration. The battery may be distributed around the vehicle, packed together at the vehicle back or located beneath the vehicle chassis. The battery in this case should have reasonable specific energy and specific power and should be able to accept regenerative energy during breaking. In the case of EVs, the battery should have both high specific energy and specific power because high specific power governs the driving range while the high-power density governs the acceleration rate and hill climbing capability.

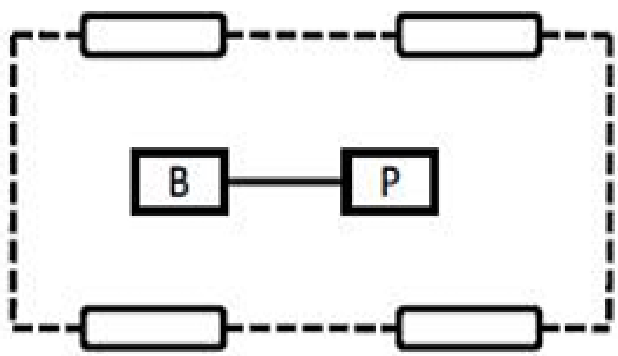


Figure 4- 8 EV Configuration with battery source

B. EV Configuration with Two Battery Sources

Instead of two batteries, this design uses two different batteries. One battery is optimized for high specific energy and the other for high specific power.

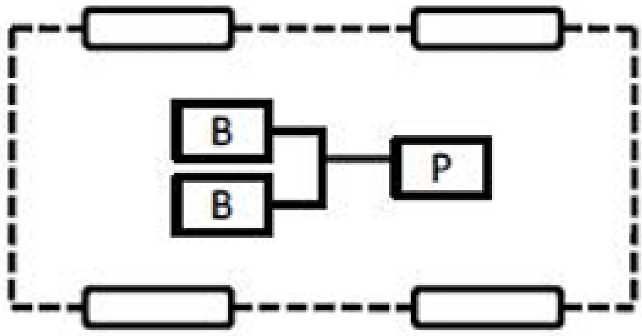


Figure 4- 9 EV Configuration with Two Battery Sources

C. EV Configuration with Battery and Fuel Cell Sources

In this arrangement fuel cells are used. The battery is an energy storage device, whereas the fuel cell is an energy generation device. The operation principle of fuel cells is a reverse process of electrolysis. In reverse and electrolysis, hydrogen and oxygen gases combine to form electricity and water. The hydrogen gas used by the fuel cell can be stored in an on-board tank whereas oxygen gas is extracted from air. Since fuel cells can offer high specific energy but cannot accept regenerative energy, it is preferable to combine it with battery with high specific power and high-energy receptivity.

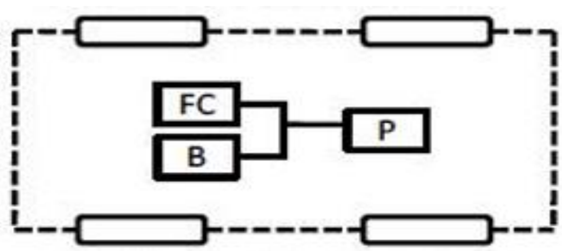


Figure 4- 10 EV Configuration with Battery and Fuel Cell Sources

D. EV Configuration with Multiple Energy Sources

Rather than storing it as a compressed gas, a liquid or a metal hydride, hydrogen can be generated on-board using liquid fuels such as methanol. In this case a mini reformer is installed in the EV to produce necessary hydrogen gas for the fuel cell.

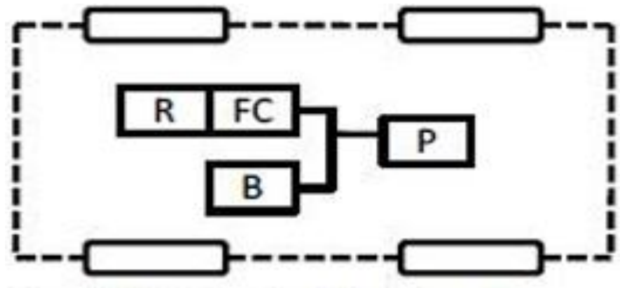


Figure 4- 11 EV Configuration with Multiple Energy Sources

E. EV Configuration with battery and capacitors source

In fuel cell and battery combination, the battery is selected to provide high specific power and high-energy receptivity. In this configuration a battery and super capacitor combination is used as an energy source. The battery used in this configuration is a high energy density device whereas the super capacitor provides high specific power and energy receptivity.

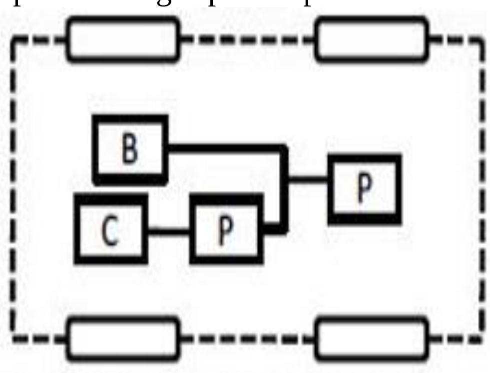


Figure 4- 12 EV Configuration with battery and capacitors source

4.2 Electric Propulsion Unit

In electric vehicles, the electric motor utilizes the energy source from battery pack and converts the electric energy into mechanical power. The electric machine and drives combine as a single unit to form propulsion unit in electric vehicles to drive them.

Electric motors are used for converting energy from electrical to mechanical and vice versa. In electric vehicles, electric machines are used to provide power and torque to the transaxle for propulsion. The electric motor provides propulsive power in electric vehicles. The efficiency of energy conversion by electric machine is higher compared to internal combustion engine, in between 80–95%. An electric motor provides high torque and high-power density with better torque characteristics at lower speed and the instantaneous power rating with two or three times the rated power of the motor. The electric machines process the power in the reverse direction when turning the electric motors into generators. The braking mode can be termed as regenerative braking.

Electric vehicles have different electric machines and drives compared to electric machines and drives developed for industrial applications. The electric propulsion system is the heart of pure electric vehicles, where electric machines and drives are the core technology for pure electric vehicle power train system that converts the electrical energy to the desired mechanical linear motion. The most electric vehicle comes with single speed reducer and most transmission systems are kept optional to drive the wheels. The stationary part stator and rotating part rotor of the electric motor play an important role in the overall performance of the motor technology.

The choice of an electric vehicle motor depends on the conditions defined by the three variables. There are the three variables are vehicle requirement, vehicle restriction, and power source. The vehicle requirements are defined by a driving cycle schedule. The vehicle restriction includes the type of vehicle, weight of vehicle, payload, and battery weight. Considering the above variables, we can choose a motor that satisfies the performance requirements of the vehicle.

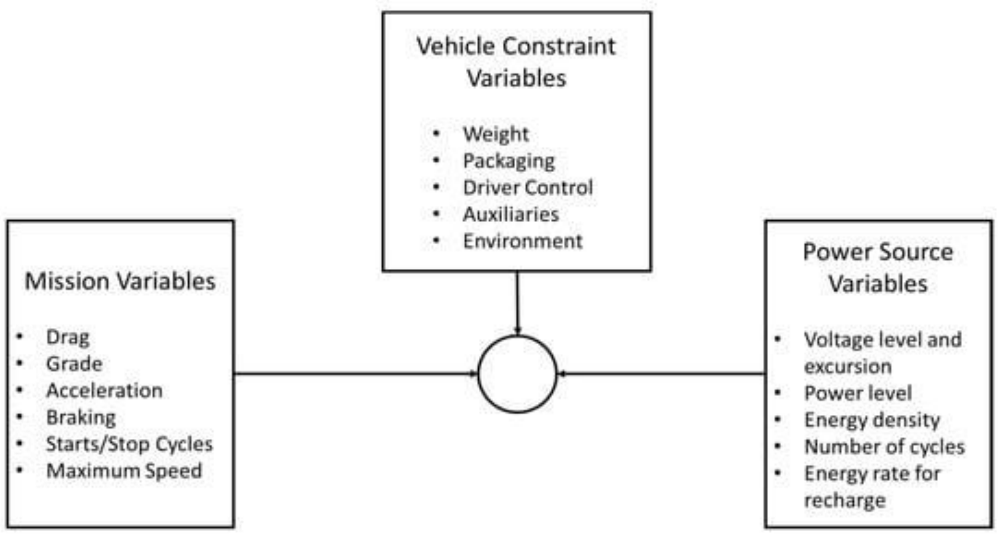


Figure 4- 13 Electric Propulsion Unit

Different electric motors exist. Two broad classes of electric machines for electric vehicles applications are: direct current (dc) and alternating current (ac) motors. The requirements for a motor to be used for EV use include higher power and torque, variable range of speed e, higher efficiency, high reliability, and affordability. Direct current (DC) motor drives used to be earlier electric vehicles choice for the propulsion, but inefficient unreliability made them less attractive induction and permanent magnet (PM) types have become most favored ones with the advance development of their power electronic systems.

4.2.1 Brushed DC Motor Drive

DC motor drives were mostly used for propulsion systems of electric vehicle (EV). Technological maturity and control simplicity made them usable for initial choice for driving EVs. DC motors have stators with permanent magnets (PM); rotors have brushes. For EV propulsion, the DC machine adopts the high-power density that it spins up to 5000 rpm and utilizes fixed gear (FG) system to step it down to 1000 rpm. A bulky, inefficient, and complicated reverse gear is avoided by offering reverse rotation.

The basic motor drive train system with different sub systems ranging from motor controller to single speed reducer differential and driving wheels. The stator integrates the field winding or permanent magnets (PMs) that helps in producing the magnetic field excitation, while the rotor installs the armature winding switched by the commutator through the carbon brushes. The basic set up of DC motor drives system to control the armature current and the output torque of the DC machine. In general, the feedback control variable is only the motor speed, while the armature current feedback is mainly for protection purposes.

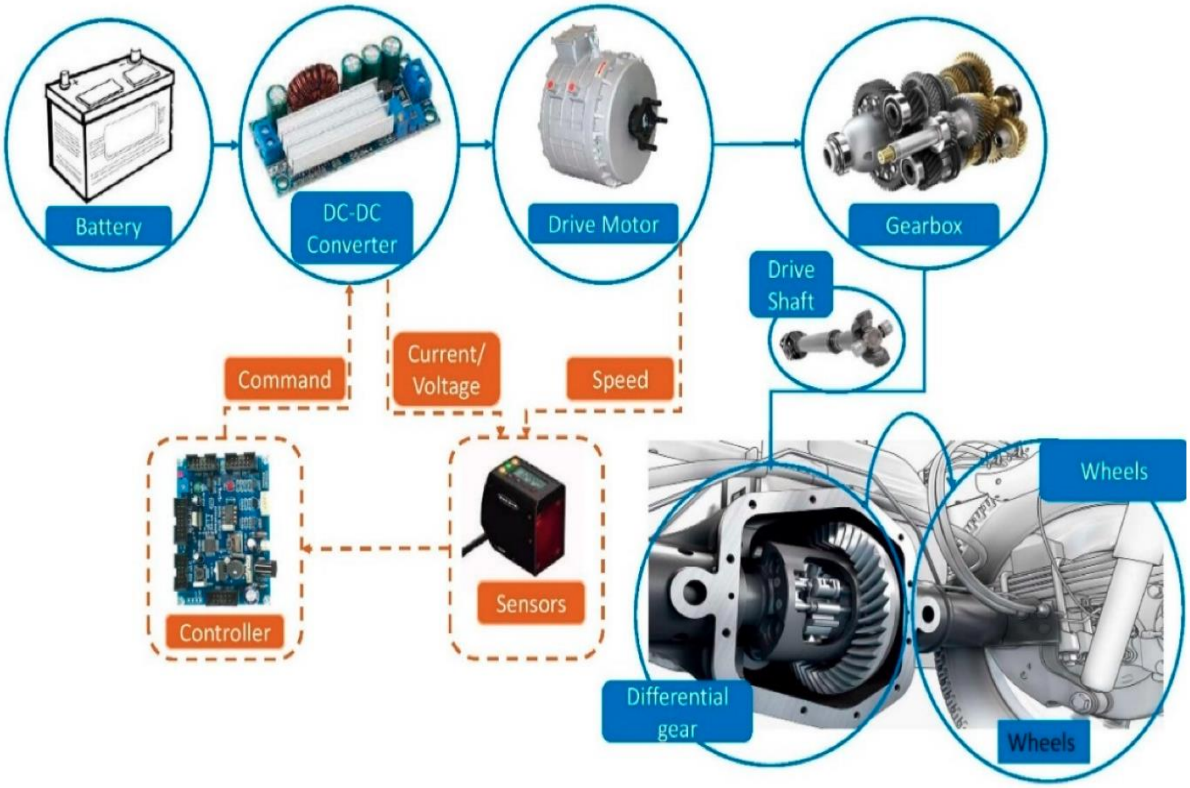


Figure 4- 14 Brushed DC Motor Drive

4.2.2 Permanent Magnet Brushless DC Motor

Permanent magnets (PM) are the major materials of PM brushless motor drives. PM BLDC motors are PM AC machines with trapezoidal back-emf waveforms due to the concentrated windings that are used in the motor. As there are no windings in the rotor, there is no rotor copper loss, which makes it more efficient than induction motors.

There is no loss of copper in the rotor due to the absence of the winding, making it more efficient than available induction machine. The motor drive has light weight, smaller size, is reliable, and provides better torque and specific power with better heat dissipation. The PM BLDC motor system has less maintenance and higher efficiency compared to the DC brushed motor system. The major advantages of using PM BLDC motor are:

- high-energy PMs, light weight, and lower volume providing higher power density offering higher efficiency due to the absence of copper loss.

- better heat dissipation and cooling.
- higher reliability due to lower heating and lower manufacturing defects.

The single-PMBLDC motor architecture system consists of a voltage-fed inverter, an electronic controller, and sensors. The position sensor ensures the synchronization of the current with the flux. The speed control is relatively simple by controlling the stator currents to align the rectangular current with trapezoidal flux.

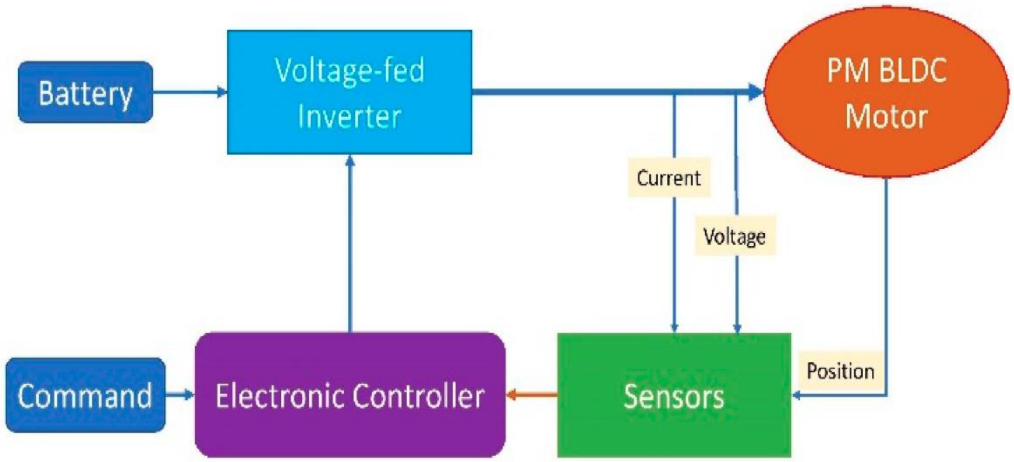


Figure 4- 15 Permanent Magnet Brushless DC Motor

4.2.3 Induction Motor System

Induction motors are simple in construction, due to their reliability, lower maintenance, lower cost, and ability to operate in hostile environments. There are two types of induction machines (IMs): the wound-rotor and squirrel-cage. The wound-rotor induction motor is less attractive than the squirrel-cage counterpart—especially for electric propulsion in electric vehicles (EVs)—due to high cost, need for maintenance, and lack of sturdiness.

Therefore, the squirrel-cage induction motor can be named as the induction motor for EV propulsion. The motors have the capacity to increase the limit for maximum speed, and higher rating of speed and develop high output due to absence of brush friction. By changing the voltage frequency, the speed of induction motors can be varied. Field orientation control (FOC) of induction motors can terminate its torque control from field control.

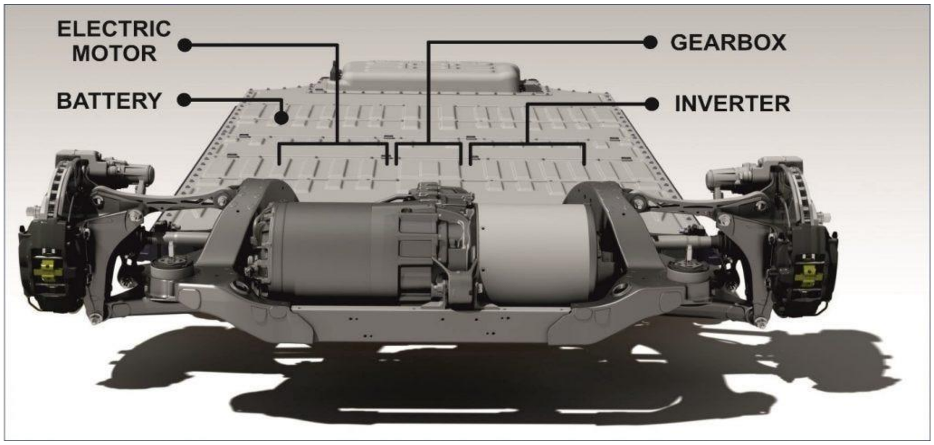


Figure 4- 16 Induction Motor System

4.2.4 Permanent Magnet Synchronous Motor Drives (PMSM)

Permanent magnet synchronous motors have sinusoidal magnetomotive force (mmf), voltage, and current waveforms. When the sinusoidal distribution of the air-gap flux and stator windings is arranged, the machine operates as a synchronous machine. The rare earth magnet material in this motor drive helps to increase the flux density in the airgap, the motor power density, and torque-to-inertia, and thus can be operated over a wide constant power speed range.

The most common types of magnet materials that have been used in PM machines are ferrites, samarium cobalt (SmCo), and neodymium-iron-boron (NdFeB). The working mechanism is identical to BLDC motor except the sinusoidal wave form of the back EMF.

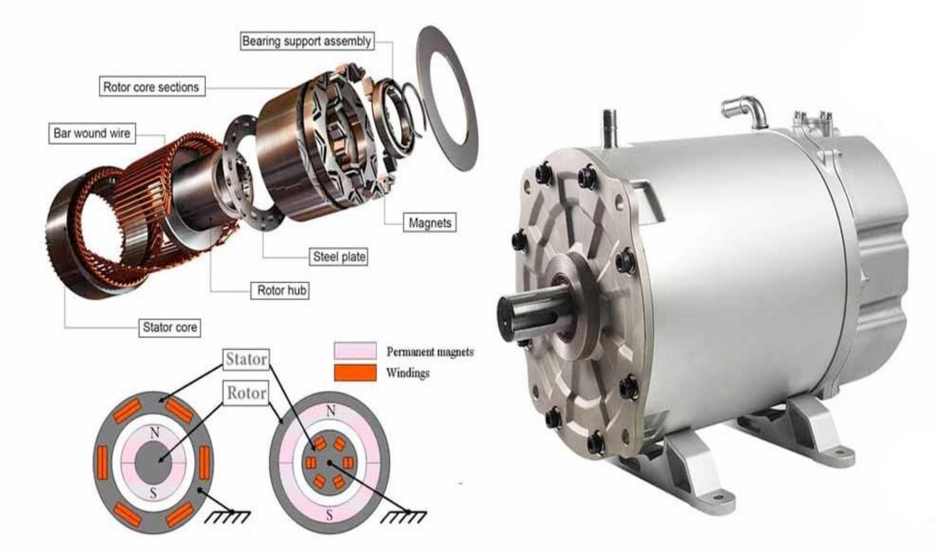


Figure 4- 17 Permanent Magnet Synchronous Motor Drives (PMSM)

4.2.5 Switch Reluctance Motor

SRMs, also known as doubly salient motors, are synchronous motors and they are driven by unipolar inverter-generated current. SRM motors work on the principle of variable reluctance. SRMs is mostly suitable for high-speed operation without mechanical failure. Due to their high mechanical integrity, they are also suitable for driving EVs as in-wheel drive systems. However, they have the disadvantages of lower torque density, higher torque ripple, and larger acoustic noise.

The simple rotor structure is and does not require winding, magnets, commutators, or brushes, so it has rapid acceleration and immensely high-speed operation. Making it suitable for gearless operation in EV propulsion. The current coping control (CCC) and the advanced angle control (AAC) are the two main control systems for SR motor control systems. The speed boundary between these two control schemes is called the base speed, at which the back EMF is equal to the DC source voltage.

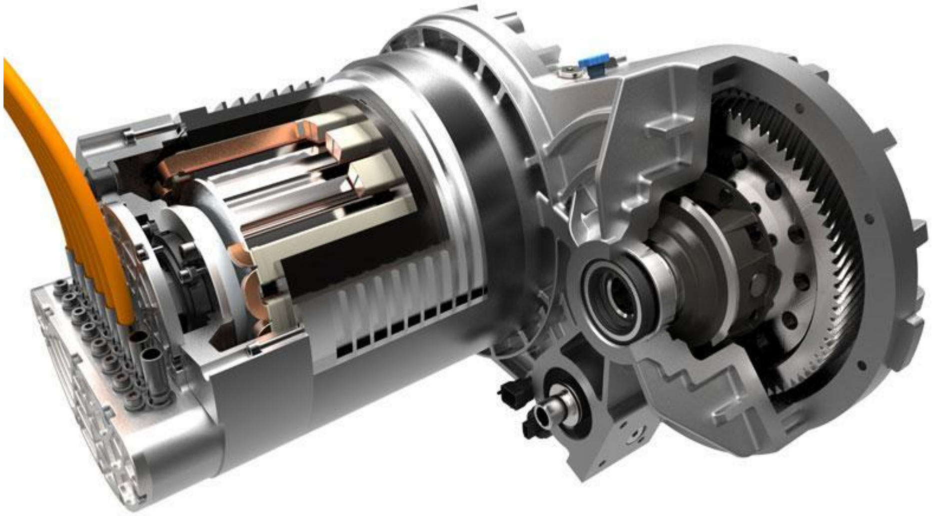


Figure 4- 18 Switch Reluctance Motor

4.2.6 Stator Permanent Magnet Motor

Stator-PM motor deviates itself from conventional permanent magnet (PM) brushless motor drives, with an advantage of all PM materials being in the stator while the rotor with salient poles offers higher robustness with better thermal stability for PM materials. For EV propulsion, there are three major stator motor types:

- Doubly salient permanent magnet (DSPM) machine
- Flux-reversal permanent magnet (FRPM) machine
- Flux-switching permanent magnet FSPM machine

Above all, the mentioned three types of stator-PM machines are based on PM excitation, and are classified as a group as uncontrollable but with the inclusion of independent field winding or magnetizing winding in the stator for flux control, the stator-PM machines become flux controllable, which can be further classified as:

- Hybrid-excited permanent magnet (HEPM)
- Flux-mnemonic permanent magnet (FMPM)

These flux-controllable techniques can be applied to form various topologies, such as the hybrid-excited flux-switching permanent (HE-FSPM) machine or flux-mnemonic doubly salient permanent (FM-DSPM) machine.

The flux-controllable group, including the HE-DSPM (hybrid-excited doubly salient permanent magnet), HE-FRPM (hybrid-excited flux-reversal permanent magnet), and HE-FSPM as well as the FM-DSPM, FM-FRPM (flux-mnemonic flux-reversal permanent magnet), and FM-FSPM (flux-mnemonic flux-switching permanent magnet) desire two external supplies, hence called the doubly fed stator-PM machines.

4.2.7 Advance Magnetless Motor

The absolute value and volatility of the neodymium price are uncertainty to the development of PM machines and has revived the research of advanced magnetless machines. The induction machine and SR machine can be considered as a magnet-less machines as they do not equip with any PMs, but they do form their own respective families and the terminology 'advanced' is incorporated to deviate them from those magnetless machines that are recently developed or relatively immature. The layout of power electronics components in a battery electric vehicle (BEV). The auxiliary supply provides the necessary power for equipment within the vehicle.

There are five majors advanced magnetless motor drives that are viable for EV propulsion, they are:

- Synchronous reluctance (SynR)
- Doubly salient DC (DSDC)
- Flux-switching DC (FSDC)
- Vernier reluctance (VR)
- Doubly fed Vernier reluctance (DFVR)

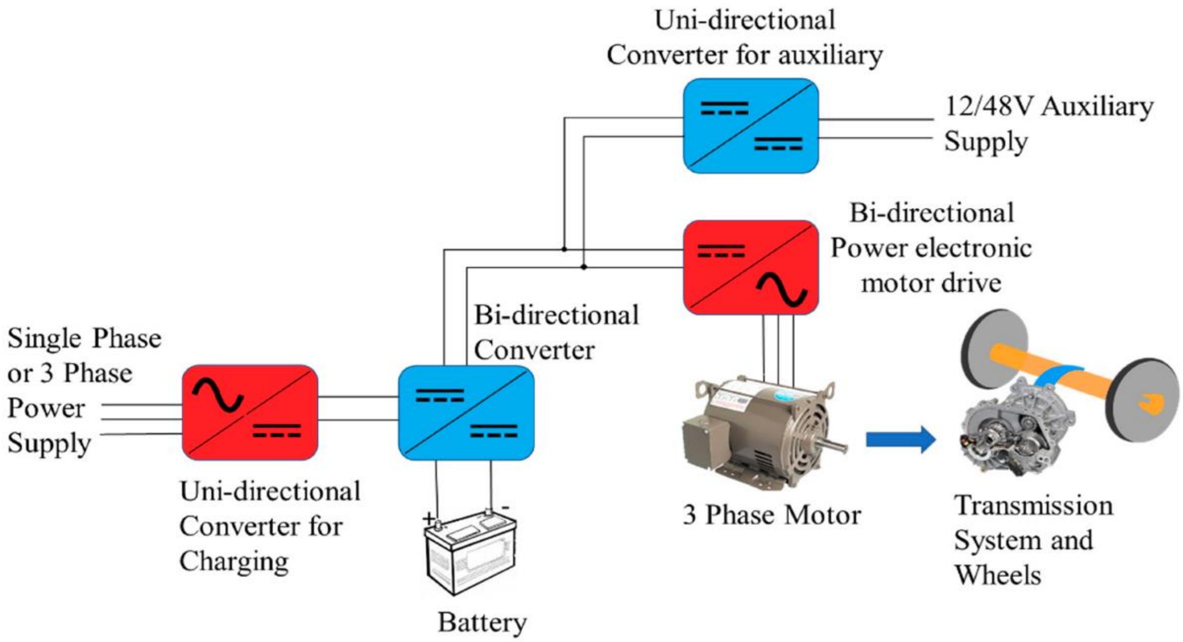


Figure 4- 19 Advance Magnetless Motor

4.3 Transmission System

There are different research-based debates going on regarding the use of single fixed gear transmission and multi transmission systems. Vehicles are specially designed to perform in different driving conditions—such as city, highway, and hilly—and thus electric propulsion motors should supply a wider range of speeds and torques to sync the demand that might force the traction motor to run outside its efficient operating region. To achieve better drivetrain efficiency and vehicle performance, transmission systems should be efficiently designed to integrate the electric power train system so that the EV can directly be driven by single motor, dual motor, transmission less, or there might be a single speed or multi speed transmission system between motor and wheel to optimize the vehicle performance.

Major EV manufacturers—like Tesla, Nissan, Hyundai, BYD, etc.—still use single-speed transmission systems as they help to minimize the associated cost, volume, energy loss, or drivetrain mass. However, the use of single speed transmission system, how EV powertrain performance significantly depends on the performance of electric motors that may not be efficient in all speed ranges while the use of a multi-speed transmission system may offer a real-world solution, keeping the electric motor efficient during the operation of EVs.

4.3.1 Multi-Motor Drive Transmission System

One can demolish the differential gears by using dual or multi-EMs. Each wheel can be coupled with an EM enabling independent speed control of each wheel through multiple electric motors.

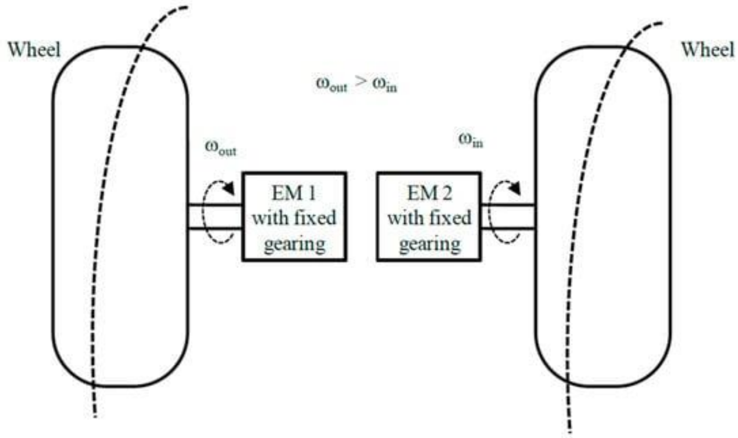


Figure 4- 20 Multi-Motor Drive Transmission System

4.3.2 In-Wheel Drive

Merits of minimizing the mechanical transmission path between the electric motor and the wheel through in wheel motor system is possible. In-wheel motor configuration reduces the drive train weight by avoiding the use of central motor, associated transmission, differential, system, and subsystems. Four-wheel drives improve the drivability of the vehicle by lowering the center of gravity of the vehicles.

Figure 4- 21 In-Wheel Drive

4.4 Electric Vehicles Brake System

The brake system for electric vehicles is a critical component designed to ensure efficient stopping power while incorporating innovative technologies unique to electric drivetrains. Unlike traditional vehicles, which rely solely on friction-based brake systems, electric vehicles (EVs) utilize regenerative braking, enhancing their overall efficiency.

In an electric vehicle, the brake system comprises various elements tailored to accommodate advanced features. These systems not only serve the primary function of stopping the vehicle but also work synergistically with the vehicle's electric motor. This integration allows energy produced during breaking to be redirected back into the battery, thus extending the vehicle's range. Understanding the brake system for electric vehicles entails recognizing how these advanced technologies function safely and effectively. Enhanced by features such as electronic stability control, EV brake systems provide improved handling and safety. Overall, the evolution of braking technologies in electric vehicles significantly contributes to performance, safety, and efficiency.

4.4.1 Components of Brake System

The brake system for electric vehicles consists of several critical components that work together to ensure effective deceleration and safety. Key elements include hydraulic disc brakes, regenerative braking systems, and electronic control units. Each part plays a unique role in optimizing performance and efficiency.

Hydraulic disc brakes are the primary mechanism for generating stopping force. They utilize brake pads and rotors to create friction, which slows down the vehicle. Regenerative breaking, another vital component, captures energy typically lost during breaking and channels it back into the battery, enhancing overall efficiency. Electronic control units manage the interaction between the hydraulic and regenerative systems. These units optimize braking force based on various inputs, which helps maintain stability and control during the braking process. Additionally, sensors monitor the vehicle's dynamics to ensure safety and performance standards are met.

The integration of these components forms a sophisticated system that caters specifically to the needs of electric vehicles. Together, they contribute to a reliable and efficient braking experience essential for modern automotive technology.

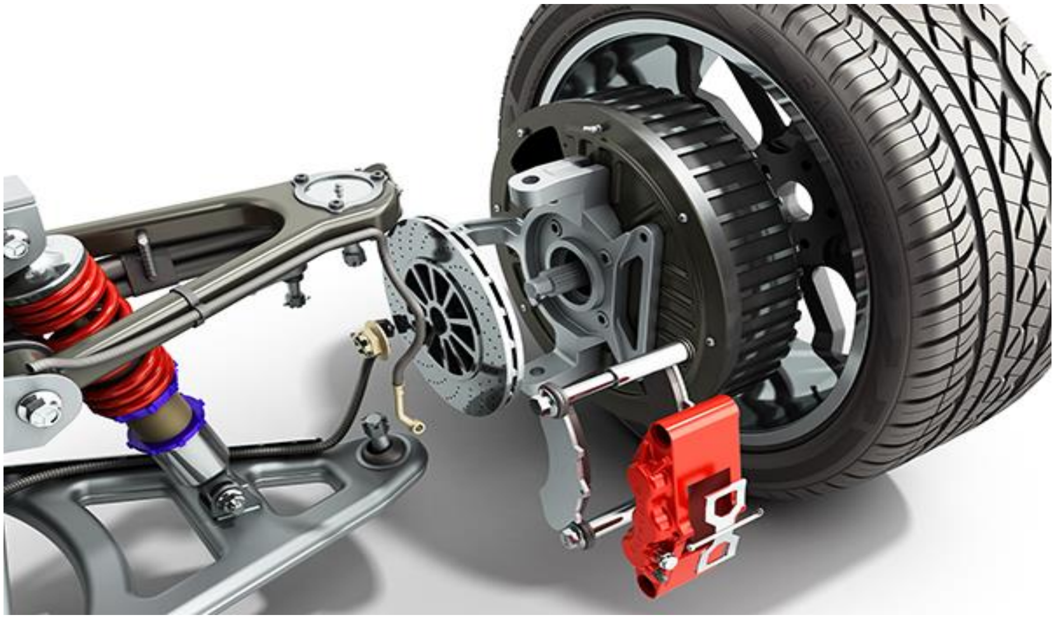


Figure 4- 22 Components of Brake System

4.4.2 Need for Regenerative Braking system

In conventional internal combustion engines (ICE) vehicles, energy from breaking is wasted as heat. When a driver applies the brakes, the kinetic energy of the moving vehicle is converted into heat through friction and dissipated into the atmosphere. In contrast, regenerative braking captures this energy and converts it into electricity that can be stored in the vehicle’s battery.

Regenerative braking works by reversing the electric motor’s function during deceleration. When the driver applies the brakes, the electric motor switches to generator mode, and instead of consuming energy, it generates it. The kinetic energy of the moving vehicle turns into the motor, which then produces electrical energy, sending it back to the vehicle’s battery. This process helps slow the vehicle down while also recovering energy that would otherwise be lost.

The regenerative braking system delivers several significant advantages over a car that only has friction brakes. In low-speed, stop-and-go traffic where little deceleration is required; the regenerative braking system can provide most of the total braking force. This vastly improves fuel economy with a vehicle and further enhances the attractiveness of vehicles using regenerative braking for city driving. At higher speeds, regenerative braking has been shown to contribute to improved fuel economy by as much as 20%.

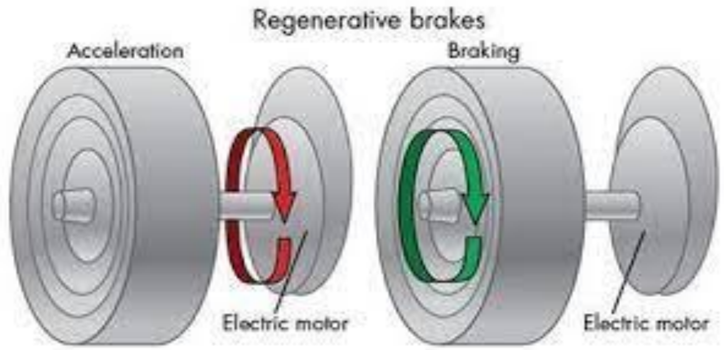


Figure 4- 23 Regenerative Braking system Principle

Consider a heavy loaded truck having very few stops on the road. It is operated near maximum engine efficiency. 80% of the energy produced is utilized to overcome the rolling and aerodynamic road forces. The energy wasted in applying brakes is about 2%. Also, its brake specific fuel consumption is 5%. Emissions reduction engine emissions reduced by engine decoupling, reducing total engine revolutions and total time of engine operation. Now consider a vehicle which is operated in the main city where traffic is a major problem here one must apply brake frequently. For such vehicles, the wastage of energy by application of brake is about 60% to 65%. And it is inefficient as its brake specific fuel consumption is high.

4.4.3 Working Principle of Regenerative Braking System

Regenerative breaking is a brake method to use mechanical energy from the motor and convert kinetic energy to electrical energy and give back to the battery. In the regenerative braking mode, the motor slows downhill the car. When we apply force to pedal brakes, then the car gets slow down and the motor works in reverse direction. When running in an invalid direction the motor acts as the generator and thus charges the battery. Thus, the car which is running in normal condition where the motor goes forward and takes energy from the battery.

When using regenerative braking in electric vehicles, it reduces the cost of fuel, increasing the fuel financial system and emissions will be lowered. The regenerative braking system provides the braking force while the speed of vehicles is low, and hence the traffic stops and go thus deceleration required is less in electric vehicles. These brakes work so effectively in driving in such an environment to stop in cities. The braking system and controller are the feeling of the structure because it controls the whole part of vehicles of the motor. The brake controller functions monitor the speed of the wheel, hence calculate the torque, electricity which is to be generated and rotational force thus to be fed to batteries. When we apply brakes to the brake controller, it controls and directs the electrical energy which is formed by the motor to the batteries.

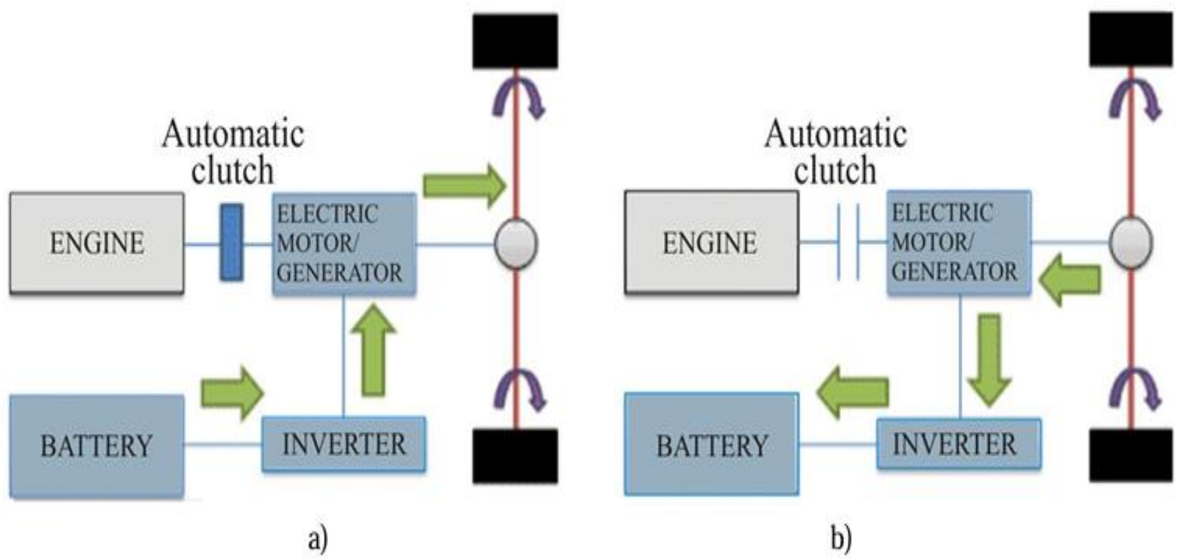


Figure 4- 24Working Principle of Regenerative Braking System

Operation pf regenerative braking system works in an EV:

- **Deceleration Trigger:** When the vehicle slows down, the energy that would normally be wasted through conventional friction brakes is harnessed. The electric motor, which powers the vehicle, switches to generator mode.

- **Kinetic Energy Conversion**: As the vehicle decelerates, its kinetic energy (the energy of motion) is converted into electrical energy by the motor-generator. The motor's rotating components create a resistance, slowing the vehicle while generating electricity.
- **Energy Storage**: The electricity generated during breaking is sent to the EV's battery, where it is stored for later use. This recovered energy can be used to power the vehicle's systems or provide additional range.
- **Blended Braking:** Many EVs use a combination of regenerative brakes and traditional friction brakes. This is especially necessary in situations where rapid deceleration is required or when the battery is fully charged and cannot accept more energy. The onboard computer system intelligently manages the transition between regenerative and friction braking to ensure safe and smooth braking.

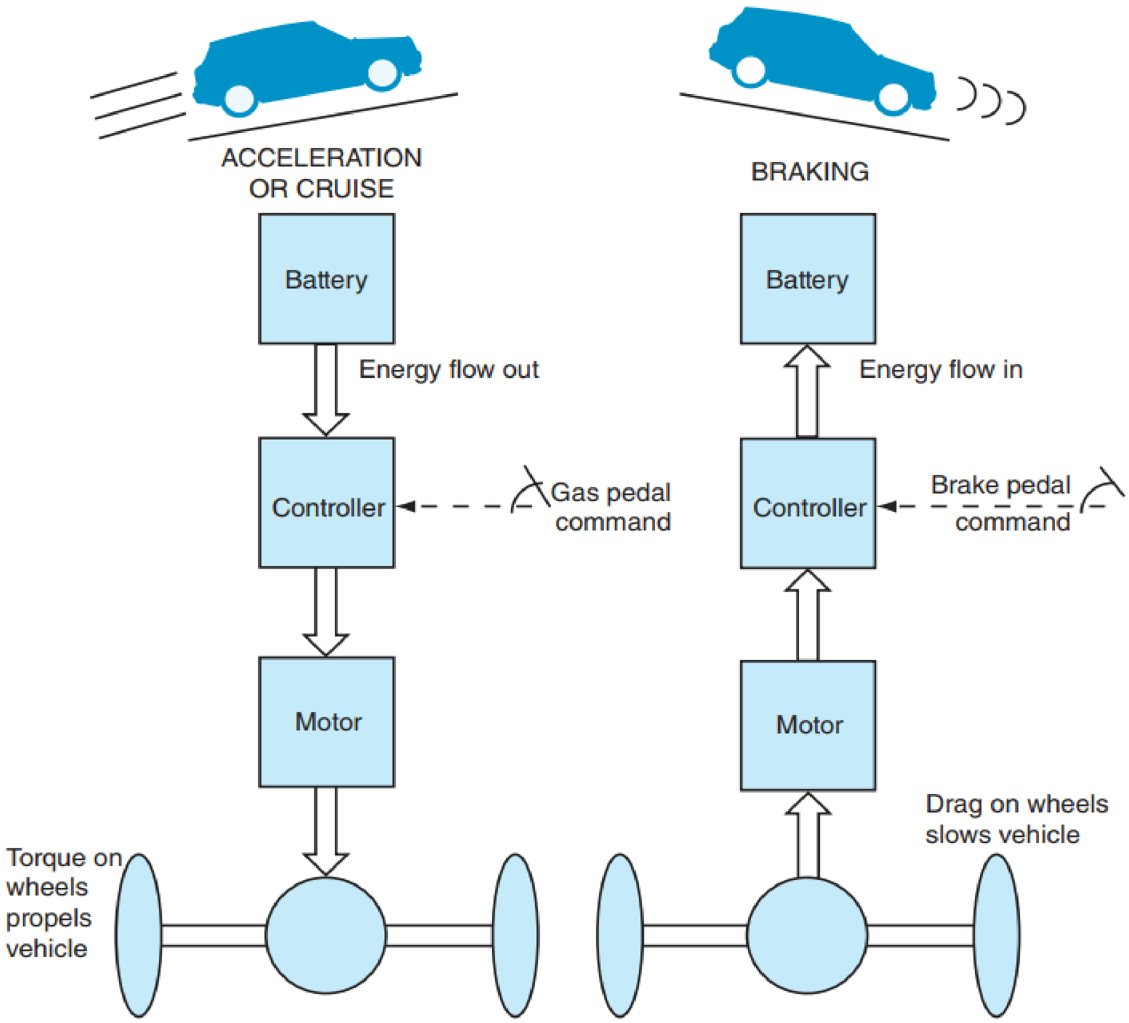


Figure 4- 25 Operation pf regenerative braking system

4.4.4 Types of Regenerative Braking System

A. Series Regenerative Braking

In this system, regenerative braking takes precedence over mechanical braking. When the vehicle decelerates, the system tries to recover as much energy as possible using the electric motor before switching to friction brakes. This is typically used in mild braking scenarios where aggressive deceleration is not needed.

B. Parallel Regenerative Braking

In parallel systems, regenerative and friction brakes work together simultaneously. This setup is commonly used when the vehicle needs to slow down quickly, allowing both energy recovery and effective deceleration.

C. Blended Braking

Most modern EVs use a blended braking system, where the car's computer determines the ideal mix of regenerative and friction braking based on driving conditions and the vehicle's energy recovery capacity.

4.4.5 Smart Brake Systems

Smart brake systems represent a significant advancement in automotive engineering, particularly within the realm of electric vehicles. These systems utilize sophisticated sensors and algorithms to enhance braking performance and vehicle control, ensuring a safer driving experience.

These systems primarily function through real-time data analysis, integrating inputs from various vehicle sensors. Key features include:

- Adaptive Brake Assist: Adjusts braking force based on driving conditions.
- Predictive Emergency Braking: Anticipates potential collisions and applies brakes proactively.
- Anti-lock Braking System (ABS): Prevents wheel lock-up during hard braking.

Smart brake systems communicate seamlessly with electronic stability control and traction control, optimizing vehicle dynamics. This interconnectedness not only improves the vehicle's handling but also enhances energy efficiency, contributing to the overall sustainability of electric vehicles.

Self-check 4.1

Directions: Answer all the questions listed below.

Part I: Say True or False

1. What are the primary factors to consider when selecting an electric motor for an EV?
2. Describe the working principle of an induction motor in an EV.
3. What are the advantages and disadvantages of using a single-speed transmission system in an EV?
4. Explain the concept of regenerative braking in EVs.
5. How does regenerative braking contribute to the overall efficiency of an EV?
6. Describe the difference between series and parallel regenerative braking systems.

Part-II: Choose the appropriate answer from the given alternatives

1. Which of the following components are NOT a part of a typical DC motor?
   a) Stator
   b) Rotor
   c) Commutator
   d) Inverter
2. Which type of motor is known for its high starting torque?
   a) Shunt motor
   b) Series motor
   c) Permanent magnet synchronous motor
   d) Induction motor
3. What is the primary advantage of brushless DC motors over brushed DC motors?
   a) Lower cost
   b) Higher maintenance requirements
   c) Reduced noise and vibration
   d) Lower power output
4. In an induction motor, the rotor speed is:
   a) Always equal to the synchronous speed.
   b) Slightly less than the synchronous speed.
   c) Always greater than the synchronous speed.
   d) Independent of the supply frequency.
5. Which of the following is NOT a key advantage of in-wheel motor configurations?
   a) Reduced drivetrain weight
   b) Lower center of gravity
   c) Increased complexity
   d) Improved traction control

6. What is the primary function of regenerative braking in an electric vehicle?
   a) To increase the vehicle's top speed.
   b) To improve fuel efficiency.
   c) To reduce brake wear.
   d) All of the above.
7. Which of the following is NOT a type of electric motor commonly used in electric vehicles?
   a) DC motor
   b) Induction motor
   c) Steam engine
   d) Permanent magnet synchronous motor
8. What is the primary purpose of the inverter in an electric vehicle?
   a) To convert DC power from the battery to AC power for the motor.
   b) To convert AC power back to DC power during regenerative break.
   c) To regulate the speed of the vehicle.
   d) To control the charging process of the battery.
9. Which of the following factors is NOT a key consideration when selecting an electric motor for an EV?
   a) Vehicle weight
   b) Driving cycle
   c) Fuel economy of the vehicle
   d) Power requirements of the vehicle
10. What is the primary function of the commutator in a DC motor?
    a) To convert AC to DC.
    b) To provide a path for current flow.
    c) To reverse the current flow through the armature coils.
    d) To protect the motor from overheating.

Part-III: Give a short answer for the following questions

1. What is the primary function of an electric propulsion unit in an electric vehicle?
2. Explain the key advantages of Permanent Magnet Brushless DC Motors (PM BLDC) in EV applications.
3. What are the primary factors to consider when selecting an electric motor for an EV?

4. Describe the working principle of an induction motor in an EV.
5. What are the advantages and disadvantages of using a single-speed transmission system in an EV?

Unit Five: EV Maintenance and Repair

This unit is developed to provide you with the necessary information regarding the following content coverage and topics:

- Common EV Problems
- Troubleshooting Common EV Electrical Problems
- Electrical Vehicle Diagnostics
- Battery Care and Maintenance
- Electric Motor and Drivetrain
- Maintenance of Brake System
- Software Updates

This guide will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this learning guide, you will be able to:

- Identify common EV Problems
- Troubleshoot Common EV Electrical Problems
- Perform Electrical Vehicle Diagnostics
- Care and Maintain Battery
- Maintain Electric Motor and Drivetrain
- Maintenance of Brake System
- Updates operating software’s

5.1 Common EV Problems

Driving an EV is a sustainable choice that reduces pollution and conserves the environment. Electric cars are extremely reliable, but like all other cars can have occasional problems that can be quite alarming about what is happening to your car. Possessing knowledge of these issues will ensure you address them immediately and prevent the problem from aggravating and causing major damage to your vehicle. Here, we discuss a few of these problems

5.1.1 Battery System

The battery system serves as the lifeblood of every electric vehicle, making its functionality paramount. Anyone worrying about an electric vehicle purchase will frequently cite battery degradation, and even warranty expiration as one of their biggest concerns. Manufacturers are constantly improving this technology by leaps and bounds almost every month – with range, quality and reliability levelling up all the time.

However, on the other end, a battery is only as good as its weakest cell. While repairs are rarely required, when needed, they can become urgent to ensure the drivability and efficiency of the vehicle. While all electric vehicle repair – even light maintenance – requires awareness training, any sort of battery repair or replacement is extra complex and requires even more extensive training and technician certification. Some issues that commonly arise with EV batteries include:

- **Capacity Degradation**: Over time, EV batteries can experience capacity loss due to factors like temperature fluctuations and frequent fast charging. Effective EV technician training equips professionals to address capacity issues through battery reconditioning or module replacement.
- **Cell Imbalance**: The performance and range of an EV can be compromised due to imbalances in individual battery cells. Qualified EV technicians can mitigate this by balancing cells or replacing defective ones.
- **Thermal Management System**: Malfunctions in the thermal management system can lead to overheating, affecting both battery efficiency and longevity. Thorough EV technician training and certification prepares professionals to diagnose and rectify cooling or heating element issues.

5.1.2 Charging System

A well-functioning charging system is imperative for the optimal performance of an electric vehicle. Repairs within this system encompass:

- **Charging Port Issues:** EVs can face hindrances due to faulty charging ports. EV technicians trained in high voltage safety protocols can expertly tackle issues like cleaning, connector replacement, or rectifying wiring complications.
- **Onboard Charger Problems:** The onboard charger's critical role in converting AC power to DC power for the battery cannot be overstated. Skilled EV technicians proficient in electric vehicle repair should be able to adeptly handle power conversion issues, fuse-related matters, or circuitry challenges as they arise. This requires a deeper understanding of the theory of electric fundamentals than many auto techicians may be used to.
- **Charging Cable Damage:** The charging cable can experience wear and tear over time, leading to compromised connectivity. EV technicians with the requisite training can seamlessly replace or repair the cable, restoring efficient charging capabilities.

5.1.3 Electric Motor and Drive Unit

The motor and drive unit(s) constitute the driving force behind an electric vehicle's movement. Common issues that may arise include:

- **Inverter Malfunctions:** The inverter plays a pivotal role in converting DC power from the battery into AC power for the motor. Proficient EV technicians can identify and resolve inverter problems, thereby averting power loss or inefficient performance.
- **Motor Issues:** EV motors can experience complications with bearings, windings, or sensors. Skilled technicians can undertake motor component replacements or rewinding, ensuring seamless functionality.

5.1.4 Regenerative Braking Systems

Regenerative braking systems capture kinetic energy during deceleration and transform it into electrical energy. Repairs within this system involve:

- **Brake-by-Wire Problems:** Regenerative braking relies on a brake-by-wire system. Expert EV technicians are equipped to diagnose and rectify any malfunctions, as they arise.

- **Sensor Failures:** Sensors responsible for monitoring vehicle speed and acceleration are pivotal for effective regenerative breaking. EV technicians trained in electric vehicle repair can address sensor malfunctions through recalibration or replacement, optimizing energy recapture

5.1.5 Electrical System

The holistic electrical system of an EV comprises multiple components, and issues can manifest in various forms:

- **Electrical Wiring Challenges:** Damaged or corroded wiring can disrupt communication between components, affecting the overall functioning of the EV. Skilled EV technicians proficient in electric safety guidelines can expertly identify and rectify wiring issues.
- **Control Units Troubles:** Diverse control units govern different aspects of EV operations. When these units malfunction, it can lead to erratic behavior or diminished performance. EV technicians can skillfully repair or reprogram control units, restoring optimal functionality.

5.1.6 HVAC System

The heating, ventilation, and air conditioning (HVAC) system within an EV contributes to both passenger comfort and vehicle efficiency. Unlike an ICE vehicle, where hot air is a by-product of the engine, EVs requires considerably more effort with varying systems which we discuss in more detail in our EV systems overview course. Common repairs in this area include:

- **Coolant Leaks:** Leaks in the coolant system can compromise HVAC efficiency and the overall thermal management of the vehicle. EV technicians trained in electric vehicle repair can adeptly identify and rectify coolant leaks.
- **Blower Motor Issues:** The blower motor plays a pivotal role in distributing air conditioning. EV technicians proficient in electric safety protocols can troubleshoot and repair blower motor problems, ensuring optimal heating and cooling.

5.1.7 Suspension and Braking System Repairs

While not exclusive to EVs, the suspension and braking systems are indispensable for vehicle safety. Repairs in these areas encompass:

- **Brake Pad Wear:** Brake pads, like those in conventional vehicles, experience wear overtime and necessitate regular replacement although at a much less frequent cadence. Skilled EV technicians are equipped to handle this maintenance requirement.
- **Suspension Component Failures**: EVs are equipped with various suspension components that contribute to riding comfort and stability. Proficient EV technicians can replace worn-out parts, optimizing both ride quality and safety.

5.1.8 Software and Firmware Updates

In contrast to traditional vehicles, EVs heavily rely on software and firmware for various systems. Regular updates can address bugs, enhance performance, and introduce new features. OEMs and manufacturers can do a lot of these over the air. You may have heard about massive recalls on thousands of EVs that were fixed overnight by the OEM through the push of a button!

5.1.9 Vehicle Parts

At the end of the day, your electric vehicle is cool, but it is a car. Windshields will break during hail, door handles will jam, low voltage batteries will need jumpstarting, collisions will lead to dents and dings, and of course, small or serious accidents may happen. Almost every time something that breaks or dents or crumples will require scrutiny and even a different protocol for approaching and fixing it than what emergency responders and auto technicians are used to. For example, an EV that has gotten into a collision requires extra caution due to the high voltage system and a different post collision emergency response.

5.2 Troubleshooting Common EV Electrical Problems

As a technician, it's beneficial to know what signs to look for when diagnosing and fixing an electrical issue that can plague one of an EV's electrical systems. In this article, we'll look at some electrical issues that commonly present themselves in electric vehicles.

If any of the above systems or components (or others) have begun to malfunction or otherwise fail to perform up to spec, there are several steps that should be followed before you grab your toolbox. It's worth noting at this point that only a trained technician should attempt to diagnose and service an electric vehicle. Think of the following as the universal first steps to troubleshooting electrical issues.

- **First,** check the vehicle for error codes. Modern EVs come with the added benefit of having a built-in diagnostics system that will provide error codes associated with the issue. Though the error codes tend to lack detail, they will provide technicians with the necessary information to begin troubleshooting. For example, an error code of "High Temperature" may indicate that the temperature inside of the Electrical Vehicle Supply Equipment (EVSE) is too high, which is causing a decrease in the available capacity of an electric generating unit.
- **Next,** visually inspect the charging equipment. If the vehicle is charging slower than expected, or if overnight charging has become less effective, take a few moments to visually inspect the charging cable and charging ports for any sign of damage. Additionally, you may need to inspect the charging station itself to determine if the equipment is defective.
- **Lastly**, try resetting the system. Electric vehicles (and most modern vehicles for that matter) are more computer than methods of conveyance. In some cases, you may successfully resolve an issue by resetting the vehicle's systems or physically disconnecting and reconnecting the battery. While resetting the vehicle's systems, take a moment to see if there are any software updates that are pending and updated as required.

5.3 Electrical Vehicle Diagnostics

Diagnosing concerns on a conventional vehicle because there are fewer components. However, most manufactured BEVs have complex electronics that are unique and require a solid understanding of how the vehicle's systems operate. Fortunately, most BEVs have self-diagnostics with retrievable trouble codes.

Manufacturer-supplied checklists are especially helpful when deciding what should be known about a particular problem and repair. In the vehicle's service manual, there may be symptoms based diagnostic aids. These can guide you through a systematic process. As you answer the questions given at each step, you are guided to the next step.

When these diagnostic aids are not available or prove to be section and then take a logical approach to solving the problem. Logical diagnosis follows these steps:

1. Gather information about the customer's concern. Find out when and where it happens and what exactly happens.
2. Verify that the problem exists. Take the vehicle for a road test and try to duplicate the problem, if possible.
3. Thoroughly define what the problem is and when it occurs. Pay strict attention to the conditions present when the problem happens. Also pay attention to the entire vehicle; another problem may be evident to you that is not evil.
4. Research all available information and knowledge to determine the possible causes of the problem. Try to match the exact problem with a symptoms chart or think about what is happening and match a system or some components to the problem.
5. Isolate the problem by testing. Narrow the probable causes of the problem by checking the obvious or easy-to-check items.
6. Continue testing to pinpoint the cause of the problem. Once you know where the problem should be, test until you find it!
7. Locate and repair the problem, then verify the repair. Never assume that your work solved the original problem. Make sure the problem is resolved before returning the vehicle to the customer.

5.3.1 Diagnostic Precautions

During diagnosis and repair of a BEV, always keep in mind that the vehicle has very high voltage. This voltage can kill you! Therefore, always adhere to the safety guidelines given by the manufacturer. Here are a few of the things that should be done to prevent being shocked by the vehicle's electrical system:

- Wear dry and undamaged insulated gloves while working on the vehicle.
- Disable or disconnect from the high-voltage system.
- Do this according to the procedures given by the manufacturer.
- After the high-voltage system is disconnected, wait for the prescribed amount of time before handling any part of the system.

- After the high-voltage system is disconnected, verify that the voltage has been safely disconnected.
- Always use insulated tools.
- When disconnecting electrical connectors, do not pull on the wires. When reconnecting the connectors, make sure they are securely connected.
- Do not leave tools or parts anywhere in the vehicle.
- Do not wear metallic objects such as rings and necklaces

5.3.2 Self-Diagnostics

The vehicle's control unit or computer may have a built-in self-diagnostic system. In these systems, a mal propulsion system can be detected. When a fault is detected, the computer will store that information and may illuminate the malfunction indicator light (MIL) on the instrument panel. The faults held in the computer's memory can be retrieved as Diagnostic Trouble Codes (DTCs). To retrieve these codes, connect the hand-held scan tool to the appropriate Data Link Connector (DLC) on the vehicle.

The scan tool will also be able to display other operational data. Many scan tools also have a freezing frame feature. With this feature, the tool records the conditions that were present when a particular malfunction was detected. Before connecting the scan tool to the vehicle, measure the voltage of the auxiliary battery. If the voltage is lower than specifications, recharge it before continuing with your tests. Also, inspect all fuses, fusible links, wiring harness, connectors, and ground in the low-voltage circuit. Repair them as necessary. Turn the motor switch to the ON position and make sure the MIL is lit. If the MIL does not light, check for a burnt-out bulb, a bad circuit fuse, or an opening in the circuit. Again, correct the problem before proceeding. The MIL should go off when the READY lamp lights. If the MIL stays on, the computer has found a problem, and related information is stored in its memory. Turn the motor switch to the OFF position. Make sure the scan tool is set up for the vehicle being tested. Then connect it securely to the DLC. Turn the motor switch to the ON position and turn the scan tool on. Check for DTCs and freeze frame data and record all codes and data displayed on the scanline what the DTCs indicate. Following the correct procedures, verify the trouble and repair the problem. After completing any repair of the motor or related parts, erase the DTCs retained in the computer's memory with the scan tool. Then test it again to make sure the fault is no longer present.

5.4 Battery Care and Maintenance

Most EV batteries are built for an extended life (about 10 to 20 years), following a regular battery repair and maintenance schedule can go a long way in maximizing its durability, overall health, and performance. One of the most significant components of an electric vehicle is the battery pack. It's the heart of the EV, providing the electric motor and systems the necessary power. Proper battery maintenance is essential for preserving driving range and overall vehicle health.

5.4.1 Battery Pack Inspection and Diagnostics

Regular inspections of an electric vehicle (EV) battery pack are crucial for ensuring optimal performance and longevity. A fundamental step in inspecting a battery pack entail checking for physical deformities, leaks, corrosion, heat build-up, and swelling, all of which could be early signs of thermal runaway.

To assess the health of a battery and its potential impact on an electric vehicle's performance, one critical metric to consider is the "State of Health" (SOH). SOH is a report that provides a comprehensive view of the battery's condition, not just its current charge level. An SOH value below 70-80% capacity may raise concerns about the EV's performance.

Monitoring the SOH is essential for electric vehicle owners as it offers valuable insights into the battery's remaining capacity and helps predict when it might need replacement or servicing. This information is crucial for maintaining the efficiency and range of the electric vehicle, ensuring that it continues to meet the owner's expectations and requirements. Addressing battery degradation through proper maintenance can help extend the life of the electric vehicle and maintain its optimal performance.

To diagnose the state of health (SOH) of a battery pack, several diagnostic methods are employed:

- Voltage Testing: Connect a multimeter to the battery terminals and set it to the "DC Voltage" mode. Place the probes on the terminals to check the voltage level, ensuring it aligns with manufacturer specifications.
- Impedance and Storage Capacity Testing: Use diagnostic equipment to assess the battery's capability to store and deliver energy efficiently. Equipment typically provides a concise report on the battery's health, longevity, and ability to operate at maximum functionality.
- Differential Voltage and Incremental Capacity Analysis: These tests, which transfer from cell to battery pack level, help detect aging-related features, such as loss of lithium inventory, thus aiding state of health estimation.

5.4.2 Battery Cell Replacement and Maintenance Procedures

Electric vehicle battery packs are composed of numerous cells. Over time, individual cells can fail due to internal manufacturing faults or excessive wear. Replacing a cell in an EV battery pack is often impractical; typically, the entire battery pack is replaced when capacity drops significantly.

- Identification and Removal: Identify defective cells during diagnostics. Carefully disconnect the negative terminal to avoid accidental short circuits. Remove the module causing access to the faulty cells.
- Replacement: Insert new, compatible cells into the designated slots. Ensure they fit securely and reconnect the terminals.
- Balancing: After cell replacement, the battery management system must balance the charge across all cells within the battery pack. to ensure uniform voltage and charge distribution across the pack.

Maintaining batteries with these procedures ensures extended usability and performance longevity.

5.4.3 Battery Degradation Factors

All battery types are subject to the process of degradation, and electric vehicle batteries are no exception. It happens for a variety of reasons, all of which lower the battery's capacity and general efficiency.

- **Calendar ageing**: Over time, even when a battery is not in use, it undergoes calendar ageing which means the degradation of battery cells independent of its charging-discharging cycles, which occurs due to the continued chemical reactions within the battery. This can eventually result in a gradual reduction in the battery capacity. The extent of calendar ageing depends on various factors, such as the battery's chemistry, state of charge (SOC), temperature, and maintenance.
- **High temperatures:** Exposing a battery to high temperatures can accelerate the rate of chemical reactions within the battery, causing it to wear out faster.
- **Thermal expansion:** As batteries go through charge and discharge cycles, they heat up, and the expansion and contraction of the battery materials occur. This repeated thermal cycling can lead to physical wear and tear on the internal components, contributing to overall battery degradation.
- **Charge and discharge cycles:** One complete charge and discharge is called one “charge cycle” of a battery. It is essential to follow a mindful charging pattern and not let the SOC reduce by below 20% to maintain good battery health.

5.4.4 Mitigating Battery Degradation

It is predicted that EV battery life could be up to 500,000 miles. New electric vehicles cannot overcharge, over-discharge, or overheat thanks to safeguards that are in place. However, there are several steps you can take to help extend the life of your EV battery.

- Avoid Discharging Below 20 Percent: Making sure that you do not operate your EV below a 20 percent charge will add life to the battery and also make sure you always have plenty of charge to get you home.
- Only Charge Up to 80 Percent: For most EV owners, their EV is more than enough for daily commutes and errands and charging up to 80 percent is plenty for a day’s travel. A

full charge to 100 percent is not good for lithium-ion batteries. You can lower the maximum charging limit with your EV's onboard charger.

- Keep Your Car at the Right Temperature: Lithium-ion batteries are at their best within the same temperature range that is comfortable for humans. If it is too hot or too cold outside for you, it is likely not good for your EV. Park your car in the shade on hot days and in the garage when it is cold.
- Don't Be Lead Foot: Moderate acceleration is key to extending battery life. Smooth, even acceleration will avoid depleting the battery.
- Limit DC Fast Charging: It is much better to charge your EV at home overnight using Level 1 or Level 2 charging rather than utilizing a DC Fast Charger at a charging station in town. It avoids pushing so much electricity into the battery pack all at once. Using one of these DC Fast Chargers while on a trip is fine, just don't make it a daily habit.

5.5 Electric Motor and Drivetrain

5.5.1 Motor Diagnostics and Performance Testing

Electric motor diagnostics involve assessing various performance metrics to ensure optimal operation. Fundamental tools like multimeter are essential for initial tests. A multimeter measures voltage, current, and resistance, and it helps in identifying continuity issues and detecting short circuits or ground faults within the motor's windings.

Advanced diagnostic methods include Constant Load Testing, where a constant load is applied to the electric vehicle motor over a specific period. This method measures the motor's speed, torque, temperature, and power consumption, providing a thorough analysis of the motor's performance under operational conditions.

Additionally, specialized equipment like the AT34 EV™ can be used for comprehensive motor health assessments. This device uses both static and dynamic testing capabilities to evaluate the electrical and magnetic performance of motor components, including the stator windings and rotor.

5.5.2 Inverter and Controller Troubleshooting

The inverter and controller are critical components that convert DC power from the battery into AC power for the motor. Issues with these components can significantly impact vehicle performance. Common troubleshooting steps include checking software updates, ensuring proper wiring connections, and using diagnostic tools to monitor system performance.

OEM vehicle diagnostics might not always provide a complete analysis of the health of the inverters or controllers. Tools like the AT34 EV™ offer more precise diagnostic capabilities, allowing technicians to pinpoint issues in the Power Inverter Module (PIM) system without disassembling the vehicle.

5.5.3 Drive Unit Maintenance and Repair Procedures

Maintaining the driving unit involves regular inspections and timely repairs to prevent potential failures. Essential tasks include:

- Visual Inspection: Regularly check for any signs of wear or damage on the drive unit components.
- Lubrication: Ensure that all moving parts are adequately lubricated to reduce friction and wear.
- Coolant Levels: Monitor and maintain appropriate coolant levels to prevent overheating.
- Software Updates: Install the latest firmware to ensure that the drive system operates efficiently and with improved performance.

Utilizing testing tools like the AT34 EV™ can also help in diagnosing issues within the drive unit without the need for extensive disassembly. This tool’s ability to evaluate stator and rotor conditions without rotor rotation simplifies the maintenance process and prevents extensive downtime.

Proper maintenance and prompt repairs are crucial for ensuring the longevity and efficacy of the electric vehicle motor and drive system. Regular diagnostic checks and leveraging advanced tools can mitigate the risk of major failures and keep the electric vehicle running optimally.

To maintain peak performance, it’s essential to keep every system in an electric vehicle well-maintained and promptly address any issues that arise. Ensuring the drive unit’s performance is just one aspect of the broader maintenance approach necessary for electric vehicles.

5.5.4 Tire Maintenance

Electric vehicles, often heavier due to their battery packs, put additional demands on tires. An EV's instant torque also influences how tires wear over time. Therefore, understanding tire maintenance and selecting suitable replacements when necessary is crucial for preserving the performance and safety of your electric car.

A) Impact of EV Weight on Tire Wear

- Increased Stress: The substantial weight of an EV can lead car owners to need to replace the tires more frequently due to increased stress and wear.
- Even Tread Wear: It's essential to monitor Tread Wear closely, as uneven patterns can signal alignment or suspension issues, which an EV's weight may accentuate.

B) Tire Care and Replacement Intervals

- Regular Tire Pressure Checks: Maintaining the correct tire pressure is vital for optimal performance and efficiency. Underinflated tires can lead to reduced range and increased wear.
- Tire Rotation: EV owners should rotate their tires according to the manufacturer's recommendations or every 5,000 to 7,500 miles to promote even wear.
- Annual Inspections: Have your tires inspected annually for signs of damage, such as cuts or sidewall bulges.
- Replacement with EV-Specific Tires: When it's time for new tires, consider those designed for electric vehicles. They can accommodate the extra weight and torque while offering low rolling resistance for increased range.

C) Tire Wear Signs

- Balding: If you notice bald spots or the tread depth is less than 4/32 of an inch, it's time to replace your tires.
- Vibration: Excessive driving vibration could mean tire balancing issues or internal tire damage.
- Sidewall Cracks: Visible cracks in a tire's sidewall indicate aging tires that may need replacement.

By staying on top of tire maintenance, EV drivers can ensure a smoother ride, better handling, and maximum efficiency. Good tire maintenance can prevent accidents due to tire failures and even extend the life of your electric vehicle by preventing additional strain on the suspension and drivetrain systems.

5.6 Maintenance of Brake System

Regular maintenance of the brake system for electric vehicles is essential to ensure optimal performance and safety. Unlike traditional vehicles, electric vehicles utilize regenerative breaking, which can affect wear patterns on brake components differently. Understanding these differences helps in scheduling appropriate maintenance intervals.

Routine inspections should focus on checking the brake pads, rotors, and fluid levels. The brake pads in electric vehicles may experience less wear due to the efficient use of regenerative braking, but monitoring their condition remains vital. Additionally, brake fluid quality should be assessed to avoid potential hydraulic system issues.

Owners should also consider utilizing specialized diagnostic tools designed for electric vehicles. These tools help in monitoring the functionality of electronic brake systems and alerting drivers to anomalies before they escalate. Regular software updates may also be part of maintenance to ensure that the brake system operates seamlessly.

Overall, maintaining the brake system for electric vehicles not only enhances driving safety but can also prolong the lifespan of the vehicle's braking components. Regular attention to these systems can lead to improved performance and reduced operational costs in the long run. For maintaining the EV Braking System:

- Regular Inspection: Regularly check brake pads, rotors, and discs for wear and tear. Despite being used less, they will eventually need replacement.
- Listen for Noises: Any grinding or squealing sounds during braking are signs that your pads or rotors need attention.
- Brake Fluid Checks: While regenerative systems reduce physical brake use, the fluid still requires regular replacement to maintain effectiveness and prevent corrosion.

- Stay Aware of Changes: If you notice a reduction in braking performance or your car pulls to one side when applying brakes, seek professional service.

Maintaining a well-functioning brake system is critical for safety. Regular checks help prevent issues compromising braking effectiveness, ensuring your EV slows and stops reliably when needed.

5.7 Software Updates

Like most new vehicles, your EV will benefit from regular manufacturer software updates. These can improve battery management, charging efficiency and overall vehicle performance. Keep informed of any software updates available for your vehicle's make and model and visit an authorized service center for installation. Here's a quick recap:

- Care for the battery by maintaining good charging habits and considering the outside temperature.
- Keep your tires in excellent condition, maintaining the correct pressure and ensuring regular rotation and alignment.
- Monitor and maintain your brakes and the braking system.
- Regularly check and maintain the cooling system to prevent overheating.
- Stay updated with the latest software upgrades to enhance overall vehicle performance.

Maintaining your electric vehicle is not as complex as it may seem, and your vehicle's service provider can help you keep things in check. With these practices in place, you can be confident that you will prolong the life of your EV, optimize its performance, and contribute to a greener future.

Self-check 5.1

Directions: Answer all the questions listed below.

Part I: Say True or False

1. The substantial weight of an EV can lead to increased stress and wear on tires.
2. Maintaining the correct tire pressure is vital for optimal performance and efficiency in electric vehicles.
3. Tire rotation is not necessary for electric vehicles due to regenerative braking.
4. Regenerative braking significantly increases brake pad wear in electric vehicles.
5. Brake fluid in electric vehicles never needs to be replaced.

Part-II: Choose the appropriate answer from the given alternatives

1. Which of the following diagnostic tools can be used for comprehensive motor health assessments in EVs?
   a) Multimeter c) Constant Load Tester
   b) AT34 EV™ d) All of the above
2. Which component is crucial for converting DC power from the battery into AC power for the electric motor?
   a) Controller c) Rectifier
   b) Inverter d) Regenerator
3. What is the primary purpose of utilizing diagnostic tools like the AT34 EV™ in EV maintenance?
   a) To simplify maintenance procedures.
   b) To evaluate motor performance without extensive disassembly.
   c) To monitor battery health.
   d) To check tire pressure.
4. How does the weight of an electric vehicle impact tire wear?
   a) It has no significant impact on tire wear.
   b) It can lead to increased stress and wear on the tires.
   c) It reduces tire wear due to smoother acceleration.

d) It increases tire pressure.

5. What is the recommended action if you notice bald spots on your EV's tires?
   a) Increase tire pressure.
   b) Rotate the tires.
   c) Replace the tires.
   d) Ignore the issue.
6. How does regenerative braking affect brake pad wear in electric vehicles?
   a) It significantly increases brake pad wear.
   b) It significantly decreases brake pad wear.
   c) It has no impact on brake pad wear.
   d) It increases brake pad wear at high speeds.
7. What is the significance of regular software updates for electric vehicles?
   a) To improve performance and efficiency.
   b) To address bugs and enhance safety features.
   c) To introduce new features and functionalities.
   d) All of the above.
8. Which of the following is NOT a common issue that can affect an EV battery pack?
   a) Capacity degradation
   b) Cell imbalance
   c) Overcharging
   d) Insufficient tire pressure
9. What is the primary function of the onboard charger in an EV?
   a) To convert DC power from the battery to AC power for the motor.
   b) To convert AC power from the grid to DC power for the battery.
   c) To regulate the speed of the electric motor.
   d) To monitor the health of the battery pack.

Part-III: Give a short answer for the following questions

1. What are three key factors that can contribute to battery degradation in an EV?
2. How can drivers minimize the impact of high temperatures on their EV battery?
3. Why is it recommended to avoid frequent DC fast charging?
4. What is the significance of "State of Health" (SOH) in relation to an EV battery?
5. How can drivers help to extend the lifespan of their EV battery?

Operation Sheet 5.1

Operation Title: Customer Problem Analysis Check

Instruction:

- Keep safe in your working area
- Refer to your vehicle's service manual to obtain the manufacturer's specifications

Purpose: To analyze the customer inquiry

Required Tools and Equipment:

Precautions: Before making a test make sure vehicle safe conditions

Quality Criteria: - Observing attentively

Procedures:

EV CONTROL SYSTEM Check Sheet

Inspector's Name ______________________

Customer's Name		Model	
Driver's Name		Model Year	
Date Vehicle Brought in		Frame No.	
License No.		Odometer Reading	km miles

Problem Symptoms	☐ READY does not turn ON ☐ Vehicle does not move ☐ Poor acceleration ☐ Noise ☐ Vibration ☐ Harshness ☐ Smoke is rising ☐ Smell of or the likes burn ☐ Other ______________________

Date Problem Occurred		
Problem Frequency		☐ Constant ☐ Sometimes(times per day/month) ☐ Once only ☐ Other ______________________
Condition When Problem Occurred	Weather	☐ Fine ☐ Cloudy ☐ Rainy ☐ Snowy ☐ Various/Other ______________
	Outdoor Temperature	☐ Hot ☐ Warm ☐ Cool ☐ Cold(approx. ____°F/____°C)
	Place	☐ Highway ☐ Suburbs ☐ Inner City ☐ Uphill ☐ Downhill ☐ Rough road ☐ Other ______________________
	Traction Motor	☐ Just after starting vehicle(min.) ☐ Standing with READY ON ☐ Driving ☐ Constant speed ☐ Acceleration ☐ Deceleration ☐ Other ______________________

Condition of MIL	☐ Remains on ☐ Sometimes lights up ☐ Does not light up
DTC Inspection	☐ Normal ☐ Malfunction code(s) (code) ☐ Freeze frame data ( )

LAP-Test

Practical Demonstration

Name: ___________________________ **Date: ____________**

Time Started: ________________ **Time finished: _________________**

Instruction I: Perform the following tasks

Task 1: Inspect visual check, and diagnosis

Task 2: Identify charging port types

Task 3: Charge an EV according to the manufacturer specifications

Task 4: Inspect the battery pack of the EV

Task 5: Service the brake system

Task 5: Update the newest version of operating system

Reference

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- Electric And Hybrid Vehicles Power Sources, Models, Sustainability, Infrastructure and the Market, Gianfranco Pistoia
- Electric Vehicles, Principles and Applications with Practical Perspectives, Chris Mi
- Modern Electric Vehicle Technology C.C. Chan and K.T. Chau

Developers Profile

No	Name	Qualification (Level)	Organization/ Institution	Mobile Number	E-mail
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