EVTECH

MODULE 1

EV ESSENTIALS

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1. INTRODUCTORY PARAGRAPH

Until a few years ago, the primary energy source used in vehicles was the internal combustion engine (ICE).

Current designs of electric vehicles are aimed at partially or completely reducing the involvement of the combustion engine as an energy source.

A zero-emissions vehicle (ZEV), also popularly known by its initials in English as ZEV (Zero Emissions Vehicle), is a vehicle that does not emit polluting substances through the exhaust pipe generated by the propulsion source onboard the vehicle.

Today, the automotive industry works on two types of electric vehicles:

- Hybrid Electric Vehicles (HEV - Hybrid Electric Vehicle)
- Pure Electric Vehicles (EV - Electric Vehicle)

1.1 LEARNING UNIT 1: OVERVIEW OF EV TECHNOLOGY

CLASSIFICATION OF ELECTRIC VEHICLES

- Series Hybrid Vehicles
- Parallel Hybrid Vehicles
- Plug-in Hybrid Vehicles (PHEV)
- Non-Plug-in Hybrid Vehicles
- Advantages and disadvantages of different configurations of hybrid vehicles

HYBRID ELECTRIC VEHICLES (HEV)

The operation of a hybrid vehicle (HEV - Hybrid Electric Vehicle) is based on the combination of two types of engines, one electric and the other conventional (internal combustion engine) through a hybrid control system and a battery pack.

In general, a hybrid vehicle operates like a conventional one to which an electric motor has been added. The mission of this electric motor is to:

• Assist the combustion engine when greater power is required

• Solely propel the vehicle (with the combustion engine disconnected) when the required power is small, for example, under favorable driving conditions.

Hybrid vehicles are equipped with an internal combustion engine (ICE), an electric motor (usually permanent magnet), and a battery pack.

In almost 100% of cases, the ICE is a spark-ignition engine (i.e., gasoline) because they are more economical (both in the cost of the engine itself and in maintenance costs) and have lower polluting emissions than compression-ignition engines (Diesel). However, nowadays, compression-ignition engines have reached emissions levels so low that they compete on equal terms with spark-ignition engines (although they are still more expensive than gasoline engines).

Within hybrid vehicles, it is possible to distinguish between two categories from the perspective of the traction system:

• Series Hybrid Vehicles

• Parallel Hybrid Vehicles

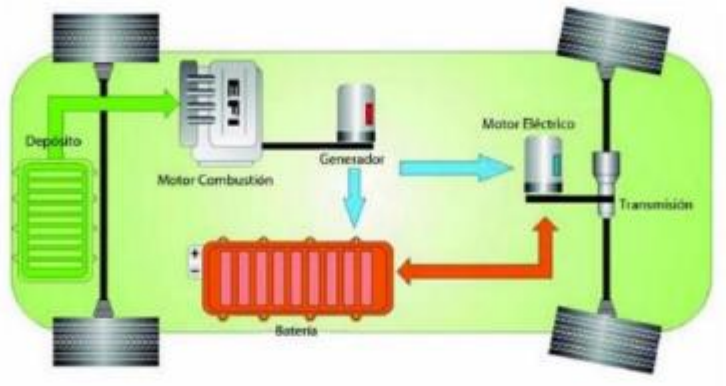
And in two other categories, from the perspective of battery charging:

• Plug-in Hybrid Vehicles (PHEV)

• Non-Plug-in Hybrid Vehicles

SERIES HYBRID VEHICLES

The vehicle is solely propelled by the electric motor thanks to the electrical energy supplied by a generator, which is powered by an internal combustion engine (ICE).



The battery acts as an electricity (energy) accumulator and, when charged, allows the temporary disconnection of the combustion engine (generator), so that the vehicle can be propelled entirely electrically (i.e., the traction electric motor is powered solely by the battery).

The mechanical output of the internal combustion engine (the crankshaft) is directly connected to an electric power generator. The electric energy thus generated is used to charge the battery and power the traction electric motor, which moves the vehicle's wheels.

There are six different possible operating modes in a series HEV:

• Battery-only mode: the internal combustion engine (ICE) is off, so the traction electric motor is powered solely by the battery.

• Independent motor mode: the traction electric motor is powered by the energy generated by the electric generator (driven by the ICE).

• Mixed mode: both the generator and the battery provide power to the traction electric motor.

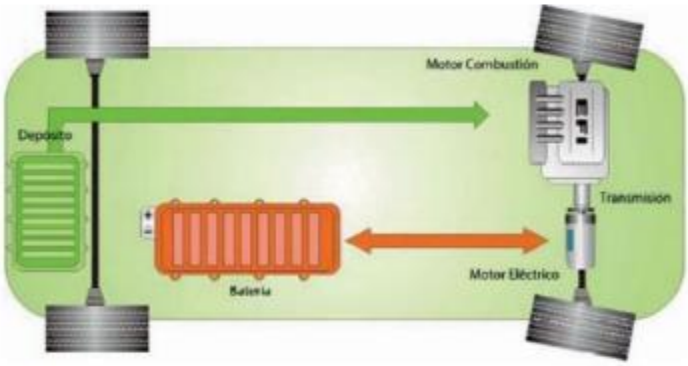
• Power split mode: the generator can distribute the generated energy to power the traction motor and charge the battery (provided that the motor does not demand all the electrical power generated by said generator).

• Stationary charging mode: with the traction electric motor turned off, all the energy produced by the generator is used to charge the battery.

• Regenerative braking mode: the energy obtained by the electric motor during the vehicle's braking process is utilized to charge the battery.

PARALLEL HYBRID VEHICLES

In parallel architecture hybrid vehicles, both the combustion engine (ICE) and the traction electric motor (TEM) work simultaneously to drive the vehicle's wheels.



The traction system is not overly complex mechanically in this architecture since the TEM simply works in parallel with the combustion engine. This represents a significant simplification when it comes to developing hybridization for any manufacturer.

Therefore, a parallel HEV has the internal combustion engine (ICE) and the traction electric motor (TEM) coupled to the final drive axle of the wheels through clutches. This configuration is used by almost all manufacturers nowadays in their hybrid models.

There are six different possible operating modes in a parallel HEV:

• Electric-only mode: the internal combustion engine (ICE) is off, and the vehicle is propelled solely by the traction electric motor (TEM).

• Internal combustion engine-only mode: the vehicle is powered solely by the internal combustion engine (ICE). The TEM is off.

• Mixed mode: both the ICE and the TEM drive the vehicle.

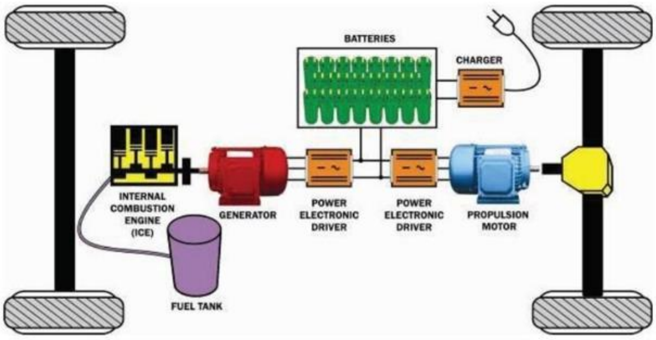
• Power split mode: the ICE distributes its power to drive the vehicle and power the traction electric motor (which operates as a power generator). This way, it's possible to charge the battery while driving.

• Stationary charging mode: with the electric motor disconnected from the traction system (the internal combustion engine is the only one propelling the vehicle), all the energy produced by the electric motor (which would act as a generator driven by the combustion engine) is used to charge the battery.

• Regenerative braking mode: the energy obtained by the traction electric motor during the vehicle's braking process is used to charge the battery.

PLUG-IN HYBRID ELECTRIC VEHICLES (PHEV)

This type of plug-in hybrid electric vehicles (PHEV - Plug-in Hybrid Electric Vehicle), whether they are series or parallel hybrids, have a battery prepared to be charged not only through the electric generator installed in the vehicle itself (driven by an ICE or by means of the traction electric motor functioning as a generator) but also by connecting it to the external electrical grid (in a building, at a charging station...).



To connect the battery to the external electrical grid, the use of an additional component is essential: the charger. This component can be installed in the vehicle itself (on-board) and be part of the external charging panel.

NON-PLUG-IN HYBRID VEHICLES

This type of vehicle (series or parallel hybrids) has a battery that is not designed to be charged by connecting to an external electrical grid.

It's not the battery itself that prevents charging from an external electrical grid, but rather the vehicle's electrical system does not have the necessary interface installed to establish such a connection with the grid.

The decision about whether or not to have a plug-in vehicle lies with the manufacturer in the vehicle's initial design phase.

ADVANTAGES AND DISADVANTAGES OF HYBRID VEHICLES

Series Hybrid Vehicles

• Allows positioning the combustion engine + generator assembly independently of the position of the traction electric motor, optimizing space utilization (aiming for an appropriate distribution of masses in the vehicle).

• The internal combustion engine (ICE) has much higher efficiency compared to a parallel hybrid since it's sized to work only connected to a generator, allowing it to operate at its maximum efficiency point during very long cycles.

• As the vehicle is solely propelled by the electric motor, its performance is limited by the amount of energy the battery can supply. On the other hand, it must have the appropriate size to provide the required performance by design (in this case, it doesn't have the assistance for vehicle traction from a combustion engine).

Parallel Hybrid Vehicles

• The main advantage of parallel hybrid vehicles compared to series ones is that the parallel hybrid has two propulsion devices, the ICE and the traction electric motor, which can be managed as desired.

• Another significant advantage is that, by being able to work together in the vehicle's propulsion, the size of both the combustion engine and the electric motor is smaller than in series hybrid vehicles.

• This difference implies that the battery can be smaller.

• The fundamental disadvantage of this configuration compared to series hybrid vehicles is that the vehicle's maximum performance depends on the battery's state. Consequently, maximum performance can only be achieved when the battery is fully charged.

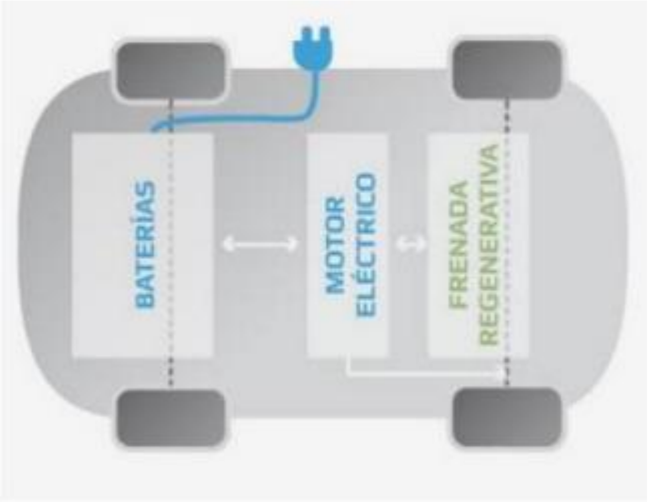
• This means that, in practice, it's necessary to oversize the combustion engine to compensate (although not entirely) for decreased performance from the electric traction part.

PURE ELECTRIC VEHICLES (EV)

These are vehicles where the traction system consists of a set of electric motors, exclusively powered through a battery (battery pack) installed in the vehicle itself.

This type of vehicle is called pure electric since there's no other energy source aside from electricity (they don't have an internal combustion engine).

Their range depends solely on the battery pack's capacity. Therefore, they must necessarily be plug-in vehicles to charge the battery



COMPARISON OF EVs AGAINST OTHER TECHNOLOGIES

Compared to a vehicle equipped with an internal combustion engine:

The electric vehicle (EV) has the following advantages:

• The torque generation in an electric motor is very rapid and precise. The motor's response time is only a few milliseconds (between 10-100 times faster than an internal combustion engine). Regarding torque, an electric motor delivers full torque from a very low speed, allowing for vastly superior acceleration performance compared to an ICE.

• The regenerative braking system allows the vehicle to brake with minimal need for the service brake system (hydraulic), leading to considerable savings in wear and maintenance of this system. It also provides a quicker response, enhancing the performance of ABS and TCS (traction control). However, a high level of regeneration means that the vehicle is very responsive to accelerator pedal movement.

• An electric vehicle has the option of placing an electric motor on each wheel, either on both wheels of a single drive axle or on all four wheels (achieving 4x4 traction). This provides the possibility of stability control based on motor torque control and regulation (torque vectoring), without the ABS system needing to intervene.

• An electric motor is simpler and more reliable than an internal combustion engine. The efficiency of an electric motor is above 90%, while that of an ICE is around 30-35%.

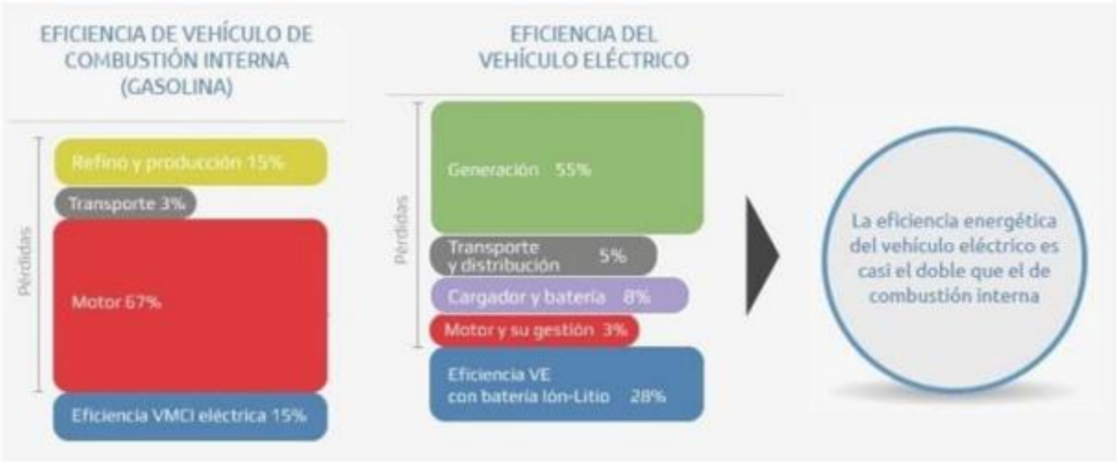
However, it has the following disadvantages:

• The performance of the electric motor is entirely dependent on the battery. On one hand, the battery must be able to supply enough electrical energy to utilize 100% of the electric motor's available power (in many cases, the battery's capabilities don't allow fully exploiting the electric motor's performance). On the other hand, the battery must supply that maximum energy for a limited time, decreasing energy performance as the battery charge decreases. This means that the vehicle loses performance as the battery charge decreases.

• Although the weight of an electric motor is usually less than that of an ICE and considering that sometimes a gearbox (or even a differential) is not necessary, the weight of the battery pack required to achieve a similar range to a combustion vehicle significantly penalizes the weight of the electric vehicle.

• Because the motor operates at high voltages (above 60V, generally close to 400V), specific measures are necessary to prevent electrical risks, both for vehicle users and technical personnel in workshops.

The image shows a comparison of the energy efficiency of an electric vehicle versus a similar combustion vehicle.



In this comparison, losses occurring during the generation of electrical energy in a power plant (thermal, nuclear, wind, etc.) or during the refining of fuel, as well as those during transportation to distribution centers, are taken into account.

If these losses were not considered and only the efficiency of the motors themselves were isolated, the electric vehicle (EV) would clearly come out ahead, possessing over 90% efficiency.

However, when comparing both technologies, it's evident that considering efficiency in its generation and the polluting emissions caused by this electrical energy generation, which later charges the EV's batteries, is crucial.

Regarding a hybrid vehicle (HEV):

Hybrid vehicles have higher efficiency than similar combustion vehicles due to the presence of a traction electric motor.

It's also recognized that currently, HEVs are more accepted by end users compared to pure electric battery-powered vehicles (EVs). However, all the energy used in HEVs with the continuous charging (CS) battery strategy comes from the burning of fossil fuels.

From an environmental and energy supply perspective, electric vehicles (EVs) have certain advantages over HEVs:

• EVs have zero dispersed emissions (meaning the EV itself doesn't pollute the area it moves in).

• Independence from fossil fuels

• Low operating and maintenance costs.

On the contrary, the main disadvantages of EVs are battery charging and the time it takes to charge them.

1.2 LEARNING UNIT 2: CURRENTLY AVAILABLE IMPLEMENTATIONS.

DRIVETRAIN ARRANGEMENT IN ELECTRIC VEHICLES (EVs)

An electric vehicle (EV) has a traction system comprised solely of electric motors.

In a combustion vehicle, there are three alternatives predominantly used by manufacturers when arranging the traction system:

• Front-Wheel Drive (FWD) vehicle

• Rear-Wheel Drive (RWD) vehicle

• All-Wheel Drive (AWD) vehicle

And two types of electric motor:

• Central motor

• Wheel motor

(FWD = Front Wheel Drive RWD = Rear Wheel Drive AWD = All Wheel Drive)

FRONT-WHEEL DRIVE (FWD) VEHICLES

For example, the Renault Zoe.

REAR-WHEEL DRIVE (RWD) VEHICLES

For example, the VW ID.3.

ALL-WHEEL DRIVE (AWD) VEHICLES

For example, the Jaguar I-Pace.

CENTRAL ELECTRIC MOTOR

An electric vehicle can have various configurations concerning the number of driven axes/wheels and the positioning of its motor(s).

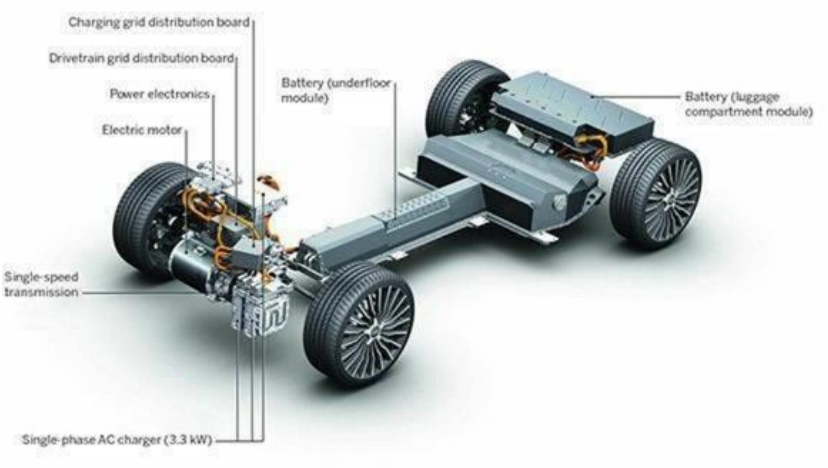
Though it will be explained in detail in the specific topic of electric motors, currently, in the market, two fundamental types are commercialized:

• Vehicles with a central electric motor (one or two motors)

• Vehicles with wheel hub motors (two or four motors)

A conventional electric motor usually coupled with a gearbox and, through a differential, connected to the driving wheels of either the front or rear axle.

In some vehicles, there's a central motor for the front axle and another motor for the rear axle.



WHEEL-HUB ELECTRIC MOTOR

These motors are directly attached to the wheels of a vehicle and, therefore, exclusively power that particular wheel.

With this type of motor, it's possible to configure front-wheel drive, rear-wheel drive, or all-wheel drive systems.

FRAME TYPES IN ELECTRIC VEHICLES

To date, all combustion vehicles have two chassis typologies:

• Body-on-frame

• Unibody (Monocoque) chassis

BODY-ON-FRAME

A structure comprised of two longitudinal beams joined by crossmembers or transverse bars

Design Objective: To withstand all vehicle demands, minimizing their impact on the body.

All vehicle systems, including the body and mechanical systems, are bolted onto the chassis.

Design concept employed in industrial vehicles and off-road vehicles.

CHASSIS OR SELF-SUPPORTING BODY

A structure that integrates the sturdy frame and the body into a single unit.

All vehicle systems are bolted onto the self-supporting body.

Design Objective:

All vehicle elements must withstand the pressures to which they are subjected.

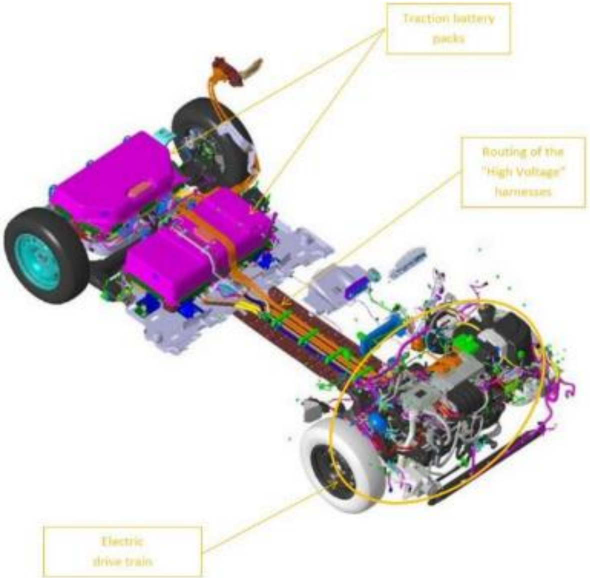
The structure is composed of stamped sheets, joined by spot welding and thin-walled structural sections.

Design concept employed in cars, light industrial vehicles, and SUVs (off-road vehicles).

This type of configuration has been used by many manufacturers to launch their initial electric vehicles, enabling them to release an electric version with minimal modifications from the combustion engine version.

For instance, the Peugeot Partner.

These configurations aren't optimal because the electric traction system (whether fully electric or hybrid) needs adaptation to the design of the combustion model. This implies, among other aspects, inefficient use of space to position the battery pack effectively.



ELECTRIC VEHICLE PLATFORM (SKATEBOARD CHASSIS)

This chassis configuration represents the current trend among electric vehicle manufacturers, where a specific framework is designed for electric vehicles. This setup is referred to as the "skateboard chassis."

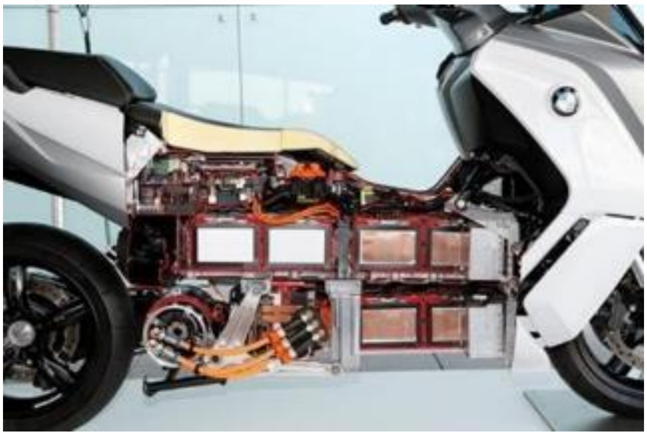
Design Objective:

Accommodate the battery pack in a flat and as low a configuration as possible.

Support all vehicle demands in conjunction with the body.

BMW C-Evolution



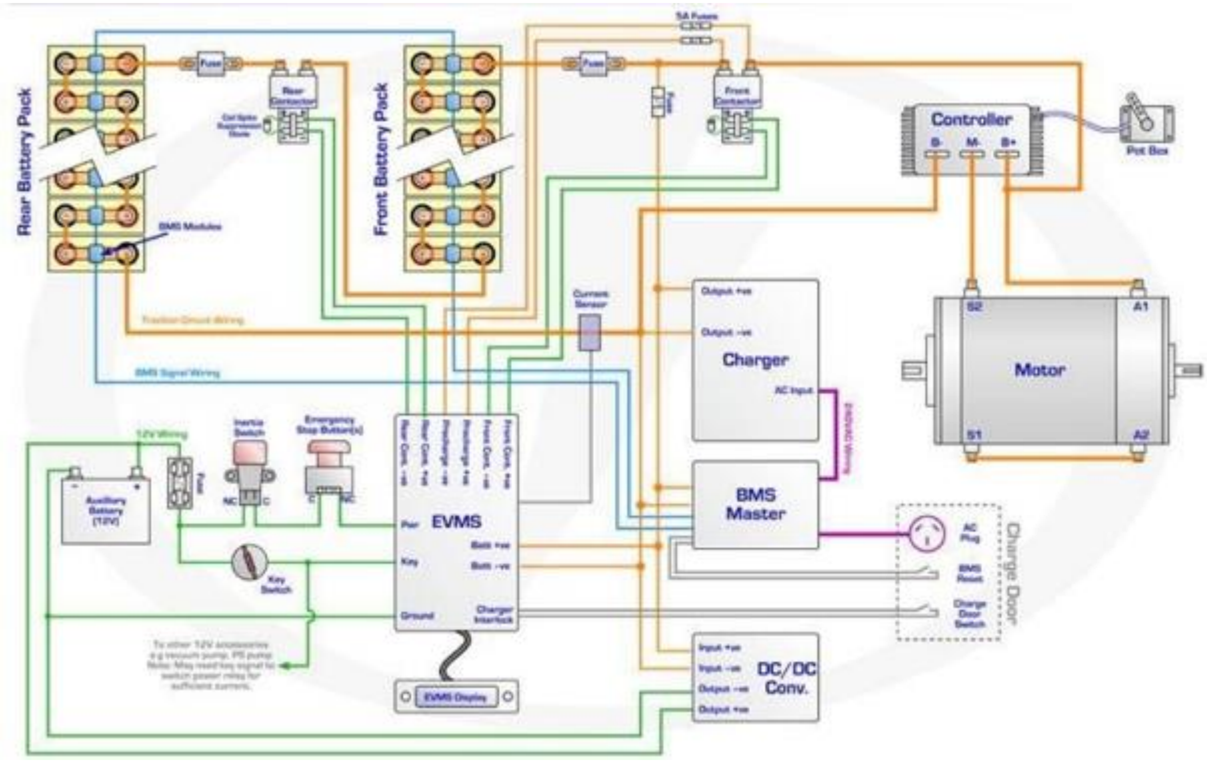



Manufacturers are focusing on designing modular platforms shared across different electric models, such as the VW Group's MEB platform.


1.3 LEARNING UNIT 3 EV achitecture (Main components)

Until now, the combination of battery pack and motor has been studied as the element to provide the necessary propulsion for a vehicle. However, there's a need to analyze how the motor's operation is managed, considering that in most cases, a synchronous motor is used (meaning it operates at synchronous speed) to adapt to the dynamic driving conditions. To control the electric propulsion of a vehicle, a system similar to the following needs to be implemented.

NOTE: The following diagram considers a direct current motor and two series-connected batteries to represent the same control required for the traction system of an electric vehicle.



Next, we'll provide a brief description of each of the components necessary for the regulation and control of the powertrain system in an electric vehicle.

POTBOX (ACCELERATOR)

The accelerator pedal is referred to as the PotBox.

It acts as the interface between the driver and the powertrain control system (engine or traction control unit). Through the accelerator, the driver sets the performance level needed from the traction system, serving as the primary input for the traction control unit.

This control unit analyzes all traction-related data and sends the necessary signals to the drivers (controllers) that govern and manage the traction motor(s).

CONTROLLER (DRIVER)

A driver (also known as a controller, inverter, or invertor) is an electronic device that performs two main functions:

• Converts the direct current from the battery pack into a three-phase alternating current necessary to power the electric motor.

• Regulates the motor's speed and torque based on the commands sent by the Engine Control Unit (ECU).

ON-BOARD CHARGER

The charger is the device that enables charging the battery pack by connecting it to an external electric grid.

DC/DC CONVERTER

This device functions to reduce the battery pack's voltage to the vehicle's low-voltage circuit (12VDC). This generates the low-voltage circuit necessary to power all other vehicle systems (similar to a combustion engine vehicle).

Electric Vehicle Management System (EVMS)

This device entirely manages battery pack charging and discharging and the 12VDC vehicle circuit. It controls various functions:

• Communicates between the Battery Management System (BMS) and the vehicle's CAN bus and can control motor power (via the driver) if the BMS detects any battery module operating outside its safe limits.

• Works with the BMS to monitor battery pack voltage, instant current, and charge status.

• Diagnoses potential faults in the battery pack's charge management circuit.

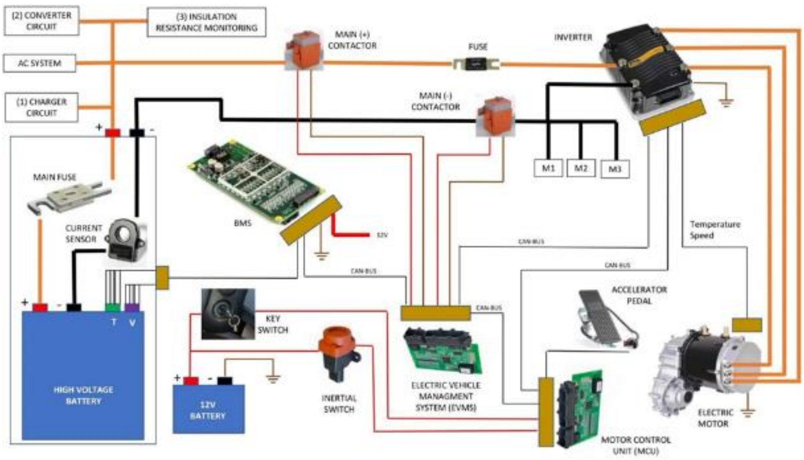
• Controls safety devices (high-voltage circuit cut-offs): inertia switch, safety mushroom button (if present), monitors the key switch, and the 12VDC battery signal.

• Monitors traction motor temperature and controls the inverter (if there's no Engine Control Unit).

• Receives the accelerator signal and could modulate it based on the driving mode. That is, it could establish a ramp to prevent abrupt accelerations (due to high torque motors at low revs) that could damage the battery.

• Provides the driver with information about the battery charge status, motor temperature, speed, instant consumption, etc., via the instrument panel.

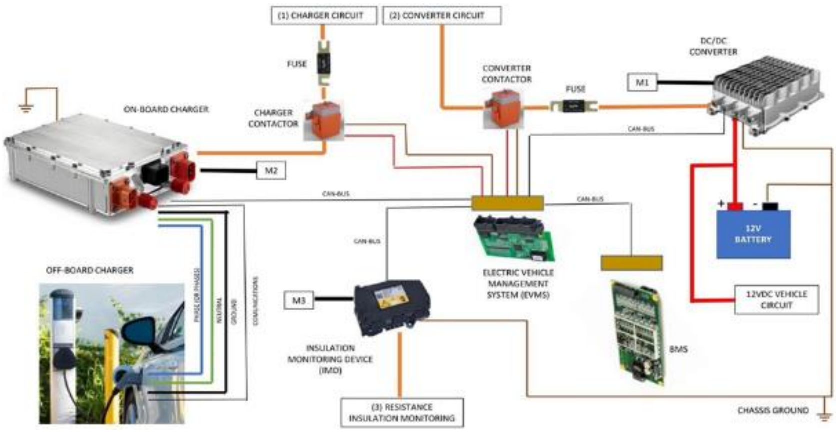
This device is the equivalent of the engine control unit (ECU) in a conventional combustion vehicle, enabling the implementation of various functions across different vehicle systems (provided it has enough inputs and outputs to do so). For instance, if the motor and/or inverters require water cooling, this ECU can manage the electric pump and send relevant alerts to the instrument cluster.



There's also the option to define a control unit for the battery pack (EVMS) separate from the one governing the electric motors (traction control unit). Since both are connected via the Can-Bus, they can share information and manage each other.

In some car brands, the EVMS goes by different names, such as Battery Energy Module (BEM).

Below is a schematic diagram of electrical connections for the high-voltage system in an electric vehicle, specifically concerning the battery pack and electric motors (powertrain). The goal is to showcase all the necessary components for implementing an electric traction system, analyzing how they connect, their functions, and the protection and control systems used.



BATTERY PACK

Every battery pack must include a main fuse (to protect the cells from a discharge that could damage them), a current intensity sensor (essential for knowing the current supplied by the pack), and a Battery Management System (BMS) for voltage and cell temperature management. These elements are typically housed inside the pack enclosure, except for the BMS, which might be inside or outside. When the pack consists of independent modules (connected in series), the manufacturer decides how many BMS units to install. Every module must be monitored by a BMS. Some manufacturers install a BMS inside each module, while others use one BMS to monitor multiple modules (depending on the BMS's capacity), resulting in several BMS units in the battery pack.

Also, there are electrical connections for measuring the voltage of each module (or submodule) and for temperature sensors. All these connections must go directly to the BMS that controls that module or modules. The connection between the battery pack and the vehicle's electrical circuit is made through a connector (regulated by CEPE 100 regulations), called a disconnect switch.

Three basic circuits can be identified for managing and controlling the vehicle's powertrain:

Power supply circuit for inverters controlling the electric traction motors.

High-voltage battery pack charging circuit (on-board charger and power inlet).

Power supply circuit for the DC/DC converter (conventional 12V vehicle circuit).

Generally, the following control units exist:

• EVMS (Electric Vehicle Management System)

Controls everything related to the battery pack's charging and discharging.

• MCU (Motor Control Unit)

Controls the electric traction motors. There might be a single unit for all motors or one for each motor (a decision made by the manufacturer). This control unit manages the operation of inverters and receives signals from the vehicle's ignition key switch and accelerator.

• Control units integrated into the inverters, on-board charger, and DC/DC converter.

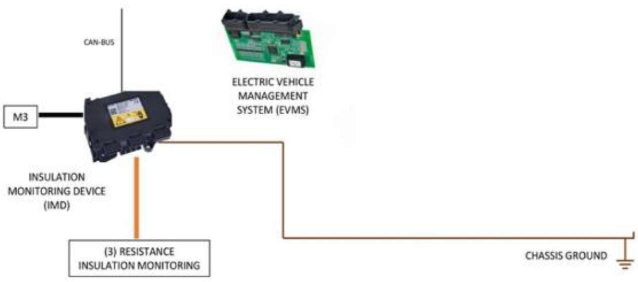
• Insulation Monitoring Device (IMD)

Although not a control unit per se, its action is crucial as it continuously monitors the insulation resistance between:

- Positive high-voltage battery conductor and 12V circuit ground (vehicle frame)
- Negative high-voltage battery conductor and 12V circuit ground (vehicle frame)

An important requirement of the high-voltage electrical system (mandatory compliance with CEPE 100 regulations) is that it must be completely isolated from the 12V electrical system. This means there should be no continuity between the positive high-voltage system cables and the positive or ground of the 12V system. When referring to the 12V ground, it encompasses all ground connections in the circuit and the vehicle frame.

Similarly, high-voltage ground cables must be completely isolated from the 12V circuit. This implies that the vehicle frame cannot be used as the high-voltage ground. Therefore, all high-voltage ground (negative) cables must return to the battery pack.



The insulation monitoring device's goal is to ensure there's no insulation fault between the high-voltage and low-voltage (12V) circuits that could cause an electric shock to anyone handling the vehicle. When an insulation fault is detected, a fault code is generated.

This insulation monitoring device can be an independent component (communicating via Can bus with other control units) or part of another control unit (usually within the EVMS).

MOTOR CONTROLLERS (INVERTERS)

This component receives positive and negative inputs from the high-voltage circuit and generates a three-phase alternating current to power the electric motor. It also receives signals for motor temperature and speed.

It communicates with the MCU (Motor Control Unit) via the Can Bus, which manages the current intensity it needs to supply to the motor (based on the throttle signal, the battery pack's state, and the current motor situation).

To enable high-voltage power to the inverter, the MCU must activate two contactors (one for positive and one for negative) using a 12V signal. At that point, the inverter receives power and ground from the battery pack.

Furthermore, the inverter must be protected by a fuse to ensure it doesn't exceed its maximum allowable input current.

Let's delve a bit more into the management carried out by the inverter.

Every electric motor used in electric vehicle traction systems requires a device that performs two primary functions:

• Current inversion function: Converts direct current from the battery pack into a three-phase alternating current necessary to power the electric motor.

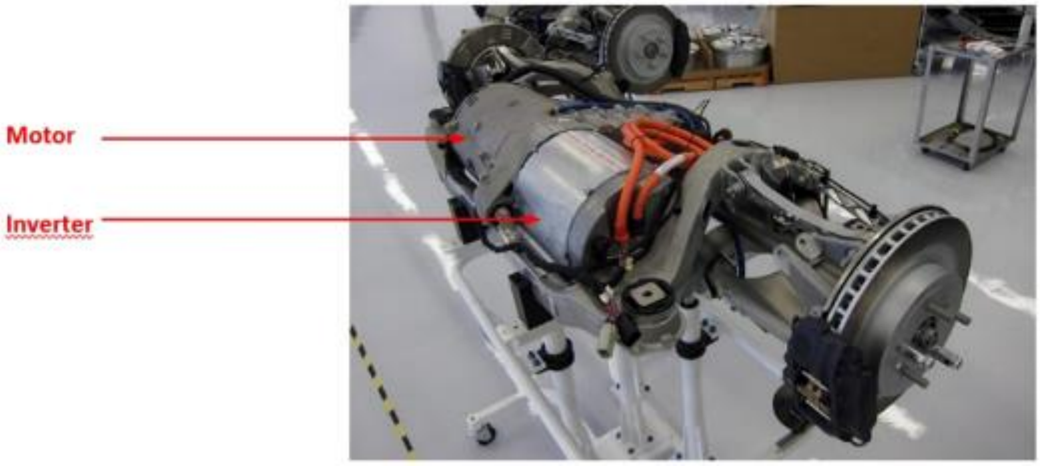
• Motor control function: Regulates speed and torque based on the commands sent by the driver.

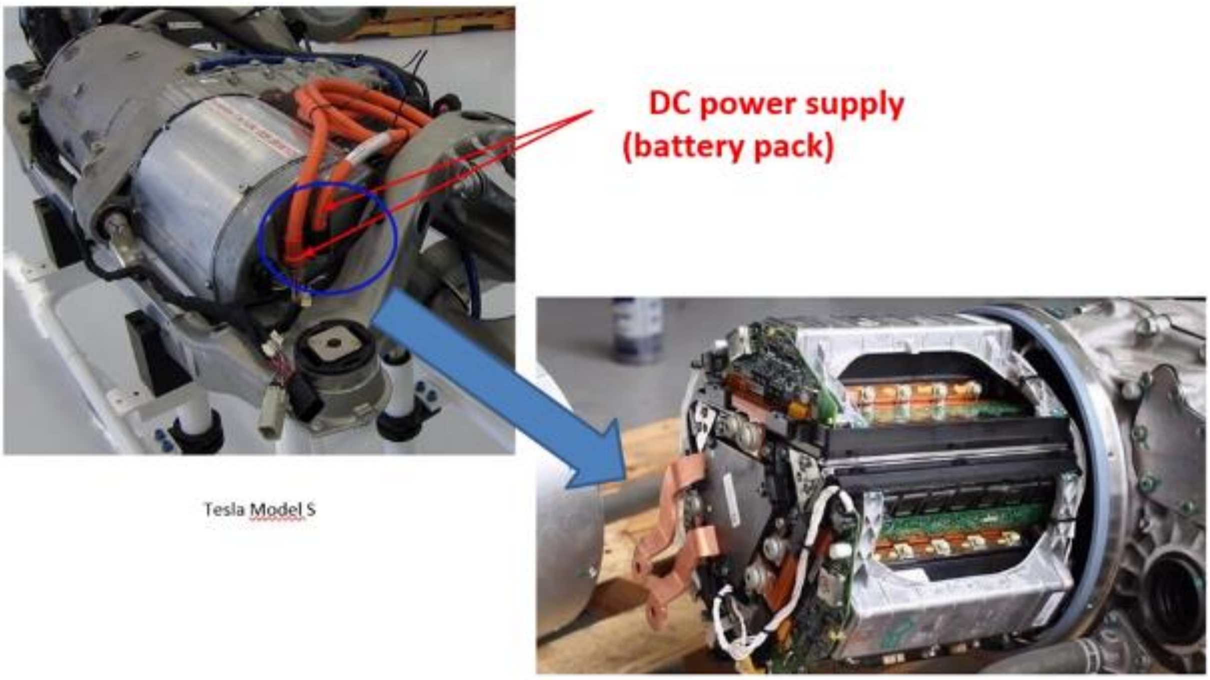
Usually, both functions are integrated into the same device, taking on different names but essentially referring to the same thing: driver, controller, or inverter.

Each inverter must be configured for each specific motor and have specifications compatible with the motor it's controlling. As seen earlier, the most commonly used motors in traction are Permanent Magnet Synchronous Motors (PMSM). These motors require a sinusoidal current in the stator to produce constant torque.

On the other hand, Brushless Direct Current Motors (BLDCM) require a rectangular current in the stator to generate constant torque. Therefore, it's crucial to choose a driver compatible with the motor being controlled and set it up correctly.

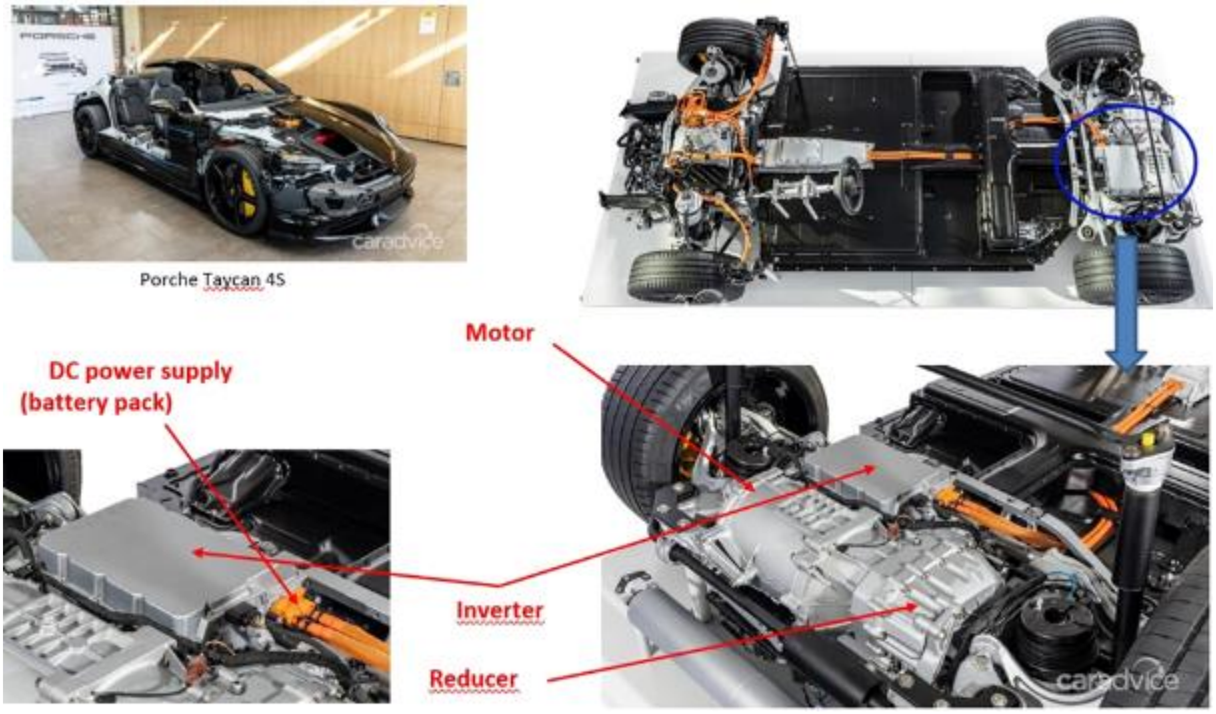
Typically, manufacturers strive to install the inverter as close as possible to the motor being controlled (often directly bolted to the motor casing). This minimizes the three-phase alternating current cables needed to power the traction motor.





Tesla Model S

Vehicle Assembly:



MOTOR CONTROL STRATEGIES

• PWM (Pulse-Width Modulation) control is used for direct current (DC) motors.

• VVVF (Variable-Voltage Variable-Frequency) control can be used for asynchronous alternating current (AC) motors, but in electric motor traction applications, it doesn't fully utilize the motor's capabilities. In such cases, a FOC (Field-Oriented Control) is the most commonly used strategy by manufacturers.

• FOC (Field-Oriented Control), also known as Vector Control, is usually employed in PMSM (Permanent Magnet Synchronous Motors) and induction AC motors.

• DTC (Direct Torque Control) is typically used in PMSM motors. This control strategy isn't suitable for induction AC motors as it can cause overcurrent situations and electromagnetic noise.

• PID (Proportional–Integral–Derivative Controller) is a widely used control strategy for various applications, but it's not commonly used for electric motor traction controllers.

PMSM Motor Control

For PMSM motors, FOC or DTC control strategies can be employed, but FOC usually yields better results.

Induction Motor Control

Induction asynchronous motors can generally be controlled using VVVF, DTC, and FOC strategies. VVVF, however, doesn't maximize the motor's capabilities.

DTC control may lead to overcurrent situations and electromagnetic noise due to the lack of feedback on the stator's feed current for control corrections. These issues are resolved using FOC control.

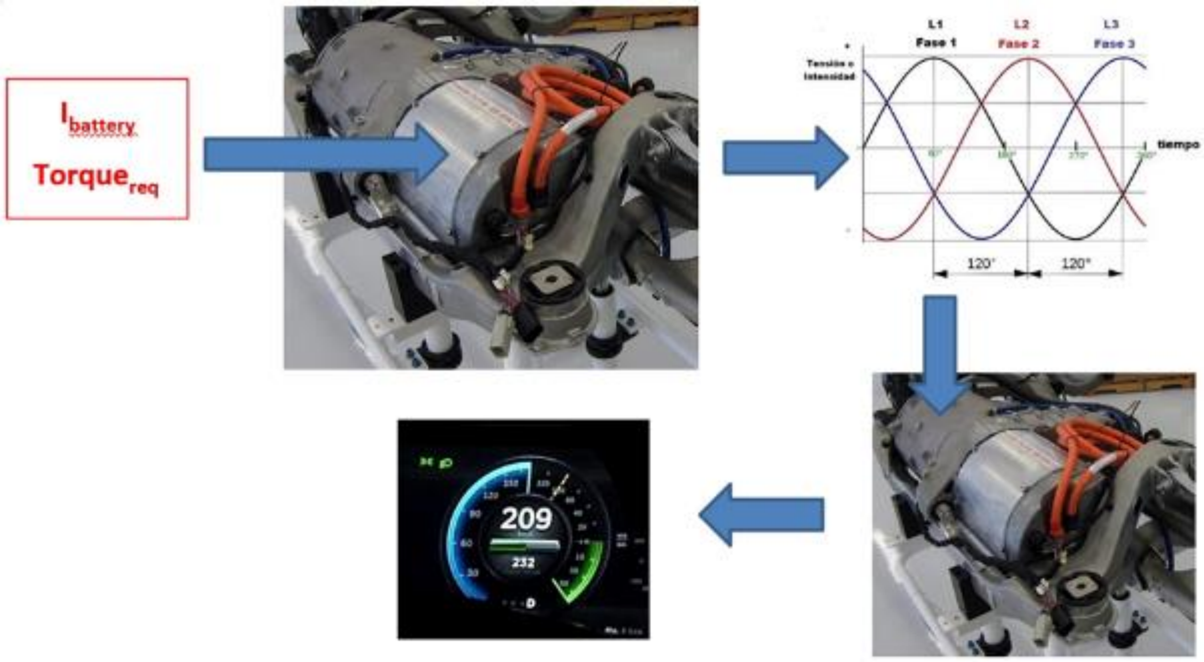
Traction Motor Control – Control Strategy

Each electric motor is controlled by its corresponding inverter. The inverter transforms the direct current received from the battery pack into alternating current.

It modulates the alternating current in terms of amplitude and frequency. That means the motor's generated torque is managed by adjusting voltage values, while the motor's rotational speed is controlled by altering the frequency (Hz) of the alternating current.

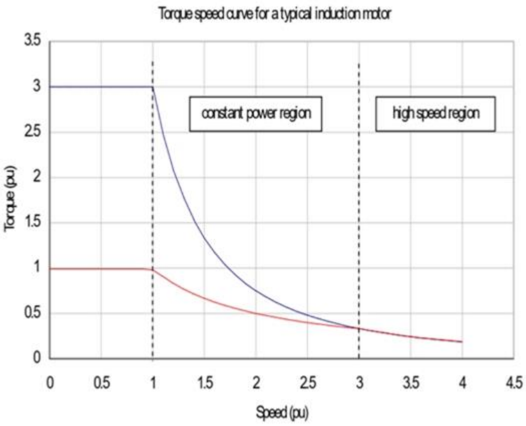
The inverter receives the desired torque information from the driver through the Motor Control Unit (MCU) via Can-Bus, which gathers data from the accelerator pedal. The Electric Vehicle Management System (EVMS) communicates via Can-Bus, providing information on the available current in the battery pack.

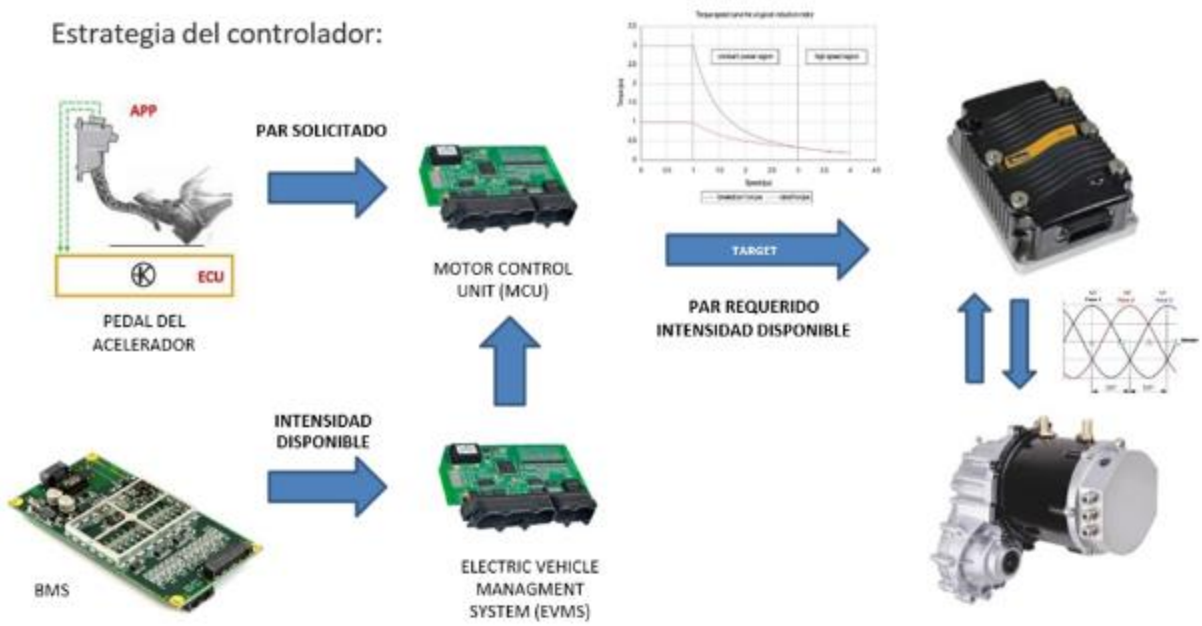
With the allowed current intensity data and the necessary torque to be achieved, the inverter modulates the alternating current to the motor to obtain the desired torque.



The vehicle manufacturer programs the inverter with the motor's torque/power curve.

The accelerator pedal sends to the Motor Control Unit (MCU) the signal of the desired torque percentage (0-100%) by the driver. Based on the selected driving mode in the vehicle (eco, sport, normal...), the MCU communicates a specific torque value to the inverter. Accordingly, depending on the driver's command and the selected driving mode, the inverter manages the traction motor to deliver the specified performance.



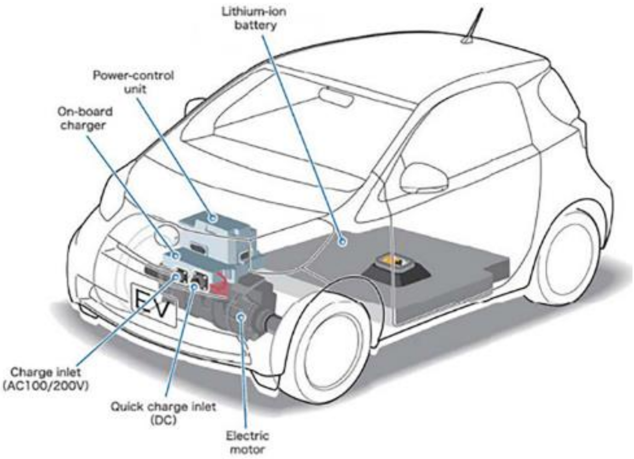


THE DC/DC CONVERTER transforms high-voltage direct current into 12V direct current (or 24V in industrial vehicles). It ensures that the 12V (or 24V) circuit is powered and the 12V (or 24V) battery/batteries are always charged. To enable high-voltage power supply to the converter, the Electric Vehicle Management System (EVMS) must activate two contactors (one for positive and one for negative) using a 12V signal. At that point, the converter receives power and ground from the battery pack.

Effectively, the high-voltage ground contactor is common for all components (once open, it 'gives ground' to all components). Therefore, it is the positive contactor that allows the current flow. Additionally, the converter must be protected by a fuse to prevent exceeding its maximum permissible feeding intensity

THE ON-BOARD CHARGER, although it will be analyzed in more depth later, is outlined below regarding its connection in the vehicle.

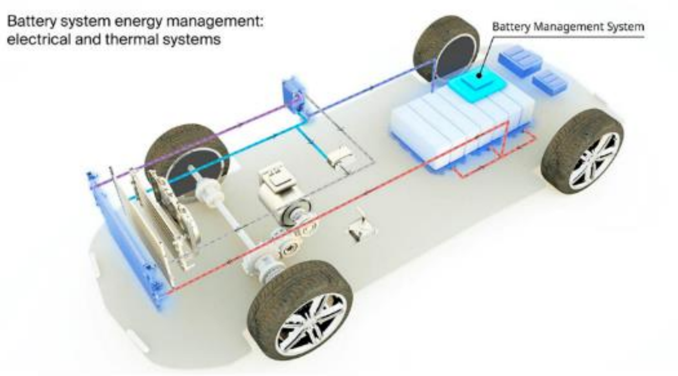
The charger is linked to the external charging port of the vehicle. Through this port, it receives alternating current (single-phase or three-phase) via the corresponding phase, neutral, and ground conductors (protective conductor). Additionally, it receives bidirectional communication signals from the external charger.



On the other hand, the charger is connected to the positive and negative high-voltage circuit. It directly communicates with the battery pack through a contactor (positive), controlled by the Electric Vehicle Management System (EVMS), and the battery pack is protected by a fuse. Its connection with the battery pack's ground, like the rest of the components, is regulated by the common ground contactor.

The charger is linked with the other control units via the Can Bus, but primarily requires communication with the EVMS to instantly regulate the battery pack's charging parameters. To enable vehicle charging, the inverters must be disconnected (contactor closed)."

THE BATTERY MANAGEMENT SYSTEM (BMS) represents the primary control unit in an electric vehicle. Through its voltage and temperature inputs, it can monitor the state of the cells and provide suitable information to the Electric Vehicle Management System (EVMS).



Generally, it does not have the capability to open or close the high-voltage contactors (positive and negative) itself, but it sends the signal for the EVMS to perform that function. However, this doesn't mean that BMS units performing such functions directly aren't used.

The BMS is directly powered by the 12V circuit. In terms of communication, the BMS can transmit via CAN Bus (allowing all control units to receive information communicated by the BMS) or communicate via a LIN line with the EVMS.

INERTIAL SWITCH (INERCIA SWITCH)

Inertia Switch in Electric Vehicles: Ensuring Safety in Case of Collisions

Electric vehicles (EVs) represent an innovation in the automotive industry by providing a more sustainable form of transportation. However, similar to conventional vehicles, safety remains a fundamental priority. The inertia switch is a critical component in safeguarding occupants and the integrity of an EV in case of collisions.

Operation of the Inertia Switch:

The inertia switch, also known as an impact switch, is an electronic device designed to detect sudden accelerations or impacts that could indicate a collision. Its primary function is to immediately send a signal to the Electric Vehicle Management System (EVMS), which is responsible for monitoring and controlling the operation of all high-voltage electrical systems in the vehicle.

Importance of the Inertia Switch:

When a collision or significant impact is detected, the inertia switch plays a critical role in opening the contactors of the high-voltage circuit in the EV. Contactors are electrical switches that control the flow of high-voltage current within the vehicle system. By opening these contactors, the electrical supply to all components operating at high voltage is interrupted, including the traction battery, inverter, electric motor, and other key components of the vehicle's electrical system.

The immediate disconnection of the high-voltage circuit is essential for several reasons:

1. Occupant Safety: By cutting power to high-voltage components, the risk of electric shocks in the event of an accident is significantly reduced. This protects vehicle occupants and rescuers involved in rescue operations.
2. Fire Prevention: EV traction batteries can be potentially hazardous if damaged or compromised in an accident. By disconnecting the high-voltage power, the risk of fires or explosions resulting from battery damage is minimized.
3. Vehicle Integrity: Disconnecting the high-voltage system also prevents the vehicle's electronic and electrical components from continuing to operate in a potentially unsafe state after a collision, which can help prevent further damage or catastrophic system failures.

Additional Considerations:

The inertia switch is strategically located in the vehicle, usually in an area sensitive to impact forces, such as the front or rear. Its design and sensitivity are adjusted to activate only in situations of significant impact, avoiding unnecessary activations caused by vibrations or minor impacts.

In summary, the inertia switch in electric vehicles is a crucial component to ensure occupant safety and protect the vehicle's integrity in case of collisions. Its ability to quickly disconnect the high-voltage circuit is a fundamental element in mitigating risks associated with high-voltage electricity and contributes to the overall safety of electric vehicles in emergency situations.

KEY SWITCH (IGNITION KEY)

The ignition key, also known as the "Key Switch," is a fundamental component in the operation of motor vehicles, both conventional and electric. Its primary function is to start or stop the vehicle's engine and, in the case of electric vehicles, play a significant role in power control and interaction with the Motor Control Unit (MCU).

Functioning of the Key Switch:

In a conventional vehicle with an internal combustion engine, the ignition key turns to the "start" position to allow electric current to flow to the starter motor. This starter motor turns the vehicle's engine until it ignites. Then, the ignition key returns to the "on" or "operating" position for the engine to run continuously.

In electric vehicles, the Key Switch has a slightly different role. When the ignition key is turned or an ignition button is pressed, a signal is sent to the MCU (Motor Control Unit) or, in some cases, to the Vehicle Energy Control Unit (VECU). This signal is interpreted by the MCU as an indication that the driver wishes to start the electric vehicle. The MCU, in turn, controls the supply of power to the electrical systems and the main electric motor, enabling the vehicle to start.

Importance of the Key Switch:

The ignition key is a crucial element for the safety and proper operation of the vehicle. In conventional vehicles, it ensures that the engine only starts when the driver intends to do so, preventing accidental starts and ensuring safety. In electric vehicles, besides fulfilling these functions, the Key Switch can also play a role in managing energy and electrical safety by being linked to the interruption of high-voltage power flow in emergency situations.

Evolutionary Technology:

With the evolution of automotive technology, the ignition key has undergone significant changes. In many modern vehicles, the physical key has been replaced by keyless start systems, where a card or fob is used to start the vehicle. These systems often use radiofrequency (RF) technology or Bluetooth communication to send the start signal to the MCU. Despite these advances, the basic function of the Key Switch remains essential for the safe and reliable operation of any vehicle.

The ignition key in vehicles, whether internal combustion or electric, is a critical component to start and stop the engine or propulsion unit. Its operation and evolution over time have played a fundamental role in driver safety and comfort, and its significance continues in the era of electrified and connected mobility.

1.4 LEARNING UNIT 4 Energy storage systems

GENERAL CONCEPTS

Every electric vehicle (EV) possesses a fundamental component without which it wouldn't make sense: the battery or battery pack.

When sizing up an electric propulsion system, it's equally important to calculate the appropriate electric motor that provides the required performance (in terms of top speed, acceleration, etc.) as it is to have a battery capable of supplying enough energy to power that motor and sustain it for the maximum number of hours.

This chapter will delve into the detailed workings of an electric vehicle battery, the types of cells that can be used, how to assemble them to form a pack, and how their discharge and subsequent recharge are managed.

The operation of a hybrid vehicle (HEV - Hybrid Electric Vehicle) is based on combining two types of engines: an electric one and a conventional one (internal combustion engine) through a hybrid control system and a battery pack.

An electric battery (or electric accumulator or simply cell or battery) is a device consisting of one or more electrochemical cells that can convert stored chemical energy into electrical current.

The batteries function based on an electrochemical cell. There are two electrodes, one positive and one negative, that when connected to form a closed circuit, generate an electric current, meaning electrons spontaneously flow from one electrode to another. Batteries consist of several pairs of electrodes placed in separate compartments called cells. In these cells, the electrodes are immersed in a solution known as the electrolyte.

This operating principle is common to all types of batteries and is therefore based on a chemical (reversible or non-reversible) process called reduction-oxidation, in which one component oxidizes (loses electrons) and the other reduces (gains electrons).

This state of oxidation can be restored (in certain cell types) through recharge operations, which simply involve applying an external electric current to reverse the reduction-oxidation processes.

In general, cells can be classified into two categories:

• Primary Cells

Known as non-rechargeable batteries, they irreversibly convert chemical energy into electrical energy.

• Secondary Cells

Known as rechargeable batteries or cells, they can be recharged by reversing the chemical reactions inside them by supplying electric energy to the cell until its original composition is restored.

FUNDAMENTAL BATTERY PARAMETERS

BATTERY VOLTAGE (ΔU)

Electrical voltage or potential difference or voltage (ΔU) is the magnitude quantifying the electric potential difference between its terminals. It's defined as the work done on the circulating unit of charge. The unit of voltage is the volt (V).

There are two types of voltage in a battery:

• Open Circuit Voltage (OCV)

It's the voltage of the fully charged battery not connected to the electrical circuit where it will be mounted. The voltage value between its terminals is usually between 5-7% higher than its nominal voltage (working or operating voltage). This OCV voltage is a consequence of its chemical composition and the number of connected cells.

This is the voltage value indicated in the battery datasheets.

• Closed Circuit Voltage (CCV)

It's the nominal or operating voltage (once connected to the consumers).

BATTERY CAPACITY (X)

The capacity (X) of a battery is the charge it can store/supply. It's measured in ampere-hours (Ah).

A capacity of 1Ah means the battery can supply a current intensity of 1A for 1 hour before becoming depleted.

Often, battery capacity is discussed in terms of kilowatt-hours (kWh) or watt-hours (Wh). Actually, this measure doesn't quantify the battery's capacity but the energy (E), measured in joules ([J] = W·s), that a battery can supply. The relationship between these measures and a battery's capacity is as follows:

$X\ [Ah] = E\ [kWh] \cdot 1000 / \Delta U\ [V]$

X = Battery capacity (Ah)

E = Energy stored in the battery (kWh)

ΔU = Voltage difference between terminals (V)

CHARGE / DISCHARGE CONSTANT (C-RATED)

The charge/discharge constant C (or C-rated) is a constant created by battery manufacturers based on the Ah specified for that battery. It's used to indicate, in a simpler way, the intensity at which a battery should be charged or discharged without damaging it.

It's calculated as follows:

$C = X / 1000$

C = C-rated [1/h]

X = Battery capacity [mAh]

Therefore, when a battery or cell indicates a certain C-rated value, it's providing the maximum discharge current it could supply or, likewise, the maximum current it could receive in the case of charging without damaging itself.

So, for a battery with a capacity (X) of 1Ah:

- 1C means the battery could supply a maximum current of 1A for 1 hour (without damage).
- 0.5C means the battery could supply a maximum current of 0.50A for 2 hours (without damage).
- 2C means the battery could supply a maximum current of 2A for 0.50 hours (without damage).

And similarly for charging currents.

For example:

A battery of 72V / 5kWh / 3C (discharge):

• Capacity (X) = 5kWh · 1000 / 72V = 69.44Ah

• This means the battery could supply 69.44A for 1 hour (60min)

• Therefore, the battery's capacity (X) is always equivalent to 1C

• As the manufacturer indicates that their battery has a C-rated of 3C, this means:

Maximum discharge current = 3 · 69.44A = 208.32A for 60/3 = 20min

• Therefore, it's necessary to limit the discharge in the following way:

The maximum discharge current of the battery (under any circumstance) cannot exceed 208.32A and must be limited to 20 minutes during which this intensity could be supplied.

If this intensity or the duration of the supply is exceeded, the battery would incur irreversible damage.

At times, certain manufacturers in the US use another term with a similar meaning. This term is RC (Reserve Capacity), which indicates the time (in minutes) a fully charged battery can supply 25A before its voltage drops below 10.50V.

This parameter is associated with the 12V batteries of a conventional vehicle's electrical circuit.

Once the concept of C-rated has been explained, it's possible to introduce two definitions related to the cell's capacity:

• Standard Discharge Capacity [Ah]

It's the initial discharge capacity (in Ah) of the cell, measured with a discharge current of 0.20C, without reaching the minimum allowable voltage difference for the cell (cut-off) at a certain temperature, for 1 hour, immediately after a standard charge.

• Rated Discharge Capacity [Ah]

It's the initial discharge capacity (in Ah) of the cell, measured with a discharge current of 1C, without reaching the minimum allowable voltage difference for the cell (cut-off) at a certain temperature, for 1 hour, immediately after a standard charge.

• Standard Charge

Process with a charging current of 0.50C at the specified charging voltage by the cell manufacturer, at a certain temperature (also specified by the manufacturer).

MINIMUM ALLOWABLE VOLTAGE (CUT-OFF)

It's the minimum allowable voltage difference between the terminals of a cell. When the voltage drops below this value, the cell is considered empty. This value is defined by the cell manufacturer.

SPECIFIC ENERGY OR ENERGY DENSITY

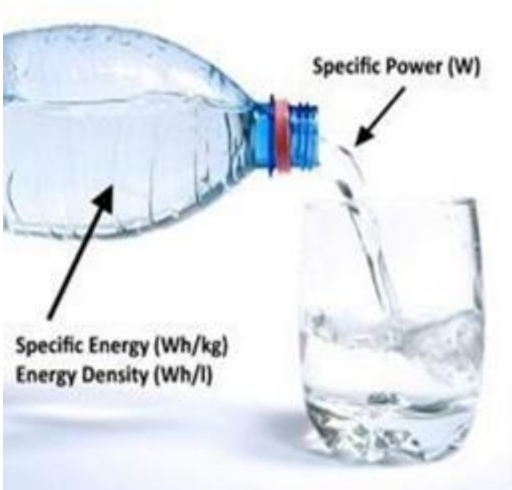
This parameter defines the battery's capacity based on the occupied volume or its mass. As the value of this parameter increases, the battery's (or cell's) performance improves in terms of occupied volume or weight:

• [Energy Density] = kWh/L

• [Specific Energy] = kWh/kg

SPECIFIC POWER

The specific power [kW/kg] indicates the maximum power per unit mass that the cell or battery can supply.



PERFORMANCE

Performance is the percentage relationship between the electrical energy received during the charging process and the energy delivered by the battery during discharge. Lead-acid batteries have a performance of over 90%. In contrast, Ni-Cd batteries have about 83%. Lithium batteries fall within the 80-90% performance range. The percentage of lost energy (which isn't useful energy) dissipates as heat (hence, the cell or battery heats up during the charging process).

MEMORY EFFECT

It's an undesired phenomenon that affects batteries. It involves the gradual loss of capacity or voltage in the battery each time it's recharged due to the formation of crystals in its electrochemical cells.

Causes include technology type and factors like prolonged charging beyond limits, high temperatures, and high current charges.

LIFE CYCLES

Battery life cycles refer to the number of complete charge/discharge cycles (from 0% to 100% SoC) that can be carried out without any reduction in battery capacity, provided they are done without exceeding the cell's cut-off.

DEPTH OF DISCHARGE (DOD) [%]

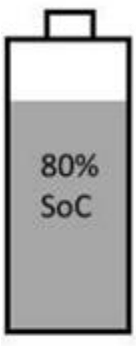
This parameter represents the current percentage of discharge of a cell or battery (in terms of capacity - Ah). When a DoD value reaches 80%, it's considered a deep discharge.

STATE OF CHARGE (SOC) [%]

It represents the current percentage of charge of a cell or battery (in terms of capacity - Ah). A battery is considered discharged when the voltage between terminals is below the cut-off specified by the manufacturer.

SoC = 0% (Battery discharged)

SoC = 100% (Battery fully charged)



$$SoC = \frac{\text{Actual Charge in battery}}{\text{Maximum charge in battery}}$$

MAXIMUM CONTINUOUS DISCHARGE CURRENT

The Maximum Continuous Discharge Current represents the highest discharge current a battery can sustain continuously without damage. It's a parameter specified by the manufacturer. This value determines the nominal power of the electric motor it could power.

MAXIMUM DISCHARGE PULSE CURRENT

The Maximum Discharge Pulse Current represents the maximum discharge current a battery can sustain for a short interval (specified by the manufacturer) without causing damage. This pulse typically lasts around 5-10 seconds and allows for peak power outputs of the electric motor it powers, achieving maximum acceleration values.

GENERAL CONCEPTS

Nominal specifications (*1)

Item	Specification
3.1 Standard discharge Capacity	Min 3,350mAh - Charge : 0.5C(1,700mA), 4.2V, 0.02C(68mA) cutoff @ RT - Discharge : 0.2C(680mA), 2.65V cutoff @ RT * 1C = 3,400mA
3.2 Rated discharge Capacity	Min 3,250mAh - Charge : 0.5C(1,700mA), 4.2V, 0.02C(68mA) cutoff @ RT - Discharge : 1.0C(3,400mA), 2.65V cutoff @ RT
3.3 Charging Voltage	4.2V
3.4 Nominal Voltage	3.60V
3.5 Charging Method	CC-CV (constant voltage with limited current)
3.6 Charging Current	Standard charge: 1,700mA For cycle life : 1,020mA
3.7 Charging Time	Standard charge: 4hours
3.8 Max. Charge Current	2,000mA (not for cycle life)
3.9 Max. Discharge Current	8,000mA (for continuous discharge) 13,000mA (not for continuous discharge)
3.10 Discharge Cut-off Voltage	2.65V
3.11 Cycle life 1	Capacity ≥ 2,010mAh @ after 500cycles (60% of the Standard Discharge Capacity @ RT) - Charge : 1,020mA, 4.2V, CCCV 100mA cut-off @ RT - Discharge: 1C(3,400mA) , 2.65V cut-off @ RT

Item	Specification
3.12 Recovery characteristics	Capacity recovery(after the storage) ≥ 2,680mAh (80% of the Standard Discharge Capacity @ RT) - Charge : 0.5C(1,700mA), 4.2V, 0.02C(68mA) cutoff @ RT - Storage : 30 days (@ 60℃) - Discharge : 0.2C(680mA) , 2.65V cut-off @ RT
3.13 Cell Weight	50g max
3.14 Cell Dimension	Height : Max. 65.25 mm Diameter: Max. Φ 18.55 mm
3.15 Operating Temperature (*2)	Charge : 0 to 45°C (Ambient) Discharge : -10 to 60°C (Ambient)
3.16 Storage Temperature(*3)	1 year : 0~23°C, 3 months : 0~45°C 1 month : 0~60°C

Note (*1): Protection function of the battery pack should be set within the specified charge, discharge and temperature range in the Cell Specification.
Note (*2): Discharge OTP(over temp. protection) should not be over 60'C of the cell surface temperature. Protection set should be based on the location of the cell surface with the highest temp increase part of the battery pack.
Note (*3): If the cell is kept as ex-factory status (30% of charge), the capacity recovery rate is more than 80%.

The lithium-ion battery, also known as Li-Ion battery, consists of a cell formed by an anode and a cathode, using a lithium salt solution (in a non-aqueous solvent) as the electrolyte.

ELECTRIC VEHICLE (EV) BATTERY CONCEPT

An electric vehicle's battery (or battery pack) is comprised of a group of lithium-ion cells connected in series and parallel configurations within a casing or enclosure (typically made of aluminum alloy or plastic). It often includes an integrated female electrical connector. This is why the term "battery pack" is commonly used.

The cells within the battery are essentially what we commonly refer to as batteries (in this case, rechargeable). Therefore, the parameters that define a battery (as explained in the previous section) apply to each of these cells. In other words, each cell will have:

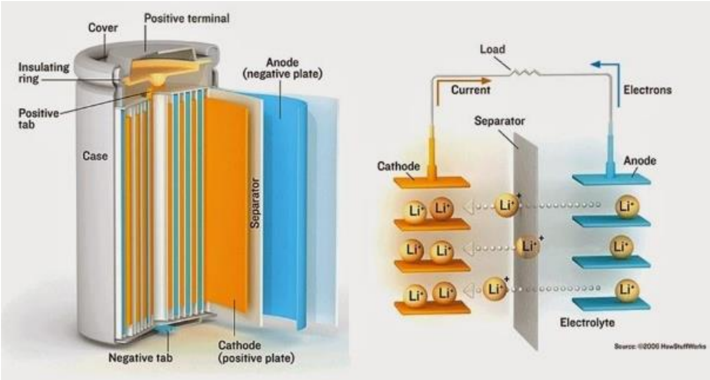
- A specific voltage
- A defined capacity
- A designated C-rated value

The total voltage between the battery terminals, capacity, and total C-rated capacity for the battery pack are determined by how these cells (or batteries) are connected.

LITHIUM CHARACTERISTICS IN BATTERIES

Lithium possesses a standard reduction potential of -3.040V, yielding a theoretical energy capacity of 3860Ah/kg. This highly negative reduction potential renders it thermodynamically unstable in protonic solvents (such as water) or in environments with humid air, causing it to react very easily. This limitation restricts the use or construction of lithium batteries in non-aqueous electrolytes.

WORKING PRINCIPLE OF LITHIUM-ION BATTERIES



The operation of lithium-ion batteries is based on processes known as lithium ion insertion/deinsertion (Li+). Oxidation/reduction reactions occur in a solid-state between two insertion compounds (electrodes) embedded in an electrolyte (lithium salt dissolved in a non-aqueous solvent). One of the compounds, known as the Host (M), which is ionic in nature, reacts by occupying vacant sites in the structure of another species called the Host (A). These oxidation/reduction reactions can occur reversibly.

For more information on how lithium batteries work, watch the following video:

https://youtu.be/VxMM4g2Sk8U?si=lFTb0bacDQpm92qp

In terms of the chemical compounds used in the manufacture of lithium cells (electrode set + electrolyte), different electrical characteristics are obtained.

As a general rule, cells with high performance tend to be the most unstable and, therefore, offer the least safety guarantees. Due to this reason, manufacturers often choose batteries that have a balance between performance and safety, as a lithium cell is inherently potentially unstable.

Similar to the previous types of batteries, it's common to assemble them grouped together to generate a pack.

PARAMETER	MAGNITUDE	UNITS
Specific energy	100-265	Wh/kg
Specific density	250-730	Wh/L
Specific power	250-340	W/kg
Charging/discharging efficiency	80-90	%
Durability	400-1200	ciclos
Nominal voltage per cell	3,20-3,70	V
Self-discharge (per month)	8	%

In this type of batteries, controlling the temperature of the cells during the charging and discharging processes is crucial. Generally, cells should not exceed 60°C to prevent the risk of explosion.

The materials used in lithium batteries are flammable, but not at room temperature. However, this dramatically changes with increased temperature and overvoltage. When a lithium battery overheats, the oxidation/reduction reactions inside it generate the formation of oxygen bubbles, carbon dioxide, and other gases.

Inside a battery, electrodes are coiled to maximize space utilization. It's precisely within these electrodes that reactions occur at certain temperatures, leading to the appearance of the gases mentioned in the previous paragraph. These gases take up an increasingly larger space, raising the battery's pressure until it can't hold anymore. Then, it cracks, and the gas starts to escape very hot, carrying along other components. At these temperatures, these enclosed components spontaneously ignite (they're self-flammable). Additionally, without the spatial constraint of the cells, the entire interior expands violently, potentially causing the battery to explode.

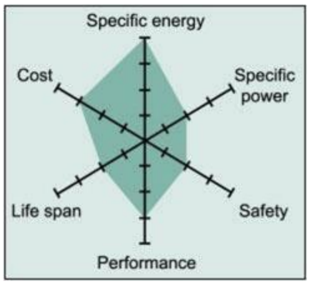
For this reason, every lithium battery must be monitored to ensure that no cell reaches a temperature higher than the permissible limit or becomes overcharged.

This monitoring is carried out through devices called BMS (Battery Management Systems).

Depending on the type of compounds forming the electrodes and electrolyte, the following types of lithium batteries are distinguished:

- Lithium Cobalt Oxide Batteries ($LiCoO_2$) - LCO
- Lithium Manganese Oxide Batteries ($LiMn_2O_4$) - LMO
- Lithium Nickel Manganese Cobalt Oxide Batteries ($LiNiMnCoO_2$) - NMC
- Lithium Iron Phosphate Batteries ($LiFePO_4$) - LFP
- Lithium Nickel Cobalt Aluminum Oxide Batteries ($LiNiCoAlO_2$) - NCA
- Lithium Titanate Batteries ($Li_4Ti_5O_{12}$) - LTO
- Lithium Polymer Batteries - LiPo

LITHIUM COBALT OXIDE BATTERIES (LCO)



This type of battery is most commonly used in mobile phones, computers, and cameras. It has a cobalt oxide cathode and a graphite anode. The electrolyte is formed by dissolving a lithium salt ($LiPF_6$) in a carbonate-based solvent.

Compared to other types of lithium batteries, it has the following disadvantages:

- Shorter lifespan (life span in the graph below). As an order of magnitude, 500 cycles can be considered a low value.
- Average thermal stability (performance in the graph below). This parameter assesses the cell's performance at high and low temperatures. Higher values of this parameter imply a lower influence of temperature on its performance.
- Low specific power (specific power in the graph below).
- Medium cost. In the graph, cost is represented as a strong point, meaning that as the radius on the graph grows, the lower the cost.

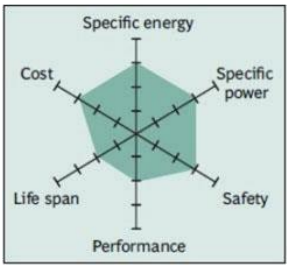
PARAMETER	MAGNITUDE	UNITS
Specific energy	150-200	Wh/kg
C-rated on load	0,70-1C	-
C-rated on discharge	1C	With a voltage variation < 2,50V (cut off)
Durability	500-1000	ciclos
Nominal voltage per cell	3,60	V

This type of battery should not be charged or discharged with a current intensity greater than 1C (or equivalently, a C-rating of 1C). For example, if the battery has a capacity of 2000mAh, the maximum charging and discharging current should be 2000mA.

This type of battery is being replaced by other types, such as NMC. This is due to the high cost of cobalt and the fact that better performance is currently achieved by alloying the cathode with other materials.

LITHIUM MANGANESE OXIDE BATTERIES (LMO)

LMO batteries are very similar to LCO batteries, but the cathode is made of a magnesium oxide. This material generates a lower internal resistance in the battery, increasing the resulting intensity of the electrochemical process.

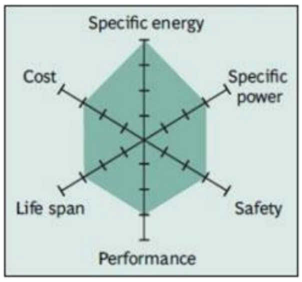


On the other hand, this cathode generates less thermal stability than LCO batteries but increases safety in the charging/discharging processes. However, it has a similar average lifespan to LCO batteries.

The significant advantage of having low internal resistance is that it allows for higher charging and discharging intensity compared to LCO batteries. In certain cells, it's possible to increase the discharge intensity to values of up to 30C during short pulses without risks of overheating or damage to the battery. On the flip side, this type of battery has less capacity than LCO batteries.

PARÁMETRO	MAGNITUD	UNIDADES
Specific energy	100-150	Wh/kg
C-rated on charge	0,70-1C	Nominal charge
	3C	Maximun charge
C-rated on discharge	1C	Nominal Discharge
	10C	Maximum discharge. Variation of voltage < 2.50V (cut off)
	30C	Maximum discharge during a 5s pulse
Durability	500-1000	Cycles
Nominal voltage per cell	3,70 - 3,80	V

LITHIUM NICKEL MANGANESE COBALT OXIDE BATTERIES (NMC)



These batteries are based on LMO batteries, where the magnesium oxide cathode is alloyed with lithium nickel manganese cobalt oxide (NMC).

This alloy significantly improves performance in terms of specific energy and lifespan (cycles) compared to LMO batteries. The electrolyte is formed by dissolving a lithium salt (LiPF6) in a carbonate-based solvent.

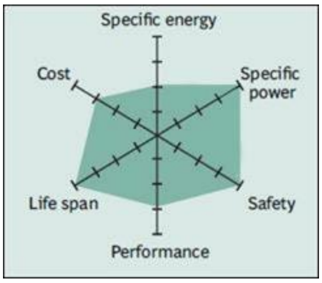
NMC batteries are used in the Nissan Leaf and the BMW i3 batteries.

In general, battery manufacturers are moving away from cobalt (Co) due to its high price and are focusing on nickel (Ni)-based alloys. These alloys applied in the cathode generate higher energy density, lower manufacturing cost, and a longer average lifespan than those based on cobalt.

PARÁMETRO	MAGNITUD	UNIDADES
Specific energy	150-200	Wh/kg
C-rated on charge	0,70-1C	Nominal charge
C-rated on discharge	1C	Nominal discharge
	2C	Maximum discharge. Variation of voltage < 2.50V (cut off)
Durability	1000-2000	Cycles
Nominal voltage per cell	3,60 - 3,70	V

LITHIUM IRON PHOSPHATE BATTERIES (LFP)

This type of battery has a graphite anode (similar to the previous ones), but the cathode is formed by a lithium/iron phosphate-based alloy (LiFePO4).

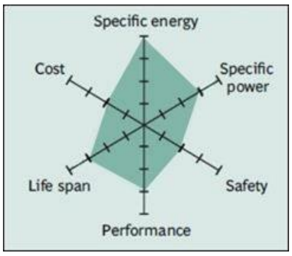


The electrolyte is formed by dissolving a lithium salt (LiPF6) in a carbonate-based solvent. This alloy generates a very low internal resistance, allowing for higher current intensities (represented by the specific power parameter) compared to previous types, a longer lifespan (charge/discharge cycles), and good thermal stability.

However, it has a higher self-discharge rate than previous types and lower specific density.

PARAMATER	MAGNITUDE	UNITS
Specific energy	90-120	Wh/kg
C-rated on charge	0,70-1C	Nominal Charge
C-rated on discharge	1C	Nominal discharge
	25C	Maximum discharge, during a 2s pulse. Voltage variation < 2.50V (cut off) to avoid damage to the battery.
Durability	1000-2000	Cycles
Nominal voltage per cell	3,20 - 3,30	V

LITHIUM NICKEL COBALT ALUMINUM OXIDE BATTERIES (NCA)



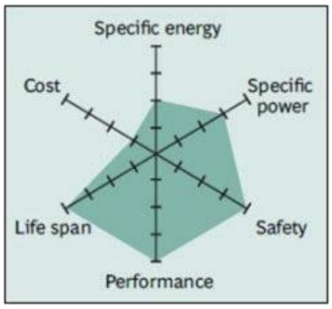
This type of battery has a graphite anode (similar to the previous ones), but the cathode is made up of a lithium/nickel/cobalt/aluminum-based alloy ($LiNiCoAlO_2$).

The electrolyte is formed by dissolving a lithium salt ($LiPF_6$) in a carbonate-based solvent. It achieves similar performances to NMC types, with high specific energy, reasonably good specific power, and a high average lifespan (cycles).

However, it has thermal stability similar to other types but comes with a high manufacturing cost.

PARAMETER	MAGNITUDE	UNITS
Specific energy	200-260	Wh/kg
C-rated on charge	0,70C	Nominal charge
C-rated on discharge	1C	Rated discharge. Voltage variation < 3V (cut off)
	500	Cycles
Durability	3,60	V

LITHIUM TITANATE BATTERIES (LTO)



This type of battery has a lithium/titanium alloy anode (different from the previously detailed types) and a magnesium oxide cathode.

The electrolyte is formed by dissolving a lithium salt ($LiPF_6$) in a carbonate-based solvent. This new configuration produces batteries with less cell voltage difference but capable of supplying a discharge current of 10C.

It's safer than other types, with excellent thermal stability, but, on the contrary, it has a higher manufacturing cost than the rest and a very low specific energy (comparable to a Ni-Cd cell).

PARAMETER	MAGNITUDE	UNITS
Specific energy	70-80	Wh/kg
C-rated on charge	0,70C	Nominal charge
	5C	Maximum charge
C-rated on discharge	1C	Nominal discharge
	10C	Maximum discharge. Variation voltage < 1.80V (cut off)
	30C	Maximum discharge in a 5s pulse. Variation of voltage < 1.80V (cut off)
Durability	3000 - 7000	Cycles
Nominal voltage per cell	2,40	V

LITHIUM POLYMER BATTERIES (LiPo)

The term 'polymer' is used to describe a different type of lithium battery from those mentioned so far. It's a common type when the batteries are pouch-type.

This type of battery differs from the rest in that the electrolyte is different. Instead of a lithium salt solution, a polymer (a mixture of synthetic plastics, bioplastics, and proteins) in a solid state is used (not liquid as seen so far).

This polymer is manufactured in the form of a film to which a specific gel is applied, surrounding the cathode and anode (eliminating the need for any separate insulating separator layer).

Regarding the cathode, any of the alloys used in the previous types can be used. Typically, cobalt oxide or magnesium oxide is employed. The anode continues to be made with graphite.

The advantage of these batteries (due to the polymeric electrolyte) is that they have a higher specific energy compared to other lithium batteries and a much slimmer construction. The downside lies in the manufacturing cost, which is higher than the rest.

These cells are manufactured in the form of a pouch or flat sack.

Until now, the other types of lithium cells required a rigid enclosure to ensure that the electrodes are tightly pressed against each other. Lithium polymer cells do not require that compression; instead, they are assembled in thin laminated sheets. This results in these cells being much lighter than the rest (around 20% less weight). For this reason, they are widely used in mobile phones, where weight is a critical aspect.

LITHIUM POLYMER BATTERIES (LiPo)

The major disadvantage of these cells is that, due to not having a rigid enclosure, they easily swell when subjected to overheating.

LITHIUM CELL TYPES BASED ON THEIR GEOMETRIC SHAPE

CYLINDRICAL CELLS

Cylindrical-shaped cells are the most commonly used type for packing cells (whether they are primary or secondary, lithium-based, Ni-Mh, etc.).

They are characterized by being easily manufacturable, having good mechanical stability (resistance), and being capable of withstanding high internal pressures without deforming.

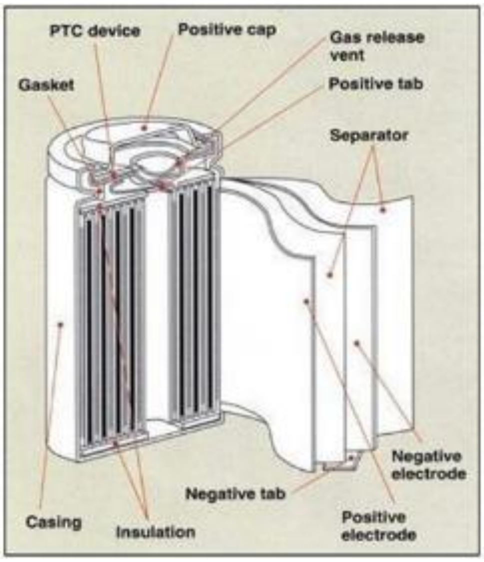
There's a criterion for encoding the size of these cylindrical cells. The code consists of 5 digits (XXYYY):

• XX = Outer diameter in mm

• YYY = Total length in tenths of mm

For example, a cell coded as 18650 has a diameter of 18mm and a total length of 65mm.

This type of cell assembly includes a temperature switch based on a Positive Thermal Coefficient (PTC) resistor.



When a cell is exposed to very high current intensity, this component heats up and increases its resistance to the extent that it cuts off the current flow (opens the circuit). Once this switch cools down (due to the absence of current), it allows current to flow again.

Moreover, another safety system is often incorporated into these types of cells. It's a Pressure Relief Mechanism (PRM). It consists of a membrane (a valve type with a calibrated spring) that opens at a certain internal pressure (set by the stiffness of the spring), releasing excess pressure and usually accompanied by a release of electrolyte.

In the case of lithium cells, some manufacturers include a Charge Interrupt Device (CID) that physically disconnects the current flow (irreversibly) as a result of unsafe pressure inside.

This cylindrical configuration is widespread in power tool batteries (drills, grinders, etc.), medical instruments or devices, laptops, and e-bikes. The most commonly used size for lithium cells in these applications is 18650.

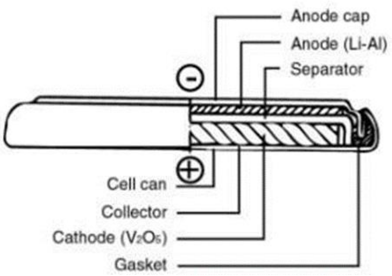
Other commonly used sizes are 20700, 21700, and 22700. Additionally, Tesla, Panasonic, and Samsung have further emphasized the 21700 size, as they find it appropriate in terms of manufacturing and achieve optimal capacity given the battery volume. While the 18650 size has a volume of 16.53cm3 (with a capacity of around 3000mAh), the 21700 size (24.23cm3 volume) achieves over 6000mAh, doubling the capacity with just a 50% increase in volume.

Although a cylindrical cell is not the optimal geometric shape for maximizing a given volume (when thinking about assembling a battery pack within an enclosure) as it leaves hollow spaces between cells (later it will be seen that this is actually an advantage in terms of cooling), the 18650 size has a higher energy density than a similar prism-shaped or pouch-type cell.

A Li-Ion battery of size 18650 with 3Ah reaches 248Ah/kg, while the equivalent pouch type does not exceed 140Ah/kg. This difference in energy density, coupled with the existence of air space between cylindrical cells (when assembling them into a pack), aids in cooling, making it the most employed geometry when assembling a pack.

BUTTON CELLS

This type of cell has a button or coin shape. It's extensively used in portable devices (such as blood pressure monitors, hearing aids, small measuring instruments, etc.) and small-sized toys.

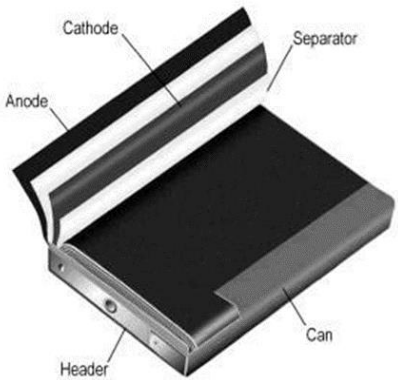


It possesses significant advantages due to its small size and very low production cost. However, it has the disadvantage of swelling very easily due to rapid charging. Because of its small size, it lacks internal pressure relief devices (like those described for cylindrical cells). This results in very long charge times (10-16h). Nowadays, they are used as primary cells (non-rechargeable).

PRISMATIC CELLS

This type of battery has a prismatic shape, usually rectangular. They are predominantly used in mobile phones and tablets. They typically have capacities ranging from 800 to 4000mAh."

Though not entirely standardized, some manufacturers use a coding system similar to cylindrical cells. They employ a code consisting of 7 digits. For example, it's common to use the size 564656P, which means the following:



- Thickness = 5.60mm
- Width = 46mm
- Length = 56mm
- P = Prismatic shape

Besides telecommunications applications, prismatic cells are also used in batteries for the propulsion system of hybrid and electric vehicles. The casing of these cells is made of aluminum alloy. They have a capacity ranging from 20 to 50Ah.

This type of cell requires a casing that ensures proper compression in the electrodes (similar to cylindrical cells). As a consequence of overcharging or very high charging speeds, these cells tend to swell. The casing deforms due to the internal pressure and as the number of charge/discharge cycles increases (typically, beyond 500 cycles).

POUCH CELLS

This flat type of cell is usually manufactured with lithium polymer cells. They are characterized by having a flexible casing (there's no need to compress the electrodes since the electrolyte is solid), allowing them to adapt to any volume.

As a result, they have very low weight, ideal for portable devices where weight and space are determining factors (such as mobile phones, for example). These types of cells achieve 90-95% efficiency in packaging terms. There are no standardized sizes; rather, they are created based on the specific application.

Due to being lithium polymer (Li-Po) type, they have very high discharge rates relative to their size.

The significant disadvantage is a high tendency to swell (expand) after about 500 cycles. The expansion is usually around 8-10% of their initial size. This means that when configuring a pack with these types of cells, it's necessary to leave free space between them to allow for this expansion and avoid generating additional pressure within the pack

The expansion of these cells is due to the formation of gases inside them as a result of excessively high temperatures. The pressure generated inside can rupture the casing, releasing gases and damaging the area where they are mounted. These gases mainly consist of CO2 and CO.

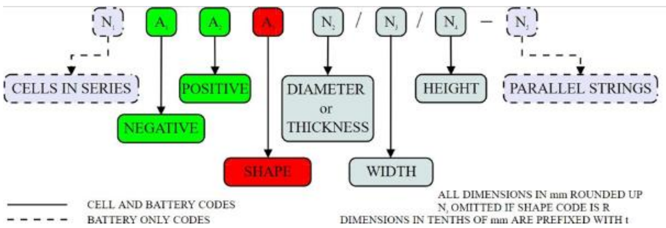
During the manufacture of these cells, a temporary gas bag is used. During the first charge of the cell, the maximum amount of gases is generated, which are collected in this bag. After this initial charge, the bag is removed from the cell, and the casing is sealed again.

Subsequent charges will produce a minimal amount of gases, but as charge cycles continue, the amount of gases stored inside increases. Overcharging and excessive heating increase the amount of generated gases.

TECHNOLOGY USED IN TRACTION BATTERIES

Currently, the batteries used in electric vehicles (to power the traction system) are lithium-based, and in almost all applications, a cylindrical geometry is employed.

Although not all manufacturers adhere to it, many follow the criteria specified in IEC 61960 (International Electrotechnical Commission) for designating cylindrical and prismatic lithium batteries. This designation follows the following scheme:



Of all available sizes for cylindrical cells, the most commonly used has been the 18650, and consequently, it's the size that's most optimized and has a more adjusted cost. However, each manufacturer has its own policy when choosing the type of cell to use.

Currently, cell manufacturers have strongly favored the 21700 size, so the latest electric vehicle models have these sized cells in their battery packs.

Regarding the chemistry chosen for the cells, the most commonly used are:

LCO / NMC / LTO

ASSEMBLY OF A BATTERY PACK

GENERAL CONCEPTS

So far, we've analyzed the technology and specifications of different cell types (based on their chemistry and geometric shape). Obviously, to power the traction system of an electric vehicle (EV), it's necessary to use a set of cells connected in series and parallel to create a pack capable of supplying the voltage and current needed by the electric motor(s) propelling the vehicle.

In addition to the cells, two components must always accompany the set of cells: a current sensor and a device called a BMS (Battery Management System). A fuse is also added, but this will be studied later.

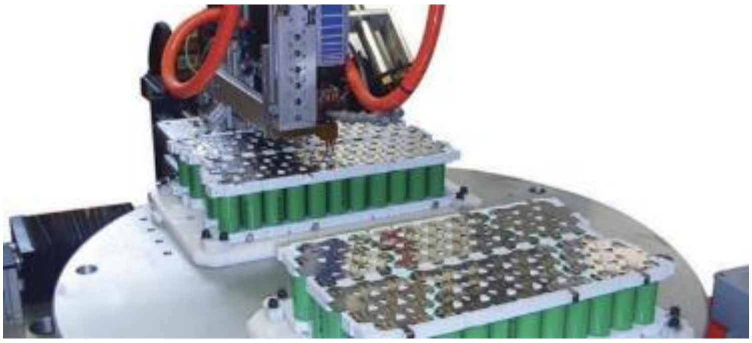
All these components are protected by an enclosure (usually made of aluminum alloy or plastic). The function of this enclosure is, first, to prevent electrical hazards resulting from direct and indirect contacts and, second, to provide the pack with sufficient mechanical strength (and sealing) to prevent damage under dynamic driving conditions.

Next, each of these components and how to connect the cells to achieve the required performance will be detailed.

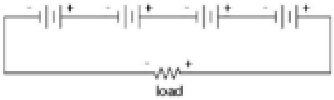
CELL CONNECTION IN A BATTERY PACK

In an electrical schematic, a cell or battery is represented by the following symbol:

All cells within a pack must be identical (both in shape, chemistry, and electrical specifications).



Series connection of cells



$$V_T = n \cdot V_i$$
$$I_T = I_i$$
$$P_T = V_T \cdot I_T = n \cdot V_i \cdot I_i$$
$$C_T = C_i$$

- n= number of cells connected in series (i.e., =1,2,3,…i=1,2,3,…n)
- Vi= Voltage of each individual cell (V)
- VT=n·Vi= Total voltage of the cell assembly (V)
- Ii= Current supplied by each cell (A)
- IT=Ii= Total current supplied by the cell assembly (A)
- Ci= Capacity of each individual cell (Ah)
- CT=Ci= Total capacity of the cell assembly (Ah)

In the image above, a pack is represented with 4 cells connected in series (4s) with the following specifications:

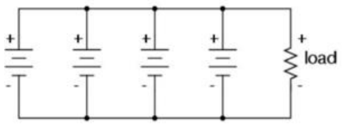
- *n*= number of cells connected in series = 4
- *Vi*= Voltage of each individual cell (V) = 3.60V
- *Ci*= Capacity of each individual cell (Ah) = 3400mAh

Therefore:

- *VT*=*n*·*Vi*= Total voltage of the cell assembly (V) = 4×3.60=14.40*V*
- *CT*=*Ci*= Total capacity of the cell assembly (Ah) = 3400mAh

This means that by connecting more or fewer cells in series, the total voltage of a battery is defined.

Parallel connection of cells



$$V_T = V_i$$
$$I_T = n \cdot I_i$$
$$P_T = V_T \cdot I_T = n \cdot V_i \cdot I_i$$
$$C_T = n \cdot C_i$$

Image 92

- n = No. of cells joined in series (i = 1, 2, 3, ... n)

- Vi = Voltage of each individual cubicle (V)

- VT = n-Vi = Total voltage of all the cells (V)

- Ii = Current intensity supplied by each cubicle (A)

- IT = Ii = Total current intensity supplied (A) by the whole cubicle (A)

- Ci = Capacity of each individual cubicle (Ah)

- CT = Ci = Total capacity of the total number of bays (Ah)

Image 93

The picture above shows a pack consisting of 4 cells connected in series (4s) with the following specifications:

- n = no. of cells linked in series = 4

- Vi = voltage of each individual cell (V) = 3,60V

- Ci = Capacity of each individual cell (Ah) = 3400mAh

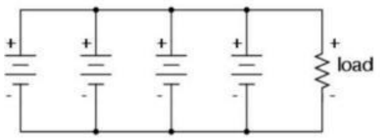
Therefore:

- VT = n-Vi = Total voltage of the cubicle assembly (V) = 4-3.60 = 14.40V

- CT = Ci = Total capacity of the cell bank (Ah) = 3400mAh

In other words, by connecting more or fewer cells in series, the total voltage of a battery is defined.

Parallel connection of switchgear



$$V_T = V_i$$
$$I_T = n \cdot I_i$$
$$P_T = V_T \cdot I_T = n \cdot V_i \cdot I_i$$
$$C_T = n \cdot C_i$$

Image 94

- n = number of cells linked in series (i = 1, 2, 3, ... n)

- Vi = Voltage of each individual cell (V)

- VT = Vi = Total voltage of the cubicle assembly (V)

- Ii = Current intensity supplied by each cell (A)

- IT = n-Ii = Total current intensity supplied (A) by the set of cubicles

- Ci = Capacity of each individual cell (Ah)

- CT = n-Ci = Total capacity of the cell bank (Ah)

The following image shows a pack consisting of 4 cells connected in parallel (4p) with the following specifications:

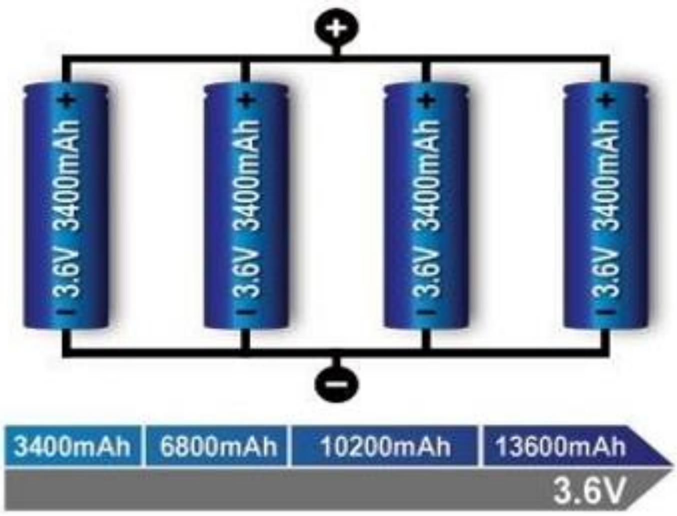


Image 95

- n = no. of cells linked in series = 4

- Vi = Voltage of each individual cell (V) = 3.60V

- Ci = Capacity of each individual cell (Ah) = 3400mAh

Therefore:

- VT = Vi = Total voltage of the cubicle assembly (V) = 3,60V

- CT = 4-Ci = Total cell capacity (Ah) = 13600mAh

That is, by connecting more or fewer cells in parallel, the total capacity of a battery is defined.

Series and parallel connection of switchgear

The series/parallel configuration of a set of cells allows the construction of a battery pack with the voltage and capacity required for each application.

A pack consisting of 2 modules connected in series, where each module is made up of 2 cells connected in parallel, is shown below. This configuration is designated as 2s2p (2-series/2-parallel).

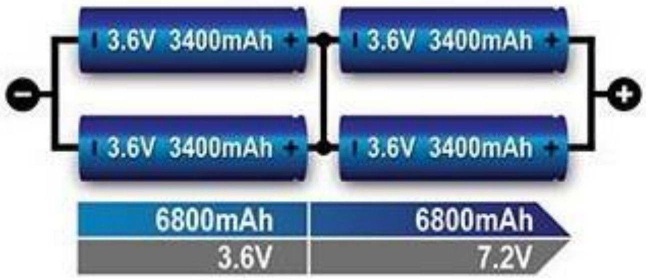


Image 96

- Each module in parallel delivers 3.60 / 6800mAh

- The two modules in series supply 7.20V / 6800mAh.

Example:

If you want to make a 72V, 4kWh battery from INR18650 cells, you need to do the following:

Specifications of an INR18650 cell:

- Cell voltage = 3,60V

- Rated capacity = 2500mAh = 2.50Ah

A battery supplying 4kWh (E) at 72V (ΔU) has a capacity (X) as follows:

E = 4kWh = ΔU-X => X = E/ΔU = 4kWh/72V = 0.05556KAh = 55.56Ah

Therefore, X = 55,56Ah

To achieve a battery pack with a voltage of 72V it is necessary to connect in series "s" modules of 3.60V/module.

72V = s-3.60 => s = 20

To achieve a battery pack with a capacity of 55.56Ah it is necessary to connect "p" cells in parallel.

55.56Ah = p-2.50Ah => p = 55.56Ah / 2.50Ah = 22.224 ≈ 22

Therefore, to achieve a pack supplying 4kWh at 72V, the following is required:

- Number of cells = s-p = 20-22 = 440 cells INR18650

- 20 (s) modules connected in series, where each module consists of 22 (p) cells connected in parallel

ASSEMBLY OF THE CELLS IN A BATTERY PACK

Once the number of cells needed and how to connect them is defined, it is necessary to design the layout of the battery, i.e. how it will be assembled inside an enclosure.

The normal part of a pack design process is to analyse where the pack will be placed in the vehicle and to define the maximum volume it can occupy inside the vehicle. Since the number of cells and their dimensions are known, it is easy to make geometric combinations to pack the cells within that maximum volume.

When assembling the cells, plastic elements (usually made of ABS) called battery holders are usually used, as shown in the image below. These hold the cells in place so that they do not move and allow an air gap to be left between them, which helps to cool them.

Image 97

Another option is to pack them together (without a battery holder) and then wrap them so they don't move. You usually apply a thermal paste to glue one cell to another.

This arrangement has the advantage that it takes up less volume, but has the disadvantage that it increases the heating of the cells (as the cells are closer together, they heat up faster as a result of charging/discharging processes).

Image 98

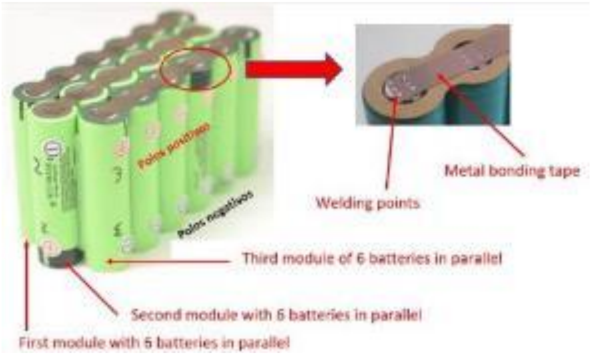
To explain the process of joining the modules (by spot welding), an example will be given of a battery consisting of 3 modules in series formed by 6 cells in parallel (3x6 or 3s6p).

- To mount the modules in parallel, a common plate is soldered to each positive pole and another plate is soldered to each negative pole.

- This plate (sheet) is made of nickel (100% or sometimes alloyed to improve the process) with a thickness of 0.10-0.15mm (in most cases). Depending on the current intensity that passes through it, it will have more or less thickness or more or less width, i.e. more or less section.

Image 99

Image 100



Once the modules formed by the parallel cubicles have been assembled, they are connected in series

Image 101.

Image 102

To make the series connections, the positive poles of a module must be connected (soldered) in parallel (1+) to the negative poles of the next module (2-). The pack is then turned over and the positive poles (2+) are soldered to the negative poles of the last module (3-).

Once the connection of the 3 modules in series has been completed, it is only necessary to solder one wire to the positive pole of the module (3) and one wire to the negative pole of the module (1).

Image 103

The ends of these cables will be the terminals of the battery pack.

SPOT WELDING FOR BAY CONNECTION

Specific spot welding machines (battery spot welder) are usually used to weld the nickel foils to the terminals or poles of the cells.

These machines are characterised by the ability to weld certain thicknesses of nickel foil (typically between 0.05-0.25mm).

Image 104

They offer the option of conventional spot welding.

Image 105

Or by means of the soldering iron (soldering part).

As an example, the following characteristics can be specified for a battery pack welding machine:

Specification for welding part:

Input voltage: AC 110 V/220 V±10%

Welding current: 50 ~ 800 A
Single pulse time: 5ms
Max. pulse quantity: 18
Max. power output: 3.2 KW (instantaneous)

Specification for soldering part:

Temperature range: 150~500℃ (302~932℉) (up to 300℃ within 7 seconds)

Soldering station power: 50 W
Output voltage: DC 20 V

Fixed welding part:
Welding thickness for nickel plated steel: 0.05 ~ 0.3 mm
Welding thickness for pure nickel: 0.05 ~ 0.25 mm

Mobile welding part:
Welding thickness for nickel plated steel: 0.05 ~ 0.2 mm
Welding thickness for pure nickel: 0.05 ~ 0.15 mm

Image 106

CONNECTION TO BMS AND CURRENT SENSOR

Once all the modules have been soldered and the terminals or ends have been placed, it is necessary to make the connections to the BMS (a pair of wires must be connected in parallel for each module to obtain the voltage value and to place as many thermistors as the BMS allows) and to make the connections to the current sensor.

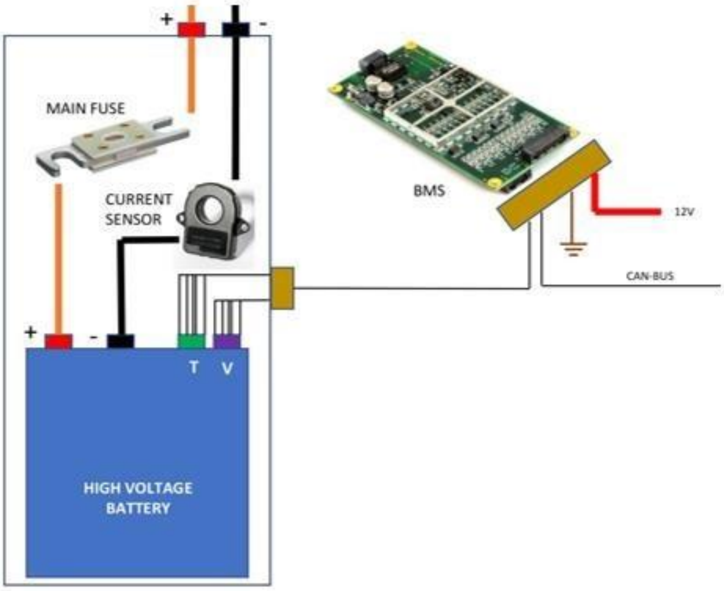


Image 107

FINAL PACKAGING

Once the above connections have been made, all that remains is the final packaging.

This packaging can be done in two ways, depending on the final application of the battery pack.

- Packaging by means of an insulating film (usually PVC)

- Packaged by means of a metal (aluminium alloy) or plastic (ABS) enclosure

Packaged in a heat shrink film:

Image 108

Packaged in a metal or plastic casing:

This is the usual way of packaging the cells in an electric vehicle. It is a box made of aluminium alloy or plastic (usually ABS).

Typically, the battery casing is designed in aluminium alloy, manufactured by injection moulding or extrusion and with a cover to allow for cell assembly.

The cubicle + enclosure assembly must be approved in accordance with ECE Regulation 100.

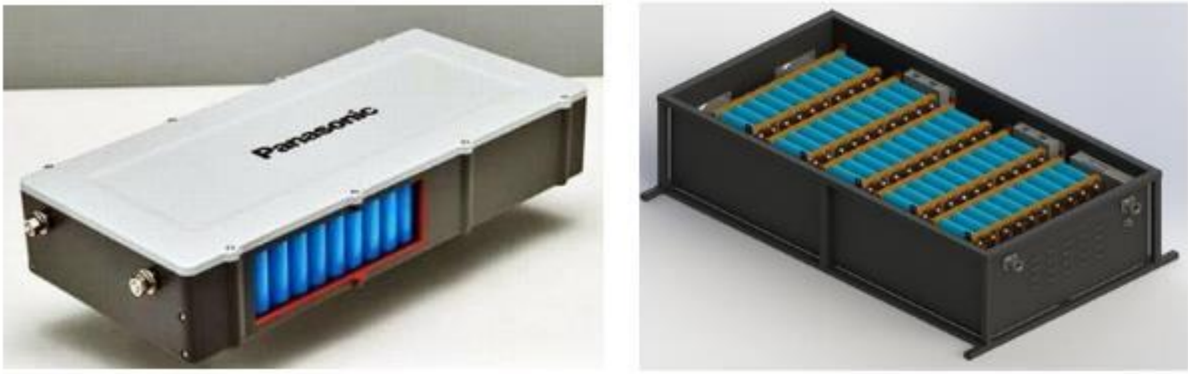


Image 109

BMS (BATTERY MANAGEMENT SYSTEM) DEVICE

A Battery Management System (BMS) is an electronic system (usually a PCB) that manages a rechargeable battery, protecting it from operating outside its safe operating area (Safe Operating Area). Installation in a battery pack is mandatory.

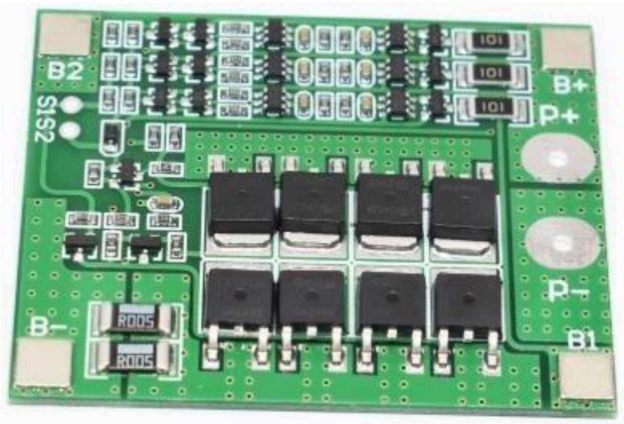


Image 110

The BMS has Can-Bus communication, so it is able to send information about the battery status to a control unit (switchboard) or to a display.

The BMS monitors the battery during the charging and discharging processes, measuring the three fundamental parameters that mark the state of a cell:

- Voltage

- Temperature

- Charging/discharging current

In addition to this monitoring or surveillance function, the BMS is capable of:

- Adjust the charging or discharging intensity of the pack in order to guarantee a

safe operation

- If it is not able to regulate the current, it is able to give a signal to open the main contactor that connects the vehicle's electrical system to the battery.

- During the charging process, it is capable of balancing the load of the cells, i.e., it is

i.e. verify that the cells are being loaded in a balanced way.

Block diagram of the BMS:

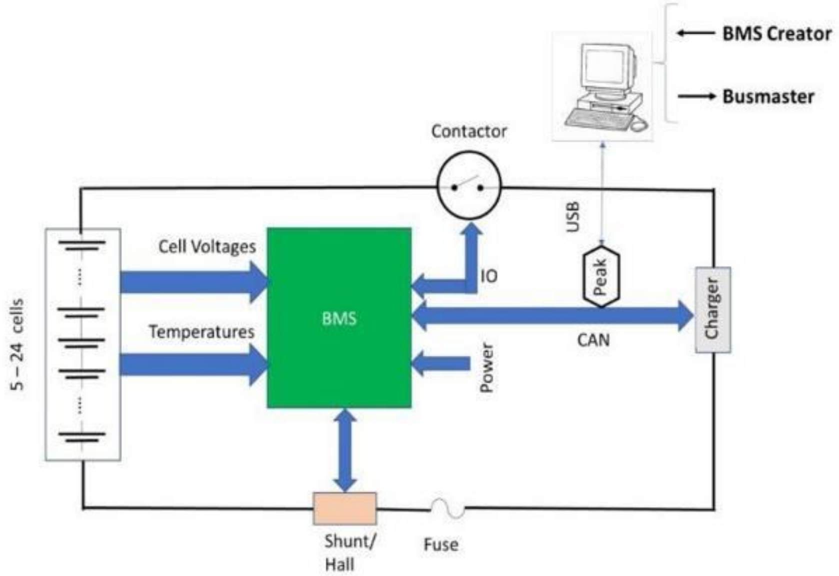


Image 111

* Shunt / Hall = Current sensor

Measurement of cell voltage.

When measuring the voltage of the cells, it is not actually the voltage of each cell that is measured, but the voltage of each module (group of cells connected in parallel).

In this way, two small cross-section cables (positive pole/negative pole) come out of each of these modules. Each pair of wires (one pair for each module in parallel) is connected to the BMS, where these voltage values are monitored.

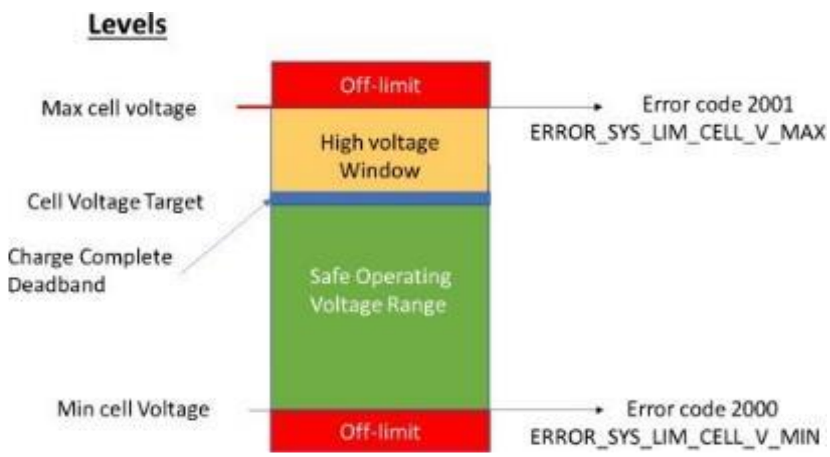


Image 112

Cell temperature measurement

NTC type thermistors are used to measure the temperature. What is actually measured is the outside temperature of some cells or the temperature of the plate that connects each module in parallel.

To do this, it is necessary to solder such a resistor in the areas where the temperature is to be monitored and connect it to the BMS. The limitation lies in the number of inputs the BMS has for the temperature measurement (as well as for the cell voltage measurement).

NTC resistor (thermistor):

Image 113

Safe operating range in terms of temperature:

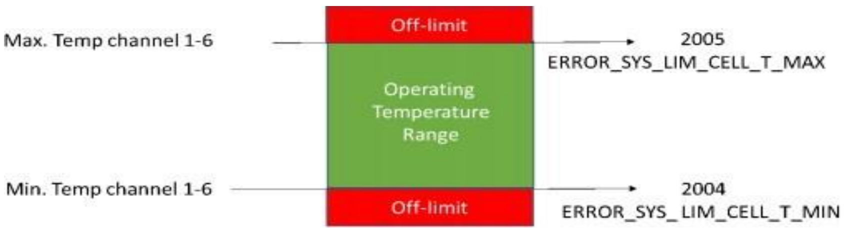


Image 114

CURRENT SENSOR

Another key component is the current sensor. This sensor is usually located on the negative cable of the battery (it could also be on the positive cable). Its main purpose is to measure the charge and discharge current of the battery and send this information to the BMS.

The BMS monitors the current value and will open the circuit (via a relay) in the following cases:

- When the maximum continuous discharge current allowed by the battery is exceeded

- When the maximum continuous charging current allowed by the battery is exceeded

- When a peak current occurs for a short period of time (limited by the battery pack cells themselves).

The most commonly used are hall effect sensors.

Hall effect current sensor:

Image 115

Safe operating range in terms of current intensity:

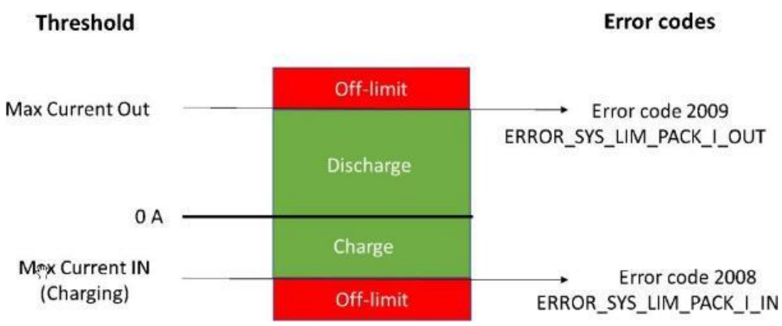


Image 116

COOLING AND AIR CONDITIONING IN ELECTRIC VEHICLES

GENERAL CONCEPTS

For years, one of the most valued details in a vehicle has been related to the ergonomics of the vehicle and, more specifically, to the thermal comfort in the passenger compartment.

In the case of an electric vehicle, the requirements associated with the air conditioning system have grown exponentially. Today, the term HVAC (Heating, Ventilation and Air Conditioning) is used, i.e. the heating, ventilation and air-conditioning system.

In a combustion vehicle, the passenger compartment climate control system is divided into heating and cooling. In this case, the passenger compartment is heated by means of the heat carried by the engine coolant. The passenger compartment is cooled by the air conditioning system.

The combustion engine is cooled by the passage of coolant through a radiator (air/liquid heat exchanger) located in the grille of the vehicle.

Phases:

1. Compression

2. Condensation

3. Filtering and drying

4. Expansion

5. Evaporation

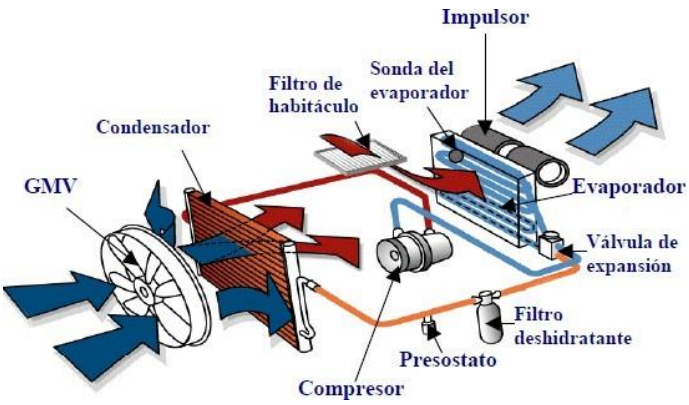


Image 117

Passenger compartment heating system in a combustion vehicle:

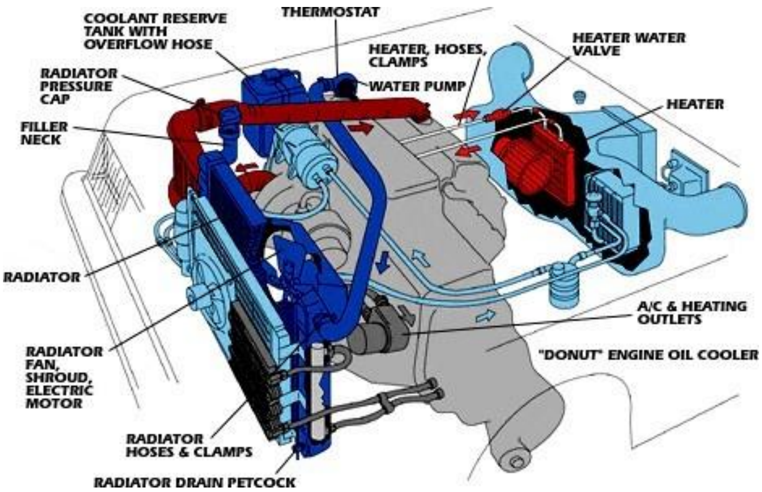


Image 118

CHANGES RESULTING FROM THE ELECTRIC DRIVE SYSTEM

In an electric vehicle, the HVAC system is more complicated than in a combustion vehicle.

This is because an electric vehicle incorporates a set of drive system components that must be cooled or heated (air-conditioned, as a general term).

These components are as follows:

- Battery pack
- Traction motors and related inverters
- DC/DC converter
- On-board charger

Therefore, a new management concept for the overall air conditioning system of an electric vehicle is essential, where the cooling of the battery pack becomes the main objective (even more so than the cooling of the passenger compartment).

THERMAL MANAGEMENT SYSTEM IN AN ELECTRIC VEHICLE

In an electric vehicle, there will be several independent air conditioning circuits. Although it will depend on the individual manufacturer, in general, the following division is possible:

- Cabin air-conditioning system
    - It manages the temperature inside the passenger compartment by means of a heating and cooling circuit for the air entering the passenger compartment.
- Battery pack climate control system
    - Manages the temperature of the battery pack by monitoring the BMS, both cooling and heating.
- Air conditioning system of the traction system
    - Circuit that manages the climate control of the other components of the traction system, i.e. traction motors, inverter, DC/DC converter and on-board charger.

BATTERY PACK AIR-CONDITIONING SYSTEM

PURPOSE OF BATTERY PACK COOLING

A traction battery consists of a pack of lithium-ion batteries inside an enclosure (usually made of aluminium alloy). These batteries or cells are responsible for generating the discharge current required to power the vehicle's electric traction motors. But they are only able to supply energy efficiently and safely when they are within a certain temperature range.

The same applies in situations where batteries are in a charging process. It is necessary that the recharging process takes place within a specific temperature range in order to achieve efficient charging without damage to the battery itself.

Therefore, the purpose of a cooling system is to keep the battery pack (each of its cells) within its specified operating temperature range, both when charging and discharging.

Key parameters of the battery pack cooling system:

Every electric vehicle manufacturer, usually together with the battery pack supplier, develops a system called BTMS (Battery Thermal Management System). This system monitors the temperature inside the battery pack (via the BMS) and regulates the cooling circuit to maintain target temperatures inside the pack.

In general, the optimum operating range of a lithium-ion cell is between 15-40°C. If you look at the data sheet of some of the batteries commonly used in batteries (whether from Samsung, LG, Panasonic, ...) you will see that they set the maximum operating temperature for discharge at 60°C (limited to 40°C in charging situations). It is common for vehicle manufacturers to limit the maximum rated temperature of the pack to values of around 30-35°C, so that at the moment when a peak of electrical current is requested (thus producing an increase in temperature), there is sufficient working margin in terms of temperature.

On the other hand, it is vitally important to minimise temperature variations between cells as much as possible. A recurring problem that needs to be solved by means of a good thermal design is to avoid that the cells located in the centre of the pack are at a higher temperature than those located at the sides of the battery enclosure. This temperature difference (ΔT) can lead to serious battery performance problems, as one group of cells may be working above their temperature limit (and need to be disconnected), while other cells are "cold". In general, care should be taken to ensure that there are no areas within the battery pack where temperature differences of more than 3-4°C exist.

The same problem occurs in charging situations, with the difference that when the battery is being charged via a charging station, the vehicle is stationary and switched off. This means that there is no fresh air flow available to generate the heat exchange necessary for cooling the pack, so a specific cooling strategy must be designed for this case.

Cooling system control strategy

The control strategy of the BTMS (Battery Thermal Management System) is as follows:

- Heat the battery pack when starting the vehicle (when ambient temperatures are low), raising the temperature to 10-15°C.

- Cool the battery pack so that it does not exceed 30-35°C in both discharging and charging situations.

- Maintain a homogeneous temperature inside the battery pack, avoiding temperature differences (ΔT) of more than 3-4°C.

TYPES OF BATTERY PACK COOLING

Air-cooled:

Air-cooled systems have mostly been used in hybrid vehicles, such as the Nissan Leaf or the Toyota Prius 1.8 VVT-I Hybrid, which has an 8.80kWh nickel hydride battery.

Image 119

An increasing number of manufacturers are now opting to use this cooling system, such as the Lexus UX 300e, which is fitted with a 54.30kWh lithium-ion battery.

Image 120

An air-cooling system takes advantage of the flow of fresh air from the environment to be introduced inside the battery pack (by forcing a certain airflow through a turbine) and recirculate it inside the battery pack to generate the heat exchange. This air flow ends up going outside to allow the entry of more fresh air flow.

Image 121

This type of cooling is much simpler and cheaper than the liquid-based alternative. In addition, it eliminates the risk of possible liquid leakage inside the battery pack. Two main disadvantages stand out: on the one hand, its efficiency is highly dependent on the outside temperature and, on the other hand, the turbine has a non-negligible power consumption, which has to be taken into account as an energy consumer.

Air cooling has been widely criticised as being insufficient to cool today's batteries, but the reality is that not all batteries (regardless of capacity) need the same cooling power.

The key is to perform a thermal simulation of the battery pack, considering its discharge profiles (in terms of current intensity) according to the target use of the vehicle and to analyse the thermal behaviour of the cells.

Liquid cooling:

This type of cooling is the most commonly used by electric vehicle manufacturers, such as the Tesla Model S (with an 85kWh lithium-ion battery).

Image 122

This system uses the same cooling fluid as the engine cooling circuit of a combustion vehicle (a 50% glycol solution in water), which is circulated inside the battery pack by means of a coil. The liquid is moved by means of a small electric pump and is cooled by means of an air radiator (exactly the same as in the case of a combustion vehicle).

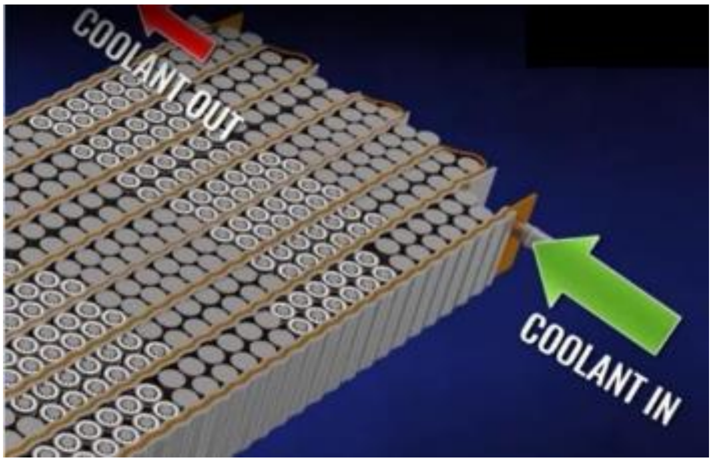


Image 123

AACC fluid cooling:

Another cooling alternative is to use the usual gas from the AACC system.

(currently R1234yf) to cool the battery pack.

For this purpose, a certain flow of compressed gas is bypassed in the AACC compressor (fed via the high-voltage circuit) and, after passing through the condenser, into the coil pack.

Inside the coil pack there is a circuit of metal pipes in the form of a coil, through which the condensed (therefore liquid) AACC gas will circulate. At the inlet of the pack there is an expansion valve (which causes the expansion of the liquid and its consequent sudden drop in temperature).

The coil acts as an evaporator, so that the air inside the battery pack gives up its heat to the expanded fluid circulating inside the pipes, causing it to evaporate. In this way, the air inside the pack is cooled.

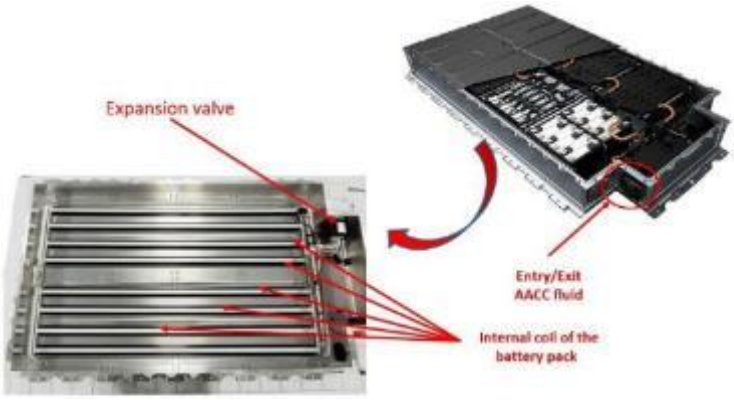


Image 124

TRACTION SYSTEM AIR-CONDITIONING SYSTEM

As discussed at the beginning of this chapter, in an electric vehicle it is necessary to cool several of the most important components of the drive system.

These components are as follows:

- Traction motors and related inverters

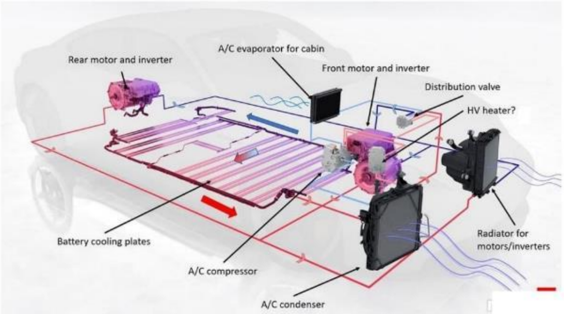
- DC/DC converter

- On-board charger

These components are cooled by a 50% water glycol circuit independent of the passenger compartment circuit. They use an electric fluid recirculation pump and an expansion tank (which, depending on the manufacturer, may be separate or shared with the passenger compartment circuit).

This circuit can be seen in the following diagrams.

Air conditioning circuits of the Porche Taycan:



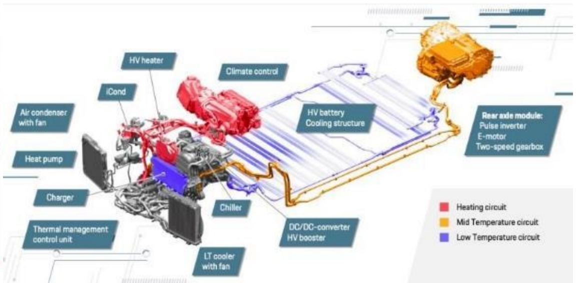


Image 125, Image 126

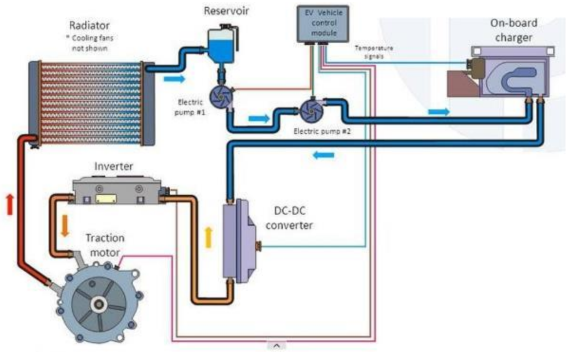


Image 127

PASSENGER COMPARTMENT AIR-CONDITIONING SYSTEM

As far as the passenger compartment air conditioning is concerned, there are two circuits (as in combustion vehicles):

- Passenger compartment cooling circuit

- Passenger compartment heating circuit

Both circuits differ little from the design in combustion vehicles. In the following, both circuits will be described.

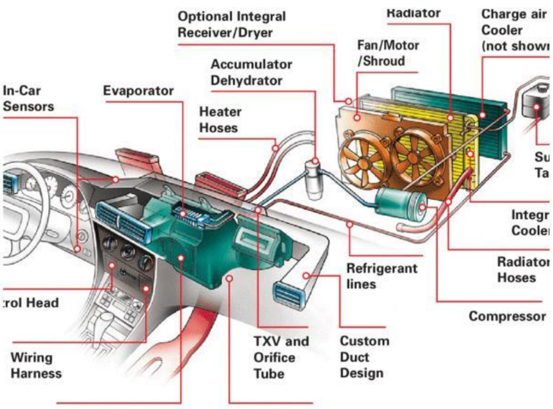


Image 128

The passenger compartment air conditioning circuit is similar to that of a combustion vehicle.

The differences appear in the compressor, which in the case of EVs is powered by the high-voltage circuit and, depending on the type of cooling of the battery pack, may incorporate a valve to distribute the fluid flow.

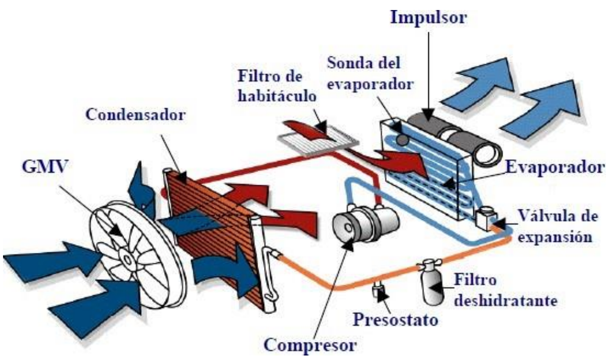


Image 129

PASSENGER COMPARTMENT HEATING CIRCUIT

The passenger compartment heating circuit is similar to that of a combustion vehicle. The differences are as follows:

- The water pump is electric, powered by the 12V circuit.

- The heat absorbed by the water (glycol + water) is not obtained from the combustion engine, but from the battery pack (when water-cooled) or by passing it through an electric heater. Other manufacturers dimension a system called a heat pump, whereby they use the AACC circuit to heat the liquid entering the passenger compartment.

Whichever way heat is built up in the heating system fluid, the next step is common to all vehicles. The air entering the passenger compartment is heated by passing through several heat exchangers inside the passenger compartment as the heated fluid circulates inside the passenger compartment.

An example of a heating circuit with an electric heater (powered by the battery pack) is shown below.

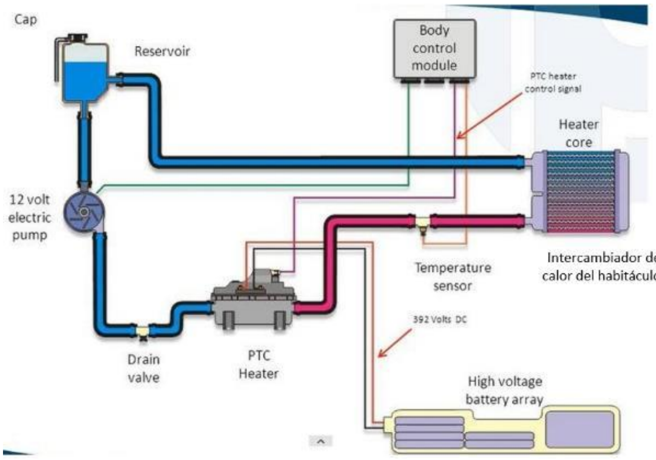


Image 130

1.5 RECHARGING THE BATTERY PACK

GENERAL CONCEPTS

The fundamental parameters of a cell have been studied and the assembly process of a battery pack has been described.

In this chapter, the charging process of a battery pack will be studied. Then, the charging system on-board the vehicle (on-board) and the external charging points installed in buildings and charging stations (off-board) will be detailed.

This charging process for electric vehicles represents a new business opportunity for many new companies, as without these charging points the existence of electric vehicles is neither viable nor feasible.

As far as Europe is concerned, the EAFO (Europe Alternative Fuels Observatory) shows the figures for public EV chargers in Europe in 2018, which show a large imbalance between countries. Although there is a common denominator, the vast majority of chargers are slow chargers (AC).

EV charging can be done in many different places, but charging at home and at the workplace is the most convenient for the driver and for the grid. On the one hand, the EV driver saves time as his vehicle is charged while parked in the places where he spends the most hours per day. On the other hand, the grid benefits from the slow demand at millions of points, being able to regulate charging at night or during off-peak hours for the rest of the system.

If the load is divided into sectors, taking into account the place where the charger is installed, a classification of 3 places can be made:

- Domestic chargers (which are the most common)

- Chargers at destination:

    - Workplaces

    - Vehicle fleets, car/motorbike sharing and electric buses

    - Car parks and shopping centres

- On-road loaders

    -Roadside chargers

    - Chargers at service stations and petrol stations.

Predictions indicate that alternating current (AC) charging will be the dominant way to fill EV batteries. However, faster direct current (DC) charging is needed for vehicles that cannot charge at home or at the workplace or for fleets.

Ultra-fast charging (DC) will be needed for transit vehicles (motorways), electric bus charging (eBUS) and electric heavy-duty vehicles (eTRUCK).

As an order of magnitude, the following consumptions can be established depending on the type of recharge:

- Domestic load = 3.20-7.40kW

- Workplace load = 7.40-11kW

- Public chargers = 22-50kW

- High Speed Chargers = 50-150-350kW

LITHIUM-ION CELL CHARGING PROCESS

A generic lithium-ion cell has a specific charging procedure. The parameters defining this process are determined by the manufacturer and are as follows:

BATTERY PACK	MAGNITUDE	UNITS
Charging voltage per cell	ΔU_{carga}	VDC
Standard charging current	$I_{standar}$	A
Optimal charging intensity (for cycle life)	I_{optima}	A
Maximum discharge intensity	I_{max}	A
Charging mode	CC-CV	-

Image 131

For almost all lithium-ion cells, the charging voltage (ΔCharge) is 4.20VDC.

The following picture shows the curve defining the charging process of a cell.

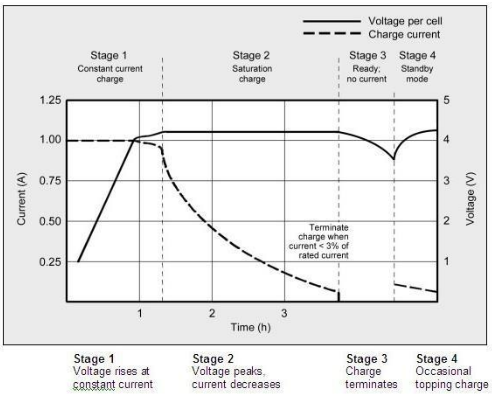


Image 132

It shows the charging mode required for this type of cell (DC-AC mode):

- Initially, the charger must supply a constant current (dashed line) of a value equal to the charging current indicated by the manufacturer (optimum/standard/maximum). Depending on the charging current value, a slow (optimum), medium (standard) or fast (maximum) charging process will take place. As this current is kept constant (DC mode = Constant Current), the voltage between the cell terminals increases until it reaches the charge voltage value (ΔLoad) specified by the manufacturer.

- From then on, the voltage remains constant and the load current is reduced (CV mode = Constant Voltage).

The cell is fully charged when the charging voltage (ΔUcharge) has been reached and when the current drops to about 3% of the rated discharge capacity [Ah].

The load parameters are set in the cell data sheet as follows:

3.11 Cycle life 1	Capacity ≥ 2,010mAh @ after 500cycles (60% of the Standard Discharge Capacity @ RT) - Charge : 1,020mA, 4.2V, CCCV 100mA cut-off @ RT - Discharge: 1C(3,400mA) , 2.65V cut-off @ RT

Image 133

That is to say:

- For optimum charging, the charger must supply a current of 1020mA@4.20VDC (DC Mode).

- When the charger detects that the cell's inter-terminal voltage has reached 4.20VDC, it will maintain that supply voltage (CV mode) until the current drops to 100mA. At this point, the cell is 100% charged.

Increasing the charge current beyond the manufacturer's limit (apart from causing damage to the cell) does not significantly speed up the charging time. Although the cell will reach its charge voltage (ΔCharge) faster, the constant voltage stage (called saturation charge) takes longer to complete. Typically, a very fast charge will charge a cell to around 70-80%.

Lithium-Ion cells do not need to be fully charged (as is the case with acid batteries), indeed, it is recommended not to do so. This is because it is preferable not to charge the cell 100% to its charging voltage (ΔUcharge) to avoid stressing the cell.

Charging at a lower voltage level, or by reducing or eliminating the saturation stage, increases the life of the cell. The trade-off is that the time between recharges (i.e. vehicle range) is reduced.

Returning to the operating curve of a charger, it can be seen that there are two more stages (stage 3 & 4).

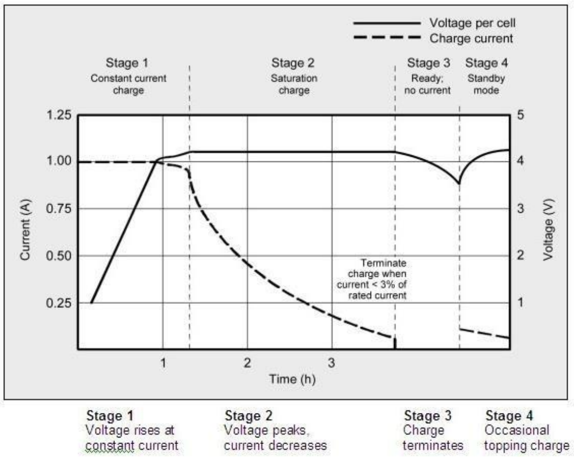


Image 134

Stage 3:

Once the charger detects that the SoC is 100%, it cuts off power to the cell. In the absence of a load, the cell tends to self-discharge.

Stage 4:

When the charger detects that the voltage between the cell terminals drops below a certain value, it supplies a small current to restore the charging voltage (ΔUcharge) of the cell.

Sleep Mode in a lithium-ion cell

Lithium-ion cells are equipped with a protection circuit to protect them against abuse. This circuit disconnects the cell. This situation is called Sleep Mode.

It is common for this to happen when a cell is stored long enough for its terminal-to-terminal voltage to drop below the cut-off, due to the self-discharge process.

And another common case is when the cell is discharged in normal operation and reaches the cut-off value. At that moment, the cell enters Sleep Mode and disconnects from the battery pack.

Many chargers have implemented a function called Wake-Up or Boost. This function reactivates the cell that has entered Sleep Mode by applying a small current that reactivates the cell. This (constant) current is maintained until the cut-off value is reached again. At this point, the charger switches to normal charging mode.

When the terminal-to-terminal voltage drops below the cut-off value to around 1.50VDC, it causes permanent damage to the switchgear.

In such cases, the Boost function should not be used, as the cell will become unstable and its temperature will rise abnormally and dangerously high.

This situation is usually programmed into the chargers.

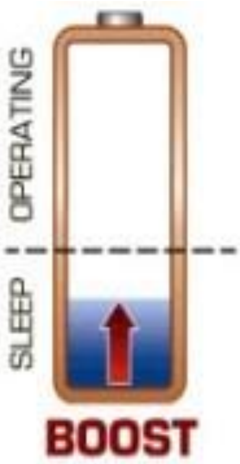


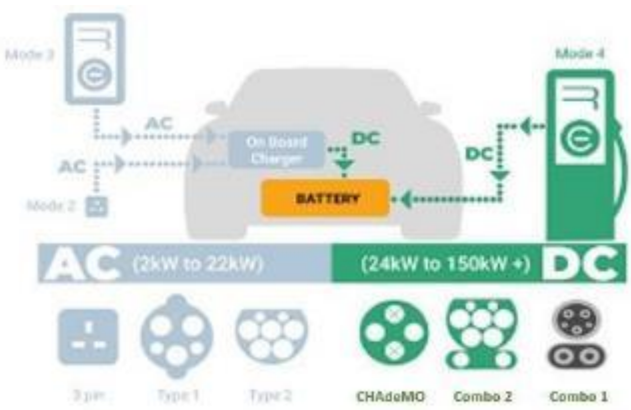
Image 135

ELECTRIC VEHICLE CHARGING SYSTEMS

STANDARDISED WAYS OF RECHARGING

In order to increase interoperability between charging infrastructures and electric vehicles, it is necessary to standardise each of the components that make them up.

Thus, the international standard IEC 61851 aims to standardise charging systems inside and outside the vehicle, for voltage levels of up to 1000V AC and 1500V DC.



In this standard, a classification is made of the different modes in which recharging can be carried out.

Image 136

Mode 1 (AC)

Recharging is carried out with alternating current (AC) using standardised connectors with currents limited to 16A per phase and up to 250VAC (in single-phase) / 480VAC (in three-phase). If charging is carried out in this way, the vehicle is connected directly to the conventional network, without the need to use any specific additional equipment or system.

The maximum power associated with this type of charging is 4kW in single-phase systems and 13.30kW in three-phase systems.

This mode is very practical for small vehicles such as bicycles or mopeds.

A type 1 connector is normally used.

Image 137

SCHUKO socket: Single-phase connection 230VAC

CETAP socket:380VAC three-phase connection

Mode 2 (AC)

In this mode the maximum current allowed is 32A per phase and up to 250VAC (single phase) / 480VAC (three phase). It is common to use this mode using a current of 16A. Maximum power levels are 8kW for single phase systems and 26.60kW for three phase systems.

This mode is provided with additional functions, such as checking that the vehicle is properly connected, ground detection at the connector and activation or deactivation of the system.

For these reasons, the connection cable to the vehicle must incorporate, in addition to the power and ground circuits, a control pilot function and a proximity pilot (both concepts will be discussed a little later).

This device (in this case integrated in the charging cable) is called EVSE.

(Electric Vehicle Supply Equipment).

A type 1 connector is normally used.

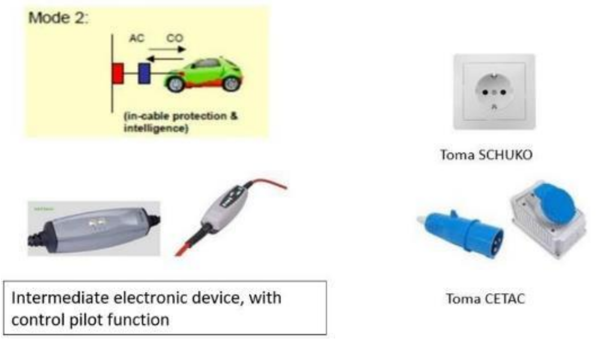


Image 138

Mode 3 (AC)

Recharging is carried out using a specific socket for electric vehicles. The maximum currents allowed are up to 80A (up to 250VAC in single-phase) and up to 63A (up to 480VAC in three-phase). Prototypes of 250A are currently being developed.

Maximum power levels are 20kW for single-phase systems and 52.38kW for three-phase systems.

The protection and control functions are permanently attached to the charging infrastructure, the so-called SAVE (System for Supplying Electric Vehicles) or Wall Box system.

The standard indicates that there must be a control pilot cable and a proximity pilot cable (both concepts will be discussed later) between this charging infrastructure and the electric vehicle. These functions are integrated into the charging infrastructure itself within the EVSE (Electric Vehicle Supply Equipment) device.

A type 1, type 2 or type 3 connector is normally used.

Image 139

Mode 4 (DC)

This form of recharging is done in direct current, through a rectifier external to the vehicle that regulates the recharge, for which a communication channel with the vehicle is necessary.

This mode is intended exclusively for fast charging, and allows the current to be increased to 200A. In Spain, the power used in mode 4 charging is usually 125kW.

The standard indicates that there must be a control pilot cable and a proximity pilot cable (both concepts will be discussed later) between this charging infrastructure and the electric vehicle. These functions are integrated into the charging infrastructure itself within the EVSE (Electric Vehicle Supply Equipment) device.

The required infrastructure is often large and costly compared to the previous ones.

A type 4 (CHAdeMO) or combined type (COMBO) connector is normally used.

Image 140

STANDARDISED RELOADING MODES - OVERVIEW OF MODES

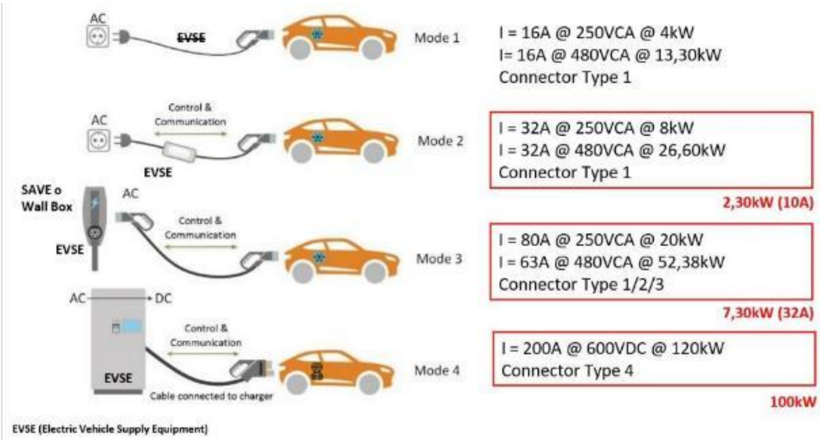


Image 141

STANDARDISED RECHARGE CONNECTORS

EEC 7/4 connector type F (Schuko)

It is mainly used in Europe in the slow charging mode. For this reason, it is suitable for charging small electric vehicles (such as electric bicycles and motorbikes).

It is equipped with phase, neutral and earth connections and is suitable exclusively for

single-phase systems with currents below 16A.

Image 142

SAE J1772 connector (Yazaki)

This connector is similar to the previous one as it is equipped with phase, neutral and ground, applicable to single-phase systems and with US origin. However, it incorporates a communication channel that allows the connectivity between the vehicle and the charging infrastructure to be detected and data to be exchanged between them. In other words, it has 5 terminals, 2 current terminals, the ground terminal and 2 parameter control terminals.

This type of connector is included in the IEC 62196-2 standard and is designated as Type 1 connector. The connector allows mode 1 and 2 loads. Geographically it is mainly used in the USA and Japan.

Image 143

Connector VDE-AR-E 2623-2-2 (Mennekes)

It is designed to perform Mode 2 and 3 recharging in accordance with IEC 61851.

It is mainly used in Europe, being similar in design to SAE J1772.

It has 7 terminals: 4 for three-phase or single-phase current (3 phases and the neutral), the earth terminal and two for load parameter control communications.

The connector allows three-phase charging (up to 63A) and slow charging (single-phase up to 16A).

This connector is designated as Type 2.

Image 144

Scame Connector

This connector is virtually obsolete due to industry support for Type 2 connectors. It has been restricted to the French market.

It has 5 or 7 terminals, depending on whether it is for single-phase or three-phase current, earthing and mains communications.

However, it is included in the IEC 62196-2 standard as Type 3. The maximum power rating is 22kW and the connection terminals are protected.

Image 145

CHAdeMO connector (CHArge de MOve)

It is a connector designed by TEPCO (Tokyo Electric Power Company) specifically for Mode 4 DC charging.

It supports power ratings up to 62.5kW and uses CAN bus as the communication system. This type of connector is classified as Type 4 in accordance with IEC 62196-2.

Image 146

COMBO Connector (Combined Charging System CCS)

It is a variant of SAE J1772 and Mennekes that incorporates a pair of DC wires to enable charging modes 2 to 4.

Image 147

STANDARDISED RECHARGE CONNECTORS - OVERVIEW

Image 148

STANDARDISED RECHARGE CONNECTORS (WIRING DIAGRAM)

CÓDIGO	DENOMINADO
CP	Control Pilot
PP	Proximity Protection
PE	Protective Earth
L1	Altern current (Fase 1)
L2	Altern current (Fase21)
L3	Altern current (Fase 3)
DC+	Direct current (Positive)
DC-	Direct current (Negative)

Image 149

Image 150

Mennekes connector

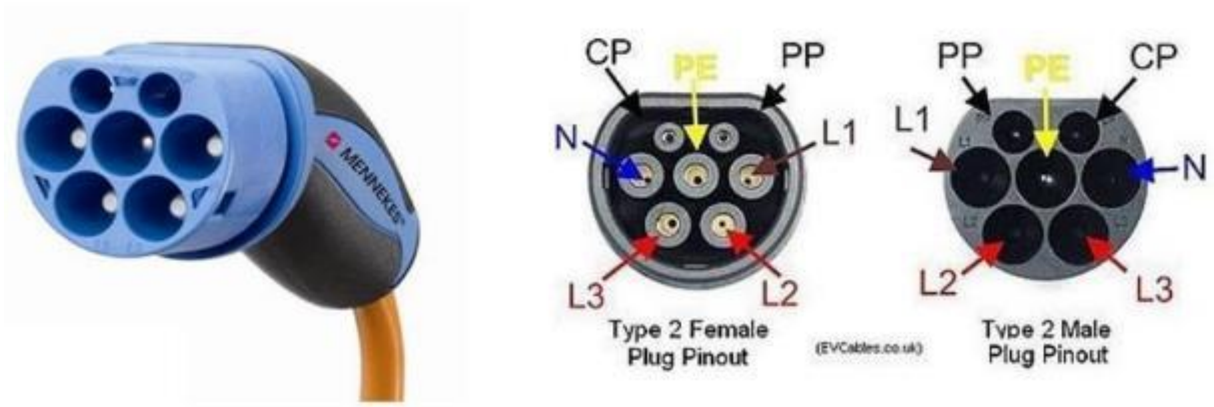


Image 151

ChaDeMo Connector

Image 152

CCS Connector

Image 153

CONTROL PILOT (CP)

The control light is able to detect that there is a physical connection between the off-board charger and the vehicle. In addition, it is able to communicate the maximum charging current allowed by the charger and the control of this charging.

In particular, the following communication flows exist:

- From off-board charger to vehicle:

  Maximum available current

- From vehicle to off-board charger:

  Charger/vehicle connection status

  Ready to accept cargo

Communication between the off-board charger and the vehicle is via the EVSE (Electric Vehicle Supply Equipment). This component can be integrated in the connection cable (for type 2 charging) or inside the charging station itself (for all other modes).

Types of charging in electric vehicles:

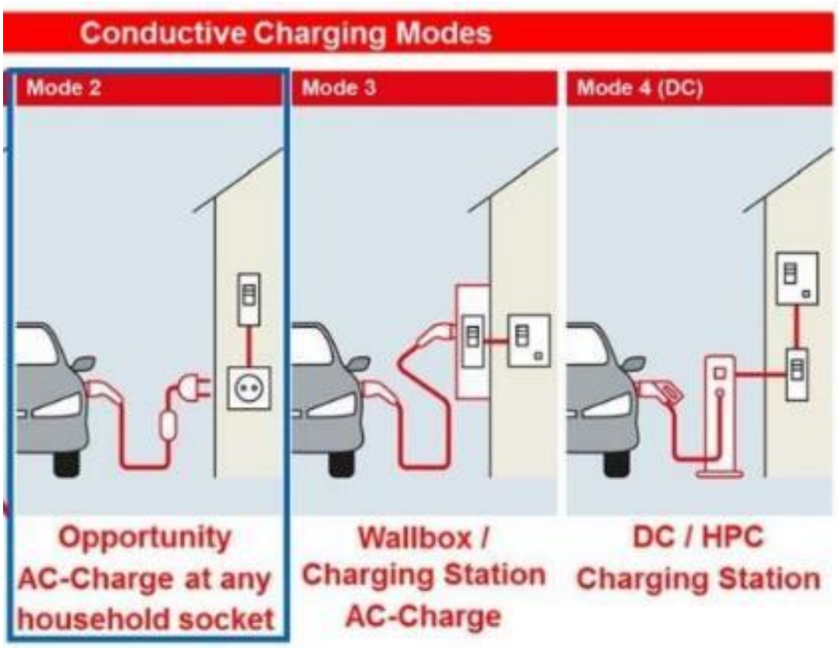


Image 154

Portable EVSE:

Image 155

The control pilot sends a 1kHz square signal (±12V) to the vehicle and receives the signal back via connector pin PE.

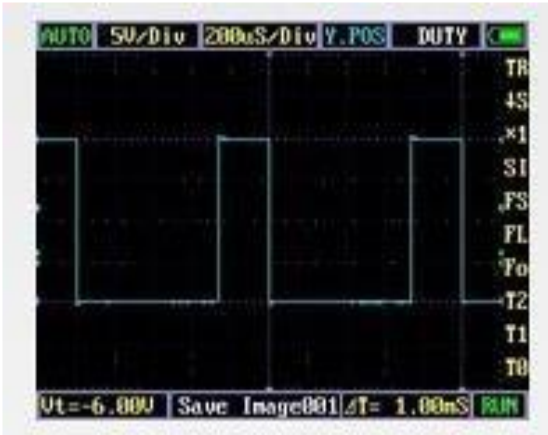


Image 156

Once the charger is connected to the vehicle, the vehicle adds a pilot resistor in order to vary the voltage of the original 12VDC pilot signal. Depending on this voltage, a certain state of charge is defined:

State	Pilot High	Pilot Low	Frequency	EV Resistance	Description
State A	+12V	N/A	DC	N/A	Not Connected
State B	+9V	-12V	1000hz	2.74k	EV Connected (Ready)
State C	+6V	-12V	1000hz	882	EV Charge
State E	0V	0V	N/A		Error
State F	N/A	-12V	N/A		Unknown/Error

Image 157

- Status A: Vehicle not connected to the charger

When the vehicle is not connected to the charger, the EVSE (which emits a continuous 12V signal) does not receive a ground signal (PE) from the vehicle, so there is no connection between the charger and the vehicle.

- Status B: Vehicle connected to the charger

As soon as the charger is plugged into the vehicle, it receives the 12V DC signal and a 2.74kΩ resistor is connected (see block diagram on the next page). This causes the pilot voltage to drop from 12VDC to 9VDC. This recognises and validates that the charging connector is plugged in.

Once the connection is detected, the EVSE feeds a 1kHz square PWM signal (±12V) to the vehicle, informing the vehicle of the current to be supplied.

- Status C: Charge accepted and start of charging

The vehicle receives the PWM signal and detects the load current communication. If this is acceptable, the vehicle (via the PP controller) activates relay K1 and an additional parallel resistor of 1300Ω is added (equivalent resistance of 2.74kΩ and 1300Ω equals 882Ω), whereby the pilot voltage drops by 3V (final voltage 6V). This means that the load current is accepted and the load is started.

- Status E: Load error (load stopped)

If no signal is received back at -12V or the initial 12V signal is not sent, a fault code is sent. This implies stopping the load.

- Status F: Load error (load stopped)

This is another fault condition, as a consequence of receiving 0V back. This implies stopping the load

Functional block diagram of the Control & Proximity Pilot function:

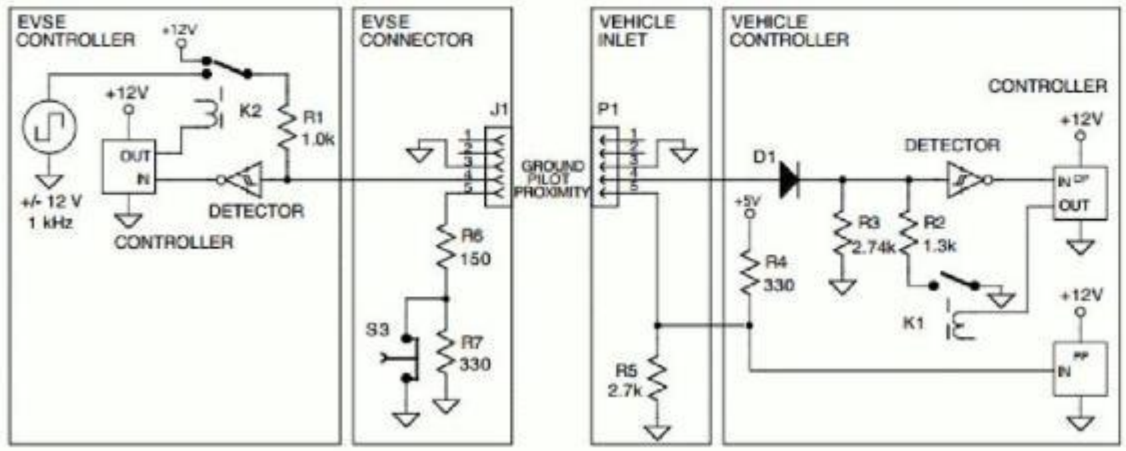


Image 158

To communicate the value of the charge current, the so-called PWM Duty Cycle is used, i.e., through the PWM (pulse-width modulation) signal sent by the EVSE pilot function, the charge value supplied by the charger is established. The vehicle, depending on the charge values implemented in its on-board charger (set via the BMS), decides whether this charge current is adequate (accepting the charge) or not adequate (not accepting it).

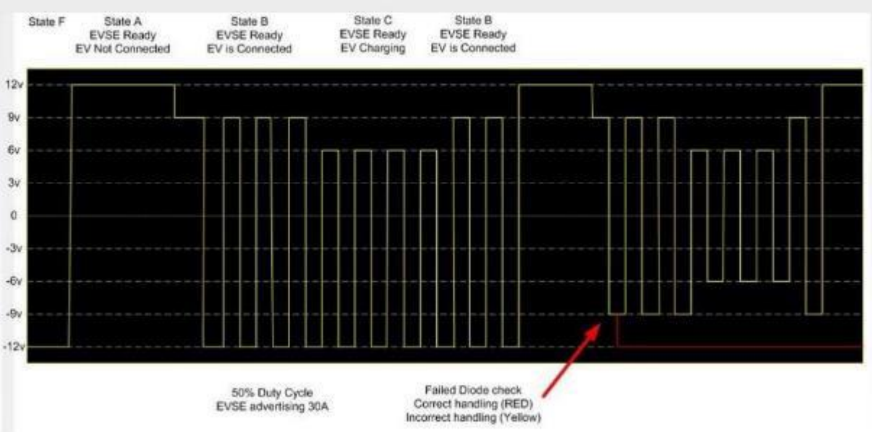


Image 159

PROXIMITY PILOT (PP)

This signal provides safety against starting the vehicle with the charging connector plugged into the vehicle and also indicates the maximum current that can flow through the charging cable (regardless of the capacity of the charging station).

The proximity pin is also called Plug Present and is governed by switch S3 (see diagram below):

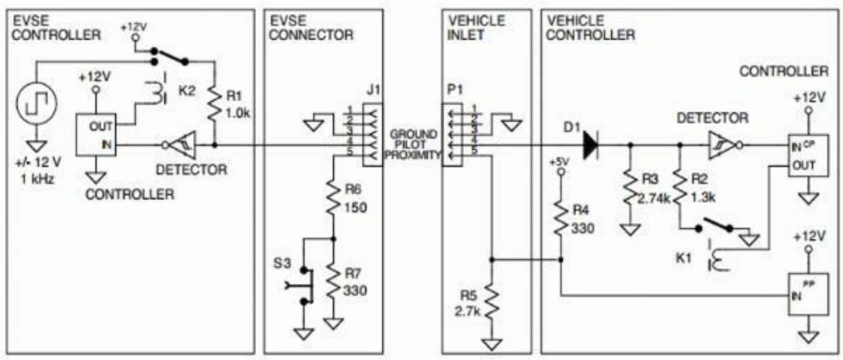


Image 160

When the charging connector is plugged into the vehicle, switch S3 closes. A voltage signal from the vehicle enters the proximity pin (the signal starts from 5V and is divided between resistors R4 and R6). This voltage drop is measured by the vehicle's PP controller, detecting that the charging connector is plugged into the vehicle.

As soon as the charging connector is unlocked, switch S3 is opened, adding resistor R7 and this new voltage drop is detected by the vehicle's PP controller. At that moment, a load disconnection signal is sent.

As soon as the connector is removed, resistors R6 and R7 are removed and detected by the vehicle's PP controller, so that the unplugged connector signal is sent.

The charging cable has an internal resistance that marks the maximum admissible current value. When this value is reached, a voltage difference is created and measured by the EVSE controller. At this point, the power supply is cut off.

ON-BOARD CHARGING SYSTEM

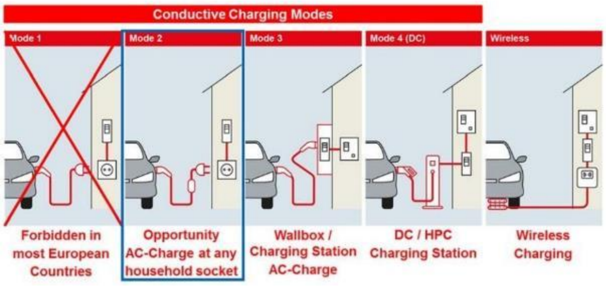


Image 161

The possibility of connecting the vehicle directly to the mains via a Schuko (single-phase) or CETAP (three-phase) connector can only be applied in charging modes 1 and 2.

Mode 1 is prohibited in the USA for direct vehicle charging, and is not recommended in most European countries (as is the case in Spain). This is due to the lack of communication between the vehicle and the grid, not because of safety problems in the vehicle, but because of possible overloads and overheating in the external electrical installation itself. On the other hand, it is an ideal face mode for motorbikes (as they have smaller battery capacities than vehicles).

The difference between the two modes lies in the need to use an intermediate electronic device with a pilot control function. This is often referred to as portable EVSE (Electric Vehicle Supply Equipment).

Image 162

Charging mode 2, which supports a higher charging intensity than mode 1, allows the vehicle to be connected directly to the mains via a Schuko (single-phase) or CETAP (three-phase) connector, but only if it is fitted with an EVSE device.

This device has an integrated control light and proximity light function, allowing direct communication with the vehicle and cutting off the power supply in the event of a dangerous situation.

On-board charger

Every electric vehicle needs a device that allows the battery pack to be charged by connecting it to a charging station, a wallbox or directly to a Schuko socket in the home.

This device is called an on-board charger or simply a charger.

Image 163

This charger has the function of rectifying the alternating current received to convert it into direct current in order to charge the battery pack.

In order to function properly, it is necessary for the manufacturer to program the specific charge curve of the cells that make up the battery pack. The BMS monitors the state of charge of each cell during the recharging process and sends the start and end of charge signal.

Chargers compatible with Lithium-Ion cells are those with a DC-VDC mode of operation.

Mode CV (Constant Voltage) = Constant Voltage Mode of operation

Typical accuracy of ± 1% (CV Accuracy)

Ripple (Ripple Voltage Coefficient) ≈ 5% (Ripple Voltage Coefficient) ≈ 5%.

Mode CC (Constant Current) = Constant Current Mode of operation

Typical accuracy ± 2% (CC Accuracy)

CAN communication parameters

All vehicle-mounted chargers have the ability to communicate with each other.

CAN. This communication is essential to control the charging of the battery pack.

Normally, the following operating parameters can be controlled via CAN bus:

- Switching the equipment on/off

- Output voltage and operating mode duration CV

- Output current intensity

- Power output (load)

On the other hand, the parameters that it is capable of emitting by CAN, in order to know its status, are the following:

- Grid voltage and current (AC)

- Output voltage and current (DC)

- Operating temperature (usually in the current rectifier, which is the area where most heat is generated).

In-vehicle connections:

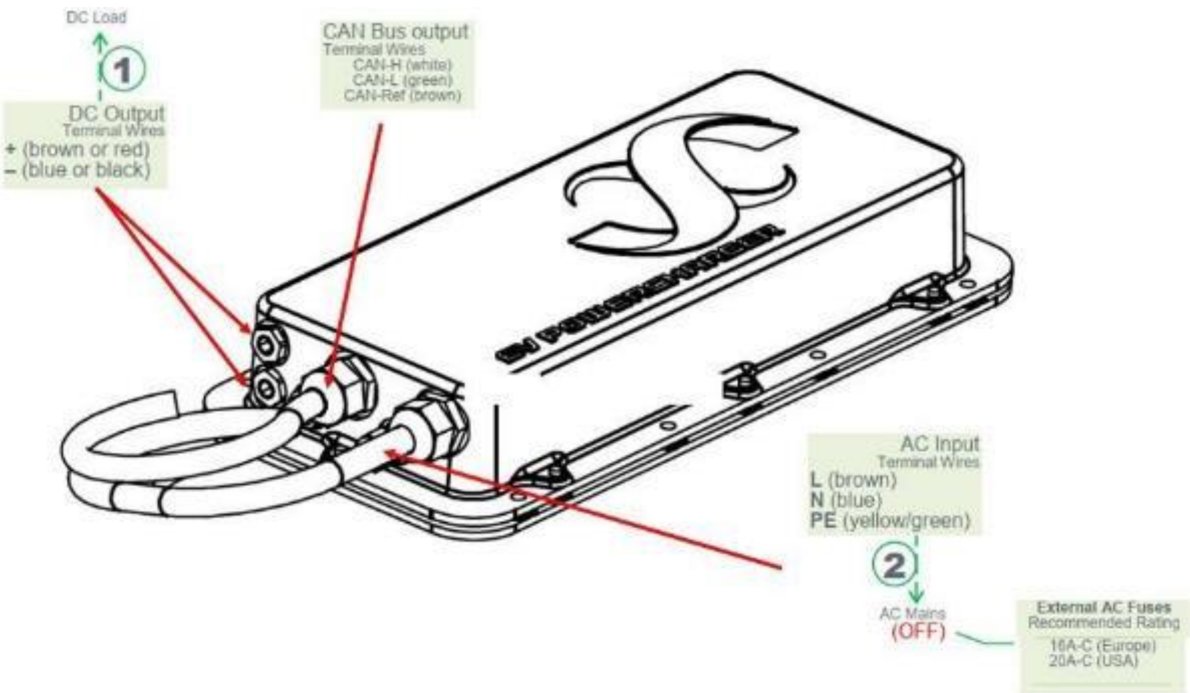


Image 164

Definition of load parameters

Every charger has an operating curve (charging curve), the characteristic parameters of which are defined by the BMS of the battery pack. For this reason, correct communication between the charger and the BMS is essential for proper and safe charging.

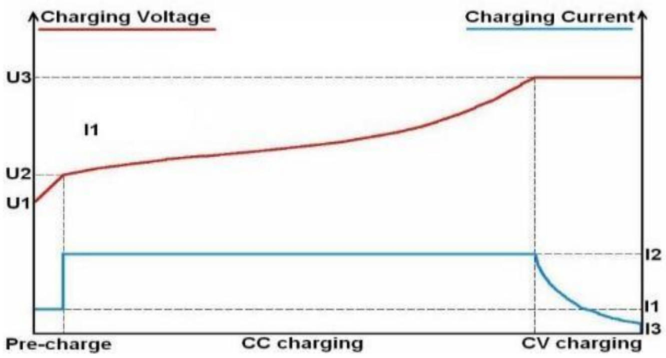


Image 165

PARAMETER		VALUE TO BE PROGRAMMED	UNITS
U_3	Battery pack charging voltage	$s \cdot \Delta U_{charge}$	VDC
U_2	Minimum pack voltage to be able to start a normal charging process	$s \cdot \Delta U_{cutoff}$	VDC
U_1	Minimum pack voltage to start preloading (*)	$0{,}50 \cdot U_3$	VDC
I_2	Maximum load intensity (**)	$p \cdot I_{max}$	A
I_1	Preload intensity	$2 \cdot I_3$	A
I_3	End of charge current	$I_2 / 6$	A

Image 166

(*) Below this value, the battery pack is not initially charged.

(**) Depending on the type of charging implemented in the charger (slow, medium or fast).

The charger initiates a pre-charge stage when the battery pack has a voltage below the cut-off value of the cells, applying a constant charging current of value I1 until the voltage between the battery pack terminals reaches the value of U2.

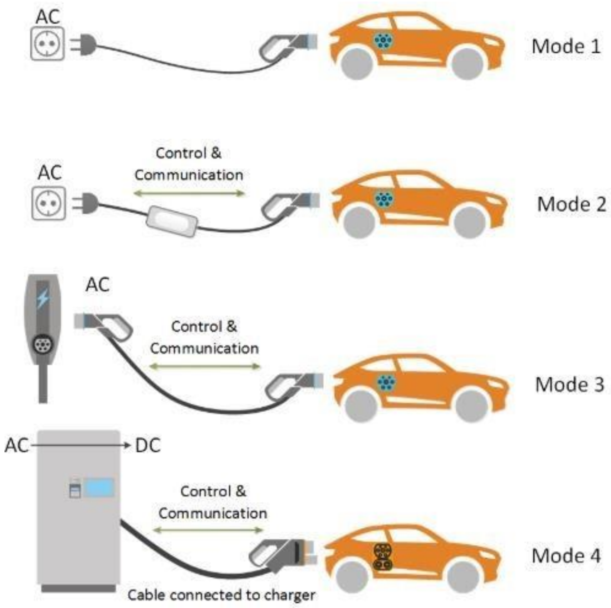
OFF-BOARD CHARGING SYSTEM

So far, in-vehicle chargers, which allow the EV to be directly connected to the grid, have been studied.

Normally, the use of these on-board chargers is limited to connection modes 1 and 2.

Image 167

If an on-board charger were to be used, it would be very large and heavy. For this reason, for these types of charging modes, the use of external charging stations (off-board chargers) is preferable.



In general, an off-board charger is any electric charging station located outside the vehicle (regardless of the charging mode used) and which has an integrated EVSE (Electric Vehicle Supply Equipment) device.

In an electric vehicle there must always be an on-board charger, to allow a charging mode 1 and 2. To allow a charging mode 3, the on-board charger must allow that mode (as the charging power it needs to transform is significantly higher than for modes 1 and 2). Not all on-board chargers allow a mode 3 charge.

Different types of charging configurations in an EV:

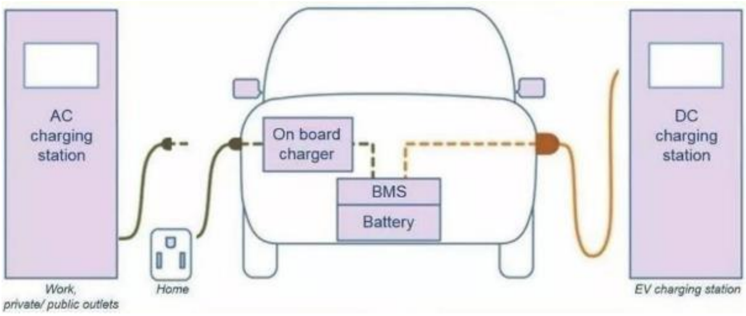


Image 168

A charging mode 4 (DC), on the other hand, works differently. Charging management is not carried out by the on-board charger, but by the BMS or EVMS (Electric Vehicle Management System). This means that it is the BMS or EVMS that communicates with the charging station (off-board charger) to govern the charging process. Normally, it is the EVMS that performs this communication based on the information it receives from the BMS.

The DC power supply lines from the charger are connected directly to the battery pack via two contactors (one for + and one for -). These contactors are controlled by the EVMS. As in the other modes studied, the control pilot and proximity pilot functions are integrated in the off-board charger.

Example of an outdoor recharging station

There are a multitude of manufacturers of outdoor charging stations. Almost all of them offer the same features and similar charging modes.

The following is an example of a data sheet for this type of charging station.

Entrada CA	Alimentación CA	3F + N + PE
	Tensión CA	400 Vc.a. ± 10%
	Corriente nominal de entrada	64 A
	Factor de potencia	> 0,98
	Eficiencia	94% de potencia nominal de salida
	Frecuencia	50 / 60 Hz
Salida CC	Máxima corriente de salida	56 Ac.c.
	Máxima potencia de salida	22 kW (@400 Vc.c.)
	Rango de tensión de salida	150 - 550 Vc.c.
Salida CA	Máxima corriente de salida	32 A
	Máxima potencia de salida	22 kW
	Rango de tensión de salida	400 Vca (3F + N + PE)
Sistema de carga	Carga CC 1	Modo 4 (**IEC 61851-1**; **IEC 61851-23**)
		JEVS G105 - CHAdeMO (**IEC 92196-3**)
	Carga CC 2	Modo 4 (**IEC 61851-1**; **IEC 61851-23**)
		Combo2 (**DIN 70121**)
	Carga CA	Modo 3 (**IEC 61851-1**; **IEC 61851-22**)
		Base Tipo 2 (**IEC 62196-2**)

Image 169

This type of outdoor station (public road) is powered by means of a three-phase current (3F + N + PE). As with the on-board chargers, the supply voltage, nominal input current, power factor, efficiency and permitted mains frequency are given.

The most important thing is to analyse the output characteristics of the station, as these are the ones that will load the vehicle:

- Charging mode 3 (AC output)

    Connector type 2 (Mennekes type)

    Maximum load current = 32A (AC)

- Charging mode 4 (DC output)

    Type 4 connector (CHAdeMO type)

    Maximum load current = 56ADC

    Load voltage range = 150-550VDC

Example of a home charging station

This type of domestic stations can be installed in private garages, so that they are powered by single-phase alternating current.

Conexión	Tipo de conector	Tipo I, Tipo II ó Schuko
	Tipo de carga	Carga en Modo 1 (Schuko) Carga en Modo 3 (según **IEC 61851-1**)
Características eléctricas	Tensión de entrada	230 Vc.a. / 400 Vc.a.
	Frecuencia de entrada	50..60 Hz
	Tensión de salida	230 Vc.a. / 400 Vc.a.
	Corriente máxima de salida	16 A / 32 A según tipo
	Medida de potencia	Contador integrado
	Medida de energía	Contador integrado

Image 170

These stations always have an AC output, allowing charging modes 1, 2 and 3 to be set, with output current intensities of 16/32A (AC) and offer options with Schuko (type 1) or type 2 (Mennekes) connectors.

ENERGY REGENERATION

So far, the use of the traction motor has been analysed in its most obvious mode, which is the generation of mechanical power from an electric current supply. That is, to move the vehicle.

But every traction motor can operate in power generation mode. This means that, if an external source can drive the motor, it is possible to generate an alternating current and thus generate electrical power.

This is the key to the energy regeneration of the battery pack. When the engine is not needed to move the vehicle (traction mode), its operation is switched to generator mode. In this way, if the vehicle is in motion (and therefore the engine is also in motion), electrical energy is generated that can be used to charge the battery pack.

Regenerative braking is the process by which the electric traction motor is used in energy-generating mode when the vehicle is braking (or stops accelerating). In this way, the kinetic energy of the wheel(s) being braked is harnessed to generate electrical energy and used to charge the battery pack.

On the other hand, there is the Kinetic Energy Recovery System (KERS), which is a process that allows a vehicle's speed to be reduced by transforming part of its kinetic energy into electrical energy and this electrical energy to be stored to allow extra energy for maximum acceleration (as happens in Formula 1 cars) or to dissipate it in the form of heat.

The difference lies in the purpose of the process, i.e. regenerative braking is used to charge the battery pack and KERS is used to allow extra energy to generate maximum acceleration. In practice, however, they are used interchangeably since, in the end, what is done is to harness the kinetic energy of the wheels that is lost during braking.

In the specific case of an electric vehicle, regenerative braking can increase the vehicle's range by 8-25%.

It is very important to note that regenerative braking cannot replace the conventional mechanical braking system, as it is not always possible to use this strategy during braking. For example, if the battery pack charge is at 100% or the temperature of the cells is close to the limit, or it is not possible to switch to regeneration mode in the motor due to a fault, high temperature, etc. Therefore, it will always be necessary to have a hydraulic service braking system, dimensioned on the assumption that there is no regenerative braking system.

In contrast, the combination of both types of braking brings the vehicle to a stop with minimal wear on the brake pads and, consequently, on the brake disc. This means significant savings in terms of maintenance.

BRAKING ENERGY REGENERATION STRATEGY

There are two strategies to follow when implementing a regenerative braking system in an electric vehicle: series control and parallel control.

- Serial regenerative braking control

- Parallel regenerative braking control

Image 171

Serial regenerative braking control

It is a combination of braking by means of the mechanical braking system (modulated by an electronic control system) and regenerative braking.

The purpose of this control is to estimate the deceleration requested by the driver and to distribute the required braking force between regenerative braking and mechanical braking.

This type of control increases the vehicle's range by about 15-30%, but requires an electrically actuated mechanical braking system (brake-by-wire).

Parallel regenerative braking control

It is a combination of braking by means of the mechanical braking system and regenerative braking, without any modulation of the mechanical braking. In other words, the regenerative braking force is added to the mechanical braking force (which depends solely on the position of the brake pedal and therefore cannot be adjusted electronically). Therefore, the only thing that can be controlled is the regenerative braking force.

The extent of regenerative braking (in this type of strategy) is based on the state of charge of the battery (state of charge SoC), the vehicle speed and the capacity of the motor acting in generator mode. If excessive braking force is generated (causing wheel slip), the ABS system acts to reduce the pressure of the mechanical braking system.

This type of control increases vehicle range by around 9-18%.

BRAKE-BY-WIRE SYSTEM

This system is essentially similar to a conventional braking system. The difference is in the type of brake pedal assistance and a change in the electronic brake management, but in both cases the service brake hydraulics and ABS are retained. As mentioned above, it is used in series regenerative braking strategies.

The Brake-By-Wire system consists of an electrically actuated (instead of vacuum-assisted) brake servo.

However, some manufacturers choose to fit an electric vacuum pump connected to the conventional brake servo lung of a combustion vehicle.

The purpose of implementing an electrically assisted brake booster is to separate the action of pressing the brake pedal from the hydraulic pressure generated to actuate the brake calipers.

Image 172

The operating diagram of this system is as follows:

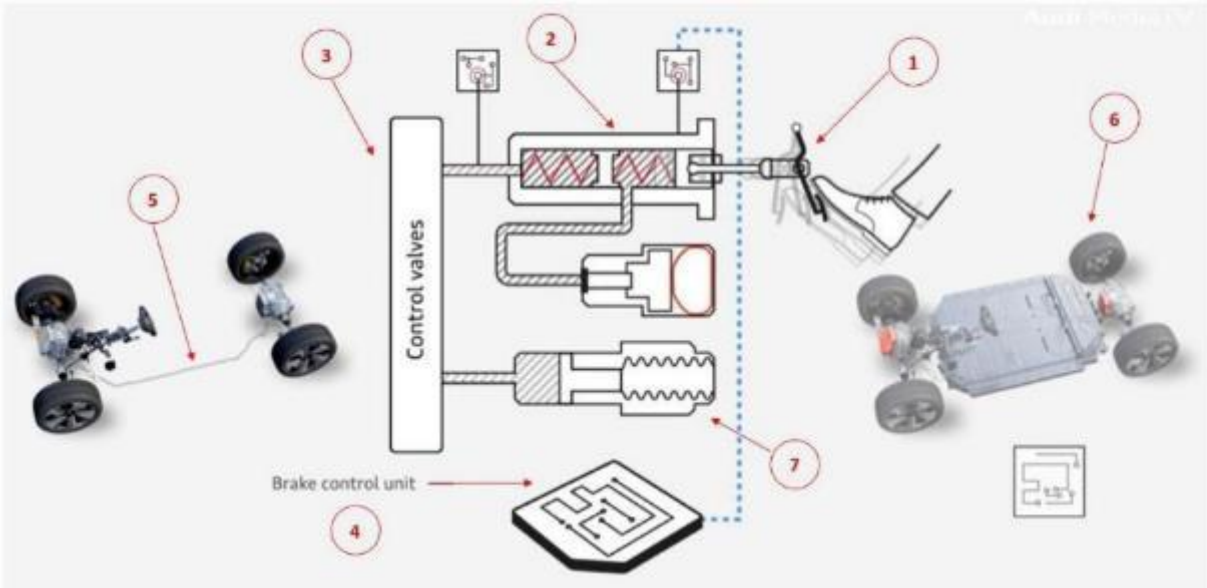


Image 173

The system, in general, consists of the following systems:

1. Brake pedal

2. electric brake servo

3. ABS (valve block)

4. Brake control unit (Brake control unit)

5. Hydraulic service braking system

6. Regenerative braking of traction motors

7. Hydraulic pressure pump

The pedal, as in a combustion vehicle, is linked to the brake servo (in this case, equipped with an electric motor that generates its assistance).

The operating diagram of the brake pedal is as follows:

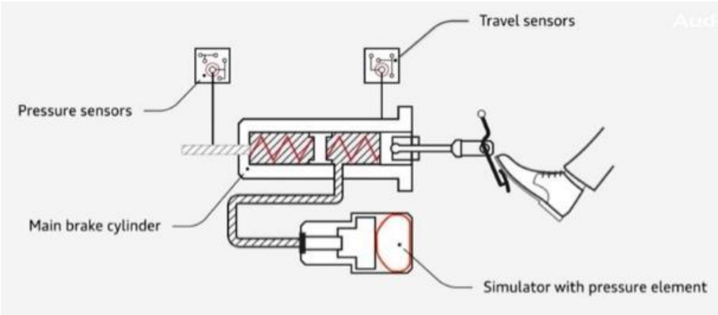


Image 174

When the driver starts to apply the brake pedal, the pedal potentiometer (travel sensor) detects the travel.

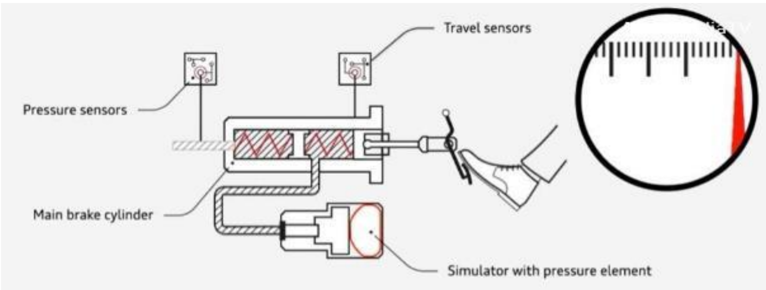


Image 175

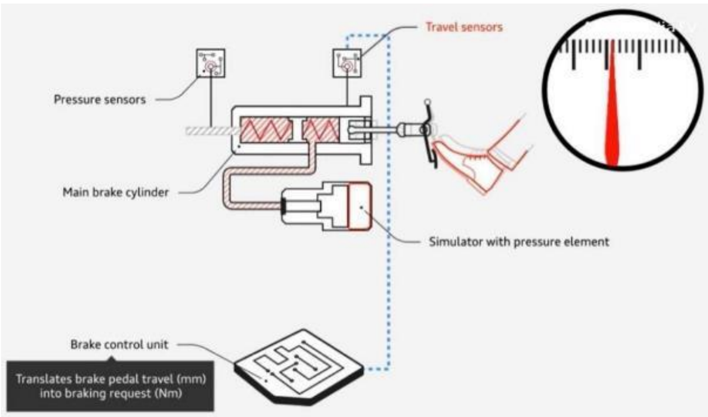


Image 176

The operating strategy is to trigger regeneration in the motors in the first instance in order to generate the braking force. This means that when the brake pedal is depressed, brake fluid pressure is not generated in the main brake cylinder, but a signal is sent to the BCU (Brake control unit) to activate regeneration based on the travel of the brake servo.

The BCU communicates this information via Can-Bus, which is received by the control unit of the electric motors.

In order to give the user the same feeling on the brake pedal as they would have in a combustion vehicle, i.e. to feel a resistance (hardness) when stepping on it, a membrane is compressed (simulator with pressure element). In this way, the driver feels that he or she is braking.

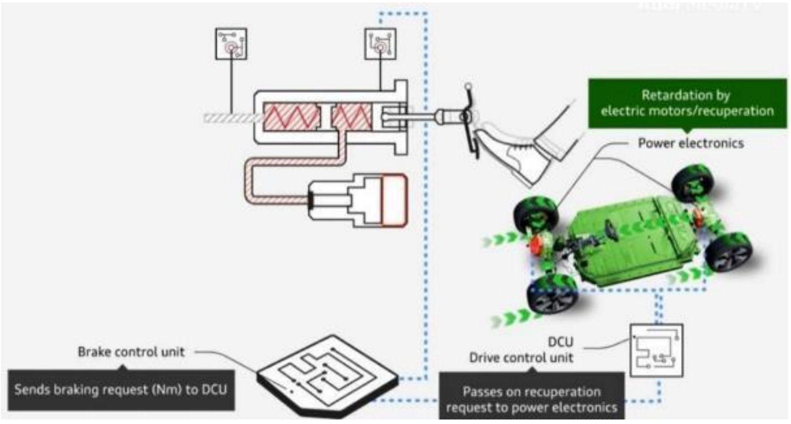


Image 177

As long as the braking capacity provided by regenerative braking complies with the driver's braking signal (each brake pedal position corresponds to a percentage of the total braking capacity), the service braking hydraulics shall not be activated.

If more braking capacity is required, the service braking hydraulics are switched on.

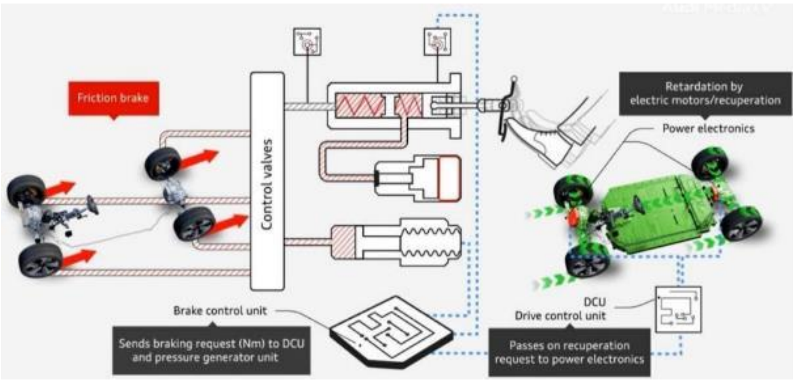


Image 178

The ABS valve block (control valves) receives pressurised brake fluid from the master cylinder and from an auxiliary pressure pump (in case a pressure increase is required) and allows the pressurised brake fluid to flow to the brake calipers (as the brake circuit of a combustion vehicle would work).

The pressure sensor integrated in the master cylinder measures the pressure generated in the master cylinder when the brake pedal is actuated. If this value does not comply with the setpoint set in the BCU, the auxiliary pressure pump is activated.

CONCLUSIONS ON THE REGENERATION STRATEGY

Whatever the strategy followed, the regeneration will always be limited to the state of the battery (SOC and cell temperature). In this case, it is the BMS that will detect if any of the modules of the battery pack have any parameter out of the normal range (voltage or temperature), in order to cancel the regeneration.

In the same way, the maximum charging current of the battery has to be implemented, in order to correctly calculate the % of regeneration that can be applied.

Between the two available regeneration strategies (series or parallel), the trend in electric vehicles is to implement series strategies (brake-by-wire) together with the e-pedal function. This strategy allows higher regenerative performance, as it is based on the assumption that as much as possible is braked by regeneration and only the hydraulic service braking system acts when the braking power needs to be increased. This has two consequences:

- An increase in vehicle range

- Minimal brake pad and disc wear

According to various studies, it is estimated (on average) that this type of series strategy can increase the range of the battery pack by 15-30%. However, it should be borne in mind that this depends on the parameters set by the manufacturer, the driving style of the vehicle user and the characteristics of the road on which the vehicle is driven.

Another important aspect to analyse is the driver's feeling. High regeneration rates can make the vehicle uncomfortable, as it continuously brakes depending on the position of the brake pedal or accelerator, so a compromise must be found between regeneration efficiency and the driver's feeling. In this sense, manufacturers usually define regeneration profiles, whereby the user can choose between several modes (off, low, medium, high, ...), so that he/she can select the desired regeneration percentage.

BATTERY PACK REPAIR

With regard to the battery pack, it is currently not allowed to repair the battery pack, but only to replace individual modules. In the event of a pack failure, the dealer or repair shop must currently inform the vehicle manufacturer to decide what needs to be done (depending on the severity of the failure). This depends on the after-sales policy of each brand.

Image 179

Obviously, the battery pack can be removed from the vehicle without any problem, except in those cases where the battery casing has a structural function in the vehicle, the removal of which is more complicated.

If it is removed from the vehicle, the defective modules can be replaced. Depending on the architecture of each manufacturer, it may be necessary to calibrate or update the engine control unit or the Electric Vehicle Management System (EVMS) to integrate the new module in the pack, as well as to pre-balance the new module to bring it to the same voltage level as the other modules.

What is not permitted under any circumstances is to open the enclosure of the battery modules in order to carry out any repairs to the cells or the internal connections. This is due to the risk of short-circuiting and generating a spark which could cause the cells to explode.

Actually, any professional with experience in the manufacture of lithium batteries could handle and repair (with the appropriate safety measures) a battery pack, but it involves many hours of work and, in case it is necessary to break welds of the cells, it becomes economically unaffordable. In such cases, replacement with a new module will always be worthwhile.

At this point, the creation of companies dedicated to the repair of battery modules for subsequent assembly in vehicles could be considered (as is currently the case with repaired engines and gearboxes that are assembled in vehicles instead of a new engine or gearbox).

1.6 OPERATION OF ELECTRIC MOTORS

The main technologies used in electric motors in traction systems are:

- Three-phase asynchronous motors (induction motors)
- Three-phase synchronous motors (permanent magnet motors)
- Axial flow motors
- Switched reluctance motors

Initially, DC motors were used for the traction system, as they are very easy to control, with a very linear response and the driver is simple and low cost. However, they have serious design problems due to the use of brushes in the gas collector, their construction is heavy and large, and they have low efficiency and reliability, together with high maintenance costs (as a consequence of the continuous replacement of brushes).

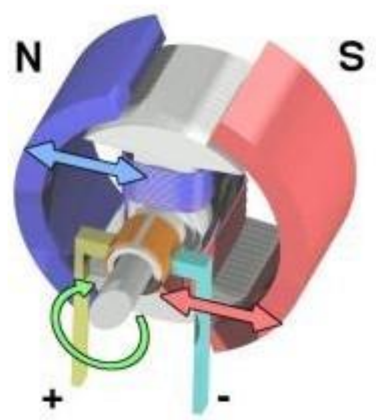


Image 180

INDUCTION MOTORS (ASYNCHRONOUS)

These are asynchronous three-phase alternating current motors. They are commonly known as AC induction motors.

Image 181

It is the most mature technology on the market, as it is widely used in industrial installations and machinery. It is characterised by its simplicity, robust construction, reliability and relatively low cost.

On the other hand, they do not reach high engine speeds (which means that they are not always suitable for the traction system of certain vehicles), which also means that in some cases the ratio between torque and maximum speed is not adequate to propel them. The efficiency of these motors, while high, is relatively low compared to other electric motor technologies.

On the other hand, this type of motor has a great advantage. In all-wheel drive arrangements, where two electric traction motors (one on each axle) are used, one of the motors is switched off in situations where low traction torques are required. PM (permanent magnet synchronous) motors have very low efficiencies when running at no load, due to high eddy current losses and hysteresis losses (a consequence of the large amount of iron present in these motors). This means that, when these motors are disconnected from the power supply and rotate as a result of the wheels being driven (remember that there is no clutch or converter), they exert a high resistance to the rotation of these wheels (due to these eddy currents and hysteresis, which tend to oppose the rotation of the wheels).

This problem has less effect on induction motors (although it also exists). For this reason, induction motors are nowadays often used when total drives consisting of one electric motor per axle are mounted on the front axle.

PERMANENT MAGNET (SYNCHRONOUS) MOTORS

These are three-phase synchronous alternating current motors (as described above) in which the rotor is made up of permanent magnets instead of a winding forming a three-phase winding driven by an alternating current. This reduces the volume of the rotor (around 30%) and increases its efficiency (around 10%). Neodymium magnets (NdFeB) are usually used.

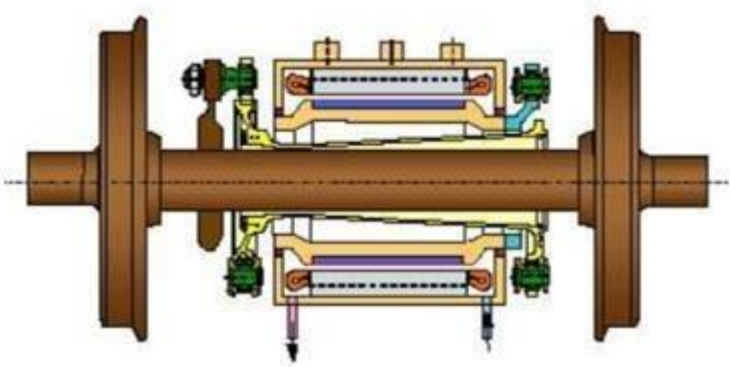


Image 182

Their name is Permanent Magnet Synchronous Machines (PMSM). Sometimes referred to as PMAC (Permanent Magnet Alternating Current).

Image 183

These motors have a higher energy density than induction motors, have a higher efficiency than induction motors and are easier to dissipate the heat generated.

It should be borne in mind that the heat dissipated is energy losses in the transformation of electrical energy into mechanical energy, so it is necessary to reduce these heat dissipations as much as possible by means of adequate cooling.

On the other hand, they have a curve in which the constant torque zone (at low speed) is shorter than induction motors and the controllers to be used are more complex. Another major drawback is, in addition to the aforementioned induced current and hysteresis losses, the current cost of magnets, where high-cost rare earths are used, which are not very abundant.

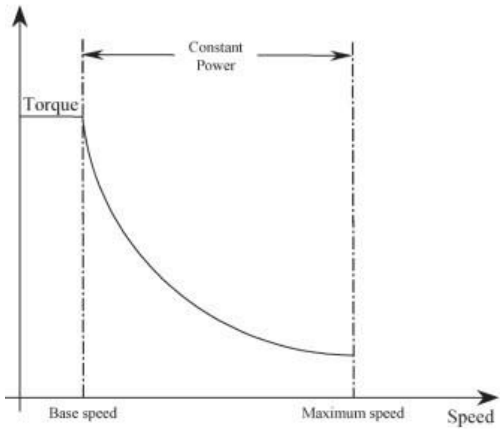


Image 184

However, they are currently the most widely used for electric drive systems, although they are losing ground to the recent design of axial flux motors.

SWITCHED RELUCTANCE MOTORS

Switched reluctance motors are an evolution of the permanent magnet motor concept. In English they are called Switched-Reluctance Motor (SRM).

The switched reluctance motor (SRM) is characterised (constructively) by having double salient poles. This means that it has salient poles on both the stator and the rotor.

The construction of an SRM is simple compared to other types of electrical machines. The rotor is not made of a magnetic material and is not wound (therefore it has neither a gas collector nor brushes). The coils are located only in the stator.

Reluctance means magnetic resistance, which the rotor opposes to the electromagnetic field.

Image 185

The rotor is made of iron and has a toothed wheel shape (salient pole configuration).

Image 186

By means of a certain switching of the magnetic field, a rotary motion of the iron core (rotor) will be achieved.

The generation and subsequent switching of the magnetic field takes place in the stator pole windings via the power electronics connected to the motor (current converter and frequency converter).

In this way, the engine speed and torque can be adjusted as desired.

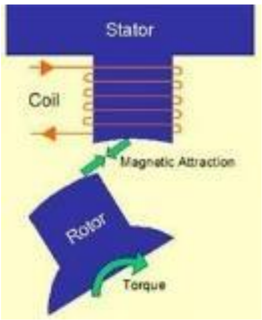


Image 187

AXIAL FLUX MOTORS

So far, all the motors analysed have a radial flux arrangement, in terms of magnetic field.

This arrangement of the magnetic field flux is due to the mounting of the windings parallel to the axis of rotation of the rotor.

Image 188

In contrast, in an axial flux arrangement, the magnetic field flux is parallel to the axis of rotation of the rotor.

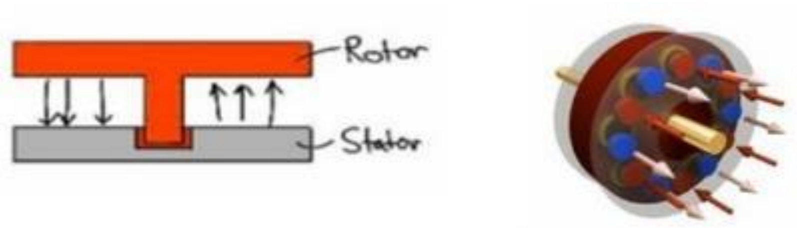


Image 189

This arrangement of the magnetic field flux (parallel to the axis of rotation of the rotor) is due to the mounting of the windings perpendicular to the axis of rotation of the rotor.

Image 191

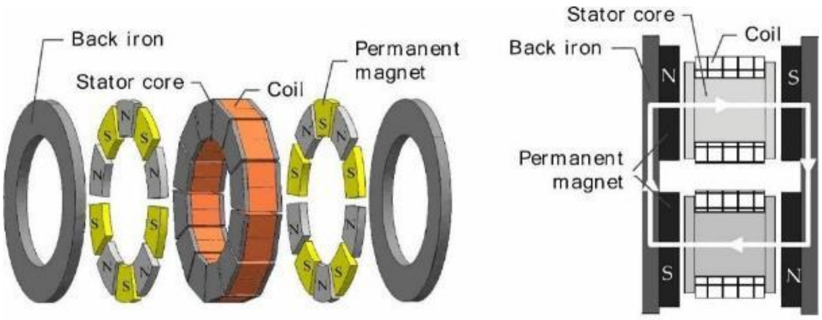


Image 192

A) Radial flow vs B) Axial flow

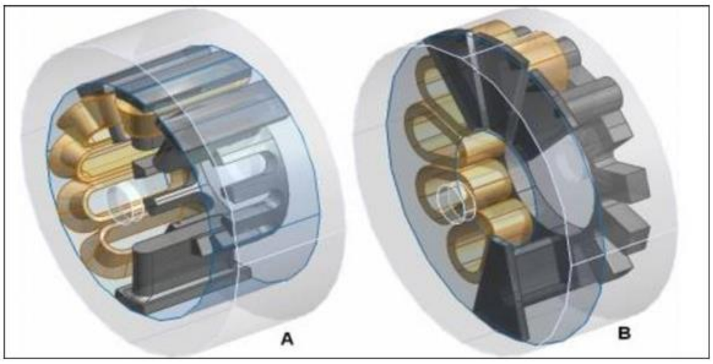


Image 193

The axial flux coil arrangement allows the manufacture of narrower motors than radial flux motors, less heavy (as there are fewer copper conductors) and a higher energy density is achieved than in the case of PM motors.

Image 194

This type of motor allows very high performance at a much lower weight than other radial morphologies, which makes it ideal for electric motors on wheels.

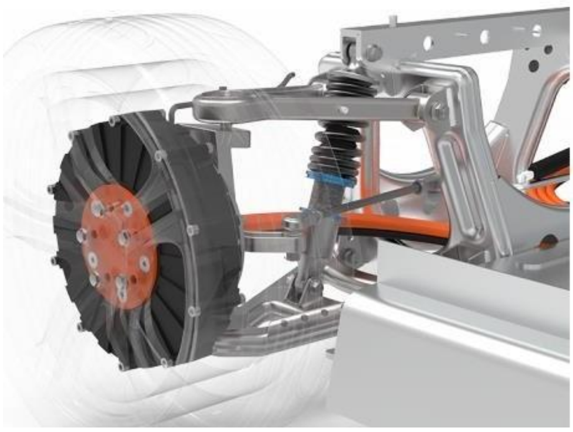


Image 195

Today, axial flux motors are permanent magnet synchronous AC motors, the only (but fundamental) difference being the way in which the coils are wound.

The current disadvantage of these motors is their high price and the fact that they are not as sophisticated as permanent magnet radial flux motors.

OPERATING PARAMETERS OF AN ELECTRIC MOTOR TRACTION

Regardless of the type of technology used in the manufacture of an electric motor, they all use the same parameters to define their operation and limits and therefore have a similar torque/power/speed curve.

The difference between one engine and another lies in the performance it is able to deliver, depending on its size and the energy consumed (efficiency).

The parameters defining an engine are as follows:

Type of electric motor

The most common types are:

- Induction motors (asynchronous alternating current motors)

- Permanent magnet synchronous alternating current (radial flux) AC motors

- Axial flux motors (which are a specific type of permanent magnet synchronous motors)

Engine cooling

All electric motors need to be cooled, either by air cooling (by natural or forced convection) or by water cooling (similar to a combustion vehicle, the difference being that the water pump must be electric).

Proper cooling is essential for good efficiency. Keep in mind that the heat dissipated by a motor is wasted energy that is not used to convert into mechanical energy.

All motors have an operating temperature range, where the maximum operating temperature is specified. Every motor is fitted with a series of temperature sensors (NTC thermistors) that measure the temperature at various points inside the motor. Their purpose is to limit the current flowing through the stator windings so as not to exceed a certain temperature.

There are two fundamental measures of temperature:

- Motor internal temperature: In general, a maximum temperature of 80-85°C is allowed. Once this temperature is exceeded, the supply current to the stator is limited or even cut off completely.

- Stator winding temperature: This is the area where the highest temperature is reached. Typically, a maximum of 100-120°C is allowed. As the temperature approaches this value, the supply current to the stator is reduced, or even cut off completely if it continues to rise.

It is the inverter that actually regulates the current (which will be discussed later), so inverters must always be programmed to adapt to the motor they are regulating.

Depending on the type of cooling, the engine manufacturer specifies the maximum ambient temperature at which the engine can operate. With air-cooled engines, the maximum ambient temperature is usually around 60-70°C. With water cooling, it is usually around 85-120°C.

TORQUE CURVE OF AN ELECTRIC TRACTION MOTOR

The ideal curve for an electric motor used in traction systems is as follows:

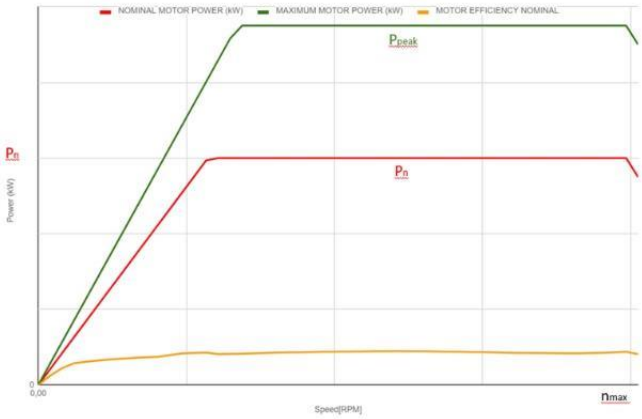


Image 196

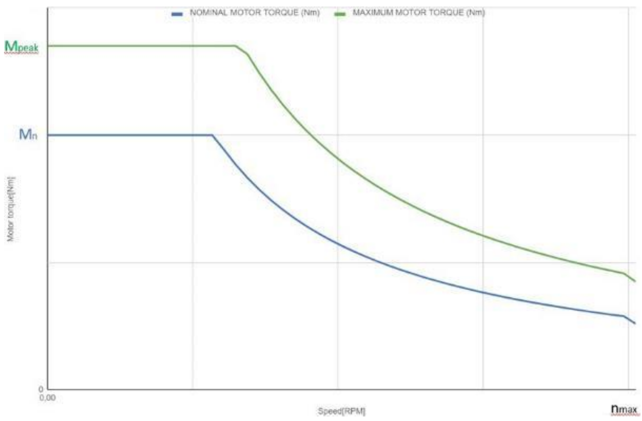


Image 197

The motors have the virtue of allowing (for a few seconds) higher supply current intensities, developing significantly higher torque and power (torque peaks and power peaks). This means that, with a motor of lower rated power (what is necessary to maintain the maximum speed of the vehicle) it is possible to achieve much higher performance for a few seconds. For example, for overtaking. In other words, it is possible to have a very lively engine with a lower power rating.

However, this curve is not always achieved, and a curve similar to the following is more common:

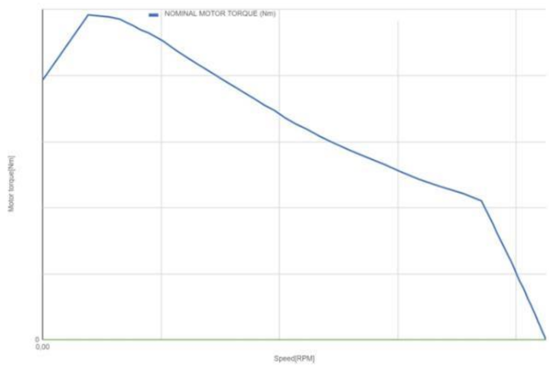


Image 198

In other words, the maximum torque zone at low revs is maintained (which still allows the vehicle to accelerate strongly), but it no longer has a flat shape like the previous curve.

Similar behaviour occurs for the power curve:

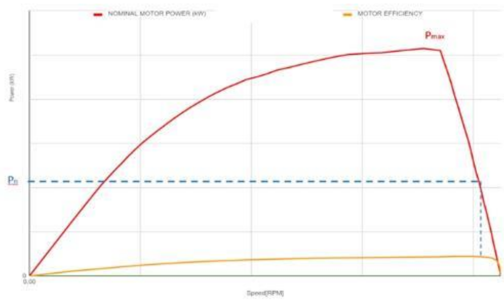


Image 199

The ultimate goal is to achieve as long a range as possible, which means trying to keep the engine working in its maximum efficiency zone.

The existence of a nominal speed and a peak speed makes it possible to play with the driving modes of a vehicle. Typically, manufacturers offer an eco mode (battery saving), a sport mode (looking for maximum performance) and a normal or comfort mode (looking for a compromise between performance and range).

In fact, you can set as many driving modes as you want or need.

REPAIR OF THE DRIVE SYSTEM

When repairing an electric vehicle, there are two fundamental concepts to keep in mind:

- Before starting any electrical work on the vehicle, it is necessary to disconnect the high voltage supply to the battery pack.

- Once disconnected, this type of vehicle is repaired in exactly the same way as a combustion vehicle, except for the special features relating to the battery pack and the electric traction motor(s).

Image 200

Therefore, the first thing to do when starting the repair of an electric vehicle is to disconnect the high voltage system. It is usual for each manufacturer to draw up a safety protocol that must be followed when carrying out this disconnection.

Currently, manufacturers have launched a set of training courses for their dealer network to train their staff in this area, developing a curriculum of electric vehicle specialists. Only these specialists will be able to handle the high-voltage system. Once it has been disconnected and verified that there is indeed no voltage, it can be repaired by any member of the workshop.

Whenever an electric vehicle is being handled (regardless of whether the high voltage system is deactivated or not), the electric vehicle and the operating status of the high voltage system must be marked (red, yellow or green).

As mentioned above, except for the battery pack and electric drive system (motors and inverters), the rest of the vehicle's systems are repaired in exactly the same way as in a combustion vehicle (because they are the same systems and the same assemblies).

TRANSMISSION SYSTEM

NEED FOR A GEARBOX

If a vehicle with a top speed of 200km/h, its wheels must turn at around 1616rpm and the output shaft of a central electric motor is in the range of 10,000-20,000rpm, it is clear that a gearbox needs to be fitted to match the wheel speed.

In the case of an in-wheel engine, its maximum rotational speed must allow the maximum speed of the vehicle to be developed. If we continue with the previous example, an in-wheel engine should reach 1616rpm.

On the other hand, the gearbox assembly multiplies the torque output to the wheels, so that it is possible to fit smaller electric motors (in the sense of developing less torque).

And finally, it remains to be seen how many gears would need to be incorporated in the gearbox. If you look at current electric vehicles, you will find that almost all of them have a single-speed gearbox (i.e. a reduction gear) instead of the typical 6- or 8-speed automatic gearbox that is so common in today's combustion vehicles.

An electric motor could be coupled (from a purely mechanical point of view) to either a manual gearbox or an automatic gearbox.

All manufacturers discard the manual gearbox in favour of a fully electronic traction management of the vehicle.

But why do electric vehicle manufacturers (with a few exceptions) use a reduction gearbox instead of an automatic gearbox like those used in combustion vehicles?

The key is, on the one hand, that an electric motor can operate over its entire rev range with quite good efficiencies (especially compared to those of a combustion engine, where efficiencies do not exceed 35-40% in the best case). We are talking about efficiencies above 80% (except at start-up, where they drop to values of 30% if a lot of output torque is demanded).

On the other hand, the electronic management of the inverter that controls it makes it possible to regulate the desired rotational speed and the necessary torque.

For this reason, it is not necessary to install a gearbox with several speeds, but by installing a simple reduction gearbox, it is possible to adjust the wheels' rotational speed, obtain the necessary traction torque to develop the required vehicle performance and achieve very good efficiency values (which means reduced electricity consumption).

This reduction gear has an integrated differential. This differential (normal, self-locking, Haldex type,...) is similar to that of combustion vehicles and has the same functions as in combustion vehicles.

To give an order of magnitude, the gear unit plus differential achieves reduction values of around 10:1.

TRANSMISSION COMPONENTS FROM THE ENGINE TO THE WHEEL

Here, again, it is necessary to distinguish between a mid-engine and a wheel motor.

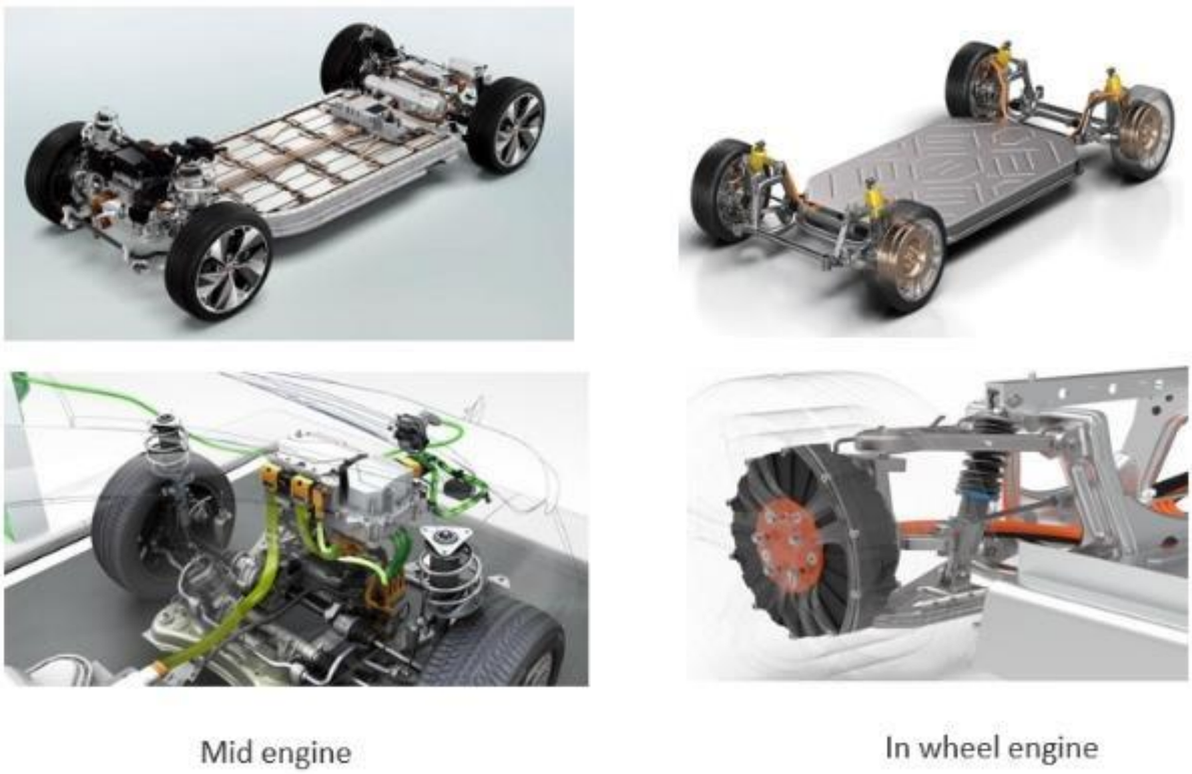


Image 201

In-wheel motor configuration

As seen above, an in-wheel motor has a direct drive, i.e. it is bolted directly to the wheel rim and the wheel/motor assembly is bolted directly to the stub axle (front axle) or suspension arm (rear axle).

Image 202

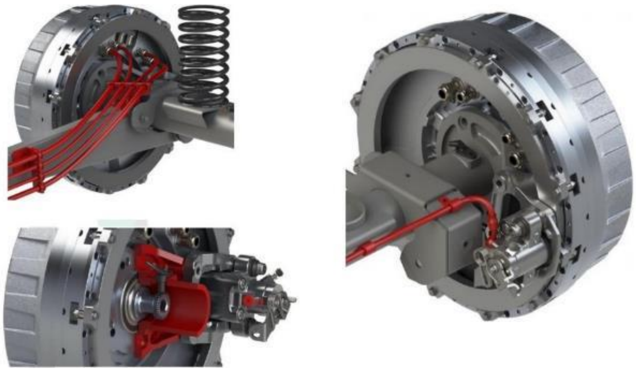


Image 203

Mid-engine configuration

This configuration is the closest to a conventional combustion vehicle.

In this case, the most significant difference is that in the case of AWD (all-wheel drive) vehicles.

In the case of a combustion vehicle, a centre differential is needed to distribute the power from the engine to the front and rear axles.

In the case of electric vehicles, all-wheel drive is provided by a motor on the front axle and another motor on the rear axle. Each is independent of the other and has its own management and control system.

Image 204

Therefore, the typical configuration for mid-engined vehicles would be as follows:

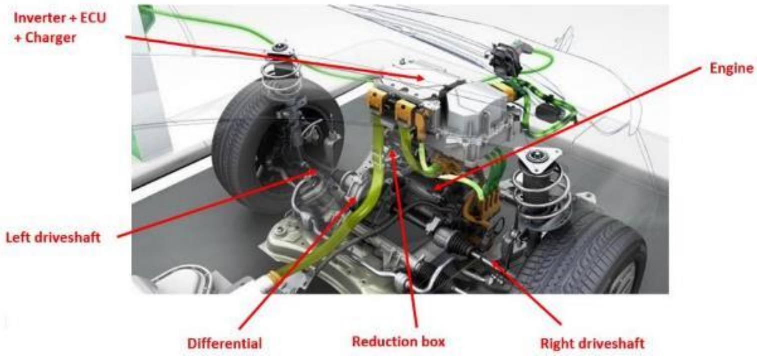


Image 205

REPAIR OF THE REMAINING COMPONENTS OF THE DRIVE SYSTEM

Inverter (controller, driver, inverter...)

The inverter is not repairable, as is the case with electric motors. In case of failure, they must be replaced.

Image 206

DC/DC converter

The DC/DC converter is not repairable, as are electric motors and inverters. In case of failure, they must be replaced.

Image 207

On-board charger

The charger is not repairable, as are electric motors and inverters. In case of failure, they must be replaced.

Image 208

PARKING BRAKE DEVICE

Every electric vehicle has an Electronic Parking Brake (EPB) system applied to the rear axle.

It is applied by means of a button located (usually) on the vehicle's centre console.

In the case of an engine-in-wheel configuration, the parking brake is provided by an electric caliper, acting on each rear brake disc.

In the case of a central motor, the motor output shaft has a toothed wheel, on which a mechanical pawl driven by an electric motor is applied. By locking this toothed wheel (which is linked to the shaft of the traction motor), the vehicle's movement is blocked.

Image 209

The parking brake management is directly linked to the position of the gear selector.

In an electric vehicle, three gear selector positions are defined:

- Position P: Parking Position

This position can be selected on the gear selector and involves automatic activation of the parking brake.

Whenever you leave the vehicle, P gear is automatically selected and therefore the parking brake is applied.

- Position N: Dead centre

In this position the parking brake is deactivated and the traction motors are de-energised (not in a position to move the vehicle).

- Position D: Status of active traction motors

In this position, the electric traction motors are energised. That is, the moment the brake is released, the vehicle will move.

Note on deadlock:

The N position of the gear selector (neutral) does not have the same meaning as in combustion vehicles. In these (combustion) vehicles, when the gear lever is in neutral, it means that the movement of the wheels is decoupled from the movement of the engine. This coupling or decoupling is due to the existence of a clutch (manual gearbox) or a converter (automatic gearbox).

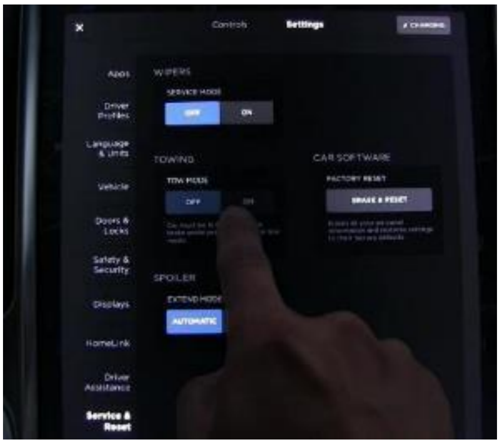
In the case of a mid-engined electric vehicle, this is not the case. There is no decoupling between engine and wheels (on that axle), as there is neither a clutch nor a converter. The output shaft of the motor is permanently connected to the gearbox and the gearbox is permanently connected to the differential and the axle shafts, so that the wheels are always coupled to the motor. Any movement of the engine generates a movement of the wheels and vice versa.

Note on towing an electric vehicle:

In order to tow an electric vehicle, it is necessary to select tow mode. This towing mode deactivates the parking brake even if the driver is in the driver's seat. This allows the vehicle to be moved by pulling (or pushing).

Image 2010

Image 211



As a general rule for any electric vehicle, towing is not allowed unless the rear axle is placed on a skid so that the wheels do not turn.

This applies when the vehicle has rear-wheel drive, because towing the vehicle with the rear wheels on the ground means that the wheels turn and consequently the engine as well. This movement is detrimental to both the inverter and the engine, so it should be restricted as much as possible and, if the vehicle has to be towed with the wheels on the ground, this should be done at low speed and for as short a time as possible.

Image 212

The mechanism by which the locking of the central motor is generated is based on a pawl driven by a small electric motor.

This mechanism is located on the engine gearbox. Normally, an additional toothed wheel is located on the intermediate shaft of the gearbox (attached to the gearbox shaft) on which the ratchet acts.

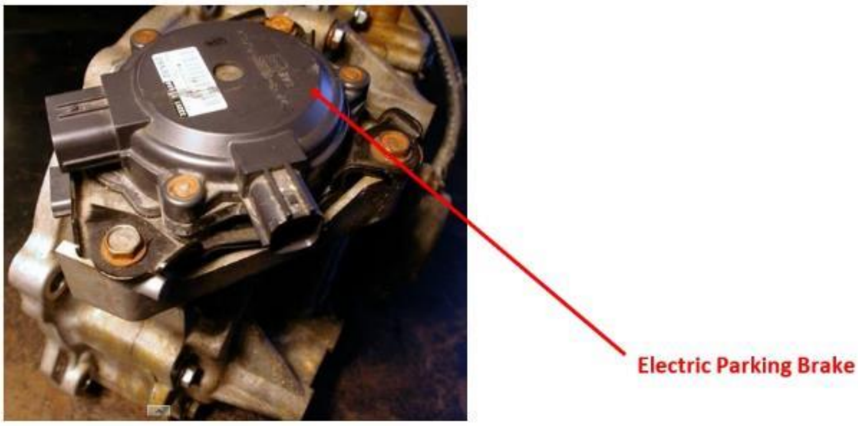


Image 213

The parking pawl is driven by an electric motor (park motor), which is governed by the motor control unit (MCU).

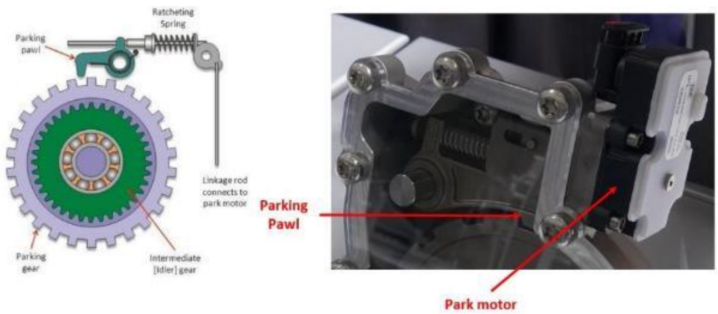


Image 214

2. LECTURE NOTES (FOR EACH LEARNING UNIT)

2.1 LEARNING UNIT 1: Overview of Electric Vehicle (EV) Technology

Classification of Electric Vehicles

This learning unit delves into the multifaceted world of Electric Vehicles (EVs), exploring the classifications that encompass Series Hybrid Vehicles, Parallel Hybrid Vehicles, Plug-in Hybrid Vehicles (PHEVs), and Non-Plug-in Hybrid Vehicles. It meticulously elucidates the distinctive features, operational modalities, and inherent advantages and drawbacks present in each classification, offering a comprehensive overview of the diverse landscape of hybrid vehicle configurations.

Hybrid Electric Vehicles (HEV)

Intricately designed to merge the functionalities of electric and conventional engines, HEVs rely on a hybrid control system and battery pack. This section unpacks their operation, akin to conventional vehicles but enhanced by an auxiliary electric motor. The electric motor serves to assist the combustion engine in high-power demands and occasionally act as the sole propeller under optimal driving conditions. This module details the composition of the system, comprising an internal combustion engine (ICE), an electric motor, and a battery pack, with a focus on the prevalence of spark-ignition engines for their economic and environmental advantages over compression-ignition engines.

Series Hybrid Vehicles

This segment navigates through the realm of Series HEVs, which predominantly rely on electric motor propulsion powered by a generator linked to an internal combustion engine. The intricacies of this propulsion system allow for various operational modes, including battery-only propulsion, independent motor mode, power split mode, stationary charging mode, and regenerative braking, offering a diverse range of energy utilization scenarios and charging modalities.

Parallel Hybrid Vehicles

In contrast, Parallel Hybrid Vehicles exhibit simultaneous operation of both the ICE and the traction electric motor, simplifying the mechanical complexity within the vehicle's architecture. The operational modes include electric-only propulsion, internal combustion engine-only mode, mixed mode, power split mode, stationary charging mode, and regenerative braking, offering a varied spectrum of propulsion and battery charging capabilities.

Plug-in Hybrid Electric Vehicles (PHEV)

This segment elucidates the innovative features of PHEVs, whether Series or Parallel hybrids, introducing external grid charging alongside internal charging mechanisms. The integration of external grid charging broadens the horizons of energy sourcing, contributing to enhanced flexibility and adaptability in charging locations and overall energy supply strategies.

Non-Plug-in Hybrid Vehicles

Exploring the constraints and design choices in hybrid vehicles, this section accentuates vehicles that lack external grid charging interfaces. These vehicles exclusively depend on internal charging mechanisms, with the text emphasizing that the capability to connect to external grids is a decision made during the vehicle's initial design phase, highlighting the manufacturer's role in this aspect.

Advantages and Disadvantages of Hybrid Vehicles

The examination delves into the nuanced merits and limitations of Series and Parallel Hybrid Vehicles. Series vehicles optimize space utilization and ICE efficiency but face limitations due to battery capacity, while Parallel vehicles offer flexibility in power management but are reliant on battery charge for optimal performance.

Pure Electric Vehicles (EV)

Transitioning from hybrid technologies, EVs solely rely on electric motors and battery packs for propulsion. This module outlines their superior torque generation, efficient regenerative braking, and simplified mechanics compared to internal combustion engines. However, the segment highlights the challenges associated with battery-dependent performance and the weight of battery packs affecting vehicle range and weight distribution.

Comparison of EVs Against Other Technologies

Drawing an intricate comparison between EVs, internal combustion vehicles, and hybrid technologies, this section delineates the efficiency and environmental impact of electric motors. It explores factors like torque generation, regenerative braking, motor reliability, and the associated challenges linked to battery performance and weight, offering a holistic perspective on the evolving landscape of electric vehicle technologies.

In Conclusion

Summarizing the intricate classifications and operational dynamics of hybrid vehicles against pure electric and combustion engine-driven vehicles, this unit highlights the technological advancements, performance dynamics, and environmental implications shaping the landscape of contemporary electric vehicle technologies, providing a comprehensive and insightful journey through the realm of EV technologies.

2.2 LEARNING UNIT 2

Drivetrain Arrangement in Electric Vehicles (EVs)

Electric Vehicles (EVs) redefine automotive propulsion through varied drivetrain arrangements, each configuration meticulously designed to optimize performance, efficiency, and handling characteristics. This comprehensive exploration dissects the nuances of Front-Wheel Drive (FWD), Rear-Wheel Drive (RWD), and All-Wheel Drive (AWD) systems prevalent in prominent EV models like the Renault Zoe, VW ID.3, and Jaguar I-Pace, respectively.

Central Electric Motor and Wheel-Hub Electric Motor

At the core of EV functionality lie the distinct electric motor designs: the central motor and the wheel-hub motor. This section meticulously articulates their individual or dual motor setups, delving into the unique attributes of wheel hub motors and their direct linkage to specific wheels, enabling versatile drive systems—be it front-wheel, rear-wheel, or all-wheel drive configurations.

Frame Types in Electric Vehicles

The structural underpinnings of EVs echo the diversity seen in conventional combustion vehicles: the robust Body-on-Frame and the integrated Chassis or Self-Supporting Body (Monocoque). This segment intricately dissects their design philosophies, highlighting the sturdy framework of Body-on-Frame systems, ideal for industrial and off-road vehicles, and contrasting it with the unified structure of the Chassis or Self-Supporting Body, commonly found in cars, light industrial vehicles, and SUVs.

Electric Vehicle Platform (Skateboard Chassis)

A paradigm shift in EV engineering unfolds through the skateboard chassis—a purpose-built framework tailored specifically for electric vehicles. This segment meticulously elaborates on its primary objectives, emphasizing strategic battery pack placement in a streamlined, low-profile format while seamlessly accommodating the multifaceted demands of the vehicle. Prominent examples like the BMW C-Evolution and the VW Group's MEB platform epitomize the industry's pivot toward adaptable, modular platforms spanning various electric models.

This comprehensive discourse navigates the intricate terrain of drivetrain configurations, electric motor variants, structural frameworks, and evolving chassis designs within Electric Vehicles. It encapsulates not only the existing landscape but also the progressive trends shaping the future of EV technology, elucidating the intricate blend of innovation and pragmatic engineering considerations driving the domain's relentless evolution.

2.3 LEARNING UNIT 3: EV achitecture (Main components)

This unit offers a comprehensive overview of the intricate components involved in managing and controlling the powertrain system of electric vehicles. Let's delve deeper into each component's functionalities and significance in the context of electric vehicle (EV) propulsion systems.

Motor Control and Regulation

In the realm of electric vehicles, understanding how motors operate is pivotal. Synchronous motors, commonly utilized, are adept at adapting to various driving conditions. The control system, reminiscent of a diagram featuring a direct current motor and two series-connected batteries, is a blueprint for requisite traction system control.

PotBox (Accelerator)

The PotBox, synonymous with the accelerator pedal, isn't merely a mechanical lever but an interface bridging the driver and the powertrain control system. It empowers drivers to set performance levels, functioning as the primary conduit to the traction control unit. This unit, pivotal in analyzing traction-related data, orchestrates essential signals to control traction motors.

Controller (Driver)

The controller, interchangeably termed an inverter or driver, boasts a dual role. It adeptly converts direct current from the battery pack into the essential three-phase alternating current required to energize the electric motor. Simultaneously, it fine-tunes the motor's speed and torque based on commands disseminated by the Engine Control Unit (ECU).

On-board Charger and DC/DC Converter

Essential for the EV's functionality, the on-board charger connects to an external electric grid, enabling the charging of the battery pack. Meanwhile, the DC/DC converter efficiently reduces the battery pack's voltage to power the vehicle's low-voltage circuit, mirroring the role of conventional combustion engine vehicles.

Electric Vehicle Management System (EVMS)

The nerve center of the EV's functionality, the EVMS reigns over battery pack charging, discharging, and the 12VDC vehicle circuit. Facilitating communication between the Battery Management System (BMS) and the vehicle's CAN bus, monitoring battery pack status, controlling safety devices, and offering crucial data to drivers via the instrument panel are among its multifaceted responsibilities.

Battery Pack and Electrical Connections

The core of EV propulsion, every battery pack comprises essential components safeguarding its functionality. The presence of a main fuse, current intensity sensor, and Battery Management System (BMS) ensures meticulous monitoring and management of the pack's voltage and cell temperature. The intricate web of electrical connections, encompassing voltage and temperature sensors, interfaces directly with the BMS, ensuring meticulous monitoring and control.

High-voltage Electrical System Control Units

A conglomerate of control units ensures seamless management of the powertrain circuits. From the EVMS overseeing charging to the MCU (Motor Control Unit) regulating motor operations, and various other control units integrated into inverters, on-board chargers, and DC/DC converters, each plays a critical role in the holistic operation and safety of the EV.

Motor Controllers (Inverters)

The motor controllers, functioning as inverters, receive high-voltage inputs and orchestrate three-phase alternating current vital for powering electric motors. Precise communication with the MCU, management of motor current intensity, and safeguarding against overcurrent situations via fused protection are integral facets of their role.

Motor Control Strategies

Strategies like PWM, VVVF, FOC, DTC, and PID epitomize the sophistication in controlling motor operations, tailored for distinct motor types—Permanent Magnet Synchronous Motors (PMSM) or induction motors. These strategies, equipped with tailored approaches, ensure optimal performance and torque for each motor type in diverse driving scenarios.

Inertia Switch and Key Switch (Ignition Key)

Safety is paramount in EVs. The inertia switch swiftly disconnects high-voltage circuits in collision scenarios, safeguarding occupants. Simultaneously, the key switch, pivotal for EV operation, initiates controlled power supply and interaction with the primary electric motor, ensuring seamless functionality and safety.

The amalgamation of these meticulously designed and intricately interlinked components exemplifies the pinnacle of technological advancement underpinning the efficient, safe, and dynamic operation of electric vehicle powertrains.

2.4 LEARNING UNIT 4

GENERAL CONCEPTS

Electric vehicles (EVs) rely on a fundamental component: the battery or battery pack. Properly sizing an electric propulsion system involves calculating the suitable electric motor and a battery capable of supplying required energy. The chapter delves into the detailed workings of EV batteries, their assembly, types of cells used, and management of discharge and recharge processes.

FUNDAMENTAL BATTERY PARAMETERS

Understanding battery voltage, capacity, and C-rated values is crucial for safe charging and discharging, preventing irreversible damage, and managing battery performance. This includes exploring parameters like Open Circuit Voltage (OCV), Closed Circuit Voltage (CCV), battery capacity, charge/discharge constants (C-rated), and minimum allowable voltage (cut-off) to ensure optimal battery utilization.

ELECTRIC VEHICLE (EV) BATTERY CONCEPT

EV batteries are assemblies of lithium-ion cells interconnected in series and parallel configurations, each with specific voltage, capacity, and C-rated capacity. This configuration determines the overall battery's performance, voltage, and capacity, essential for powering electric motors in vehicles.

LITHIUM CHARACTERISTICS IN BATTERIES

Different lithium-based batteries, including LCO, NMC, LTO, among others, possess distinct properties impacting energy density, lifespan, power output, and safety. Managing temperatures is crucial due to the potential risks associated with overheating in lithium batteries.

LITHIUM CELL TYPES BASED ON THEIR GEOMETRIC SHAPE

Battery geometry significantly influences performance, applications, and safety features. The discussion covers cylindrical, button, prismatic, and pouch-shaped cells, emphasizing their advantages, limitations, and suitability for specific applications.

TECHNOLOGY USED IN TRACTION BATTERIES

The predominant use of lithium-based batteries in electric vehicles involves various chemistries like LCO, NMC, and LTO. Understanding their properties aids in optimizing EV design, ensuring safety measures, and determining the most suitable battery type for different vehicle models.

ASSEMBLY OF A BATTERY PACK

GENERAL CONCEPTS

In electric vehicles (EVs), propelling the electric motor requires a set of cells connected in series and parallel to generate the needed voltage and current. This pack involves various components: cells, a current sensor, a Battery Management System (BMS), and an enclosure. These parts not only prevent electrical hazards but also provide mechanical strength and sealing for dynamic driving conditions.

CELL CONNECTION IN A BATTERY PACK

- **Series Connection:** Combining cells in series determines the total voltage and capacity of the battery assembly. By altering the number of cells connected in series, the total voltage of a battery is defined.
- **Parallel Connection:** Cells connected in parallel define the total capacity of a battery. Changing the number of cells in parallel modifies the total capacity.
- **Series and Parallel Connection:** Configurations like 2s2p (2-series/2-parallel) demonstrate how modules interconnected in series and parallel create the desired voltage and capacity for specific applications.

ASSEMBLY OF CELLS IN A BATTERY PACK

Determining the layout within the enclosure involves analyzing placement within the vehicle, maximizing space utilization, and ensuring mechanical stability. Methods of assembly include using battery holders or tightly packing cells, potentially employing thermal paste for adherence.

Connecting these cells via spot welding involves soldering nickel foils onto the cell terminals, establishing parallel and series connections, and finally, attaching wires to create the battery pack terminals.

SPOT WELDING FOR CELL CONNECTION

Specific spot welding machines, capable of welding nickel foils of certain thicknesses, are utilized to weld these connections securely.

CONNECTION TO BMS AND CURRENT SENSOR

Wiring connections from the modules to the BMS and current sensor are critical for monitoring cell voltage, temperature, and current intensity. These components are essential for managing safe charging, discharging, and overall battery health.

FINAL PACKAGING

Final packaging includes insulating films or enclosures (metal or plastic) depending on the application, conforming to regulatory standards for safety.

BMS (BATTERY MANAGEMENT SYSTEM) DEVICE

The BMS is a crucial system managing and protecting the battery. It monitors vital parameters like voltage, temperature, and current, adjusting the pack's operations for safety and balanced cell charging.

COOLING AND AIR CONDITIONING IN EVs

GENERAL CONCEPTS

EVs require an efficient Heating, Ventilation, and Air Conditioning (HVAC) system. Unlike combustion vehicles, EVs necessitate cooling for various critical components, making thermal management integral.

THERMAL MANAGEMENT SYSTEM IN EVs

The Battery Thermal Management System (BTMS) ensures the battery stays within its optimal temperature range during charging and discharging. This involves controlling the cooling and heating of the battery pack.

TYPES OF BATTERY PACK COOLING

- **Air-Cooled:** Utilizes fresh air flow to cool the battery pack. Simple and cost-effective but temperature regulation relies on external conditions.
- **Liquid Cooling:** Commonly used, circulating a cooling fluid through the battery pack. Provides efficient and controlled cooling but potentially complex and prone to leaks.

- **AACC Fluid Cooling:** Uses the vehicle's air conditioning gas to cool the battery pack, relying on specific temperature control strategies.

TRACTION SYSTEM AIR-CONDITIONING SYSTEM

Critical components like traction motors, inverters, and converters require a separate cooling system, usually utilizing a glycol-based fluid and an independent circuit.

PASSENGER COMPARTMENT AIR-CONDITIONING SYSTEM

The HVAC system manages both cooling and heating within the passenger compartment, similar to combustion vehicles but with variations in the compressor and heating methods.

Overall, the efficient assembly and thermal management of battery packs are vital for ensuring the safety, performance, and longevity of electric vehicles.

2.5 LEARNING UNIT 5

Recharge of Electric Vehicle Batteries

In this comprehensive exploration, the charging process of electric vehicle (EV) batteries is detailed along with the various methodologies and standardizations embraced in the EV charging landscape. The chapter delves into the fundamental concepts of cell parameters and assembly before venturing into the dynamics of charging.

General Concepts

The chapter initiates by laying the groundwork for understanding battery pack assembly and the integral parameters of cells. It delves into the significance of the charging process for electric vehicles and how it presents a pivotal business opportunity for companies. Europe's Alternative Fuels Observatory highlights the distribution of public EV chargers and emphasizes the importance of charging points for the viability of electric vehicles.

Charging Scenarios and Classification

Diverse charging scenarios are examined, stressing the convenience and impact of charging at home and workplaces for both the EV driver and the grid. The classification of charging locations into domestic chargers, destination chargers, workplace chargers, and other public access points is discussed, reflecting on their significance and impact.

Charging Predictions and Parameters

The chapter outlines predictions and identifies the varying power consumptions for different types of recharging setups, emphasizing the dominant role of AC charging for EV batteries. It forecasts the necessity for ultra-fast DC charging for specific vehicles like transit vehicles and electric heavy-duty vehicles.

Lithium-Ion Cell Charging Process

A specific focus is placed on the charging process of lithium-ion cells, delineating the stages involved and the critical parameters influencing optimal charging. It details the ideal charging modes, the significance of maintaining charging voltage, and the implications of different charging levels on cell life and performance.

Charging System Standardization

The chapter dives into the standardization of charging systems both inside and outside the vehicle, in compliance with international standards like IEC 61851. It breaks down the different standardized modes of recharging (Mode 1 to Mode 4) and the connectors associated with each mode, shedding light on their specific characteristics and applicability.

Charging Connectors and Pilots

A comprehensive overview of standardized recharge connectors is provided, encompassing different types of connectors and their applications in varying charging modes. It elaborates on the functions of Control Pilot (CP) and Proximity Pilot (PP) in facilitating communication and safety during charging.

On-board and Off-board Charging Systems

The distinction between on-board and off-board charging systems is expounded upon, elucidating their roles and limitations in enabling different charging modes. It underscores the necessity of an on-board charger for modes 1 and 2, while highlighting the significance of off-board chargers for higher power charging modes.

Energy Regeneration and Braking Systems

The concept of energy regeneration in electric vehicles is explored, detailing the mechanisms involved in regenerative braking and Kinetic Energy Recovery Systems (KERS). It emphasizes the significance of these systems in increasing vehicle range while shedding light on their limitations and the need for traditional braking systems.

Regenerative Braking Strategies

Two primary strategies in implementing regenerative braking systems—series control and parallel control—are delineated, highlighting their unique approaches and impact on vehicle range. The role of Brake-By-Wire systems in facilitating series control regenerative braking strategies is also discussed.

Este es un resumen más amplio que cubre los diversos aspectos tratados en el texto sobre la recarga de baterías para vehículos eléctricos.

2.6 EARNING UNIT 6

The main technologies used in electric motors for traction systems encompass several types:

1. Three-phase Asynchronous Motors (Induction Motors) These motors, known as AC induction motors, are robust, reliable, and cost-effective. However, their limitations include lower top speeds and a less ideal torque-to-speed ratio for certain vehicle traction systems. In all-wheel drive setups, they can be advantageous as one motor can be shut off in low-traction scenarios, mitigating some efficiency issues present in other motor types.

2. Permanent Magnet (Synchronous) Motors These motors use permanent magnets in the rotor, offering higher efficiency and energy density compared to induction motors. However, they are challenged by the high cost of rare earth magnets and complexities in managing their constant torque zone at low speeds.

3. Switched Reluctance Motors An evolution from permanent magnet motors, these boast a simpler construction, using a rotor without magnetic materials. They leverage magnetic resistance in the rotor against the electromagnetic field to generate motion, controlled through power electronics.

4. Axial Flux Motors Differing from radial flux arrangements, these motors exhibit magnetic field flux parallel to the rotor's axis. They enable a more compact and lighter design, providing higher energy density ideal for wheel-mounted electric motors.

These motor technologies each have their strengths and weaknesses, influencing their suitability for various electric vehicle applications.

Operating Parameters of Electric Motors Parameters like motor type and cooling significantly impact an electric motor's efficiency and operation. Proper cooling, be it through air or water cooling, is essential for maintaining efficiency and temperature within permissible ranges.

Torque Curve of Electric Traction Motors Electric motors exhibit torque/power/speed curves similar to combustion engines. They can momentarily produce higher torque and power but usually adhere to specific curves aimed at optimizing efficiency and performance.

Repair and Maintenance of Drive Systems Repairing electric vehicles necessitates careful attention to high-voltage safety protocols. While certain components like electric motors, inverters, DC/DC converters, and on-board chargers are irrepairable and need replacement, other aspects of the vehicle can be repaired akin to conventional combustion vehicles.

Transmission Systems Electric vehicles often utilize reduction gearboxes to adjust wheel speeds and manage torque. These gearboxes can differ from conventional combustion vehicle transmissions due to electric motors' broader operating ranges.

Parking Brake and Vehicle Handling Electric vehicles have electronic parking brake systems linked to the gear selector, allowing for different modes of operation (parking, neutral, and active traction). Towing an electric vehicle requires specific precautions, especially to safeguard the motor and inverter.

Each component of an electric vehicle's drive system contributes uniquely to its overall functionality, efficiency, and safety, signifying a shift in automotive technology and repair considerations from traditional combustion vehicles.

3. QUESTIONS AND ANSWERS (FOR THE ENTIRE MODULE)

1. **Describe the fundamental difference between a Series Hybrid Vehicle and a Parallel Hybrid Vehicle, highlighting their respective operational mechanisms and primary distinctions.**

Answer: (Learning UNIT 1)

A Series Hybrid Vehicle primarily operates with the electric motor solely propelling the vehicle through the electrical energy supplied by a generator, itself powered by an internal combustion engine (ICE). This configuration enables various modes of operation: from using the battery alone to solely propelling the vehicle, to mixed modes combining generator and battery power for the electric motor. In contrast, a Parallel Hybrid Vehicle functions with both the ICE and the traction electric motor (TEM) working simultaneously to drive the vehicle's wheels. Here, the ICE and TEM collaborate directly in the vehicle's propulsion through different modes, including scenarios where the vehicle is propelled solely by the TEM or only by the ICE. These distinctions showcase how each vehicle type manages power sources and their integration into the propulsion system, defining their operational differences and performance characteristics.

2. **Explain the drivetrain arrangements in electric vehicles (EVs), highlighting the distinctions between Front-Wheel Drive (FWD), Rear-Wheel Drive (RWD), and All-Wheel Drive (AWD) configurations. Additionally, elaborate on the two types of electric motors commonly used in EVs and their respective roles in the drivetrain.**

Answer: (Learning UNIT 2)

Electric vehicles (EVs) exhibit various drivetrain arrangements, including Front-Wheel Drive (FWD), Rear-Wheel Drive (RWD), and All-Wheel Drive (AWD). FWD, illustrated by the Renault Zoe, propels the vehicle using the front wheels, while RWD, exemplified by the VW ID.3, powers the rear wheels. AWD, demonstrated by the Jaguar I-Pace, utilizes both front and rear wheels for propulsion.

Two prevalent electric motor configurations contribute to these drivetrain setups. First, the central electric motor, found in the market with either one or two motors, is typically coupled with a gearbox and connected to the driving wheels through a differential. Some vehicles feature a central motor for the front axle and another for the rear axle. Second, the wheel-hub electric motor is directly attached to specific wheels, enabling configurations like front-wheel drive, rear-wheel drive, or all-wheel drive.

Furthermore, electric vehicle platforms, particularly the "skateboard chassis," have become a trend. This design, exemplified by BMW's C-Evolution and VW Group's MEB platform, aims to accommodate the battery pack in a flat and low configuration, supporting various vehicle demands while enhancing adaptability across different electric models.

3. **What are the primary functions of the Electric Vehicle Management System (EVMS) in an electric vehicle powertrain? Explain how it contributes to ensuring safety and efficient operation."**

Answer: (Learning UNIT 3)

The Electric Vehicle Management System (EVMS) holds pivotal functions within an electric vehicle's powertrain. It oversees battery charging and discharging, controls the 12VDC electrical circuit, monitors traction motor temperature, and can modulate the accelerator signal to prevent abrupt accelerations that might harm the battery. Moreover, the EVMS conducts fault diagnostics, oversees safety devices like high-voltage circuit cutoffs, and provides the driver with essential information such as battery charge status, motor temperature, speed, and instant consumption via the instrument panel. In terms of safety, the EVMS plays a critical role by disconnecting the high-voltage circuit in a collision through the inertia switch, thereby averting risks of electric shocks, fires, or catastrophic failures. In summary, the EVMS is integral to the safety and efficient performance of an electric vehicle, managing multiple facets of the electric propulsion system to ensure optimal operation.

4. **Explain the fundamental components of an electric vehicle's powertrain, highlighting the crucial relationship between the battery pack and the electric motor in achieving optimal performance. Additionally, describe the operational principle underlying the functioning of electric batteries and outline the primary types of batteries used in electric vehicles.**

Answer: (Learning UNIT 4)

The core of an electric vehicle's powertrain involves a symbiotic relationship between the battery pack and the electric motor. The battery pack acts as the reservoir of stored energy, supplying power to the electric motor to achieve essential functions such as top speed and acceleration. This synergy underscores the importance of selecting an electric motor and a battery capable of complementing each other to deliver the desired performance efficiently.

Electric batteries function based on electrochemical cells, converting stored chemical energy into electrical energy. These cells comprise two electrodes - positive and negative - immersed in an electrolyte, facilitating electron flow between them. Batteries fall into two primary categories: primary cells, irreversible in energy conversion, and secondary cells, capable of recharging by reversing chemical reactions. These batteries are fundamental in electric vehicles, powering their propulsion systems and storing energy for sustained operation.

5. **Explain lithium-ion batteries—structural composition, operational principles, and various geometric cell forms within these batteries—highlighting their advantages, applications, and potential limitations.**

Answer: (Learning UNIT 4)

Lithium-ion batteries comprise cells with lithium salt electrolytes in non-aqueous solvents, featuring anodes and cathodes. In electric vehicles, these cells are grouped into a battery, offering voltage, capacity, and C-rate characteristics based on their configuration. Several chemical types and geometric forms (cylindrical, prismatic, etc.) have specific advantages for diverse applications, such as cylindrical cells' durability in tools or pouch cells' flexibility in mobile devices. These differences underscore the trade-offs between performance, safety, and cost across industries, notably in electric vehicles.

6. **What is the role of the Battery Management System (BMS) in an electric vehicle's battery pack?**

Answer: (Learning UNIT 4)

The BMS oversees battery health, monitors voltage, temperature, and current, and manages charging to ensure safe operation and balanced charging.

7. **What are the two main methods of cooling battery packs in electric vehicles?**

Answer: (Learning UNIT 4)

The main methods are air-cooling, reliant on external airflow, and liquid cooling, circulating a cooling fluid through the battery pack.

8. **What function do the components of an electric vehicle's air conditioning system serve outside the passenger compartment?**

Answer: (Learning UNIT 4)

These components, such as traction motors, inverters, and chargers, have independent cooling systems, often using a glycol fluid and separate circuits.

9. **How is a battery pack assembled in an electric vehicle, and what components are crucial for its proper functioning?**

Answer: (Learning UNIT 4)

Assembling a battery pack for an electric vehicle involves combining cells in series and parallel to create the necessary voltage and current for the vehicle's electric motors. Components like a Battery Management System (BMS), current sensors, and enclosures are vital. The connection, layout, and construction of cells within the pack require consideration for efficient functioning and safety. Cooling systems, whether air-cooled, liquid-cooled, or utilizing the vehicle's air conditioning, are essential for maintaining optimal operating temperatures for the battery pack, ensuring efficiency and longevity. The BMS plays a critical role in monitoring voltage, temperature, and current, regulating charging and discharging, and even balancing cell loads. Overall, proper assembly and integration of these components are crucial for the battery pack's performance and safety in an electric vehicle.

10. **Why is standardization crucial in electric vehicle charging systems?**

Answer: (Learning UNIT 5)

Standardization ensures compatibility across different vehicles and charging points, facilitating a uniform and safe charging experience for EV drivers.

11. Why is regenerative braking essential in electric vehicles?

Answer: (Learning UNIT 5)

Regenerative braking allows the recovery of kinetic energy, extending the electric vehicle's range and enhancing its energy efficiency by converting braking energy into electricity for battery recharge.

12. What are the fundamental parameters defining the lithium-ion cell charging process, and how do they contribute to the efficient charging of electric vehicles?

Answer: (Learning UNIT 5)

The lithium-ion cell charging process is primarily defined by the charging voltage (ΔCharge), typically set at 4.20VDC, and the charging procedure, involving two distinct modes: constant current (DC mode) and constant voltage (CV mode). The charging current, designated as optimum/standard/maximum, determines the pace of the charging process—slow, medium, or fast. Efficient charging occurs when the charger supplies a consistent current until the terminal voltage reaches the charge voltage specified by the manufacturer (ΔLoad). Once this voltage is attained, the charger maintains the supply voltage (CV mode) until the current diminishes to about 100mA, indicating the cell is fully charged.

13. What role do the Control Pilot (CP) and Proximity Pilot (PP) play in ensuring safe and effective electric vehicle charging, and how do they contribute to interoperability between charging infrastructure and vehicles?

Answer 2: (Learning UNIT 5)

The Control Pilot (CP) serves as a communication interface between the off-board charger and the vehicle, conveying critical information like the maximum available current and charging status. Through a 1kHz square signal, it ensures physical connection verification and regulates charging. Meanwhile, the Proximity Pilot (PP) ensures safety by preventing vehicle start-up when connected to the charging connector. It also determines the maximum allowable current flow through the charging cable. The CP and PP, integrated into the Electric Vehicle Supply Equipment (EVSE), foster interoperability by facilitating communication and ensuring safe, standardized charging protocols between the vehicle and various charging stations.

14. What are the advantages and disadvantages of Permanent Magnet Synchronous Motors (PMSM) compared to Induction Motors in electric vehicle technology?

Answer 1: (Learning UNIT 6)

Permanent Magnet Synchronous Motors (PMSM) offer higher efficiency and energy density compared to Induction Motors. They have a reduced rotor volume, leading to increased efficiency (around 10%). However, PMSMs have drawbacks, including higher costs due to the use of rare earth magnets, which are expensive and not abundantly available. Additionally, their torque at low speeds (constant torque zone) is shorter than that of Induction Motors, and their controllers tend to be more complex.

15.What distinguishes Axial Flux Motors from other electric motors used in vehicles?

Answer 2: (Learning UNIT 6)

Axial Flux Motors stand out due to their magnetic field arrangement, which is parallel to the rotor's axis of rotation. This configuration allows for the creation of narrower and lighter motors with higher energy density compared to traditional radial flux motors. They provide high performance at a lower weight, making them suitable for wheel-mounted electric motors. However, their current downside lies in their higher cost and less sophistication compared to radial flux motors, despite their enhanced efficiency and compact design.

4. CASE STUDIES (FOR THE ENTIRE MODULE)

4.1 CASE STUDY 1: Motor Selection for Electric Vehicle Implementation

Background:

A leading automotive manufacturer is planning to introduce a new line of electric vehicles (EVs) into the market. They aim to select the most efficient and cost-effective electric motor technology for their fleet.

Scenario:

The manufacturer is evaluating various electric motor options based on the provided curriculum. They are considering between Permanent Magnet Synchronous Motors (PMSM), Induction Motors, and Axial Flux Motors. The primary concern is achieving high efficiency, reliability, and optimal performance suitable for their vehicles.

Analysis:

Permanent Magnet Synchronous Motors (PMSM):

- Pros: Offers higher efficiency and energy density compared to other motor types. Reduced rotor volume can lead to increased efficiency.
- Cons: Higher costs due to rare earth magnets. Shorter torque at low speeds might impact certain vehicle applications.

Induction Motors:

- Pros: Known for their simplicity, robustness, and relatively low cost. Widely used in industrial installations and machinery.
- Cons: Lower efficiency compared to PMSM and limitations with high engine speeds might not suit certain vehicle traction systems.

Axial Flux Motors:

- Pros: Parallel magnetic field flux, enabling the production of lighter, narrower motors with high energy density, ideal for wheel-mounted applications.
- Cons: Current disadvantages include higher costs and lower sophistication compared to radial flux motors.

Recommendation:

After comprehensive analysis and considering the requirements for their EVs, the manufacturer chooses Axial Flux Motors for their fleet. Despite the current downsides, the advantages of lightweight design and increased energy density align well with their focus on efficiency and performance in wheel-mounted electric motors.

4.2 CASE STUDY 2: Repair and Maintenance Protocol for Electric Vehicle Systems

Background:

An automotive repair and maintenance service provider is expanding its services to include electric vehicles (EVs). They aim to establish a standardized repair protocol for handling EVs safely and effectively.

Scenario:

The service provider acknowledges the distinct safety and repair protocols essential for working on EVs due to their high-voltage systems. They intend to outline a step-by-step procedure for handling repairs, focusing on the electric drive system components like motors, inverters, and chargers.

Analysis:

Safety Protocol:

- Emphasize the need to disconnect the high-voltage supply to the battery pack before commencing any electrical work on the vehicle.
- Highlight the necessity of specialized training for handling high-voltage systems and the designation of EV specialists within the repair team.

Repair of Electric Drive System Components:

- Electric Motors: Stress the non-repairable nature of electric motors, inverters, DC/DC converters, and onboard chargers. Advocacy for their replacement in case of failure.
- Inverter and Controller: Acknowledge their non-repairable nature and the importance of professional replacement.

Handling Safety Features:

- Discuss the Electronic Parking Brake (EPB) system in EVs, its function, and the protocol to be followed during repair and maintenance.
- Outline the procedures for towing an EV safely, including activating tow mode and avoiding damage to high-voltage components.

Recommendation:

The repair and maintenance service provider establishes a detailed safety protocol highlighting the criticality of disconnecting high-voltage systems. They incorporate specialized training for EV specialists and stress the importance of component replacement rather than repair for electric drive system components to ensure safety and compliance with EV manufacturer guidelines.

5. MULTIPLE CHOICE QUESTIONS (FOR THE ENTIRE MODULE)

5.1 A purely electric vehicle (EV):

Select one:

a. It has a traction system consisting of a set of electric motors, powered exclusively by a battery (or battery pack) installed in the vehicle itself.

b. It is powered solely by the electric motor thanks to the electrical energy supplied by a generator, which is driven by an internal combustion engine (ICE).

c. Can only be designed with a front-wheel drive arrangement.

5.2 With regard to the drive system arrangement of an electric vehicle:

Select one:

a. Only an architecture in which the front axle is the driving axle is possible.

b. Allows for as many configurations as are currently possible in an internal combustion vehicle, in addition to the in-wheel motor architecture.

c. Always has a drive system consisting of two electric motors.

5.3 To make the series connections of the modules that make up a pack:

Select one:

a. Never connect modules in series

b. The positive poles of one module must be connected in parallel to the positive poles of the next module.

c. The positive poles of one module in parallel must be connected to the negative poles of the next module.

5.4 The materials from which lithium batteries are made are flammable,

Please select one:

a. For this reason, every lithium battery must be monitored to ensure that no cell reaches a higher than permissible temperature or is overcharged.

b. For this reason, every lithium battery must be monitored to ensure that no cell is overcharged, regardless of the temperature it reaches.

c. For this reason, they are prohibited in the automotive industry.

5.5 Lithium-ion batteries:

Select one:

a. Do not need to be fully charged (as with acid batteries) to ensure a longer life span.

b. They need to be fully discharged, in order to recover their full capacity at a later date.

c. They need to be fully charged (as with acid batteries) to ensure a longer life.

5.6 The mains electricity supply is alternating current:

Select one:

a. Whereas batteries must always be charged in direct current.

b. Whereas batteries can be charged in DC or single-phase alternating current

c. Whereas batteries must be charged on alternating current

5.7 The main technologies used in electric motors in traction systems are:

Select one:

a. Induction motors, permanent magnet synchronous motors, axial flux motors and switched reluctance motors.

b. Induction motors, the vast majority of which are induction motors.

c. Synchronous DC motors

5.8 Axial flux motors:

Select one:

a. Have an arrangement of the magnetic field flux created by the stator parallel to the axis of rotation of the rotor.

b. Have an arrangement of the magnetic field flux created by the stator perpendicular to the rotor rotation axis

c. None of the above

5.9 The lithium-ion cells that make up a battery pack:

Select one:

a. Are only capable of supplying energy efficiently and safely when below 5ºC.

b. They are capable of supplying energy efficiently and safely when in any temperature range.

c. They are only capable of supplying energy efficiently and safely when within a given temperature range.

5.10 Regarding the repair of electric traction motors:

Select one:

a. Like combustion engines, they have a wide range of workshop repair operations.

b. It is not necessary, as they are exempt from breakdowns, so repair or replacement will never be necessary.

c. At present, they are considered as black boxes, which means that they are not repairable. In case of failure, they are replaced by a new one.

Correct answers:

1	2	3	4	5	6	7	8	9	10
A	B	C	A	A	A	A	A	C	C

MODULE 1

EV ESSENTIALS

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1 LECTURE NOTES (FOR EACH LEARNING UNIT)

1.1 LEARNING UNIT 1: Overview of Electric Vehicle (EV) Technology

Classification of Electric Vehicles

This learning unit delves into the multifaceted world of Electric Vehicles (EVs), exploring the classifications that encompass Series Hybrid Vehicles, Parallel Hybrid Vehicles, Plug-in Hybrid Vehicles (PHEVs), and Non-Plug-in Hybrid Vehicles. It meticulously elucidates the distinctive features, operational modalities, and inherent advantages and drawbacks present in each classification, offering a comprehensive overview of the diverse landscape of hybrid vehicle configurations.

Hybrid Electric Vehicles (HEV)

Intricately designed to merge the functionalities of electric and conventional engines, HEVs rely on a hybrid control system and battery pack. This section unpacks their operation, akin to conventional vehicles but enhanced by an auxiliary electric motor. The electric motor serves to assist the combustion engine in high-power demands and occasionally act as the sole propeller under optimal driving conditions. This module details the composition of the system, comprising an internal combustion engine (ICE), an electric motor, and a battery pack, with a focus on the prevalence of spark-ignition engines for their economic and environmental advantages over compression-ignition engines.

Series Hybrid Vehicles

This segment navigates through the realm of Series HEVs, which predominantly rely on electric motor propulsion powered by a generator linked to an internal combustion engine. The intricacies of this propulsion system allow for various operational modes, including battery-only propulsion, independent motor mode, power split mode, stationary charging mode, and regenerative braking, offering a diverse range of energy utilization scenarios and charging modalities.

Parallel Hybrid Vehicles

In contrast, Parallel Hybrid Vehicles exhibit simultaneous operation of both the ICE and the traction electric motor, simplifying the mechanical complexity within the vehicle's architecture. The operational modes include electric-only propulsion, internal combustion engine-only mode, mixed mode, power split mode, stationary charging mode, and regenerative braking, offering a varied spectrum of propulsion and battery charging capabilities.

Plug-in Hybrid Electric Vehicles (PHEV)

This segment elucidates the innovative features of PHEVs, whether Series or Parallel hybrids, introducing external grid charging alongside internal charging mechanisms. The integration of external grid charging broadens the horizons of energy sourcing, contributing to enhanced flexibility and adaptability in charging locations and overall energy supply strategies.

Non-Plug-in Hybrid Vehicles

Exploring the constraints and design choices in hybrid vehicles, this section accentuates vehicles that lack external grid charging interfaces. These vehicles exclusively depend on internal charging mechanisms, with the text emphasizing that the capability to connect to external grids is a decision made during the vehicle's initial design phase, highlighting the manufacturer's role in this aspect.

Advantages and Disadvantages of Hybrid Vehicles

The examination delves into the nuanced merits and limitations of Series and Parallel Hybrid Vehicles. Series vehicles optimize space utilization and ICE efficiency but face limitations due to battery capacity, while Parallel vehicles offer flexibility in power management but are reliant on battery charge for optimal performance.

Pure Electric Vehicles (EV)

Transitioning from hybrid technologies, EVs solely rely on electric motors and battery packs for propulsion. This module outlines their superior torque generation, efficient regenerative braking, and simplified mechanics compared to internal combustion engines. However, the segment highlights the challenges associated with battery-dependent performance and the weight of battery packs affecting vehicle range and weight distribution.

Comparison of EVs Against Other Technologies

Drawing an intricate comparison between EVs, internal combustion vehicles, and hybrid technologies, this section delineates the efficiency and environmental impact of electric motors. It explores factors like torque generation, regenerative braking, motor reliability, and the associated challenges linked to battery performance and weight, offering a holistic perspective on the evolving landscape of electric vehicle technologies.

In Conclusion

Summarizing the intricate classifications and operational dynamics of hybrid vehicles against pure electric and combustion engine-driven vehicles, this unit highlights the technological advancements, performance dynamics, and environmental implications shaping the landscape of contemporary electric vehicle technologies, providing a comprehensive and insightful journey through the realm of EV technologies.

1.2 LEARNING UNIT 2: Currently available implementations

Drivetrain Arrangement in Electric Vehicles (EVs)

Electric Vehicles (EVs) redefine automotive propulsion through varied drivetrain arrangements, each configuration meticulously designed to optimise performance, efficiency, and handling characteristics. This comprehensive exploration dissects the nuances of Front-Wheel Drive (FWD), Rear-Wheel Drive

(RWD), and All-Wheel Drive (AWD) systems prevalent in prominent EV models like the Renault Zoe, VW ID.3, and Jaguar I-Pace, respectively.

Central Electric Motor and Wheel-Hub Electric Motor

At the core of EV functionality lie the distinct electric motor designs: the central motor and the wheel-hub motor. This section meticulously articulates their individual or dual motor setups, delving into the unique attributes of wheel hub motors and their direct linkage to specific wheels, enabling versatile drive systems—be it front-wheel, rear-wheel, or all-wheel drive configurations.

Frame Types in Electric Vehicles

The structural underpinnings of EVs echo the diversity seen in conventional combustion vehicles: the robust Body-on-Frame and the integrated Chassis or Self-Supporting Body (Monocoque). This segment intricately dissects their design philosophies, highlighting the sturdy framework of Body-on-Frame systems, ideal for industrial and off-road vehicles, and contrasting it with the unified structure of the Chassis or Self-Supporting Body, commonly found in cars, light industrial vehicles, and SUVs.

Electric Vehicle Platform (Skateboard Chassis)

A paradigm shift in EV engineering unfolds through the skateboard chassis—a purpose-built framework tailored specifically for electric vehicles. This segment meticulously elaborates on its primary objectives, emphasising strategic battery pack placement in a streamlined, low-profile format while seamlessly accommodating the multifaceted demands of the vehicle. Prominent examples like the BMW C-Evolution and the VW Group's MEB platform epitomise the industry's pivot toward adaptable, modular platforms spanning various electric models.

This comprehensive discourse navigates the intricate terrain of drivetrain configurations, electric motor variants, structural frameworks, and evolving chassis designs within Electric Vehicles. It encapsulates not only the existing landscape but also the progressive trends shaping the future of EV technology, elucidating the intricate blend of innovation and pragmatic engineering considerations driving the domain's relentless evolution.

1.3 LEARNING UNIT 3: EV architecture (Main components)

This unit offers a comprehensive overview of the intricate components involved in managing and controlling the powertrain system of electric vehicles. Let's delve deeper into each component's functionalities and significance in the context of electric vehicle (EV) propulsion systems.

Motor Control and Regulation

In the realm of electric vehicles, understanding how motors operate is pivotal. Synchronous motors, commonly utilised, are adept at adapting to various driving conditions. The control system, reminiscent of a diagram featuring a direct current motor and two series-connected batteries, is a blueprint for requisite traction system control.

PotBox (Accelerator)

The PotBox, synonymous with the accelerator pedal, isn't merely a mechanical lever but an interface connecting the driver to the powertrain control system. It empowers drivers to set performance levels, functioning as the primary conduit to the traction control unit. This unit, pivotal in analysing traction-related data, orchestrates essential signals to control traction motors.

Controller (Driver)

The controller, interchangeably termed an inverter or driver, boasts a dual role. It adeptly converts direct current from the battery pack into the essential three-phase alternating current required to energise the electric motor. Simultaneously, it fine-tunes the motor's speed and torque based on commands disseminated by the Engine Control Unit (ECU).

On-board Charger and DC/DC Converter

Essential for the EV's functionality, the on-board charger connects to an external electric grid, enabling the charging of the battery pack. Meanwhile, the DC/DC converter efficiently reduces the battery pack's voltage to power the vehicle's low-voltage circuit, mirroring the role of conventional combustion engine vehicles.

Electric Vehicle Management System (EVMS)

The nerve center of the EV's functionality, the EVMS reigns over battery pack charging, discharging, and the 12VDC vehicle circuit. Facilitating communication between the Battery Management System (BMS) and the vehicle's CAN bus, monitoring battery pack status, controlling safety devices, and offering crucial data to drivers via the instrument panel are among its multifaceted responsibilities.

Battery Pack and Electrical Connections

The core of EV propulsion, every battery pack comprises essential components safeguarding its functionality. The presence of a main fuse, current intensity sensor, and Battery Management System (BMS) ensures meticulous monitoring and management of the pack's voltage and cell temperature. The intricate web of electrical connections, encompassing voltage and temperature sensors, interfaces directly with the BMS, ensuring meticulous monitoring and control.

High-voltage Electrical System Control Units

A conglomerate of control units ensures seamless management of the powertrain circuits. From the EVMS overseeing charging to the MCU (Motor Control Unit) regulating motor operations, and various other control units integrated into inverters, on-board chargers, and DC/DC converters, each plays a critical role in the holistic operation and safety of the EV.

Motor Controllers (Inverters)

The motor controllers, functioning as inverters, receive high-voltage inputs and orchestrate three-phase alternating currents vital for powering electric motors. Precise communication with the MCU, management of motor current intensity, and safeguarding against overcurrent situations via fused protection are integral facets of their role.

Motor Control Strategies

Strategies like PWM, VVVF, FOC, DTC, and PID epitomise the sophistication in controlling motor operations, tailored for distinct motor types—Permanent Magnet Synchronous Motors (PMSM) or induction motors. These strategies, equipped with tailored approaches, ensure optimal performance and torque for each motor type in diverse driving scenarios.

Inertia Switch and Key Switch (Ignition Key)

Safety is paramount in EVs. The inertia switch swiftly disconnects high-voltage circuits in collision scenarios, safeguarding passengers. Simultaneously, the key switch, pivotal for EV operation, initiates controlled power supply and interaction with the primary electric motor, ensuring seamless functionality and safety.

The amalgamation of these meticulously designed and intricately interlinked components exemplifies the pinnacle of technological advancement underpinning the efficient, safe, and dynamic operation of electric vehicle powertrains.

1.4 LEARNING UNIT 4: Energy storage systems

General concepts

Electric vehicles (EVs) rely on a fundamental component: the battery or battery pack. Properly sizing an electric propulsion system involves calculating the suitable electric motor and a battery capable of supplying required energy. The chapter delves into the detailed workings of EV batteries, their assembly, types of cells used, and management of discharge and recharge processes.

Fundamental battery parameters

Understanding battery voltage, capacity, and C-rated values is crucial for safe charging and discharging, preventing irreversible damage, and managing battery performance. This includes exploring parameters like Open Circuit Voltage (OCV), Closed Circuit Voltage (CCV), battery capacity, charge/discharge constants (C-rated), and minimum allowable voltage (cut-off) to ensure optimal battery utilisation.

Electric vehicle (ev) battery concept

EV batteries are assemblies of lithium-ion cells interconnected in series and parallel configurations, each with specific voltage, capacity, and C-rated capacity. This configuration determines the overall battery's performance, voltage, and capacity, essential for powering electric motors in vehicles.

Lithium characteristics in batteries

Different lithium-based batteries, including LCO, NMC, LTO, among others, possess distinct properties impacting energy density, lifespan, power output, and safety. Managing temperatures is crucial due to the potential risks associated with overheating in lithium batteries.

Lithium cell types based on their geometric shape

Battery geometry significantly influences performance, applications, and safety features. The discussion covers cylindrical, button, prismatic, and pouch-shaped cells, emphasizing their advantages, limitations, and suitability for specific applications.

Technology used in traction batteries

The predominant use of lithium-based batteries in electric vehicles involves various chemistries like LCO, NMC, and LTO. Understanding their properties aids in optimizing EV design, ensuring safety measures, and determining the most suitable battery type for different vehicle models.

ASSEMBLY OF A BATTERY PACK

General concepts

In electric vehicles (EVs), propelling the electric motor requires a set of cells connected in series and parallel to generate the needed voltage and current. This pack involves various components: cells, a current sensor, a Battery Management System (BMS), and an enclosure. These parts not only prevent electrical hazards but also provide mechanical strength and sealing for dynamic driving conditions.

Cell connection in a battery pack

- **Series Connection:** Combining cells in series determines the total voltage and capacity of the battery assembly. By altering the number of cells connected in series, the total voltage of a battery is defined.
- **Parallel Connection:** Cells connected in parallel define the total capacity of a battery. Changing the number of cells in parallel modifies the total capacity.
- **Series and Parallel Connection:** Configurations like 2s2p (2-series/2-parallel) demonstrate how modules interconnected in series and parallel create the desired voltage and capacity for specific applications.

Assembly of cells in a battery pack

Determining the layout within the enclosure involves analysing placement within the vehicle, maximising space utilisation, and ensuring mechanical stability. Methods of assembly include using battery holders or tightly packing cells, potentially employing thermal paste for adherence.

Connecting these cells via spot welding involves soldering nickel foils onto the cell terminals, establishing parallel and series connections, and finally, attaching wires to create the battery pack terminals.

Spot welding for cell connection

Specific spot-welding machines, capable of welding nickel foils of certain thicknesses, are utilized to weld these connections securely.

Connection to bms and current sensor

Wiring connections from the modules to the BMS and current sensor are critical for monitoring cell voltage, temperature, and current intensity. These components are essential for managing safe charging, discharging, and overall battery health.

Final packaging

Final packaging includes insulating films or enclosures (metal or plastic) depending on the application, conforming to regulatory standards for safety.

Bms (battery management system) device

The BMS is a crucial system managing and protecting the battery. It monitors vital parameters like voltage, temperature, and current, adjusting the pack's operations for safety and balanced cell charging.

COOLING AND AIR CONDITIONING IN EVs

General concepts

EVs require an efficient Heating, Ventilation, and Air Conditioning (HVAC) system. Unlike combustion vehicles, EVs necessitate cooling for various critical components, making thermal management integral.

Thermal management system in EVs

The Battery Thermal Management System (BTMS) ensures the battery stays within its optimal temperature range during charging and discharging. This involves controlling the cooling and heating of the battery pack.

Types of battery pack cooling

- **Air-Cooled:** Utilises fresh air flow to cool the battery pack. Simple and cost-effective but temperature regulation relies on external conditions.
- **Liquid Cooling:** Commonly used, circulating a cooling fluid through the battery pack. Provides efficient and controlled cooling but potentially complex and prone to leaks.
- **AACC Fluid Cooling:** Uses the vehicle's air conditioning gas to cool the battery pack, relying on specific temperature control strategies.

Traction system air-conditioning system

Critical components like traction motors, inverters, and converters require a separate cooling system, usually utilising a glycol-based fluid and an independent circuit.

Passenger compartment air-conditioning system

The HVAC system manages both cooling and heating within the passenger compartment, similar to combustion vehicles but with variations in the compressor and heating methods.

Overall, the efficient assembly and thermal management of battery packs are vital for ensuring the safety, performance, and longevity of electric vehicles.

1.5 LEARNING UNIT 5: Battery recharge

Recharge of Electric Vehicle Batteries

In this comprehensive exploration, the charging process of electric vehicle (EV) batteries is detailed along with the various methodologies and standardisations embraced in the EV charging landscape. The chapter delves into the fundamental concepts of cell parameters and assembly before venturing into the dynamics of charging.

General Concepts

The chapter initiates by laying the groundwork for understanding battery pack assembly and the integral parameters of cells. It delves into the significance of the charging process for electric vehicles and how it presents a pivotal business opportunity for companies. Europe's Alternative Fuels Observatory highlights the distribution of public EV chargers and emphasizes the importance of charging points for the viability of electric vehicles.

Charging Scenarios and Classification

Diverse charging scenarios are examined, stressing the convenience and impact of charging at home and workplaces for both the EV driver and the grid. The classification of charging locations into domestic chargers, destination chargers, workplace chargers, and other public access points is discussed, reflecting on their significance and impact.

Charging Predictions and Parameters

The chapter outlines predictions and identifies the varying power consumptions for different types of recharging setups, emphasizing the dominant role of AC charging for EV batteries. It forecasts the necessity for ultra-fast DC charging for specific vehicles like transit vehicles and electric heavy-duty vehicles.

Lithium-Ion Cell Charging Process

A specific focus is placed on the charging process of lithium-ion cells, delineating the stages involved and the critical parameters influencing optimal charging. It details the ideal charging modes, the significance of maintaining charging voltage, and the implications of different charging levels on cell life and performance.

Charging System Standardisation

The chapter dives into the standardisation of charging systems both inside and outside the vehicle, in compliance with international standards like IEC 61851. It breaks down the different standardised modes of recharging (Mode 1 to Mode 4) and the connectors associated with each mode, shedding light on their specific characteristics and applicability.

Charging Connectors and Pilots

A comprehensive overview of standardised recharge connectors is provided, encompassing different types of connectors and their applications in varying charging modes. It elaborates on the functions of Control Pilot (CP) and Proximity Pilot (PP) in facilitating communication and safety during charging.

On-board and Off-board Charging Systems

The distinction between on-board and off-board charging systems is expounded upon, elucidating their roles and limitations in enabling different charging modes. It underscores the necessity of an on-board charger for modes 1 and 2, while highlighting the significance of off-board chargers for higher power charging modes.

Energy Regeneration and Braking Systems

The concept of energy regeneration in electric vehicles is explored, detailing the mechanisms involved in regenerative braking and Kinetic Energy Recovery Systems (KERS). It emphasises the significance of these systems in increasing vehicle range while shedding light on their limitations and the need for traditional braking systems.

Regenerative Braking Strategies

Two primary strategies in implementing regenerative braking systems—series control and parallel control—are delineated, highlighting their unique approaches and impact on vehicle range. The role of Brake-By-Wire systems in facilitating series control regenerative braking strategies is also discussed.

1.6 LEARNING UNIT 6: Operation of electric motors

The main technologies used in electric motors for traction systems encompass several types:

1. Three-phase Asynchronous Motors (Induction Motors) These motors, known as AC induction motors, are robust, reliable, and cost-effective. However, their limitations include lower top speeds and a less ideal torque-to-speed ratio for certain vehicle traction systems. In all-wheel drive setups, they can be advantageous as one motor can be shut off in low-traction scenarios, mitigating some efficiency issues present in other motor types.

2. Permanent Magnet (Synchronous) Motors These motors use permanent magnets in the rotor, offering higher efficiency and energy density compared to induction motors. However, they are challenged by the high cost of rare earth magnets and complexities in managing their constant torque zone at low speeds.

3. **Switched Reluctance Motors** An evolution from permanent magnet motors, these boast a simpler construction, using a rotor without magnetic materials. They leverage magnetic resistance in the rotor against the electromagnetic field to generate motion, controlled through power electronics.

4. **Axial Flux Motors** Differing from radial flux arrangements, these motors exhibit magnetic field flux parallel to the rotor's axis. They enable a more compact and lighter design, providing higher energy density ideal for wheel-mounted electric motors.

These motor technologies each have their strengths and weaknesses, influencing their suitability for various electric vehicle applications.

Operating Parameters of Electric Motors Parameters like motor type and cooling significantly impact an electric motor's efficiency and operation. Proper cooling, be it through air or water cooling, is essential for maintaining efficiency and temperature within permissible ranges.

Torque Curve of Electric Traction Motors Electric motors exhibit torque/power/speed curves similar to combustion engines. They can momentarily produce higher torque and power but usually adhere to specific curves aimed at optimising efficiency and performance.

Repair and Maintenance of Drive Systems Repairing electric vehicles necessitates careful attention to high-voltage safety protocols. While certain components like electric motors, inverters, DC/DC converters, and on-board chargers are irreparable and need replacement, other aspects of the vehicle can be repaired akin to conventional combustion vehicles.

Transmission Systems Electric vehicles often utilise reduction gearboxes to adjust wheel speeds and manage torque. These gearboxes can differ from conventional combustion vehicle transmissions due to electric motors' broader operating ranges.

Parking Brake and Vehicle Handling Electric vehicles have electronic parking brake systems linked to the gear selector, allowing for different modes of operation (parking, neutral, and active traction). Towing an electric vehicle requires specific precautions, especially to safeguard the motor and inverter.

Each component of an electric vehicle's drive system contributes uniquely to its overall functionality, efficiency, and safety, signifying a shift in automotive technology and repair considerations from traditional combustion vehicles.

M1 EV Essentials

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Presentation

LEARNING UNITS

- 1.1 EV technology overview
- 1.2 Currently available implementations
- 1.3 EV architecture (main building blocks)
- 1.4 Energy storage systems
- 1.5 Battery recharge
- 1.6 Operation of electric motors

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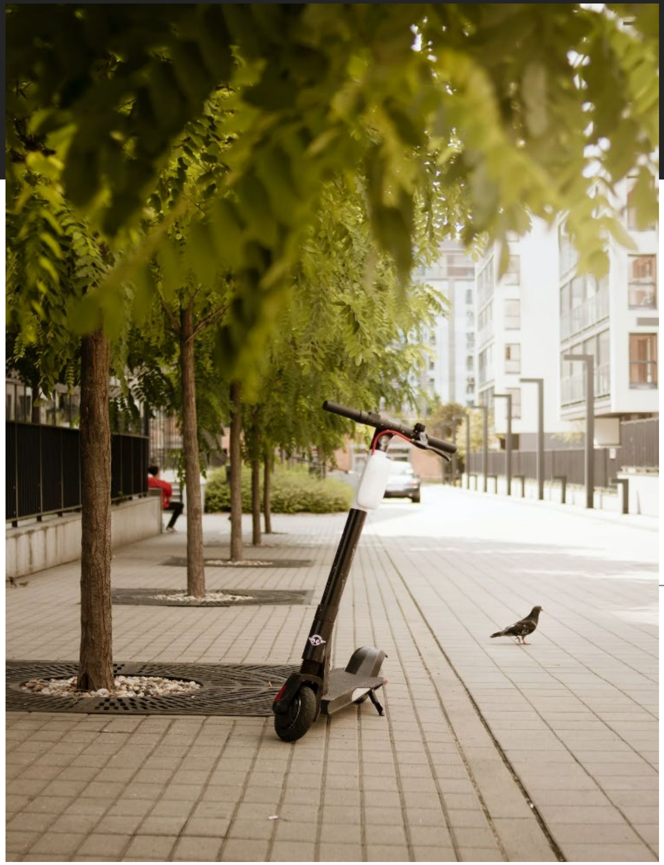
Introduction



INTRODUCTION

This module will cover a comprehensive understanding of various hybrid electric vehicle types and the configuration of front-wheel drive electric vehicles. It also explains the general architecture of electric vehicles, highlighting key components. Battery fundamentals, including capacity, voltage, and charge/discharge rates, are emphasised for their importance in EV performance. The charging process of Lithium-Ion cells is detailed, with a focus on safety and efficiency considerations. Finally, an explanation of different electric motor types used in EV traction systems is provided, offering insights into propulsion technologies.

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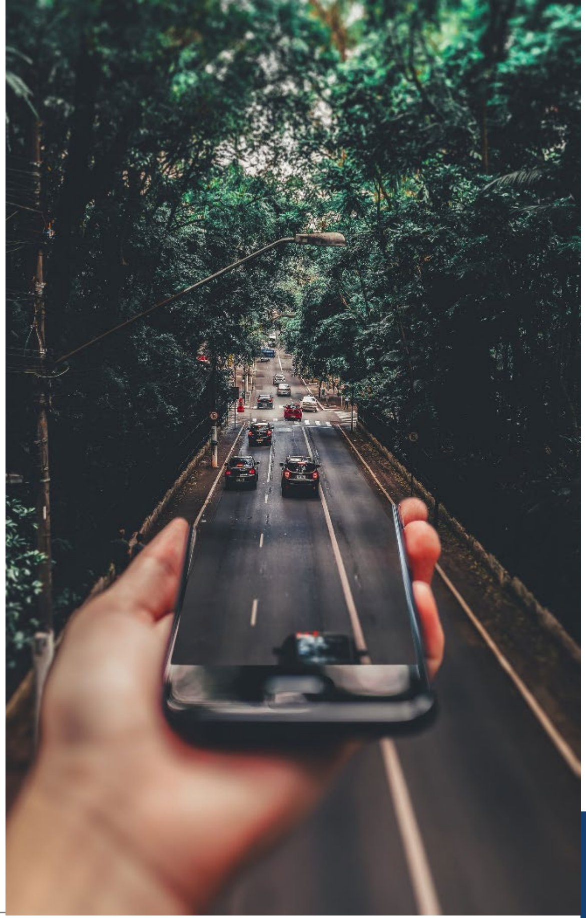
KEY DEFINITIONS

1. Describe the characteristics of series, parallel, plug-in and non-plug-in hybrid electric vehicles.
2. Describe the configuration of a front-wheel drive electric vehicle with a motor located in the front.
3. Describe the general architecture of an electric vehicle and its main components
4. Describe the fundamental parameters of a battery and its relevance in electric vehicles
5. Explain the charging process of a Lithium-Ion cell and the relevant aspects to take into account during this process.
6. Explain the different types of electric motors used in the traction systems of electric vehicles.



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Learning Unit 1: Overview of EV Technology

Hybrid Electric Vehicles (HEVs) blend internal combustion engines with electric motors, categorised as Series or Parallel depending on power distribution. Series hybrids rely on an electric motor powered by a generator connected to the internal combustion engine, offering various operational modes for efficiency. Parallel hybrids involve both the engine and electric motor working together to propel the vehicle, allowing for different driving modes. Plug-in Hybrid Electric Vehicles (PHEVs) can charge from external grids, while Non-Plug-in hybrids lack this capability. Pure Electric Vehicles (EVs) solely rely on electric motors powered by batteries, boasting rapid torque and regenerative braking but depending heavily on battery performance and charging infrastructure, influencing their efficiency and range compared to traditional internal combustion vehicles.

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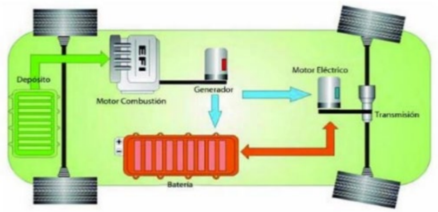
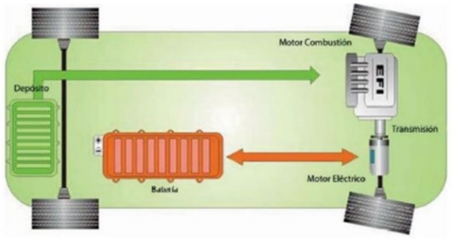
Introduction to various types of electric vehicles:



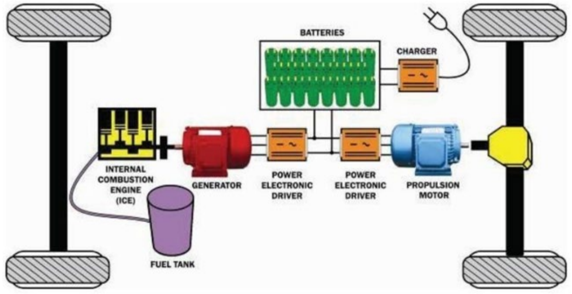
Hybrids (Series and Parallel):

Hybrid vehicles combine an internal combustion engine with an electric motor for propulsion.



Plug-in Hybrids (PHEVs):

These hybrids have batteries that can be charged both internally and externally, offering extended electric-only range.



Pure Electric Vehicles (EVs):

These vehicles solely rely on electric motors powered by batteries and require external charging.

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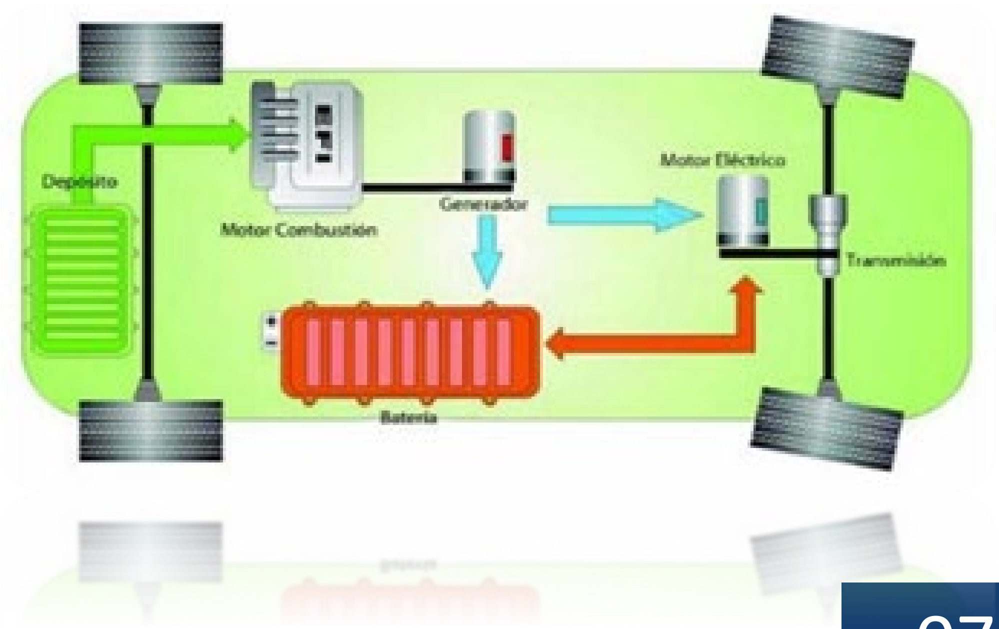
Hybrids (Series and Parallel)

Explanation of series and parallel hybrids:

1. Series: The vehicle is primarily propelled by the electric motor, which is powered by a generator connected to an internal combustion engine. Various operating modes optimise efficiency.

2. Parallel: Both the internal combustion engine and the electric motor work together to drive the vehicle. Different operational modes balance power delivery and efficiency.



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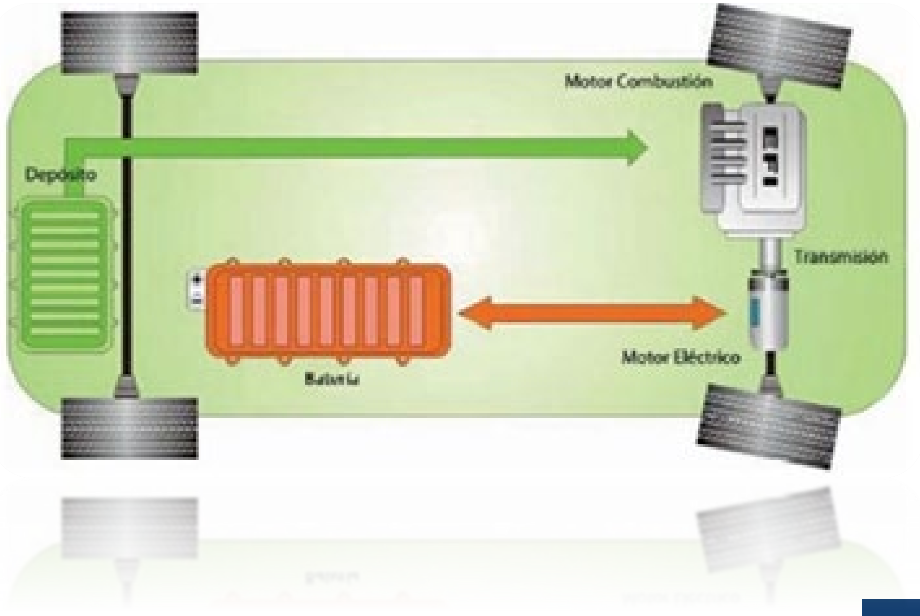
Plug-in and Non-Plug-in Hybrids

Details about Plug-in Hybrids (PHEVs):

1. Plug-in Hybrids (PHEVs) allow charging from an external electrical grid, enhancing electric-only range and reducing reliance on internal combustion.

2. Non-Plug-in Hybrids lack the ability to charge externally and solely rely on internal mechanisms for recharging.



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Comparison with Internal Combustion and Pure Electric Vehicles

Advantages and disadvantages of pure electric vehicles:

1. Pure Electric Vehicles (EVs) offer instant torque, regenerative braking benefits, but their performance is dependent on battery capacity and charge level. The weight of the battery pack affects overall vehicle weight and range.

2. Efficiency comparison with internal combustion vehicles considering energy generation and emissions: despite the high efficiency of electric motors, the overall efficiency of EVs might be influenced by factors like energy generation sources and associated emissions compared to traditional internal combustion vehicles.

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CONCLUSIONS

- ✓ **Hybrid Variants:** Series and Parallel hybrids differ in their power distribution. Series prioritises electric power via a generator, while Parallel balances power between the engine and electric motor.
- ✓ **Charging Abilities:** Plug-in Hybrids (PHEVs) can charge externally, extending their electric range, while Non-Plug-in hybrids lack this feature.
- ✓ **Pure Electric Vehicles (EVs):** Solely battery-powered, EVs offer rapid torque but heavily rely on charging infrastructure and battery performance, impacting their efficiency and range.
- ✓ **Efficiency Factors**: The performance of these electric vehicles is closely tied to factors like battery capabilities, charging infrastructure, and electricity sources, crucial for their overall efficiency against traditional internal combustion vehicles

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Learning Unit 2: Currently Available Implementations

- ✓ Definition of an Electric Vehicle (EV): An automobile powered by an electric motor, using energy stored in rechargeable batteries or another energy storage device.
- ✓ Comparison with Combustion Vehicles: Highlighting the distinct traction system in EVs compared to internal combustion vehicles.

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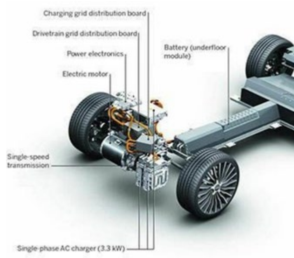
DRIVETRAIN ARRANGEMENT IN ELECTRIC VEHICLES (EVs)

Drivetrain Arrangements

- ✓ Front-Wheel Drive (FWD): The propulsion system that powers the front wheels of the vehicle.
- ✓ Rear-Wheel Drive (RWD): Propulsion system driving the rear wheels.
- ✓ All-Wheel Drive (AWD): Powering all wheels simultaneously for enhanced traction and control.

Types of Electric Motors

1. Central Motor: Positioned centrally within the vehicle, driving one or both axles.
2. Wheel Motor: Directly attached to vehicle wheels, enabling varied drive configurations.



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Front-Wheel Drive (FWD) Vehicles

Explanation:

Characteristics of FWD Vehicles: Discussing advantages and limitations of this drivetrain arrangement, such as better traction in slippery conditions but potential understeering.

Example

Renault Zoe: Highlighting specific features and technical aspects that typify FWD EVs.

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Rear-Wheel Drive (RWD) Vehicles

Explanation

Characteristics of RWD Vehicles: Explaining benefits like better weight distribution while noting potential challenges such as traction in certain conditions.

Example

VW ID.3: Showcasing notable aspects of the RWD EV.

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All-Wheel Drive (AWD) Vehicles

Explanation

Characteristics of AWD Vehicles: Discussing advantages like superior traction control across different terrains or road conditions.

Example

Jaguar I-Pace: Highlighting features that demonstrate AWD functionality and its significance in EVs.

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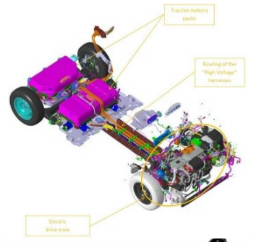
Electric Vehicle Frame Types & Platforms

Frame Types

- ✓ Body-on-Frame: Explaining its structure and where it's typically employed.
- ✓ Chassis or Self-Supporting Body: Describing the integration of frame and body in this design.

Challenges in Current Configurations



Inefficient use of space for battery placement: Discussing the drawbacks of adapting traditional vehicle frames for electric powertrains.

Electric Vehicle Platform: Skateboard Chassis

- ✓ Design Objective: Detailing the purpose of this specialized framework for EVs.
- ✓ Examples: Highlighting vehicles like the BMW C-Evolution and VW Group's MEB Platform to showcase the application of this concept in real-world models.

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CONCLUSION

Transition to Electric Mobility

- ✓ Advantages: Highlighting benefits such as reduced emissions, lower operational costs, and technological advancements in EVs.
- ✓ Challenges: Discussing obstacles like infrastructure development, range limitations, and manufacturing complexities.

Evolution in Design & Implementation

- ✓ Drivetrain Adaptation: Noting the evolution from traditional combustion engine layouts to specialised electric drivetrain configurations.
- ✓ Platform Innovations: Emphasising the shift toward purpose-built EV platforms like the skateboard chassis for optimal battery placement and performance.

Future Prospects

- ✓ Market Trends: Considering the ongoing trend of modular EV platforms and the potential for standardisation across manufacturers.
- ✓ Technological Developments: Speculating on advancements in battery technology, charging infrastructure, and autonomous capabilities impacting future EV implementations.

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Learning Unit 3: EV Architecture (Main Components)

- ✓ Briefly highlight the necessity of managing the motor's operation in electric vehicles.
- ✓ Introduce the diagram depicting the control system's components.

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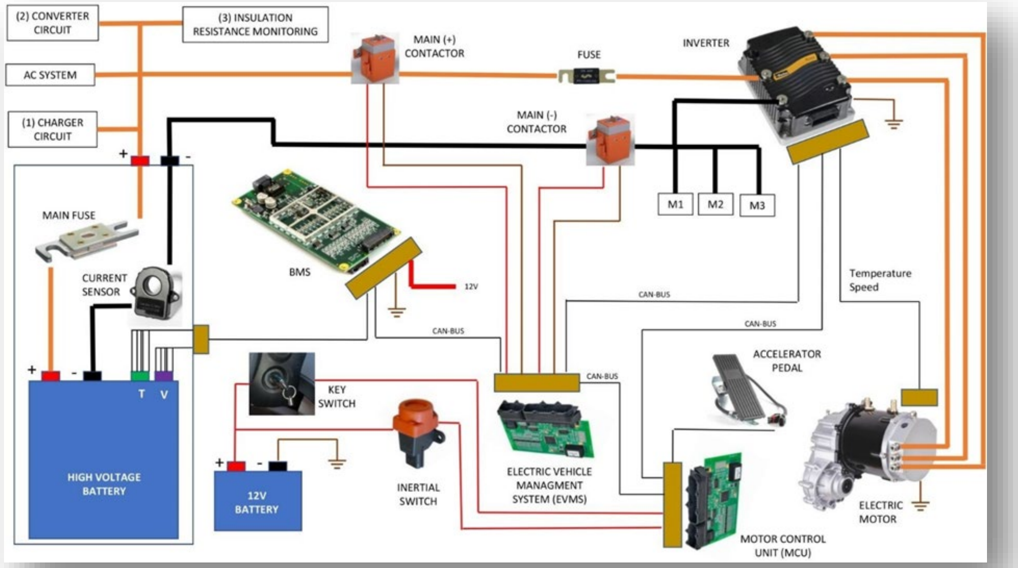
Electric Vehicle Powertrain Control System Overview

Components for Powertrain Regulation and Control

PotBox (Accelerator)
Controller (Driver)
On-board Charger
DC/DC Converter
Electric Vehicle Management System (EVMS)



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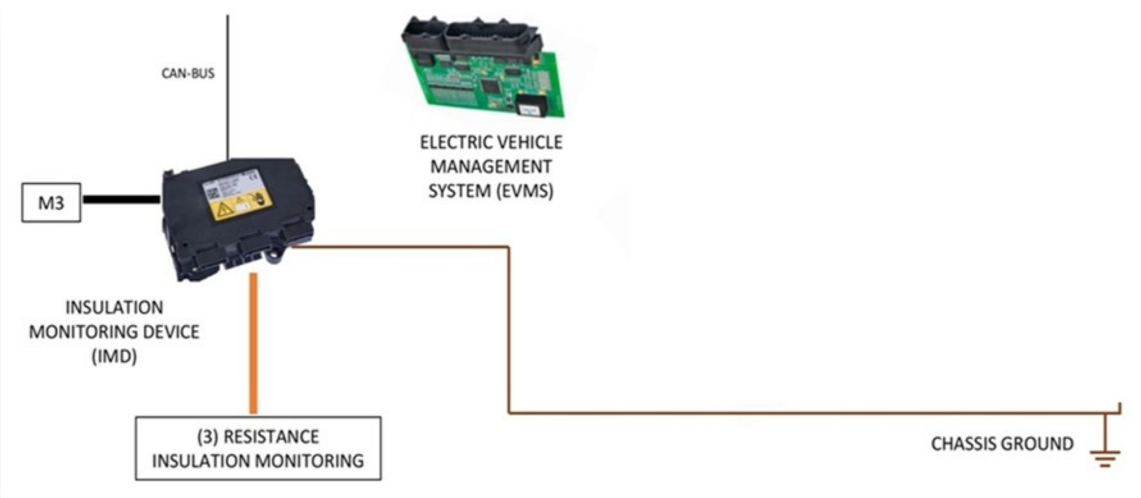
Battery Pack and Electrical Connections

Battery Pack Overview

- ✓ Description of essential elements: main fuse, current intensity sensor, BMS for voltage and temperature management.
- ✓ Explain monitoring systems and connection specifics.

High-Voltage System Diagram

- ✓ Schematic representation of connections and components in the high-voltage system.
- ✓ Emphasis on the integration and functioning of control units.



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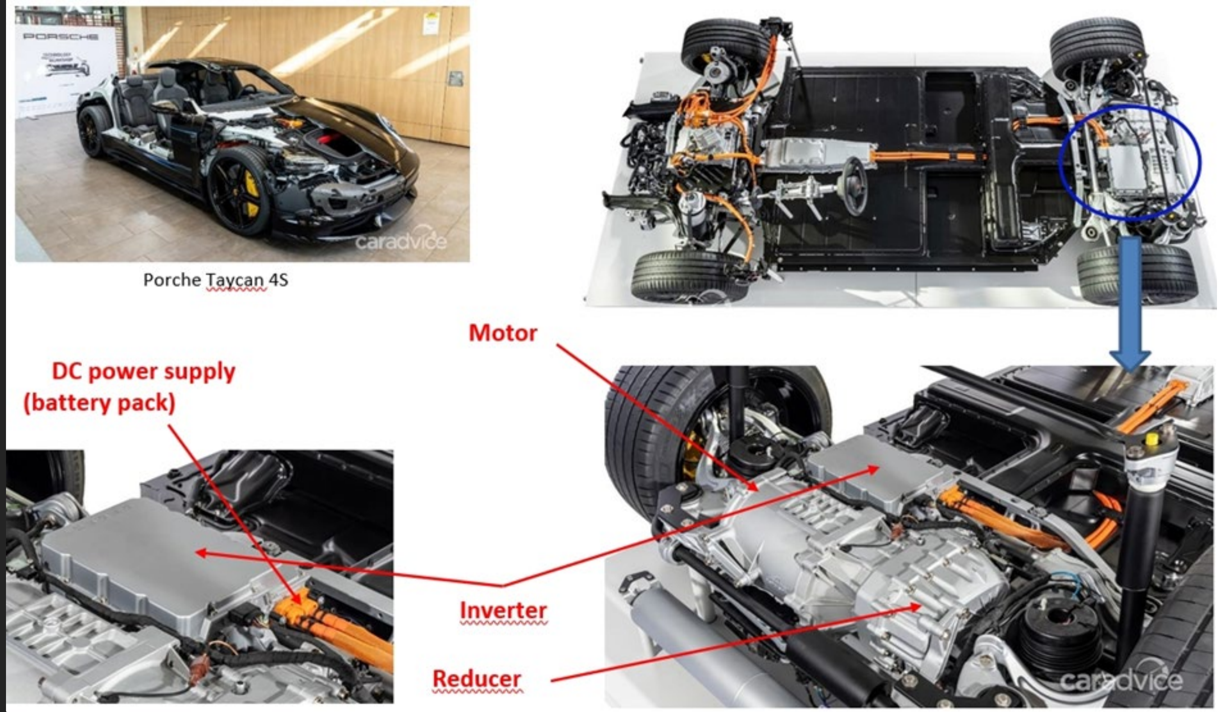
Motor Controllers (Inverters) and Control



Inverter Functionality

- ✓ Explanation of inverter operations, including its connection and protection.
- ✓ Description of its role in converting current and controlling motor functions.

Motor Control Strategies

- ✓ Overview of control methods: PWM, VVVF, FOC, DTC, PID.
- ✓ Focus on suitability for different motor types and their effectiveness.

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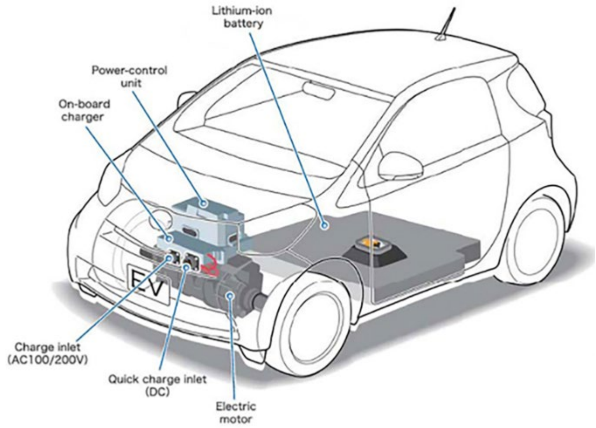
DC/DC Converter, On-board Charger, BMS, and Safety Components

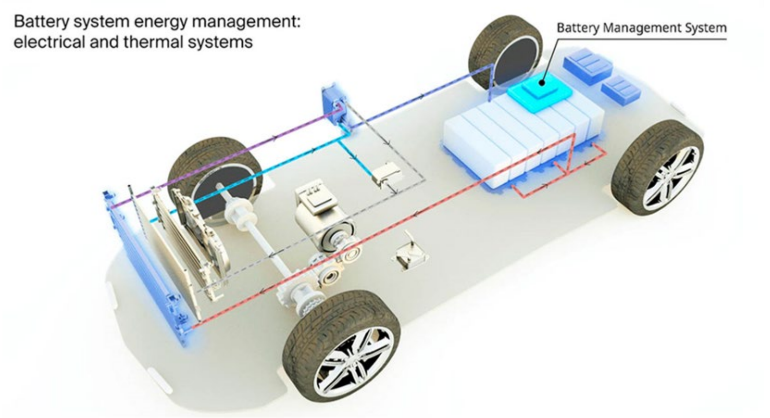
DC/DC Converter & On-board Charger

- ✓ Explanation of functions and connections.
- ✓ Highlight their roles in power transformation and management.



Battery Management System (BMS) & Safety Components

- ✓ Overview of BMS functions and its importance in EV management.
- ✓ Description of the Inertial Switch and Key Switch for safety.



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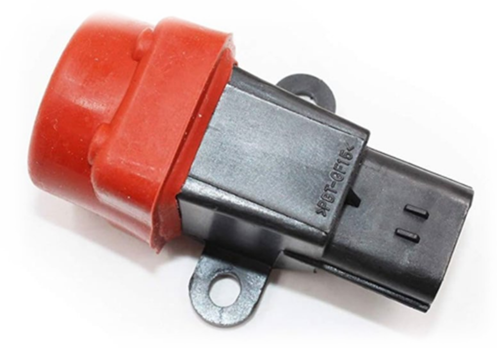
Inertia Switch and Key Switch Significance

Inertia Switch

- ✓ Importance in collision safety, immediate disconnection of high-voltage circuit, and its operation.
- ✓ Additional considerations and placement strategies.



Key Switch

- ✓ Role in starting/stopping the vehicle, interaction with MCU, and safety functions.
- ✓ Evolutionary technology and its significance in vehicle operation.

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CONCLUSION

Integration of Electric Vehicle Powertrain Control

- ✓ Acknowledgment of the intricate network of components regulating and managing electric propulsion systems.
- ✓ Emphasis on the holistic approach required for seamless operation and safety.

Technological Complexity & Safety Measures

- ✓ Recognition of the complexity in integrating multiple systems for efficient electric vehicle operation.
- ✓ Highlighting the critical role of safety measures like the Inertia Switch and Key Switch in emergency scenarios.

Advancements in EV Management Systems

- ✓ Appreciation for the evolution of control units like EVMS and MCU in optimising performance and battery management.
- ✓ Understanding the importance of innovative motor control strategies for diverse motor types.

Future Directions in Electric Mobility

- ✓ Speculation on continued technological advancements and standardised systems across electric vehicle platforms.
- ✓ Consideration of potential advancements in safety, efficiency, and user-friendly functionalities.

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Learning Unit 4: Energy Storage Systems

- ✓ Briefly highlight the necessity of managing the motor's operation in electric vehicles.
- ✓ Introduce the diagram depicting the control system's components.

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Energy Storage Systems - Basics

- ✓ **Introduction to EV Components**: Discuss the fundamental role of batteries in electric vehicles.
- ✓ **Key Considerations in Propulsion**: Emphasise the significance of an appropriately sized electric motor and battery to meet performance requirements.
- ✓ **Battery Dynamics**: Delve into battery functionalities, cell types, assembly, discharge, and recharge management.

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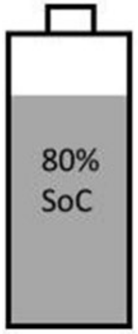
Battery Parameters & Charging Characteristics

- ✓ **Fundamental Battery Parameters**: Explore battery voltage, capacity, C-rating, and their implications on performance and charging.
- ✓ **Battery Performance Metrics**: Discuss metrics like specific energy, specific power, and their impact on overall battery capabilities.
- ✓ **Charging & Discharge Parameters**: Explain concepts like Depth of Discharge (DoD), State of Charge (SoC), and their significance in battery operation.



$$SoC = \frac{\text{Actual Charge in battery}}{\text{Maximum charge in battery}}$$

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Lithium-Ion Battery Types & Characteristics

Lithium-Ion Batteries: Types, Geometries, & EV Applications

- ✓ Overview of Lithium Battery Types: Highlight different lithium-ion battery variations (LCO, LMO, NMC, LFP, NCA, LTO, LiPo) and their distinctions.
- ✓ Battery Geometry & Uses: Discuss cylindrical, prismatic, button, and pouch cells, their applications, advantages, and limitations.
- ✓ EV Traction Battery Tech: Address the prevalent use of lithium-based batteries in electric vehicles, focusing on various cell sizes and chemical compositions.

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Assembly of a Battery Pack

Overview of Battery Pack Components

✓ Introduction to EV Battery Pack Assembly:
  1. Purpose: Powering electric vehicle traction systems.
  2. Components: Series-parallel cell connections, BMS, current sensors, enclosures.

✓ Purpose of Assembly:
  - Voltage and Current Capacity: Combining cells for required voltage and current.
  - Safety and Performance: Enclosures for protection and mechanical strength.

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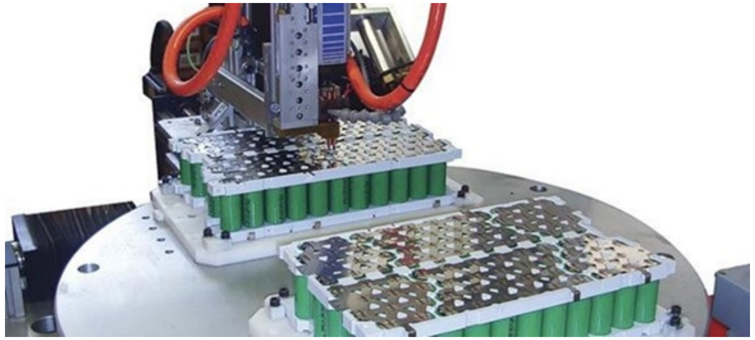
Cell Connection in a Battery Pack



Series and Parallel Configurations

- ✓ Series and Parallel Configurations Explained:
  - Series: Increasing total voltage by connecting cells end-to-end.
  - Calculation Example: Number of Cells x Individual Cell Voltage.
- ✓ Parallel: Enhancing total capacity by connecting cells side-by-side.
  - Calculation Example: Summing Individual Cell Capacities.
  - Visuals: Illustrations demonstrating 4s (4 Cells in Series) and 4p (4 Cells in Parallel) Configurations.

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Assembly of Cells in a Battery Pack

Layout Design and Spot Welding

- ✓ Designing Battery Layout within Enclosures:
  - Geometric planning based on cell dimensions and vehicle space.
  - Assembly Methods:
    - Battery Holders: Using ABS holders or direct packing without holders.
    - Impact on Volume and Heat Management: Heat dispersion and space utilisation.
  - Spot Welding Modules: Creation of parallel cell modules.
- ✓ Series Connection and Final Terminal Creation:
  - Explanation of series connection process for modules.
  - Final Terminal Formation for battery pack.

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CONCLUSION

Integration of Electric Vehicle Powertrain Control

- ✓ Acknowledgment of the intricate network of components regulating and managing electric propulsion systems.
- ✓ Emphasis on the holistic approach required for seamless operation and safety.

Technological Complexity & Safety Measures

- ✓ Recognition of the complexity in integrating multiple systems for efficient electric vehicle operation.
- ✓ Highlighting the critical role of safety measures like the Inertia Switch and Key Switch in emergency scenarios.

Advancements in EV Management Systems

- ✓ Appreciation for the evolution of control units like EVMS and MCU in optimising performance and battery management.
- ✓ Understanding the importance of innovative motor control strategies for diverse motor types.

Future Directions in Electric Mobility

- ✓ Speculation on continued technological advancements and standardised systems across electric vehicle platforms.
- ✓ Consideration of potential advancements in safety, efficiency, and user-friendly functionalities.

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Learning Unit 5: Recharging the Battery Pack

- ✓ Overview of the importance of charging infrastructure for electric vehicles.
- ✓ Europe's charging station disparities by EAFO figures.
- ✓ Impact of charging locations on convenience for drivers and grid stability.

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Recharging the Battery Pack - Concepts

Understanding Battery Cell Parameters and Charging Processes

- ✓ Fundamentals of battery cell parameters and assembly process of battery packs.
- ✓ Focus on studying the charging process, both on-board and off-board systems.
- ✓ Highlight the significance of charging infrastructure for the viability of electric vehicles.
- ✓ Discuss the classification of charging sectors: domestic, workplace, public chargers, and high-speed chargers.

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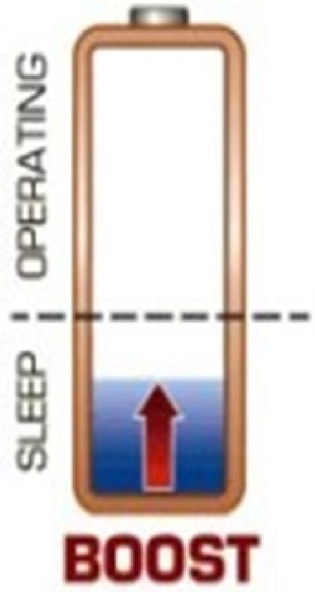
Lithium-Ion Cell Charging Process

Charging Protocols for Lithium-Ion Cells

- ✓ Describe the specific charging procedure of lithium-ion cells.
- ✓ Emphasise the stages in the charging process: constant current and constant voltage modes.
- ✓ Mention the importance of not overcharging cells for their longevity.



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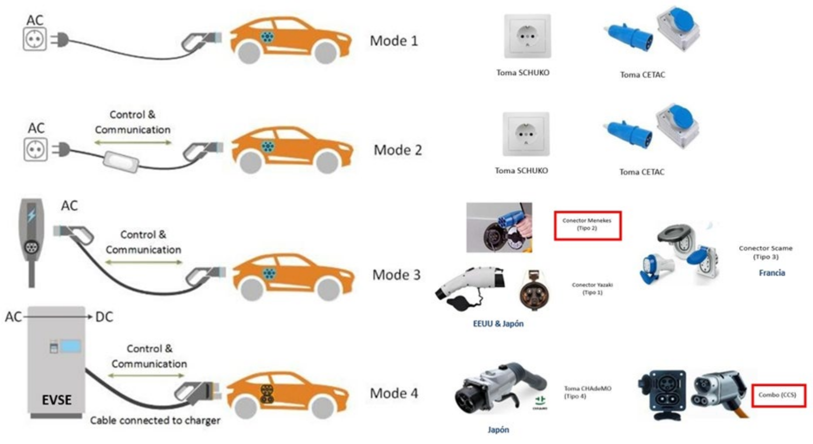
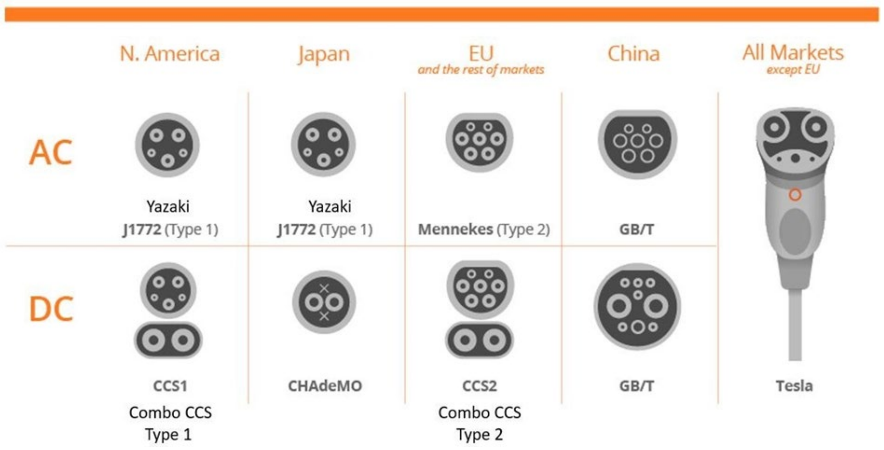
Recharging the Battery Pack - Concepts

Electric Vehicle Charging Systems - Standardized Ways of Recharging

- ✓ Introduce the standardised modes (Mode 1 to Mode 4) for recharging electric vehicles.
- ✓ Detail the specifications of each mode, including maximum power, current, and connectors used.





Recharging the Battery Pack - Concepts

Standardised Recharge Connectors

- ✓ Present the standardised recharge connectors: EEC 7/4, SAE J1772, VDE-AR-E 2623-2-2, CHAdeMO, and Combo.
- ✓ Display the wiring diagrams and overview of each connector type

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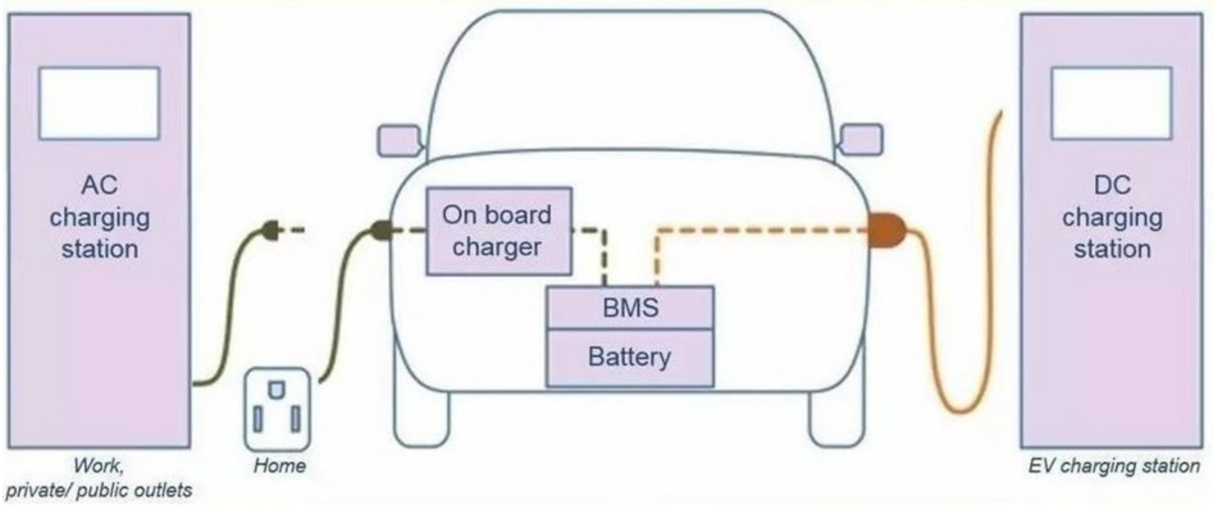
Recharging the Battery Pack - Concepts

On-Board and Off-Board Charging Systems

- ✓ Differentiate between in-vehicle chargers (on-board) and external charging stations (off-board).
- ✓ Highlight the necessity of on-board chargers for modes 1 and 2, while mode 3 charging requires specific on-board capabilities.
- ✓ Discuss examples of outdoor and home charging stations, highlighting their output characteristics and features.



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CONCLUSION

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Learning Unit 6: Operation of Electric Motors

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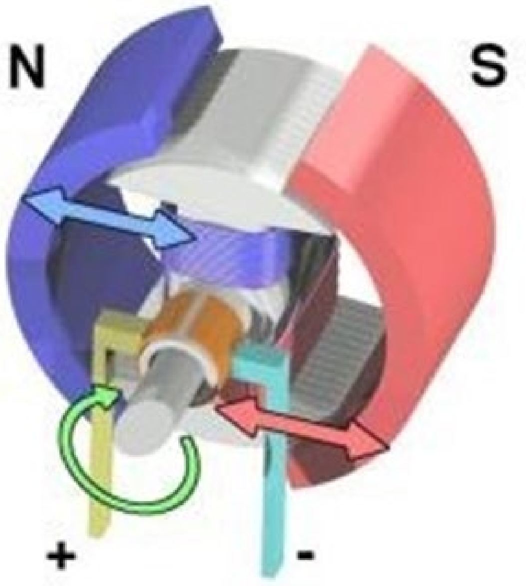
Electric Motor Technologies in Traction Systems

Key Technologies:

- ✓ **Three-Phase Asynchronous Motors**: Widely used due to their simplicity, robust construction, and low cost. Limited in high speeds and efficiency.
- ✓ **Permanent Magnet Synchronous Motors**: Superior efficiency and energy density. Use of neodymium magnets to enhance efficiency.
- ✓ **Axial Flow and Switched Reluctance Motors**: Evolutions with specific advantages in energy density and constructive simplicity.



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Induction Motors (Asynchronous)

Characteristics:

- ✓ Asynchronous alternating current motors.
- ✓ Widely employed in industries for their simplicity and robust construction.
- ✓ Limitations in high speeds and efficiency compared to other technologies.

Permanent Magnet Motors (Synchronous)

Characteristics:

- ✓ Synchronous motors with permanent magnet rotors.
- ✓ Higher energy density and efficiency compared to induction motors.
- ✓ Use of neodymium magnets to enhance efficiency.
- ✓ Challenges in costs and availability of rare earths.

Switched Reluctance Motors

Characteristics:

- ✓ Evolution from permanent magnet motors.
- ✓ Salient poles in both stator and rotor.
- ✓ Constructive simplicity and motion control through magnetic fields.
- ✓ Improved efficiency and robustness compared to some technologies.

Axial Flux Motors

Characteristics:

- ✓ Magnetic flux parallel to the rotor's rotation axis.
- ✓ Narrower, lighter, and higher energy density.
- ✓ Ideal for wheel applications, providing high performance with lower weight.

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Electric Motor Operating Parameters

Parameters Defining an Engine:

- **Type of electric motor:**
  - ✓ Induction motors (asynchronous alternating current motors)
  - ✓ Permanent magnet synchronous AC motors
  - ✓ Axial flux motors (a specific type of permanent magnet synchronous motors)

- **Engine cooling:**
  - ✓ Essential for efficiency
  - ✓ Methods: air cooling (natural or forced convection), water cooling

- **Operating Temperature Range:**
  - ✓ Monitored with NTC thermistors
  - ✓ Internal temperature: Typically 80-85°C
  - ✓ Stator winding temperature: Max around 100-120°C

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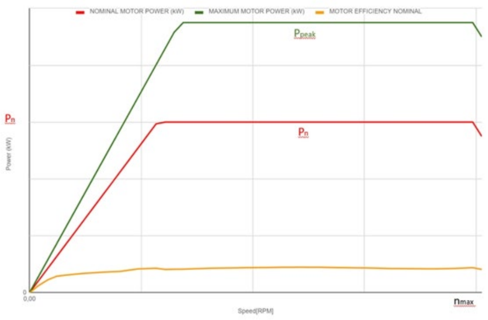
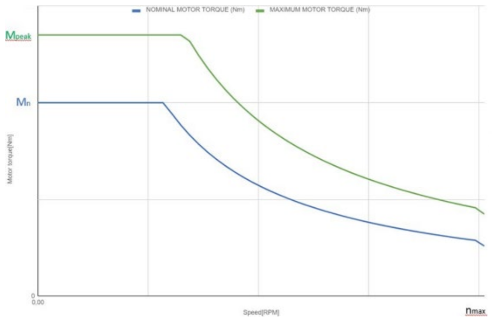
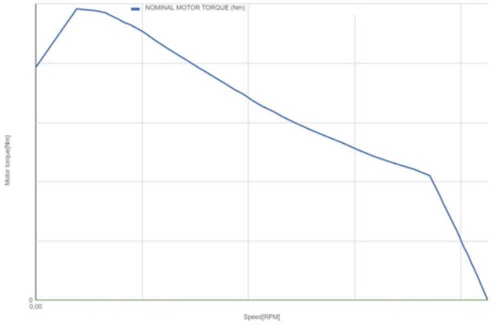
Torque Curve of Electric Traction Motor

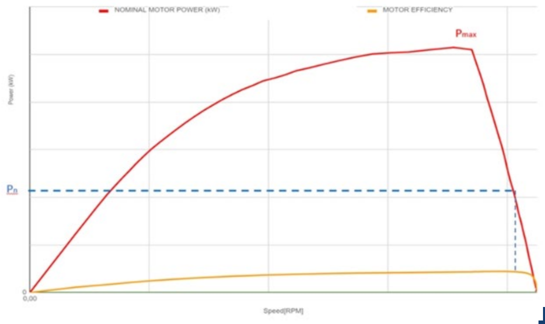
Ideal Torque Curve:

- ✓ Electric motors allow higher current for brief periods, generating higher torque/power (torque peaks).
- ✓ Enables enhanced performance with a lower-rated power motor.
- ✓ Not always achieved; often, a curve maintaining maximum torque at low revs is observed.









LEARNING UNIT 6: Operation of electric motors

05 - 15

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Power Curve of Electric Traction Motor

Power Curve Behavior:

- ✓ Similar behavior to torque curve.
- ✓ Aim to operate within the maximum efficiency zone for longer ranges.
- ✓ Existence of nominal speed and peak speed allows various driving modes (eco, sport, normal).

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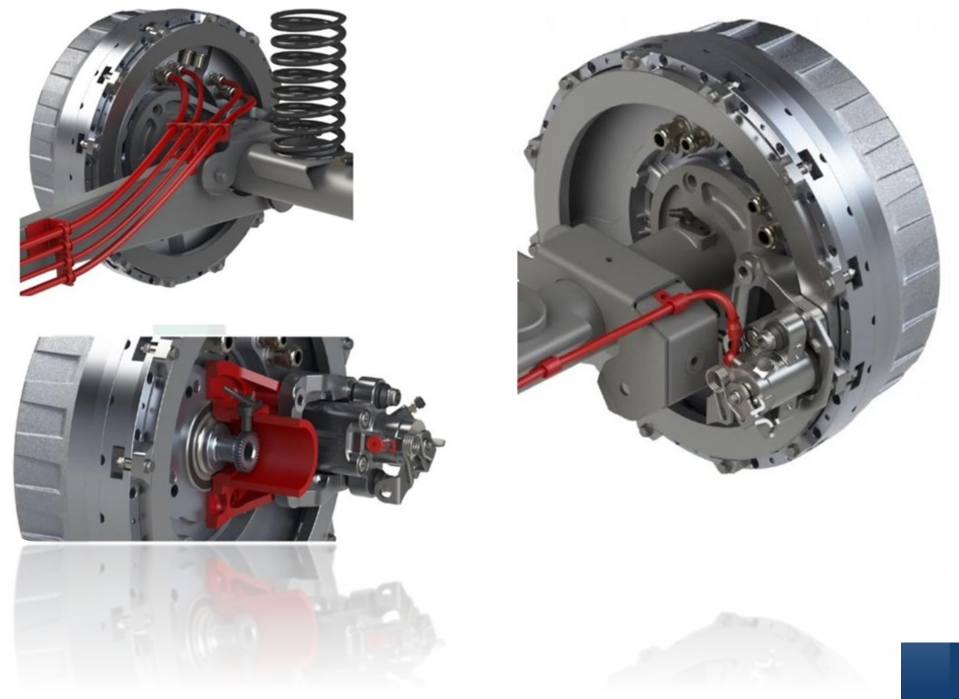
Repair and Transmission System

Repair of Drive System:

- **High voltage disconnection before repairs.**
- **Electric vehicle specialists handle high-voltage systems.**
- **Transmission System and Gearbox Necessity:**
  - ✓ Importance of gearbox to match wheel speed.
  - ✓ Reduction gears increase wheel torque, enable smaller motors.
  - ✓ Single-speed gearbox often used for efficiency.
  - ✓ Transmission System



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CONCLUSION

Operating Parameters:

- ✓ All motors share similar operating parameters: motor type, cooling, and efficiency.
- ✓ Motor selection depends on specific application and performance.

Drive System Repair:

- ✓ Necessary disconnection of high voltage before repairs.
- ✓ Electric vehicle specialists required to handle the high-voltage system.
- ✓ Repair process similar to internal combustion vehicles, except for specific electrical components.

Transmission System and Gearbox Necessity:

- ✓ Importance of a gearbox to match wheel speed to the vehicle's maximum speed.
- ✓ Gear reduction to increase torque at the wheels and enable smaller motors.
- ✓ Higher efficiency and reduced electricity consumption.

Braking and Parking System:

- ✓ Use of regenerative braking to recover energy during braking.
- ✓ Electronic parking system with Electric Parking Brake (EPB).

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REFERENCES

These resources provide relevant and updated information on the specific topics of electric vehicles addressed in this module.

- ✓ Society of Automotive Engineers (SAE) International
- ✓ InsideEVs: https://insideevs.com/
- ✓ Battery University by Cadex Electronics
- ✓ Charging Infrastructure Expo
- ✓ IEEE Transactions on Energy Conversion

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MODULE 1

EV ESSENTIALS

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1 QUESTIONS AND ANSWERS (FOR THE ENTIRE MODULE)

1.1 Describe the fundamental difference between a Series Hybrid Vehicle and a Parallel Hybrid Vehicle, highlighting their respective operational mechanisms and primary distinctions.

Answer: (Learning UNIT 1)

A Series Hybrid Vehicle primarily operates with the electric motor solely propelling the vehicle through the electrical energy supplied by a generator, itself powered by an internal combustion engine (ICE). This configuration enables various modes of operation: from using the battery alone to solely propelling the vehicle, to mixed modes combining generator and battery power for the electric motor. In contrast, a Parallel Hybrid Vehicle functions with both the ICE and the traction electric motor (TEM) working simultaneously to drive the vehicle's wheels. Here, the ICE and TEM collaborate directly in the vehicle's propulsion through different modes, including scenarios where the vehicle is propelled solely by the TEM or only by the ICE. These distinctions showcase how each vehicle type manages power sources and their integration into the propulsion system, defining their operational differences and performance characteristics.

1.2 Explain the drivetrain arrangements in electric vehicles (EVs), highlighting the distinctions between Front-Wheel Drive (FWD), Rear-Wheel Drive (RWD), and All-Wheel Drive (AWD) configurations. Additionally, elaborate on the two types of electric motors commonly used in EVs and their respective roles in the drivetrain.

Answer: (Learning UNIT 2)

Electric vehicles (EVs) exhibit various drivetrain arrangements, including Front-Wheel Drive (FWD), Rear-Wheel Drive (RWD), and All-Wheel Drive (AWD). FWD, illustrated by the Renault Zoe, propels the vehicle using the front wheels, while RWD, exemplified by the VW ID.3, powers the rear wheels. AWD, demonstrated by the Jaguar I-Pace, utilizes both front and rear wheels for propulsion.

Two prevalent electric motor configurations contribute to these drivetrain setups. First, the central electric motor, found in the market with either one or two motors, is typically coupled with a gearbox and connected to the driving wheels through a differential. Some vehicles feature a central motor for the front axle and another for the rear axle. Second, the wheel-hub electric motor is directly attached to specific wheels, enabling configurations like front-wheel drive, rear-wheel drive, or all-wheel drive.

Furthermore, electric vehicle platforms, particularly the "skateboard chassis," have become a trend. This design, exemplified by BMW's C-Evolution and VW Group's MEB platform, aims to accommodate the battery pack in a flat and low configuration, supporting various vehicle demands while enhancing adaptability across different electric models.

1.3 What are the primary functions of the Electric Vehicle Management System (EVMS) in an electric vehicle powertrain? Explain how it contributes to ensuring safety and efficient operation."

Answer: (Learning UNIT 3)

The Electric Vehicle Management System (EVMS) holds pivotal functions within an electric vehicle's powertrain. It oversees battery charging and discharging, controls the 12VDC electrical circuit, monitors traction motor temperature, and can modulate the accelerator signal to prevent abrupt accelerations that might harm the battery. Moreover, the EVMS conducts fault diagnostics, oversees safety devices like high-voltage circuit cutoffs, and provides the driver with essential information such as battery charge status, motor temperature, speed, and instant consumption via the instrument panel. In terms of safety, the EVMS plays a critical role by disconnecting the high-voltage circuit in a collision through the inertia switch, thereby averting risks of electric shocks, fires, or catastrophic failures. In summary, the EVMS is integral to the safety and efficient performance of an electric vehicle, managing multiple facets of the electric propulsion system to ensure optimal operation.

1.4 Explain the fundamental components of an electric vehicle's powertrain, highlighting the crucial relationship between the battery pack and the electric motor in achieving optimal performance. Additionally, describe the operational principle underlying the functioning of electric batteries and outline the primary types of batteries used in electric vehicles.

Answer: (Learning UNIT 4)

The core of an electric vehicle's powertrain involves a symbiotic relationship between the battery pack and the electric motor. The battery pack acts as the reservoir of stored energy, supplying power to the electric motor to achieve essential functions such as top speed and acceleration. This synergy underscores the importance of selecting an electric motor and a battery capable of complementing each other to deliver the desired performance efficiently.

Electric batteries function based on electrochemical cells, converting stored chemical energy into electrical energy. These cells comprise two electrodes - positive and negative - immersed in an electrolyte, facilitating electron flow between them. Batteries fall into two primary categories: primary cells, irreversible in energy conversion, and secondary cells, capable of recharging by reversing chemical reactions. These batteries are fundamental in electric vehicles, powering their propulsion systems and storing energy for sustained operation.

1.5 Explain lithium-ion batteries—structural composition, operational principles, and various geometric cell forms within these batteries—highlighting their advantages, applications, and potential limitations.

Answer: (Learning UNIT 4)

Lithium-ion batteries comprise cells with lithium salt electrolytes in non-aqueous solvents, featuring anodes and cathodes. In electric vehicles, these cells are grouped into a battery, offering voltage, capacity, and C-rate characteristics based on their configuration. Several chemical types and geometric forms (cylindrical, prismatic, etc.) have specific advantages for diverse applications, such as cylindrical cells' durability in tools or pouch cells' flexibility in mobile devices. These differences underscore the trade-offs between performance, safety, and cost across industries, notably in electric vehicles.

1.6 What is the role of the Battery Management System (BMS) in an electric vehicle's battery pack?

Answer: (Learning UNIT 4)

The BMS oversees battery health, monitors voltage, temperature, and current, and manages charging to ensure safe operation and balanced charging.

1.7 What are the two main methods of cooling battery packs in electric vehicles?

Answer: (Learning UNIT 4)

The main methods are air-cooling, reliant on external airflow, and liquid cooling, circulating a cooling fluid through the battery pack.

1.8 What function do the components of an electric vehicle's air conditioning system serve outside the passenger compartment?

Answer: (Learning UNIT 4)

These components, such as traction motors, inverters, and chargers, have independent cooling systems, often using a glycol fluid and separate circuits.

1.9 How is a battery pack assembled in an electric vehicle, and what components are crucial for its proper functioning?

Answer: (Learning UNIT 4)

Assembling a battery pack for an electric vehicle involves combining cells in series and parallel to create the necessary voltage and current for the vehicle's electric motors. Components like a Battery Management System (BMS), current sensors, and enclosures are vital. The connection, layout, and construction of cells within the pack require consideration for efficient functioning and safety. Cooling systems, whether air-cooled, liquid-cooled, or utilising the vehicle's air conditioning, are essential for maintaining optimal operating temperatures for the battery pack, ensuring efficiency and longevity. The BMS plays a critical role in monitoring voltage, temperature, and current, regulating charging and discharging, and even balancing cell loads. Overall, proper assembly and integration of these components are crucial for the battery pack's performance and safety in an electric vehicle.

1.10 Why is standardisation crucial in electric vehicle charging systems?

Answer: (Learning UNIT 5)

Standardisation ensures compatibility across different vehicles and charging points, facilitating a uniform and safe charging experience for EV drivers.

1.11 Why is regenerative braking essential in electric vehicles?

Answer: (Learning UNIT 5)

Regenerative braking allows the recovery of kinetic energy, extending the electric vehicle's range and enhancing its energy efficiency by converting braking energy into electricity for battery recharge.

1.12 What are the fundamental parameters defining the lithium-ion cell charging process, and how do they contribute to the efficient charging of electric vehicles?

Answer: (Learning UNIT 5)

The lithium-ion cell charging process is primarily defined by the charging voltage (ΔCharge), typically set at 4.20VDC, and the charging procedure, involving two distinct modes: constant current (DC mode) and constant voltage (CV mode). The charging current, designated as optimum/standard/maximum, determines the pace of the charging process—slow, medium, or fast. Efficient charging occurs when the charger supplies a consistent current until the terminal voltage reaches the charge voltage specified by the manufacturer (ΔLoad). Once this voltage is attained, the charger maintains the supply voltage (CV mode) until the current diminishes to about 100mA, indicating the cell is fully charged.

1.13 What role do the Control Pilot (CP) and Proximity Pilot (PP) play in ensuring safe and effective electric vehicle charging, and how do they contribute to interoperability between charging infrastructure and vehicles?

Answer 2: (Learning UNIT 5)

The Control Pilot (CP) serves as a communication interface between the off-board charger and the vehicle, conveying critical information like the maximum available current and charging status. Through a 1kHz square signal, it ensures physical connection verification and regulates charging. Meanwhile, the Proximity Pilot (PP) ensures safety by preventing vehicle start-up when connected to the charging connector. It also determines the maximum allowable current flow through the charging cable. The CP and PP, integrated into the Electric Vehicle Supply Equipment (EVSE), foster interoperability by facilitating communication and ensuring safe, standardized charging protocols between the vehicle and various charging stations.

1.14 What are the advantages and disadvantages of Permanent Magnet Synchronous Motors (PMSM) compared to Induction Motors in electric vehicle technology?

Answer 1: (Learning UNIT 6)

Permanent Magnet Synchronous Motors (PMSM) offer higher efficiency and energy density compared to Induction Motors. They have a reduced rotor volume, leading to increased efficiency (around 10%). However, PMSMs have drawbacks, including higher costs due to the use of rare earth magnets, which are expensive and not abundantly available. Additionally, their torque at low speeds (constant torque zone) is shorter than that of Induction Motors, and their controllers tend to be more complex.

1.15 What distinguishes Axial Flux Motors from other electric motors used in vehicles?

Answer 2: (Learning UNIT 6)

Axial Flux Motors stand out due to their magnetic field arrangement, which is parallel to the rotor's axis of rotation. This configuration allows for the creation of narrower and lighter motors with higher energy density compared to traditional radial flux motors. They provide high performance at a lower weight, making them suitable for wheel-mounted electric motors. However, their current downside lies in their higher cost and less sophistication compared to radial flux motors, despite their enhanced efficiency and compact design.

2 CASE STUDIES (FOR THE ENTIRE MODULE)

2.1 CASE STUDY 1: Motor Selection for Electric Vehicle Implementation

Background:

A leading automotive manufacturer is planning to introduce a new line of electric vehicles (EVs) into the market. They aim to select the most efficient and cost-effective electric motor technology for their fleet.

Scenario:

The manufacturer is evaluating various electric motor options based on the provided curriculum. They are considering between Permanent Magnet Synchronous Motors (PMSM), Induction Motors, and Axial Flux Motors. The primary concern is achieving high efficiency, reliability, and optimal performance suitable for their vehicles.

Analysis:

Permanent Magnet Synchronous Motors (PMSM):

- Pros: Offers higher efficiency and energy density compared to other motor types. Reduced rotor volume can lead to increased efficiency.
- Cons: Higher costs due to rare earth magnets. Shorter torque at low speeds might impact certain vehicle applications.

Induction Motors:

- Pros: Known for their simplicity, robustness, and relatively low cost. Widely used in industrial installations and machinery.
- Cons: Lower efficiency compared to PMSM and limitations with high engine speeds might not suit certain vehicle traction systems.

Axial Flux Motors:

- Pros: Parallel magnetic field flux, enabling the production of lighter, narrower motors with high energy density, ideal for wheel-mounted applications.
- Cons: Current disadvantages include higher costs and lower sophistication compared to radial flux motors.

Recommendation:

After comprehensive analysis and considering the requirements for their EVs, the manufacturer chooses Axial Flux Motors for their fleet. Despite the current downsides, the advantages of lightweight design and increased energy density align well with their focus on efficiency and performance in wheel-mounted electric motors.

2.2 CASE STUDY 2: Repair and Maintenance Protocol for Electric Vehicle Systems

Background:

An automotive repair and maintenance service provider is expanding its services to include electric vehicles (EVs). They aim to establish a standardised repair protocol for handling EVs safely and effectively.

Scenario:

The service provider acknowledges the distinct safety and repair protocols essential for working on EVs due to their high-voltage systems. They intend to outline a step-by-step procedure for handling repairs, focusing on the electric drive system components like motors, inverters, and chargers.

Analysis:

Safety Protocol:

- Emphasise the need to disconnect the high-voltage supply to the battery pack before commencing any electrical work on the vehicle.
- Highlight the necessity of specialised training for handling high-voltage systems and the designation of EV specialists within the repair team.

Repair of Electric Drive System Components:

- Electric Motors: Stress the non-repairable nature of electric motors, inverters, DC/DC converters, and onboard chargers. Advocacy for their replacement in case of failure.
- Inverter and Controller: Acknowledge their non-repairable nature and the importance of professional replacement.

Handling Safety Features:

- Discuss the Electronic Parking Brake (EPB) system in EVs, its function, and the protocol to be followed during repair and maintenance.
- Outline the procedures for towing an EV safely, including activating tow mode and avoiding damage to high-voltage components.

Recommendation:

The repair and maintenance service provider establishes a detailed safety protocol highlighting the criticality of disconnecting high-voltage systems. They incorporate specialised training for EV specialists and stress the importance of component replacement rather than repair for electric drive system components to ensure safety and compliance with EV manufacturer guidelines.

3 MULTIPLE CHOICE QUESTIONS (FOR THE ENTIRE MODULE)

3.1 A purely electric vehicle (EV):

Select one:

a. It has a traction system consisting of a set of electric motors, powered exclusively by a battery (or battery pack) installed in the vehicle itself.

b. It is powered solely by the electric motor thanks to the electrical energy supplied by a generator, which is driven by an internal combustion engine (ICE).

c. Can only be designed with a front-wheel drive arrangement.

3.2 Regarding the drive system arrangement of an electric vehicle:

Select one:

a. Only an architecture in which the front axle is the driving axle is possible.

b. Allows for as many configurations as are currently possible in an internal combustion vehicle, in addition to the in-wheel motor architecture.

c. Always has a drive system consisting of two electric motors.

3.3 To make the series connections of the modules that make up a pack:

Select one:

a. Never connect modules in series.

b. The positive poles of one module must be connected in parallel to the positive poles of the next module.

c. The positive poles of one module in parallel must be connected to the negative poles of the next module.

3.4 The materials from which lithium batteries are made are flammable,

Please select one:

a. For this reason, every lithium battery must be monitored to ensure that no cell reaches a higher than permissible temperature or is overcharged.

b. For this reason, every lithium battery must be monitored to ensure that no cell is overcharged, regardless of the temperature it reaches.

c. For this reason, they are prohibited in the automotive industry.

3.5 Lithium-ion batteries:

Select one:

a. Do not need to be fully charged (as with acid batteries) to ensure a longer life span.

b. They need to be fully discharged, in order to recover their full capacity at a later date.

c. They need to be fully charged (as with acid batteries) to ensure a longer life.

3.6 The mains electricity supply is alternating current:

Select one:

a. Whereas batteries must always be charged in direct current.

b. Whereas batteries can be charged in DC or single-phase alternating current.

c. Whereas batteries must be charged on alternating current.

3.7 The main technologies used in electric motors in traction systems are:

Select one:

a. Induction motors, permanent magnet synchronous motors, axial flux motors and switched reluctance motors.

b. Induction motors

c. Synchronous DC motors

3.8 Axial flux motors:

Select one:

a. Have an arrangement of the magnetic field flux created by the stator parallel to the axis of rotation of the rotor.

b. Have an arrangement of the magnetic field flux created by the stator perpendicular to the rotor rotation axis.

c. None of the above

3.9 The lithium-ion cells that make up a battery pack:

Select one:

a. Are only capable of supplying energy efficiently and safely when below 5ºC.

b. They are capable of supplying energy efficiently and safely when in any temperature range.

c. They are only capable of supplying energy efficiently and safely when within a given temperature range.

3.10 Regarding the repair of electric traction motors:

Select one:

a. Like combustion engines, they have a wide range of workshop repair operations.

b. It is not necessary, as they are exempt from breakdowns, so repair or replacement will never be necessary.

c. At present, they are considered as black boxes, which means that they are not repairable. In case of failure, they are replaced by a new one.

Correct answers:

1	2	3	4	5	6	7	8	9	10
A	B	C	A	A	A	A	A	C	C

MODULE 2

VEHICLE ELECTRICAL AND ELECTRONIC

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1. INTRODUCTORY PARAGRAPH

The objectives aim to provide a comprehensive understanding of electrical principles in the context of direct current vehicles. This encompasses gaining familiarity with fundamental concepts like voltage, current, and resistance. Moreover, the significance of protection devices in electrical circuits is emphasized, elucidating their vital role in averting overcurrents and short circuits. Grounding in electrical systems is highlighted for its critical role in ensuring safety and guarding against electric shock hazards. Additionally, the importance of diagnostic procedures for identifying faults in both electrical and electronic systems is underscored, recognizing their pivotal role in vehicle maintenance and repair efforts.

1.1 LEARNING UNIT 1: D.C. VEHICLE ELECTRIC CIRCUITS: PRINCIPLES AND PROPERTIES OF MAGNETISM APPLIED TO VEHICLE CIRCUIT DEVICES

BASIC CONCEPTS OF ELECTRICITY AND MAGNETISM

What is electric current? It is basically the movement of negative electric charges (electrons) through a conductive material. This movement of charges is capable of doing work, such as turning on a light bulb, turning a motor, etc.

In the field of electricity, the concept of charge movement focuses, as mentioned above, on the displacement of negative charges, commonly known as free electrons. The magnitude of this charge is quantified in Coulombs (C).

The electric current flowing through a conductor is characterised by the movement of these free charges within the conductor in each unit of time. The unit of measurement for electric current is the Ampere (A), equivalent to one Coulomb (a given amount of negative electric charges) per second.

To induce the movement of these free charges, it is essential to apply a force, known as Electromotive Force (EMF). This force is expressed in volts (V) and is generated by devices such as batteries and alternators.

The actual direction of electric current flow is established as the direction in which charges move from a region with excess charges (negative terminal) to a region with a deficit of charges (positive terminal). However, conventionally, in electricity, the direction of electric current is adopted as that of decreasing potentials, i.e. from the positive terminal to the negative terminal. This conventional approach simplifies the analysis and description of electrical circuits.

In the context of magnetism, we are introduced to the study of the behaviour of magnetic materials and the interaction between magnetic charges. A magnet, for example, has the ability to exert attractive or repulsive forces on other magnetic materials, and this property is explained by the existence of magnetic poles, i.e. the north and south poles.

The strength of a magnetic field is measured in units called Gauss (G) or Tesla (T), and this field is essential for understanding how magnets interact with each other or with ferromagnetic materials.

The magnetisation of a material is a phenomenon related to the alignment of magnetic dipoles in one direction under the influence of an external magnetic field. This property is measured in terms of amperes per metre (A/m) in the international system.

Magnetic force can also induce the motion of charged particles in a magnetic field, known as the Lorentz force. This principle is fundamental to understanding the operation of electric motors and other electromagnetic devices.

Electric currents are responsible for creating magnetic fields around the conductors through which they flow.

In summary, magnetism manifests itself through the interaction of magnetic fields, the alignment of dipoles in materials, and the influence of electric currents on the generation of magnetic fields, crucial aspects for understanding both natural phenomena and for the design and operation of technological devices, especially generators and motors.

OHM'S LAW

The most elementary electrical circuit consists of a generator (the battery) and a receiver or load with a resistor R, such as a lamp.

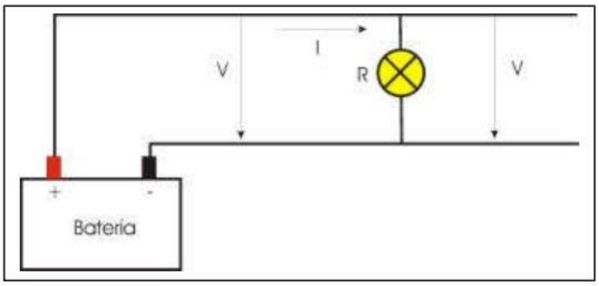


Image 01

When voltage is applied to the ends of the receiver (a lamp), the movement of charges, called current, from the positive terminal of the battery through the lamp to the negative terminal of the battery will cause the lamp to light up.

The relationship between voltage, resistance and current is established from Ohm's law by the following equation:

Voltage is measured in volts (V) Current I in amperes (A) Resistance R in ohms (Ω)

$$I=V/R$$

From this equation, the resistance and voltage terms can be cleared, so that two other equations are obtained:

$$V=IxR \quad R=V/I$$

Another useful equation is the equation for the power consumed or the power delivered by a receiver or a generator respectively. Power P is measured in watts (W) and is defined as the product of voltage and current:

$$P=V\times I$$

In cars, the ground terminal is not connected directly to the receivers, but the negative terminal of the battery is connected to the body, which then acts as the ground, so the elementary circuit applied to the car would be:

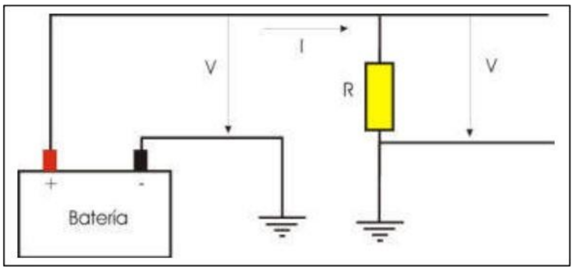


Image 02

FARADY'S LAW

Faraday's Law and electromagnetic induction play a fundamental role in the operation of electrical devices in a vehicle, providing a key understanding of how electric currents are generated by changing magnetic fields.

In the context of a vehicle, there are numerous devices that operate thanks to electromagnetic induction. Consider, for example, the alternator, an essential part of a car's electrical system. When the engine rotates, the alternator produces a variable magnetic field which, according to Faraday's Law, induces an electric current in the surrounding conductors.

Faraday's Law states that the magnitude of the electromotive force induced in a circuit is directly proportional to the rate at which the magnetic flux in that circuit changes. Mathematically, this is expressed as EMF (electromotive force) = $-d\Phi/dt$, where Φ represents the magnetic flux.

This electromagnetic induction allows electricity to be generated from the mechanical movement of the vehicle, providing energy to charge the battery and power the various electrical systems, such as the lights, ignition system, engine management system and other electronic devices.

The application of this Law in vehicle devices results in the efficient design of electrical systems that harness the mechanical energy generated during engine operation. In addition to the alternator, other components, such as speed sensors and safety systems, can also rely on similar principles of electromagnetic induction.

Faraday's Law and electromagnetic induction are fundamental to the generation of electrical power in vehicles, enabling the operation of various electrical devices and systems crucial to their performance and safety.

PRINCIPLES OF OPERATION OF ELECTRICAL DEVICES USED IN DC VEHICLE CIRCUITS. DC ELECTRIC MOTORS AND THEIR APPLICATION IN THE PROPULSION SYSTEM

Electric motors are rotating electrical machines, capable of transforming the electrical energy they are supplied with (either in the form of DC direct current or AC alternating current) into mechanical energy, by rotating on a shaft.

If a conductor is wound around a core of soft iron and an electric current is passed through it, the core behaves like a magnet, with the particularity that when the current ceases, it loses the properties that these elements possess.

On the other hand, if an electric current flows through a conductor, another magnetic field is created around it. Therefore, if a conductor carried by an electric current is introduced into a magnetic field, it is displaced due to the interaction between the two magnetic fields, since they can attract or repel each other, depending on their position.

This principle is used in the starter motor of a car, for example:

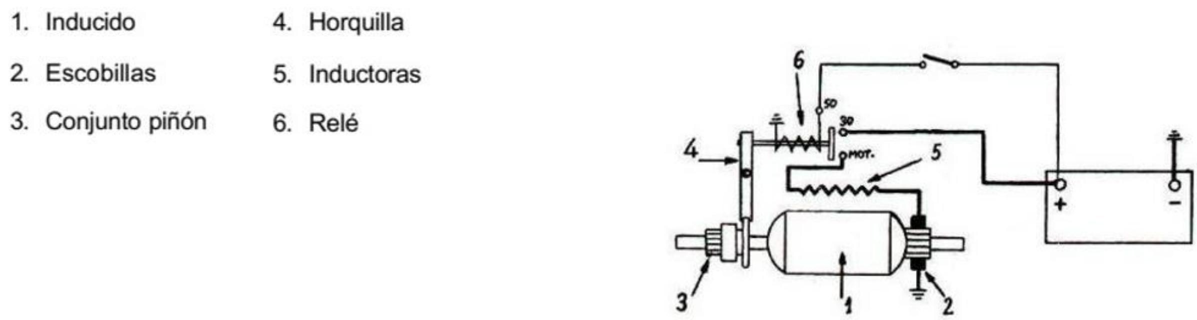


Image 08

When the relay is operated and the contacts are closed, current flows through the armature coils creating a magnetic field. Once through the armature coils, the current passes through the brushes to the armature coils, creating another magnetic field. As the armature coils rotate and remain in the same position and the brushes do not move, the different armature coils are constantly affected by the repulsion effect of the magnetic lines.

The armature windings and inductor coils in starter motors are connected in series. This results in a very high torque when the engine is started, which is essential for driving the vehicle's internal combustion engine.

To supply this energy, the car has a battery. But if current is constantly being drawn from the accumulator, there will come a time when it will have no power at all, i.e. it will be exhausted. To prevent this from happening, the car has a system called the charging or supply system, whose task is to charge the battery and supply the other electrical power systems. The generator uses the same operating principle, but in reverse. What we have seen for the starter motor is valid for any DC motor.

There are three fundamental quantities when defining an engine:

- Electrical input power (Pe)

- Mechanical power output (Pm)

Pm = η - Peη   = Engine efficiency

- Output shaft rotational speed

Image 03

Every electric motor works by means of an electromagnetic induction process, i.e. by creating a variable magnetic field (through the passage of electric current) which induces or produces a rotating force on a shaft (output shaft).

Depending on the power supply (either direct current or alternating current), two types of electric motors can be distinguished:

- Direct current motors (DC motors)

- Alternating current motors (AC motors) or induction motors

DC MOTORS

As mentioned above, the example of the starter motor is valid for any DC motor. The DC power supply always has the same direction. The current is transmitted from the mains to a winding by means of the delgas collector (the collector is a conductive ring cut into several parts, in the following picture into two parts called delgas) by means of brushes that are continuously rubbing against the collector.

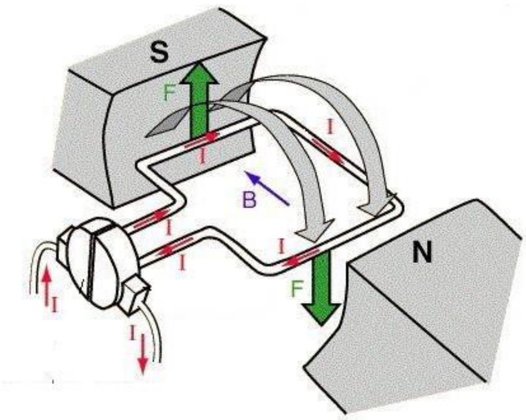


Image 04

When an electric current flows through a coil (or winding) within a magnetic field (generated by the two magnets), a magnetic force is induced on the coil which generates a pair of forces that makes the coil rotate (always in the same direction).

The picture on the right corresponds to the simplest possible motor. In order to increase the torque value generated, many turns are arranged in a coil or winding, also called a winding.

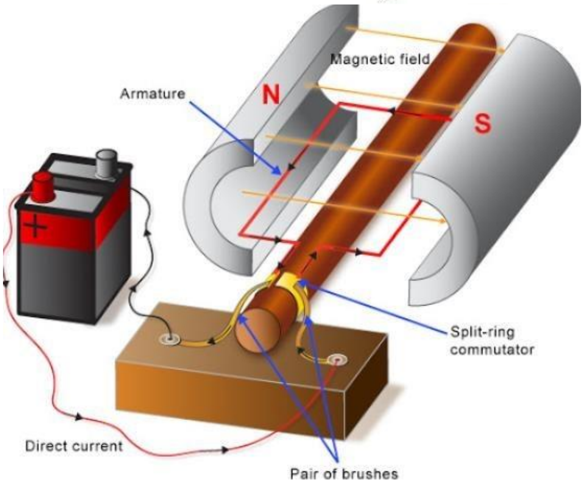


Image 05

If, in addition, coils of electric wire are wound on the fixed magnet and an electric current is passed through these coils (an electromagnet is created), it is capable of generating a greater magnetic field and, therefore, greater torque in the inner coil or winding.

And not only that, if a ferromagnetic core is added to the winding, the torque generated is again amplified.

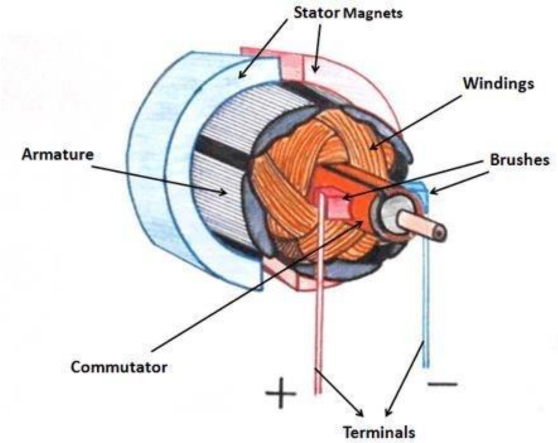


Image 06

Therefore, in a DC motor, two main parts can be distinguished:

- Fixed Part:

It is an electromagnet that produces a magnetic field that induces a force on the coil or moving part. It is called Stator (static) or Inductor (induces force on the rotating part).

- Moving Part:

Composed of many coiled coils of wire or coils. It is called Rotor (rotation) or Induced (on which a force is induced).

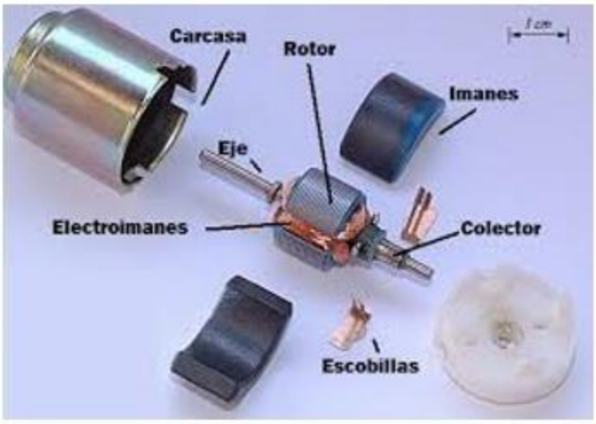


Image 07

MAGNETIC PROPERTIES OF MATERIALS USED IN DC VEHICLE CIRCUIT DEVICES.

Magnetic materials play a crucial role in DC vehicle circuit devices, as their response to magnetic fields directly affects the performance and efficiency of these systems. In the following, we will explore some of the key magnetic properties and relevant materials:

Magnetic Permeability:

Magnetic permeability is the measure of a material's ability to allow magnetic flux lines to pass through it. Ferromagnetic materials, such as iron and steel, have high magnetic permeability and are commonly used in transformer cores and inductive components in vehicles. For example in loudspeakers, relays, motors, etc.

Magnetic Susceptibility:

Magnetic susceptibility indicates the ease with which a material becomes magnetised under the influence of an external magnetic field. Ferromagnetic materials have significant susceptibility and can intensify the magnetic field when exposed to it, thus improving the efficiency of devices such as inductors and transformers.

Magnetic hysteresis:

Magnetic hysteresis describes the tendency of a material to retain some of its magnetisation even after the magnetic field is removed. The hysteresis curve is essential for understanding energy losses in magnetic components. Minimising these losses is crucial in the design of devices to ensure the efficiency of the vehicle electrical system.

Electrical conductivity:

Although not a magnetic property per se, the electrical conductivity of a material is also vital in DC devices. Materials such as copper and aluminium, which are good electrical conductors, are used in connections and windings to minimise energy losses and improve the efficiency of devices.

Composites and Ferrites:

In some cases, composite materials and ferrites are used in the manufacture of specific magnetic components to enhance certain properties. These materials can be tailored to meet specific design and performance requirements in vehicle devices.

Careful selection of magnetic materials in DC vehicle circuit devices is essential to ensure the efficiency and reliability of the vehicle electrical system. Understanding the magnetic properties of these materials allows engineers to design components that meet performance requirements and contribute to the efficient and safe operation of vehicles.

APPLICATION OF MAGNETIC MATERIALS IN RELAYS, INDUCTORS, TRANSFORMERS AND ELECTRIC MOTORS.

The application of magnetic materials in relays, inductors, transformers and electric motors is essential to optimise the performance of these devices. In the following, we will explore how different magnetic materials are used in each of these components:

Relays:

Relays are switches controlled by a magnetic field, used to control high-power electrical circuits with low-power signals. In their operation, an electromagnet, often consisting of an iron core, is activated by an electric current. This electromagnet, in turn, attracts or repels a metal contact, opening or closing the main circuit. Magnetic materials play a key role in the efficiency of relays, as they influence how quickly the magnetic field is established and released. Ferromagnetic cores inside the releases contribute to the concentration of the magnetic flux, improving the response and reliability of the switch. In addition, in more specialised applications, composite materials and ferrites can be used to control specific magnetic field characteristics and minimise electromagnetic interference, ensuring accurate and reliable performance in a variety of environments.

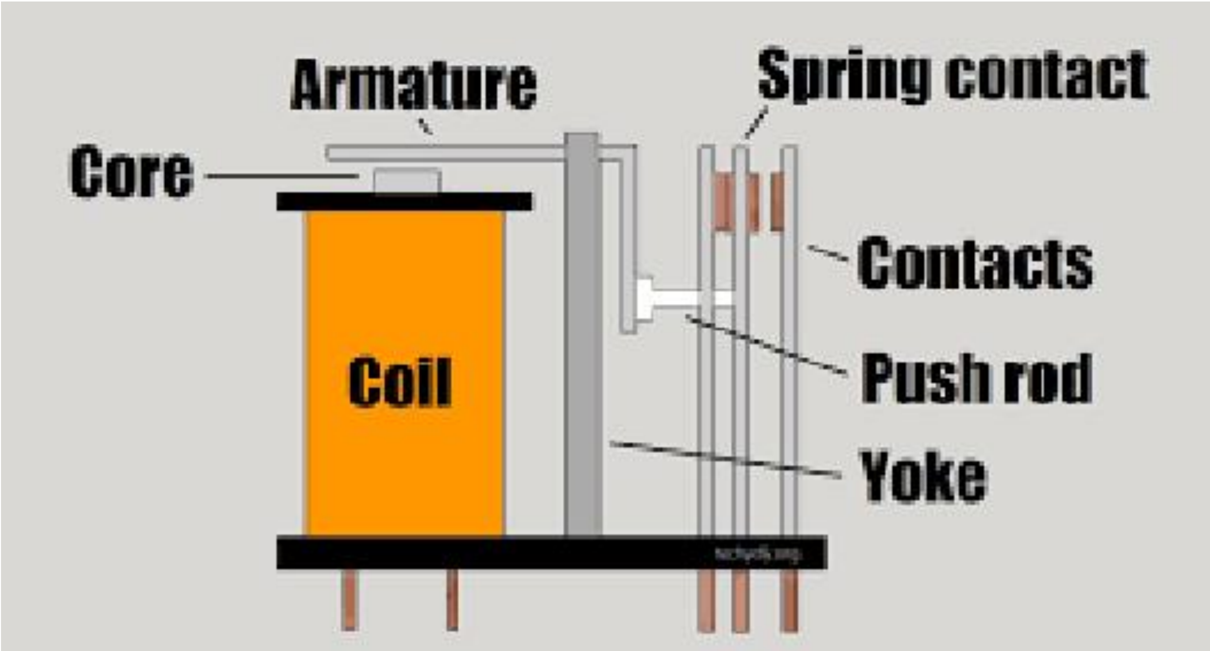


Image 09

Inductors:

Inductors are components that store energy in the form of a magnetic field when an electric current flows through them. Inductor cores are usually made of ferromagnetic materials, such as iron or iron alloys, due to their high magnetic permeability. These materials allow the magnetic flux to be concentrated, which increases the inductance of the device and improves its efficiency.

Transformers:

Transformers are devices that transfer electrical energy between two windings by means of a shared magnetic field. Transformer cores are usually constructed with ferromagnetic materials to increase the efficiency of energy transfer. Laminated silicon iron is commonly used due to its low energy loss and high magnetic permeability. These materials minimise eddy currents and power losses, ensuring efficient operation.

Electric Motors:

In electric motors, the interaction between magnetic fields is crucial for generating motion. Permanent magnets made of strong magnetic materials, such as neodymium alloys, are used in direct current (DC) and stepper motors to create stable magnetic fields. In addition, the rotors of induction motors and synchronous motors often contain ferromagnetic materials to improve the efficiency and performance of the motor.

The choice of suitable magnetic materials in these devices is crucial to achieve optimum performance. Engineers carefully consider factors such as operating frequency, magnetic flux density, power losses and saturation resistance to select the most appropriate material. Taken together, the precise application of magnetic materials in all of these elements contributes significantly to the efficiency and reliability of electrical systems.

APPLICATION OF THE PRINCIPLES OF MAGNETISM TO SENSORS USED IN DC VEHICLE CIRCUITS.

The application of the principles of magnetism in sensors used in DC vehicle circuits plays a crucial role in the precise measurement and control of various vehicle functions. Here, we will explore how these principles manifest themselves in different types of sensors:

Speed Sensors (ABS):

Image 10

Anti-lock braking systems (ABS) employ magnetic sensors to measure the rotational speed of the wheels. These sensors use magnetic toothed rings mounted on rotating wheel components, and a Hall effect or magnetic reluctance sensor detects changes in the magnetic field as the teeth pass in front of the sensor. This information is used to dynamically adjust brake pressure, preventing wheel lock-up during braking.

Crankshaft Position Sensors:

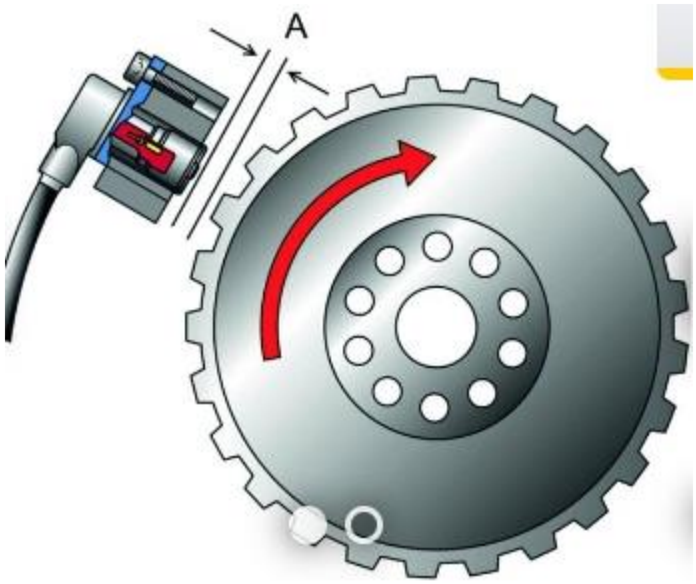


Image 11 (www.hella.com)

In the engine, crankshaft position sensors use magnetic principles to track the position and speed of the crankshaft. A magnetic disc or sprocket, mounted on the crankshaft, interacts with a sensor that detects changes in the magnetic field as the disc rotates. This information is essential to synchronise fuel injection and spark in the cylinders, thus optimising engine efficiency.

Hall Effect Sensors for Positioning and Speed:

Image 15 (www.autodoc.es)

Hall-effect sensors are widely used in vehicle applications to measure both position and speed. For example, in electrically assisted steering systems, these sensors detect the position of the steering wheel, allowing steering assistance to be adapted according to vehicle speed. Furthermore, in electric motors used in electric and hybrid vehicles, Hall-effect sensors monitor rotor speed and position to efficiently control the power supply.

Door and boot sensors:

Image 13

In the field of comfort and safety, magnetic sensors are applied in the detection of the status of doors and luggage compartments. These sensors, often based on magnetic reed switches, detect the presence or absence of a magnetic field when the door or boot is opened or closed. This activates lighting, safety and security alerts, enhancing the driver experience and vehicle safety.

HALL EFFECT SENSORS AND THEIR PERFORMANCE IN DETECTING MAGNETIC FIELDS.

Hall effect sensors are fundamental devices in the detection of magnetic fields, exploiting the physical principle known as the Hall effect. These sensors operate by means of a small semiconductor foil through which an electric current flows. When this foil is placed in a magnetic field, an electromotive force is generated perpendicular to the current flow and the magnetic field.

This induced voltage, known as Hall voltage, is proportional to the strength of the magnetic field. Hall-effect sensors convert this voltage into an electrical signal that can be measured and used to determine the presence, strength and, in some cases, polarity of the surrounding magnetic field.

The versatility of Hall-effect sensors makes them useful in a variety of applications, from position and velocity sensing in motors to implementation in safety and control systems. Their efficient operation and fast response make them essential tools for measuring and monitoring magnetic fields in automotive, industrial and electronic environments.

For example, this camshaft position sensor from Renault:

Image 14 (www.autodoc.es)

CURRENT SENSORS AND THEIR USE IN MEASURING CURRENT IN CIRCUITS.

Current sensors detect and measure the electrical current flowing through a conductor. Those based on the Hall effect generate a voltage proportional to the current, while those based on resistance measure the change in resistance of a conductive material due to current.

Image 12 (www.siriored.com)

They play a key role in the accurate measurement of current in electric vehicle circuits and are crucial to ensure optimum system performance and safety. These sensors, applied in various areas, are particularly prominent in the current monitoring of BMDs (Battery Module Blocks) in electric vehicles. Their function in this specific context is highlighted here:

Sensors in Battery BMD:

In electric vehicles, the battery is the heart of the propulsion system, and current sensors play a critical role in its management. These sensors are integrated into the MDBs to accurately measure the current flowing to and from the battery. By monitoring the current, valuable information about the charging and discharging of the battery is obtained, allowing for precise thermal management control and performance optimisation.

Thermal Control:

Current measurement in MDBs contributes to the thermal control of batteries. By understanding how current flows during charging and discharging, efficient cooling or heating strategies can be implemented to keep the battery temperature within safe and operational ranges.

Lifetime Optimisation:

The information provided by the current sensors assists in the implementation of charging and discharging strategies that optimise battery life. This is essential to maximise the durability and efficiency of the electric propulsion system.

Security:

Early detection of current anomalies, such as overcharging or excessive discharging, contributes to system safety. Battery management systems can take preventive measures based on sensor information to avoid risky situations.

Energy Efficiency:

By accurately measuring current, it facilitates the implementation of energy management strategies that improve system efficiency, enabling more effective use of the energy stored in the battery.

The application of current sensors in the BMDs of electric vehicle batteries is essential for efficient and safe energy management, contributing significantly to the performance and reliability of these vehicles.

1.2 LEARNING UNIT 2: Interpretation of wiring diagrams

BASIC ELECTRICAL UNITS

Potential difference

The term volt is used to define the difference in potential between two points in a circuit, after the scientist Alessandro Volta.

1 Volt (V) is the difference in potential between two points on a conductor carrying a current of 1 ampere (A).

Current intensity

Electric current is the flow of electrons between two points in a circuit. It is measured in Amperes (A), by the scientist André Marie Ampére. One Ampere (A) is a flow of 1 Coulomb per second.

Electrical resistance

The term Ohm (Ω) is used for this quantity, after the German scientist Georg Simon Ohm.

An ohm is the resistance of a conductor when a potential difference of 1 Volt is applied to it to obtain a current of 1 Ampere.

Electrical power

To define the electrical power consumed by a device, the word Watt is used, after the Scottish engineer James Watt.

A Watt is the power consumed by a device that absorbs a current of one ampere when a potential difference of one Volt is applied to it.

One horsepower (hp) equals 736 watts.

BASIC ELEMENTS IN A CIRCUIT

Electric current through an electrical conductor is a movement of free charges through that conductor per unit time.

In order for free charges to move, a force, called electromotive force (EMF), must be applied to them.

This electromotive force is measured in volts, and the devices in charge of producing this force are called generators (it can be a battery, an alternator, etc.).

As basic elements in a circuit, the following will be analysed:

- Energy sources

- Drivers

- Recipients and consumers

Energy sources

Among the different types, the following can be highlighted:

- Batteries: Transform chemical energy into electrical energy.

- Accumulators: They receive electrical energy and transform it into chemical energy, keeping it accumulated, to later undo the transformation and return electrical energy again.

- Generators: Transform the mechanical energy of rotation into electrical energy.

In the automobile, the electrical current used is direct current (DC or DC), i.e. the current is of a fixed value and does not vary over time. The voltage (EMF) supplied by the battery is of the DC type (12 or 24 volts).

Drivers

Wires are conductors surrounded by insulators, and are used to carry electric current. The insulators are of different colours so that the cable can be identified.

In a vehicle, the cables are bundled into harnesses, forming common paths. These cables are clamped to the bodywork, and protected in their passage through panels with rubber grommets.

When laying a new cable in an installation, there are certain factors to take into account.

The maximum current that a cable can carry depends on the cross-section and length of the cable. Thus, a cable that is too thin will have a high resistance, will cause a voltage drop in the circuit, and will overheat and may even burn. Cables should be made as short as possible to reduce the voltage drop on the line.

The conductors are designated by their normal cross-section in square millimetres. The standardised cables most commonly used in automotive electricity, according to UNE are: 0.5 - 0.75 - 1 - 1.5 - 2.5 - 4 - 6 - 10 - 16 - 25 - 35 mm2 cross-section.

When there is a need to install a cable in a vehicle, not just any cable can be used; one with the appropriate cross-section must be chosen. The calculation of the cross-section of a cable is carried out by the following formula:

Minimum cross-section = Resistivity x cable length / Resistance

The following table will indicate the maximum current that a cable can withstand, depending on the number of wires that form it and its thickness:

n° Wires/mm	Amper
14/0,25	6
14/0,30	8,75
28/0,30	17,5
44/0,30	27,5
65/0,30	35
84/0,30	45
97/0,30	50
120/0,30	60

Image 16

To connect wires is to join them in such a way that the electric current passes smoothly through them. Putting them together is called making a connection. Any kind of connection has to meet two requirements:

- To achieve a true and secure connection between the wires of one and the other cable, for the perfect passage of the current.

- To have effective protection against possible damage caused by the working conditions to which the car will be subjected.

Cable connections can be made in various ways: by splicing, by means of terminals or by soldering. Splicing in an electrical installation should be avoided if possible. When it is not possible to avoid this, it should be done as well as possible, because during the course of its use in the car, it may be subject to a lot of pulling, heating, water, mud, etc. which will greatly weaken the strength of the joint.

Recipients and consumers

All circuits have a source of energy and a means of transporting that energy in the form of wires, but, in turn, they will need some element that consumes that energy, such as a light bulb, a motor, a window regulator.

Switches are used to open and close an electrical circuit and thus start or stop a certain element.

There are different types of switches, depending on the needs of operation and use:

- Manually operated switches: are designed to be operated at the will of a person. In the automobile, they are often used for operation by the driver. The most common are: rotary switches (light control), slide switches (passenger compartment air temperature), on/off switches (heated window) and push/pull switches (headlights).

- Motion switches: are switches that are actuated by the movement of another vehicle component, such as the opening and closing of a door.

- Pressure/pressure switches: usually consist of a spring attached to a diaphragm. Pressure variations move the diaphragm, overcoming the resistance of the spring. The diaphragm is attached to a contact, and its movement opens and closes the contact. An example of this type of switch is the oil pressure sensor.

- Temperature switches: This type of switch uses a temperature-sensitive component to operate the contacts. Typically, bimetallic elements are used, which deform with temperature changes, thereby moving the contacts.

TYPES OF CIRCUITS

The components of an electrical circuit (a power source, conductors, and receivers and consumers) can be connected in different ways, resulting in different performances.

Basically, several types of connections can be distinguished: single, series, parallel or mixed.

Simple electrical circuit

In such a circuit there is a battery, a resistor, and interconnecting wires.

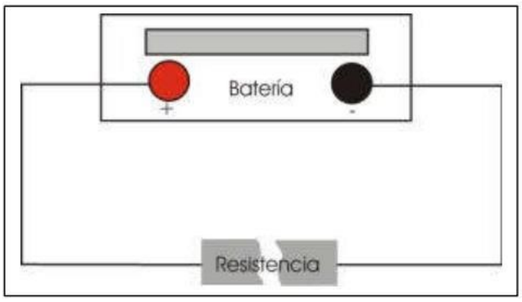
If Ohm's Law is applied, it will be seen what happens when a fault occurs, either a short circuit or an open circuit. In the case of an open circuit, and assuming that the resistance (the filament of the lamp) has broken, the value of the resistance therefore becomes infinite.

When applying Ohm's Law:

If R=Infinite, applying Ohm's law I=V/R we will have that I=V/Infinite, therefore I=0.

There will be no current flow in the circuit.

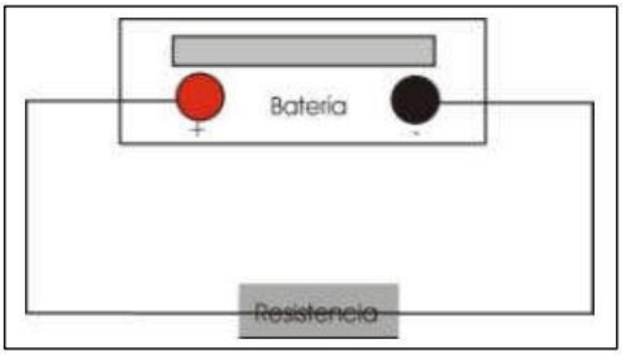
Image 17



Considering that, in the same circuit, the fault is a short circuit in the resistance, in this case, the value of R is zero, and applying Ohm's law:

I=V/R, i.e. IV/0, so I=Infinite

Image 18



The current flowing through the circuit is infinite, i.e. the circuit will absorb the maximum current that the battery can give, and may cause the cables to burn or blow the fuse, if there is one.

Electric circuit in series

A series circuit consists of a single line where two or more electrical devices are connected to each other: the end of the terminal of one receiver to the beginning of the other and so on.

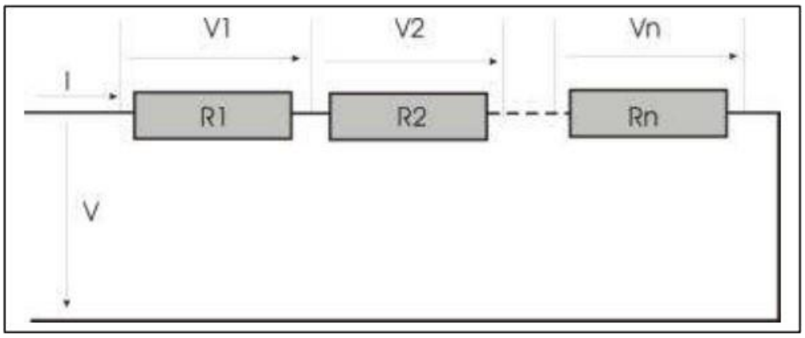


Image 19

As can be seen, in the series association, the current that circulates is always the same, while the voltage is distributed, so that the current is always the same:

$$V = V_1+V_2+.....+Vn = R_1I+R_2I+.....+RnI = (R_1+R_2+......+Rn)I = RTI$$

Image 20

It can be seen that the total resistance of the series circuit is the sum of all the resistances in the circuit.

$$R_T = R_1+R_2+.....+Rn$$

Image 21

The power consumed by the whole is the sum of the powers consumed by each element of the circuit:

$$P = P_1+P_2+.....+Pn = V_1I+V_2I+......+VnI = (V_1+V_2+.....+Vn)I = VI$$

Image 22

The series connection, as can be seen, is a voltage divider, as there is a voltage at the input which is then divided by each resistor.

Parallel circuit

A parallel circuit is composed of two or more branches, each of which contains at least one electrical device.

In this case, a different current will flow through each branch, depending on the consumption of the device.

In case of failure of one of the devices, the other devices continue to function.

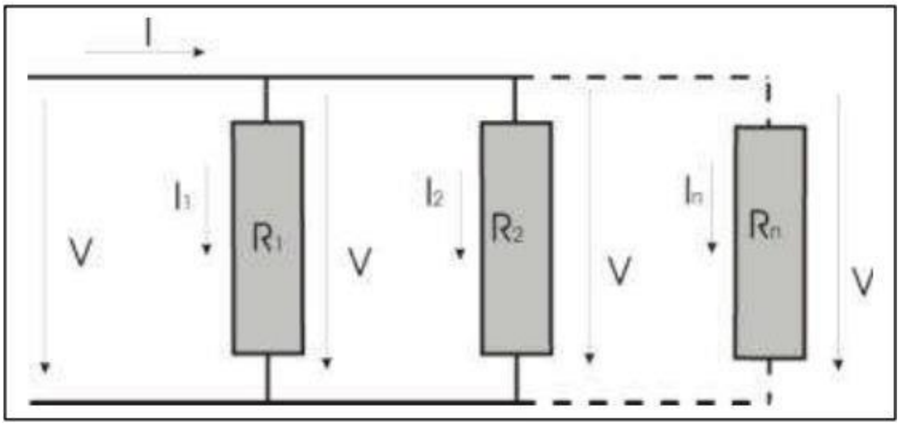


Image 23

For the parallel association, the voltage is the same in all the receivers, while the current is distributed according to the resistance of each receiver, the higher the resistance, the lower the current. The total current will be:

$$I = I_1+I_2+...+In = V/R_1+V/R_2+....+V/Rn = V(1/R_1+1/R_2+...+1/Rn)I = V/R_T$$

Image 24

The equivalent total resistance of the circuit would be RT

The power consumed by the whole is the sum of the powers consumed by each element of the circuit:

$$P = P_1+P_2+...+Pn = VI_1+VI_2+...+VIn = v(I_1+I_2+...+In) = VI$$

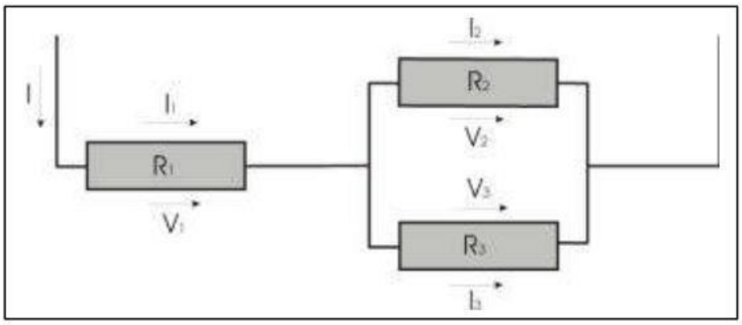
Image 25

This is the type of combination that is used by almost all automotive consumers. As can be seen, it is a current divider, as the input current is divided between all resistors.

Mixed circuit

It is the combination of series and parallel association.

Image 26



The circuit consists of a resistor R1, in series with two parallel resistors R2 and R3.

It can be seen that R2 and R3 are two resistors in parallel, so V2 = V3. The current flowing into resistor R1 is the same as the current flowing out, so I=I1

MAIN ELECTRICAL COMPONENTS

Every electrical circuit has at least some electrical components, whether they are resistors, switches, relays, coils, motors or generators.

Fixed resistors

Any electrical conductor through which an electric current circulates or may circulate presents a certain difficulty to the passage of this current.

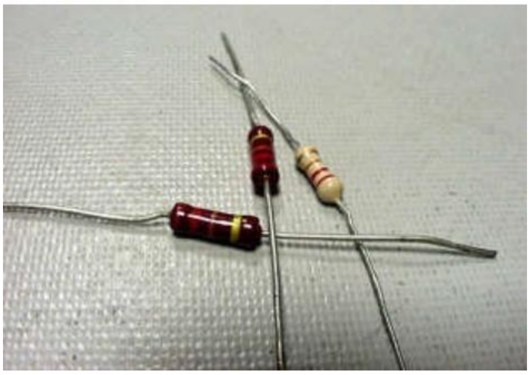


Image 27

This opposition is due to the amount of free electrons that each material can release, as well as to the electrons that are not able to circulate freely and are in constant motion due to a process of thermal agitation as a consequence of the energy they receive from the environment in the form of heat.

In a conductor, the increase in temperature increases its opposition to the passage of current, this opposition is called the resistivity of the conductor.

The inverse of resistivity is called conductivity "s" and represents the facility that a conductor offers to the passage of current.

When studying an electrical circuit, the resistance of wires, printed circuit boards, etc., is usually neglected, as it is much lower than the resistances that exist in the circuit.

Variable resistors

The most commonly used resistors in the automobile are variable resistors, whose value can change either manually, by the action of the driver, or automatically, depending on some external factor.

Potentiometers: These are resistors whose value is varied manually, at the driver's will. In a car, they are used to regulate the brightness of the instrument panel, the volume of the radio or the speed of the air fan in the passenger compartment.

Image 28

Automatic potentiometer: like the previous ones, it is a variable resistor, but its activation is produced by the movement of some component of the vehicle to which it is connected. Examples of this type of potentiometer are the fuel level detector, or the body height detectors for automatic headlight adjustment.

Temperature-dependent resistors

The value of certain resistors varies according to the temperature to which they are subjected. Some resistors have a negative temperature coefficient (NTC), which decreases the resistance as the temperature increases. Others, with a positive temperature coefficient (PTC), do the opposite, i.e. their value increases as the temperature to which they are subjected increases. This type of resistor can be found in the automobile to measure engine water and air temperature.

Light-dependent resistors

In this type of light dependent resistors (LDR), also known as photoresistors, their value varies as the ambient light conditions change, with the resistance decreasing as the light falling on this component increases. One application of these components in the automotive industry is as glare detectors for interior rear-view mirrors, another application can be found in the switching on of a vehicle's situation lights when ambient light is low.

Switches

Switches are used to open and close an electrical circuit. There are different types of switches, depending on the needs of operation and use.

Manually operated switches

They are designed to be operated at the will of a person. In the automobile, they are often used to be operated by the driver. The most common are:

(a) Rotary switches (light control)

b) Slide switches (passenger compartment air temperature)

c) On/off switches (heated bezel)

(d) Push/pull switches (main-beam headlamps)

Image 29

Motion switches

These are actuated by the movement of another vehicle component, such as the opening and closing of a door.

Image 30

Pressure/pressure switches

They usually consist of a spring attached to a diaphragm. Pressure variations move the diaphragm, overcoming the resistance of the spring. The diaphragm is attached to a contact, and its movement opens and closes the contact. An example of this type of switch is the oil pressure sensor.

Image 31

Temperature switches

This type of switch uses a temperature-sensitive component to operate the contacts. Typically, bimetallic elements are used, which deform with temperature changes, thereby moving the contacts.

Level switches

This type of switch generally controls the level of a fluid, so that when the level drops below a preset limit, the switch changes the position of its contacts from open to closed or vice versa. An example is the level switch located on the brake fluid oil reservoir.

Image 32

Relays

The relay is an electrical component that functions as a switch. It consists of an electromagnetic coil which, when excited, causes a magnetic field that closes the contacts of the switch. There are many types of relays but the operation is always the same.

In automobiles, relays are used whenever very high electrical currents have to be regulated and it is not desirable to overload the control switch or pushbutton. With this system, it is possible to open or close a circuit with a high current by passing through the contacts of the switch or pushbutton only the weak current required to actuate the electromagnet. In the automobile, they are used in most of the vehicle's electrical systems, starter motor, lights, ABS, glow plugs, injection...

Image 34

Simple relay

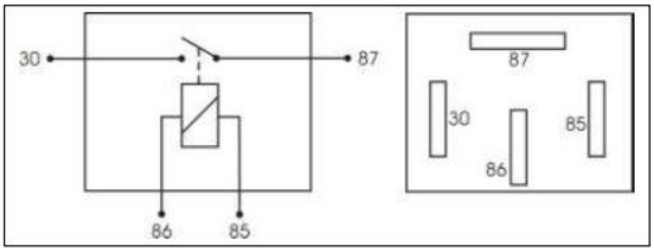


Image 35

30.
Control current input
(negative)
86. Control current input (positive)
87.Simple relay with one input terminal only

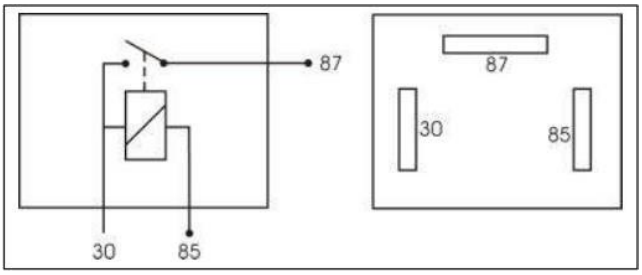
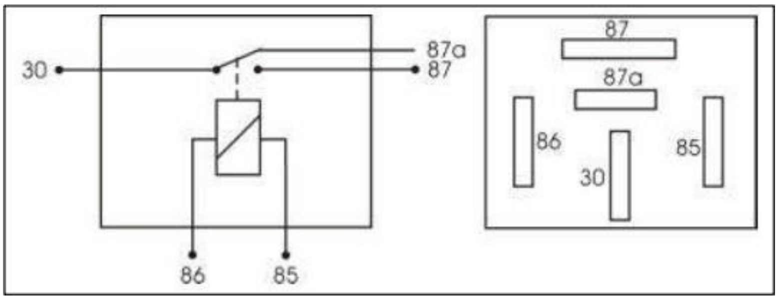


Image 36

30. Main current input
85. Control current input (negative)
87.Switching relays

In simple relays, a circuit is closed when the control current is applied. Switching relays can be used to perform two or three different functions.



30. Main current input
85. Control current input (negative)
86. Control current input (positive)

Motors and generators

As we have already seen in another section, if a conductor is wound around a soft iron core and an electric current is passed through it, the core behaves like a magnet, with the particularity that when the current ceases, it loses the properties that these elements possess.

This principle is used in the starter motor of a car.

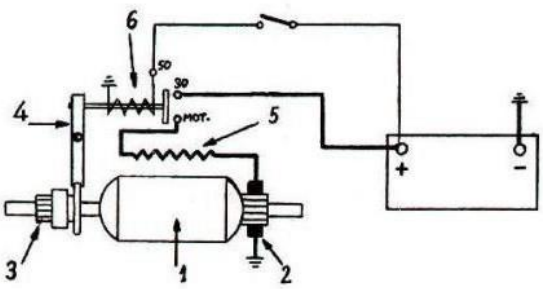


Image 38

When the relay is operated and the contacts are closed, current flows through the armature coils creating a magnetic field. Once through the armature coils, the current passes through the brushes to the armature coils, creating another magnetic field. As the armature coils rotate and remain in the same position and the brushes do not move, the different armature coils are constantly affected by the repulsion effect of the magnetic lines.

The armature windings and inductor coils in starter motors are connected in series. This results in a very high torque when the engine is started, which is essential for driving the vehicle's internal combustion engine.

To supply this energy, the car has a battery. But if current is constantly being drawn from the accumulator, there will come a time when it will have no power at all, i.e. it will be exhausted. To prevent this from happening, the car has a charging or supply system which charges the battery and supplies the other electrical power systems.

Fuses

Protection element in electrical and electronic systems. Composed of a conductor wire of a certain cross-section, when the current in a circuit exceeds the preset limit, the conductor wire of the fuse melts, causing an "open circuit" situation. Depending on the cross-section of the wire, the fuse will withstand more or less current. It is connected in series with the circuit and once it is damaged, it is necessary to replace it with a new one.

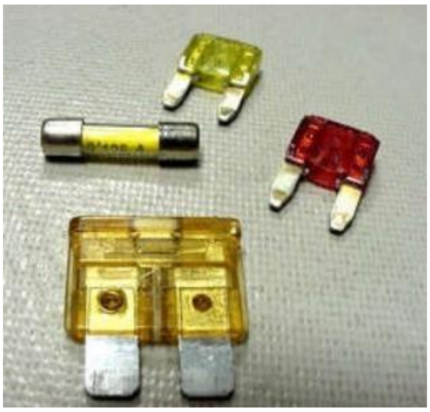


Image 39

When replacing a fuse, it is essential to replace it with another of the same value, so as not to damage the circuit in the event of overcurrent.**ELECTRICAL SYMBOLOGY**

The different components of the installation are assigned a letter, and if there is more than one, a number is added to the identification letter.

DIN 40719 assigns the following letters to the different elements:

E: Lamps and accessories

F: Fuses

G: Power supply (alternator, battery)

H: Audible warning devices

K: Relays, electrical and electronic modules

L: Coils

M: Monitors

Q: Measurements, indicators, probes

A: Electrical resistors

S: Switches

X: Terminals, connectors and plugs

Y: electromechanical components

U: Electronic Driver Information Elements

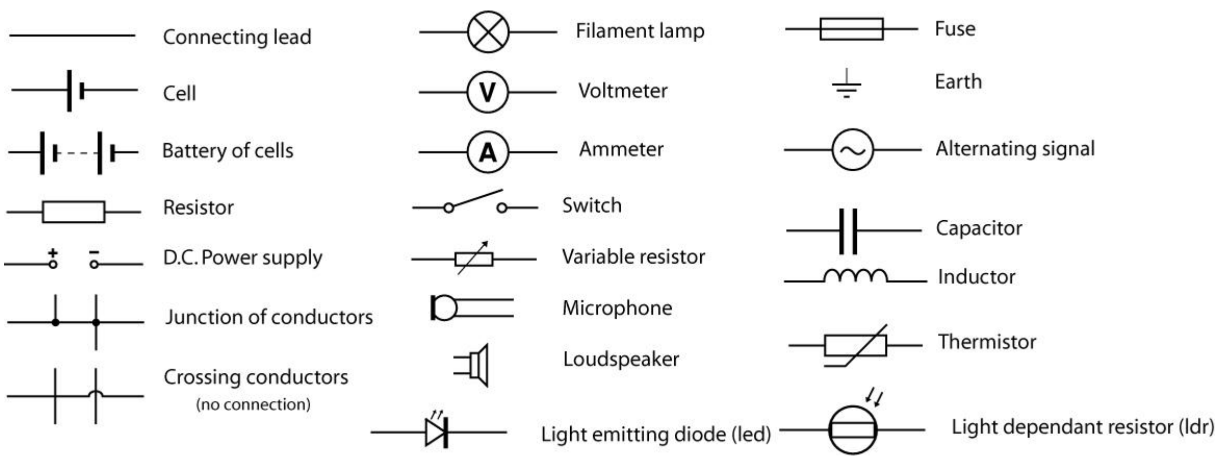


Image 40 (https://commons.wikimedia.org/)

INTERPRETATION OF AUTOMOTIVE WIRING DIAGRAMS

The interpretation of wiring diagrams is a crucial skill in the diagnosis and repair of vehicle electrical systems. It should be noted that while there are standard conventions and symbols in the automotive industry, each manufacturer may use their own codes and systems for creating wiring diagrams.

Standard Symbols and Conventions:

Despite differences among manufacturers, many of the symbols and conventions in wiring diagrams are industry standard. Technicians should be familiar with these common elements, which represent components such as switches, relays, motors and electrical connections. Some of these symbols can be seen in the image above.

However, each manufacturer may use its own interpretation of symbols and colours to represent specific components, wiring and electrical connections. When working with vehicles of different makes, technicians must adapt to each manufacturer's particular conventions to ensure correct interpretation of diagrams. It is vital for the electro-mechanic to have access to reliable manuals and technical information.

Manufacturers provide service manuals and technical documentation detailing the specific symbols and codes they use in their wiring diagrams. These resources are essential to understand each manufacturer's specifics and ensure accurate interpretation.

Some manufacturers also offer specific diagnostic software that includes interactive wiring diagrams and search functions. These tools are valuable to technicians as they simplify interpretation and provide detailed information about the vehicle's electrical systems.

Industry professionals must be adaptable and willing to continually learn about the wiring conventions of different manufacturers. The ability to quickly understand brand-specific systems improves efficiency in electrical troubleshooting.

In workshop environments, collaboration between technicians can be beneficial. Sharing experience and knowledge of manufacturer-specific conventions can facilitate the interpretation of wiring diagrams and streamline diagnostic and repair processes.

In summary, the interpretation of automotive wiring diagrams requires not only general knowledge of standard symbols and conventions, but also the ability to adapt to manufacturer-specific practices. The combination of manufacturer documentation, diagnostic software and collaboration between professionals contributes to an effective interpretation of electrical systems in vehicles, regardless of the specific brand.

Component Identification:

Each electrical component in the vehicle is represented by a unique symbol on the wiring diagram. Technicians must be able to identify these symbols and relate them to the actual components in the car. This includes the identification of specific wires, connectors and devices.

Current Direction:

Wiring diagrams indicate the direction of current flow through the electrical system. Understanding this direction is crucial in determining how components are interconnected and how electricity flows through the system.

Legend and Colour Codes:

The legend attached to the diagram provides information on the colour codes used for the wires. Understanding these codes is essential for tracing the routing of wires and locating specific connections in the vehicle.

Location of Grounding and Feeding Points:

The wiring diagrams show key ground and power points in the automotive electrical system. Identifying these points is crucial for diagnosing grounding-related problems and for ensuring that components receive proper electrical power.

Circuit Tracking:

Following the path of a specific circuit in the diagram helps to understand how the different components are interconnected. This is crucial for isolating problems and making effective repairs.

Fuse and Relay Identification:

Wiring diagrams show the location and function of fuses and relays. Being able to identify these components is essential for diagnosing and troubleshooting electrical problems, as fuses often protect specific circuits and relays control critical functions.

The interpretation of wiring diagrams is a valuable skill that improves efficiency in identifying and troubleshooting electrical problems in vehicles. Whether for routine maintenance or diagnosing more complex problems, this competence is essential to ensure optimal electrical performance in automobiles.

Example of a wiring diagram:

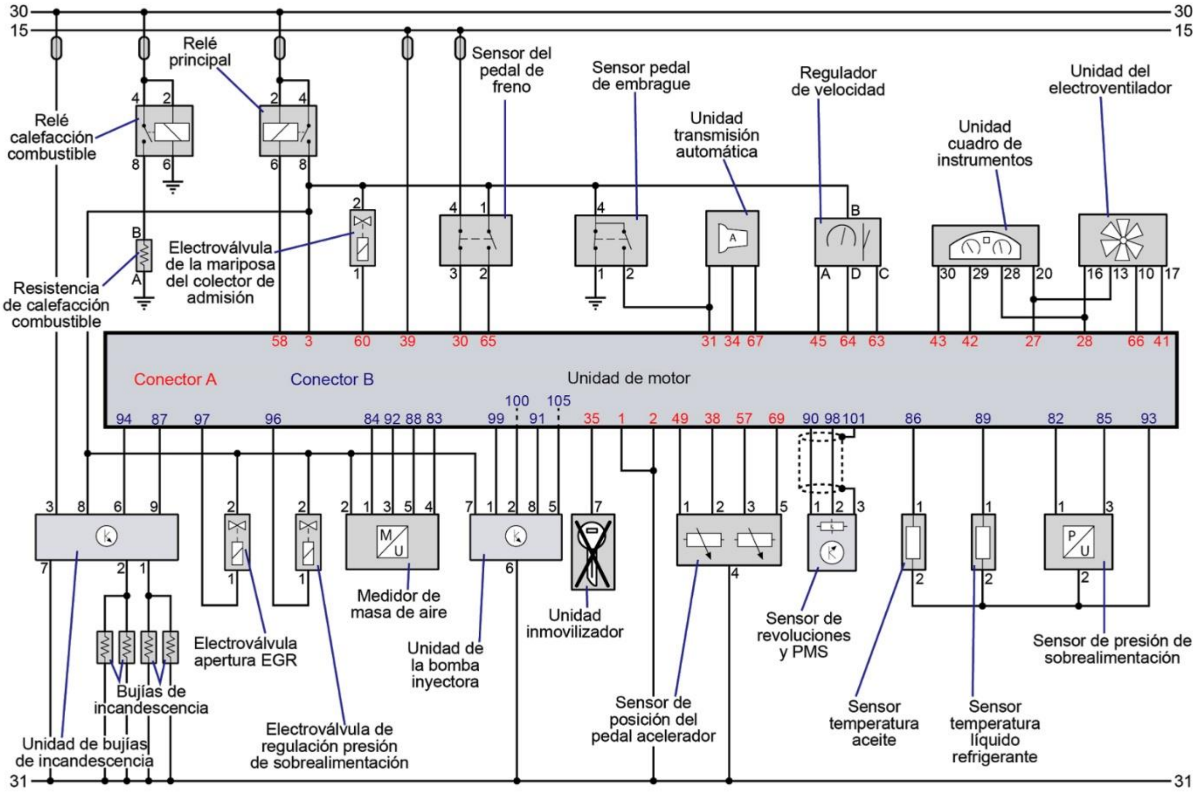


Image 41

1.3 LEARNING UNIT 3: Circuit protection devices

FUSES: TYPES, CLASSIFICATION AND THEIR ROLE IN OVERCURRENT PROTECTION.

Fuses play a crucial role in the protection of automotive and electric vehicle (EV) electrical systems, safeguarding electronic components and preventing possible damage caused by overcurrents. The most common fuse types, their classification and their specific protective function in the automotive context are discussed here.

Fuse Types

Blade fuses:

Widely used in automobiles, these fuses have a flat shape and are inserted in fuse blocks that allow for easy visual inspection. They come in various amperage ratings and are common in both conventional and electric vehicles.

Image 42 (www.alamy.es)

Tube fuses:

Although less common in modern automobiles, some vehicles still employ tube fuses, especially in specific applications. These fuses consist of a glass or ceramic tube containing a conductive filament.

Image 43

Mini and micro fuses:

Designed to take up less space, mini and micro fuses are used in vehicles where space is limited. They are common in more compact electrical systems, such as those found in electric vehicles.

Image 44

Classification of Fuses, according to their:

Rated Current:

Each fuse has a current rating that represents the maximum amount of current it can carry before opening the circuit. It is crucial to select fuses with appropriate current ratings based on the specific electrical requirements of each circuit in the vehicle.

Nominal Voltage:

The voltage rating of the fuse indicates the maximum voltage for which the fuse is designed. It must match the voltage of the system in which it is installed to ensure safe performance.

Response Time:

Some fuses are designed to respond more quickly to overcurrents, while others offer a slower response time. The choice depends on the application and the sensitivity of the vehicle electronics.

LOCATION AND DISTRIBUTION OF PROTECTIVE DEVICES IN VEHICLE ELECTRICAL CIRCUITS

Fuses are strategically placed in the electrical system to protect specific components. For example, one fuse may safeguard the lighting system, another may protect the engine control system, and so on.

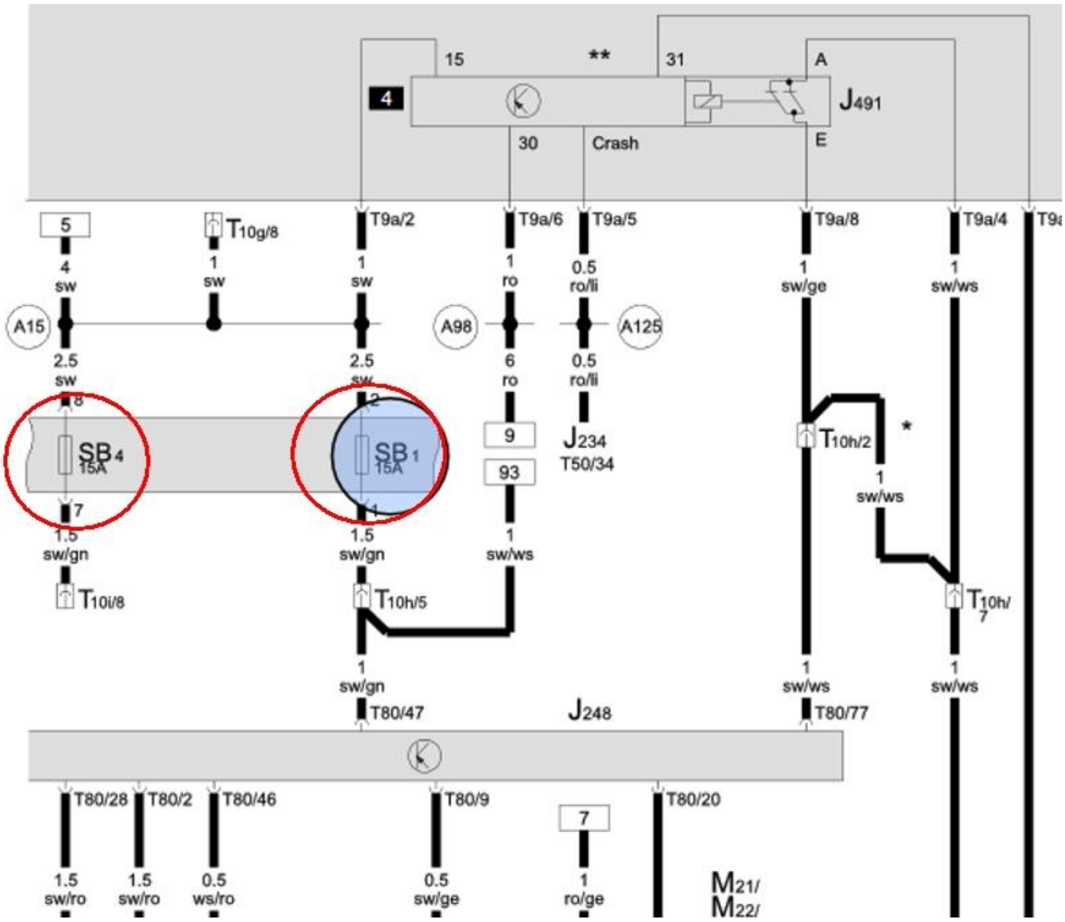


Image 47

In the event of an overload or short circuit, the fuse blows, interrupting the current flow and preventing damage to expensive and sensitive electrical and electronic components.

Fuses often have specific colours and codes that indicate their amperage, making it easy to visually identify their current rating. This is crucial in order to replace them correctly and maintain the integrity of the electrical system.

Image 48

Vehicles are often equipped with spare fuses stored near the fuse block. This allows drivers and technicians to quickly replace a blown fuse and restore the functionality of the affected system.

Battery system protection. In electric vehicles, battery system protection is critical. Specific fuses are used to protect the battery and high voltage circuits, ensuring safe operation.

High Voltage Fuses:

Because electric vehicles operate on high voltage systems, they have fuses that are specifically designed to handle these conditions, providing effective protection in higher power environments.

Electronic Fuses:

In more modern electric vehicles, electronic fuses or smart fuses are used. These devices not only interrupt the current, but can also send fault information to on-board diagnostic (OBD) systems.

Pyroelectric fuse high voltage battery disconnect for Tesla Model 3:

Image 45

Fuses in automotive and electric vehicles are essential elements for overcurrent protection. Their proper selection and maintenance are essential to ensure the integrity of electrical systems, protecting both conventional and electric vehicles against damage caused by adverse electrical conditions.

CIRCUIT-BREAKERS: CHARACTERISTICS AND THEIR ROLE IN OVERLOAD AND SHORT-CIRCUIT PROTECTION:

Circuit breakers, also known as circuit breakers, are essential devices in electrical systems, both in automotive, residential and industrial installations. Their primary function is to protect against overloads and short circuits by interrupting the flow of current when they detect abnormal conditions. The key features of automotive circuit breakers are explored below.

Main features.

Interruption Capacity.

Circuit breakers are designed with a specific interrupting capacity, indicating the maximum current they can safely interrupt. This rating is matched to the requirements of the circuit in which they are installed.

Response time:

The trip curve defines the relationship between the current and the time required for the circuit breaker to trip.

Overloads.

When the current exceeds the preset limit, the thermal element of the circuit breaker is activated. This temperature rise causes the circuit to open, interrupting the current flow and thus protecting against prolonged overloads.

Short circuits.

In the event of a short circuit, the magnetic element of the circuit breaker detects the sudden increase in current and causes a rapid opening of the circuit. This helps prevent significant damage to the equipment and protects against more severe fault conditions.

Circuit breakers are installed at strategic points in the electrical system to allow a quick response to overload or short-circuit conditions.

Vehicle circuit breakers are compact and can withstand very demanding conditions, such as those required in vehicle environments.

In systems that power sensitive equipment, such as electric vehicle electronics, circuit breakers play a critical role in preventing damage caused by overloads that could affect the integrity of electronic components.

They are therefore essential components for electrical safety in automobiles and electric vehicles. Their ability to detect and respond quickly to overloads and short circuits makes them essential to prevent damage to the electrical system, thus ensuring the safe and reliable operation of electrical equipment.

With regard to installations for charging electric vehicle batteries, they must have automatic protection switches or circuit breakers. For example, the Intelligent Protector for Electric Vehicles (hereinafter PIVE). This is an innovative solution that integrates a magneto-thermal circuit breaker designed to safeguard electrical installations in the field of electric vehicle charging.

The PIVE acts as an all-round guardian by protecting the installation against short circuits, overcurrents, transient and permanent overvoltages as well as power failures. Its circuit breaker effectively disconnects the circuit in the event of electrical faults.

Intelligent automatic reconnection. After disconnection due to adverse events, PIVE is distinguished by its ability to automatically reconnect intelligently once the power supply has been restored.

Remote actuation. PIVE offers the convenience of remote actuation, allowing remote control of the device. This feature facilitates efficient management and monitoring of the electrical installation in electric vehicles.

A distinctive feature of the PIVE is its Safety Control function, which prevents the automatic reactivation of the device in the event of manual switch-off. This ensures electrical safety by preventing any unintentional hazards in the installation.

Image 46

PROTECTION RELAYS IN ELECTRIC VEHICLES: PRINCIPLES OF OPERATION AND SPECIFIC APPLICATIONS:

Protective relays play a vital role in the safety and performance of electric vehicle (EV) electrical systems. Their operation is based on specific principles designed to detect and mitigate adverse conditions, thus ensuring the integrity of the vehicle's electrical components. Here we explore the fundamentals of their operation and how they are specifically applied in the context of EVs.

Principles of Operation Adapted to Electric Vehicles:

Anomaly detection:

Protective relays in EVs are designed to constantly monitor specific electrical conditions in the vehicle's systems. They detect anomalies such as overcurrents, overvoltages, short circuits and other situations that could affect the safety and performance of the EV.

Given the dynamic nature of electric vehicles, protection relays must be adaptable to rapid changes in load and driving conditions. Their ability to adjust to these variations ensures an effective response even in highly mobile situations.

Protection in electric vehicles is not only limited to internal electrical conditions, but also to external factors such as sudden changes in temperature or fluctuations in the power supply during charging. Relays must be sensitive to these elements to provide comprehensive protection.

Battery Protection:

Protective relays play a crucial role in the safety of the electric vehicle battery. They detect and respond to conditions that could jeopardise the integrity of the battery, such as overcharging, overheating and short circuits.

Charging System Protection:

Ensuring safety during the charging process is essential. Protective relays intervene to prevent overvoltage situations, protecting both the charging infrastructure and the vehicle's energy storage system.

In modern electric vehicles, the integration of protection relays with vehicle control systems enables a fast and coordinated response to adverse conditions. This capability optimises the effectiveness of electrical protection in real time.

Differential protection in motors and power systems. They are essential for safeguarding motors and power systems in electric vehicles. They detect current imbalances that could indicate faults, preventing damage to critical components.

Protective relays are crucial elements that ensure electrical and electronic safety and performance. Their ability to adapt to the specific dynamics of electric mobility and their precise application in the protection of the battery, charging system and other systems make them essential elements for the safe and efficient operation of modern electric vehicles.

LOCATION AND DISTRIBUTION OF PROTECTIVE DEVICES IN VEHICLE ELECTRICAL CIRCUITS.

The strategic placement and distribution of protective devices in vehicle electrical circuits are critical to ensure the safety, efficiency and reliable performance of electrical systems. The careful arrangement of these devices considers the complexity of the vehicle electrical network as well as the need to protect key components. Below, we explore how the location and layout of protective devices in vehicle circuits is determined.

Key location factors:

Proximity to critical components. Protective devices are placed in direct proximity to critical components, such as the battery, charging system and electric motors. This ensures a rapid response to unwanted events, protecting the essential elements of the vehicle.

Accessibility for maintenance. Accessibility for maintenance is a crucial factor. Protective devices should be located so that they are easily accessible for inspection, testing and replacement, ensuring efficient maintenance and reducing downtime.

Isolation of sensitive components. Protective devices are strategically placed to isolate and protect sensitive components from adverse electrical events. This is particularly important in electric vehicles, where the integrity of power electronics and charging systems is critical.

Distribution at Different Circuit Levels. Protection in the Main Panel:

Higher-level protective devices, such as circuit breakers and main fuses, are located in the main panel, which acts as the electrical distribution centre. These devices protect the overall integrity of the electrical system.

Critical Point Protection:

Additional protection is implemented at critical points, such as the power input to the battery or the charging connector. Devices such as surge relays and high amperage fuses are strategically placed to prevent damage at these vital points.

Protection of High Voltage Systems:

As high voltage systems are operated in electric vehicles, specific protection is provided to ensure safety in these critical areas. Devices such as isolation relays and high voltage fuses.

Location in Safe Zones:

The location of protective devices in safe areas, away from areas prone to impact or exposure to liquids, is critical. This minimises the risk of physical damage or short circuits caused by external conditions.

The location and distribution of protective devices in vehicle electrical circuits are carefully planned to ensure effective and efficient protection. Taking into account factors such as proximity to critical components, accessibility for maintenance and distribution at different circuit levels, an effective implementation is achieved that safeguards the integrity of the vehicle's electrical system.

Fuse arrangement in the battery pack:

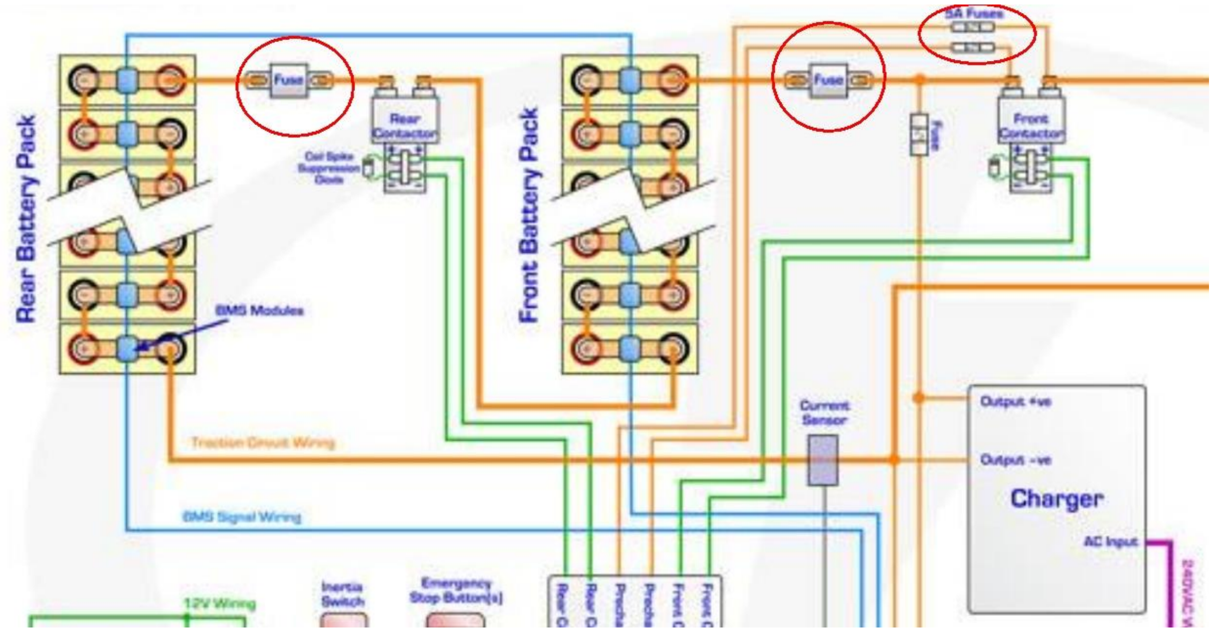


Figure 49

1.4 LEARNING UNIT 4: Earthing principles and methods

The grounding of electric and hybrid vehicles is a crucial aspect to ensure safe operation and prevent electrical hazards. The application of specific principles and methods ensures effective grounding, reducing the likelihood of electric shock and protecting both occupants and vehicle electronics. The fundamentals of grounding principles and methods are explored below in this context.

Basic Principles:

Potential Reference. Grounding in electric vehicles establishes a common potential reference between the vehicle's electrical components and earth. This helps to avoid dangerous potential differences that could arise during operation of the electrical system.

Every manufacturer of electric vehicles must plan and protocol the disconnection of the vehicle's high-voltage electrical system. This is the operation that entails the greatest risk and from which safe work is possible (as there is no voltage in the circuit).

Disconnection means physically separating the vehicle's electrical circuit from the battery pack. UNECE Regulation 100 sets out a number of safety specifications for such a "disconnecting device", which is basically just an electrical connector.

On the other hand, the aforementioned regulation stipulates that all high-voltage electrical cables must have an orange outer sheath. This makes it much easier to detect high-voltage conductors.

Image 50

It is very important to bear in mind that it is not only in a repair shop that this type of vehicle will be handled, but that in a traffic accident the fire brigade has to act and, in many cases, have to cut off parts of the vehicle to extract the occupants. This implies that the location(s) of high voltage disconnection devices must be marked.

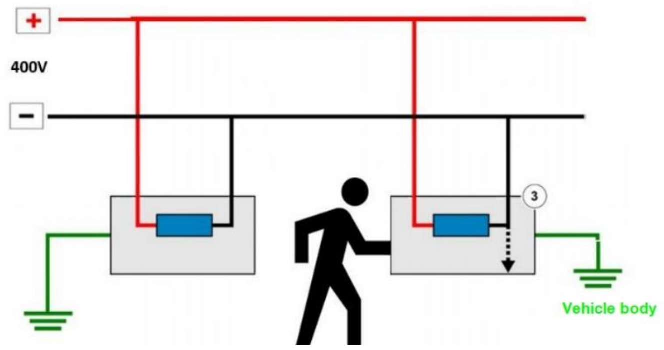
Many manufacturers design a triptych specifying the position of such a disconnector and the areas where it could be cut off. In general, all high voltage circuits should be located underneath the occupant compartment (survival cell) or in the engine compartment or under the luggage compartment floor.

Direct Grounding:

In this method, a direct physical connection is established between the vehicle's electrical component blocks and earth. This is achieved through the use of suitable grounding points on the vehicle chassis, providing a safe path for the current.

Effect of a negative shunt:

Image 51

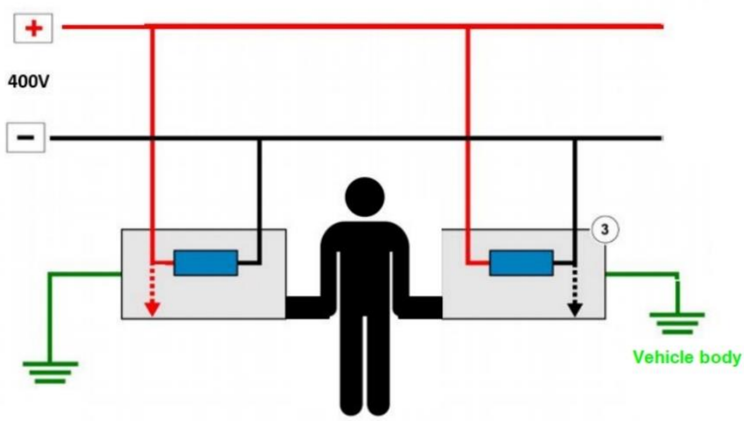


Current will not flow through the person, as only the negative of the high circuit has been contacted.

Positive shunt (with a previous negative shunt)

Image 52

Current will flow through the person, as positive and negative have been contacted.



EV insulation verification

Insulation resistance testing is an essential part of maintenance and inspection to prevent electric shock to EVs. This is especially true as the test verifies proper insulation that protects against the dangerously high voltages of EVs. Furthermore, this test will continue to grow in importance as the EV market continues to increase EV voltages year after year. We will review EV insulation endurance testing below.

Insulation measurement

1. The vehicle's high voltage system must have the service plug or circuit breaker disconnected before any electrical tests or measurements are made.

2. After performing the zero voltage measurement and other safety procedures, which confirm that the vehicle is completely off, the insulation test can proceed.

3. The test voltage applied during insulation measurement must be higher than the vehicle battery voltage. When measuring insulation resistance with the insulation tester use the 500V range if the vehicle's high voltage battery is 400V. Note that the test voltage may vary depending on the vehicle model.

4. Judge whether the insulation is good or bad according to the insulation resistance value specified by the manufacturer for the vehicle model.

5. The tests are performed on both the high voltage battery connector (battery side) and the inverter connector (inverter side). The test is performed between each of the HV cable connectors on the side (battery and inverter) and the vehicle chassis ground. Since there is a diode on the inverter side, it is necessary to change the polarity, so the test is performed twice.

Removal of high voltage components is hazardous work. This operation must be performed by qualified personnel specified by laws and regulations with professional training for work on electric vehicles.

Image 53 (https://www.hioki.com/us-es/learning/applications/detail/id_113356)

Insulation test on the HV battery side (left picture) and on the inverter side (right picture)

Insulation Verification Instruments for High Voltage Systems in Hybrid and Electric Vehicles:

Effective insulation verification in high voltage systems is a critical aspect of the safety and performance of hybrid and electric vehicles. Insulation verification instruments play a vital role in providing accurate diagnostics on the integrity of electrical insulation in these vehicles. Here, we explore the key instruments used for insulation verification in high voltage systems.

Megometers:

Operating Principle: Megmeters apply a significant DC voltage to high voltage systems to assess the insulation resistance. The resulting current is measured, and from this measurement, the insulation resistance is determined.

Specific Applications: Megmeters are effective for checking insulation on cables, electrical connections and high voltage system components. They are particularly useful during preventive maintenance to identify potential problems before they become critical faults.

Image 56

Insulation analysers:

Insulation analysers evaluate insulation resistance, capacitance and leakage current. By measuring over a range of frequencies, they provide detailed information on the quality of the insulation and the presence of possible defects.

These instruments can detect problems such as moisture, contaminants or insulation damage. Some insulation analysers also offer graphing functions for easy interpretation of the results.

Image 57 (https://instrumentosdemedida.es/)

Insulation fault locators:

Operating Principle: Insulation fault locators are used to identify the exact location of faults or short circuits in insulation. They use techniques such as time-of-flight measurement of test pulses to determine the distance to the fault point.

These instruments are essential for corrective maintenance, as they allow to efficiently locate and repair specific areas of insulation failure.

Image 58

Partial discharge testing: Partial discharge testing involves the controlled application of test voltages to cause partial discharges in the insulation. The detection and measurement of these discharges provide information on the quality of the insulation. Since hybrid vehicles often operate on high-voltage systems, PD testing is critical for assessing the integrity of insulation on batteries and critical electrical components.

The Chroma 19501-K partial discharge tester is an instrument equipped with partial discharge detection and AC hipot test functions, providing 0.1 kV~10 kV AC output, 0.01 µA~300 µA leakage current and partial discharge detection of 1pC~2000pC range for measurement. It is specifically designed for testing high voltage semiconductor components and high insulation materials.

Image 59

Insulation verification instruments are critical to ensuring the safety and reliability of high voltage systems in hybrid and electric vehicles. From mego-meters to insulation analysers and fault locators, each instrument plays a specific role in the effective assessment and maintenance of electrical insulation, contributing to the safe and efficient operation of these vehicles.

Other insulation verification tools:

Image 54

A suitable ohmmeter for testing insulation resistance can be Hioki's IR4057-50,

For the HV range (500 V or 1000 V), the IR4057-50 has a safety feature that requires the technician to unlock it in addition to choosing the voltage to prevent erroneous operation of applying a high voltage to low voltage equipment.

Another verification device is the Launch ES200.

Image 55

2.5 LEARNING UNIT 5: Diagnosis, repair & maintenance of electric & electronic systems

TECHNIQUES FOR DIAGNOSING FAULTS IN ELECTRICAL AND ELECTRONIC SYSTEMS IN ELECTRIC VEHICLES.

In addition to conventional measuring devices (multimeters, oscilloscopes, thermometers, etc.), it is necessary to use devices with specific programs to read error codes stored in the vehicle's electronic modules to diagnose electrical faults and malfunctions in any current vehicle, whether thermal, hybrid or electric, providing information on problem areas. These devices also provide a multitude of important data on the operation of all systems, wiring diagrams, verification and repair procedures, actuator checks, etc. Most brands have or recommend their own diagnostic device and software. Some examples are:

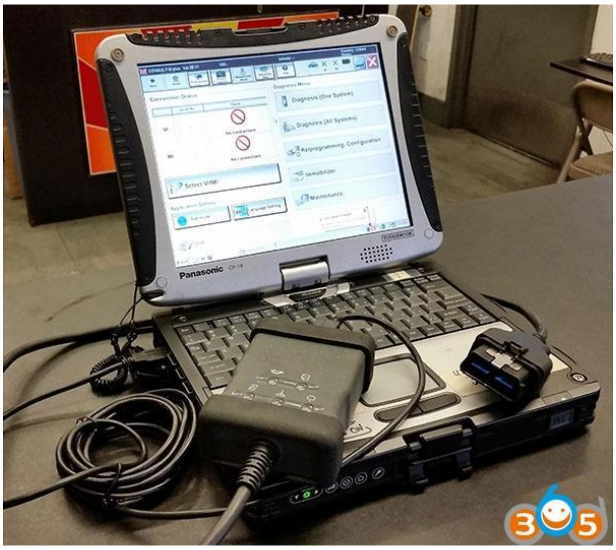
Devices with diagnostic software:

Tesla Diagnostic Tool (Tesla Service Tool): Tool used specifically for Tesla vehicles. Provides access to advanced diagnostics, firmware updates and vehicle-specific configurations.

Image 60

Nissan Consult: Designed for Nissan electric vehicles, this software enables error code reading, system monitoring, component testing and reprogramming of certain modules.

Image 61 (www.obdii365.com)



BMW ISTA (Integrated Service Technical Application): Used for BMW vehicles, including electric and hybrid models. Allows detailed diagnostics, adjustments and software updates.

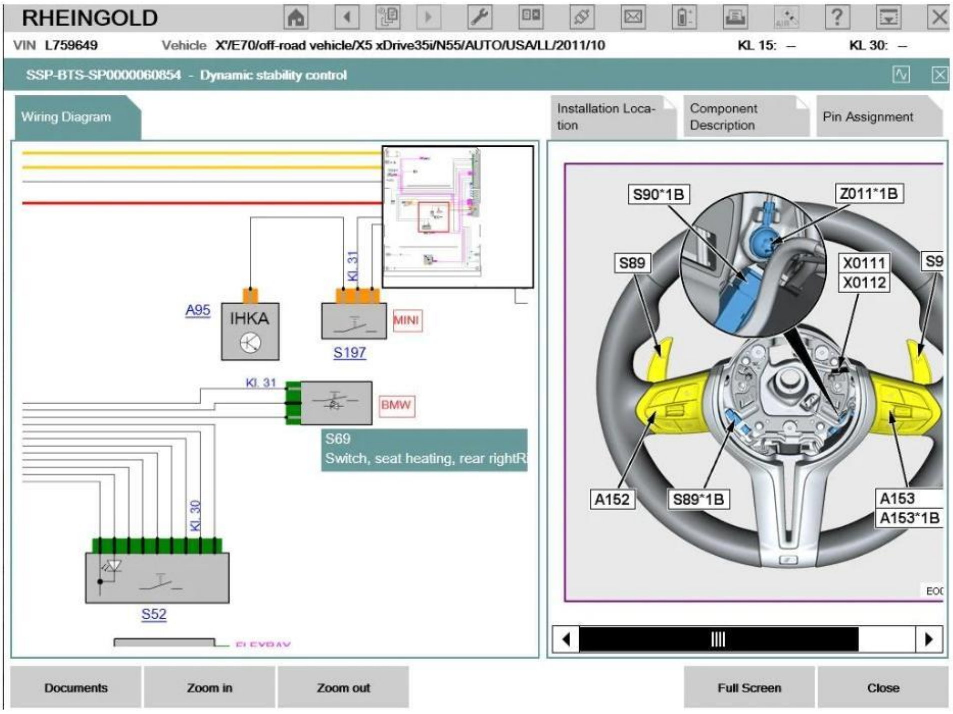


Image 62 (https://techroute66.com/top-5-bmw-diagnostic-software/)

GM Global Diagnostic System (GDS2): Tool used for General Motors electric vehicles, including Chevrolet Bolt EV. Provides advanced diagnostics and access to vehicle systems.

Image 63 (www.obdii.shop)

Ford Integrated Diagnostic System (IDS): Used for Ford electric vehicles. Allows diagnosis, programming and calibration of electronic modules.

Image 64 (www.tradeindia.com)

Volvo VIDA (Vehicle Information and Diagnostics for Aftersales): Software used for Volvo vehicles, including electric and hybrid models. Provides detailed diagnostics and access to technical vehicle information.

Image 65 (www.obdii.shop)

These are just a few examples of specialised diagnostic software used by manufacturers and authorised workshops to perform accurate diagnostics on electric vehicles. These and similar tools provide access to vehicle-specific systems, reading and clearing fault codes, component testing. They have the software updates necessary for the proper maintenance and repair of these vehicles.

Component and wiring tests:

The measurement of voltages, resistances, currents and frequencies in the different components of the electrical system is what enables the detection of faulty components or open or short circuits.

Obviously, we cannot deal in this unit with the diversity of possible failures in components or systems, as each failure or problem would require a specific diagnosis protocol, use of testing devices, repair tools, tools and procedures. Therefore, we will deal, in a general way, with the different devices and techniques that we can use to diagnose and thus be able to solve electrical faults.

Use of Multimeters

Image 66

Multimeters are versatile devices that allow accurate measurements in electrical systems. Their use in electric vehicles covers:

- Voltage Measurement (Voltage): Determines the voltage present in various areas of the vehicle's electrical system, using different measurement ranges depending on the expected voltage in a specific circuit.

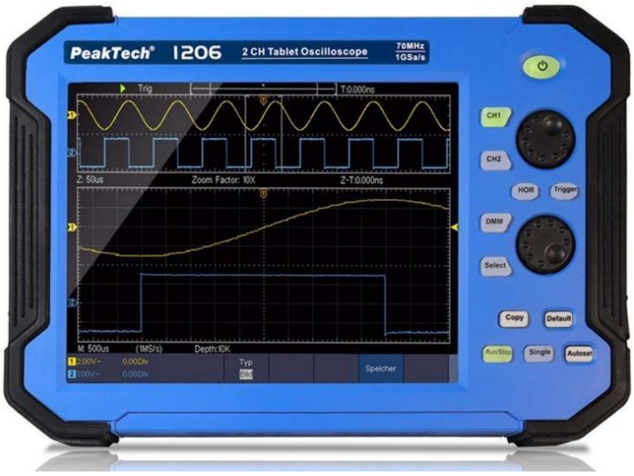
- Current intensity measurement: Allows the current flowing through a component or circuit to be measured, usually by interrupting the circuit for accurate measurement.

- Resistance Measurement: Evaluates the integrity of components, identifying abnormal resistances that could indicate damaged components or open circuits.

- Short Circuit Detection: By measuring the resistance between two points, the presence of short circuits can be identified if the resistance is very low or zero, indicating a direct connection between the measurement points.

Use of oscilloscopes

Image 66



Oscilloscopes, on the other hand, offer the ability to analyse electrical signals as a function of time, providing crucial details in electric vehicle diagnostics:

- Waveform Analysis: Allows visualisation of electrical signal waveforms, making it easier to identify problems such as fluctuations, electrical noise or distorted signals.

- Frequency Measurement: Ability to measure the frequency of periodic signals, identifying irregularities or frequency problems outside expected parameters.

- Electronic Systems Diagnostics: Helps to analyse signals from sensors, actuators or other electronic components, facilitating the identification of problems in these systems.

- Intermittent Trouble Identification: Captures transient or intermittent events that might be difficult to detect with other instruments, facilitating the identification of sporadic problems in the electrical system. It allows the storage of all the waves generated during a given time for later study.

Visual and audible inspection

Visual and auditory inspection of electrical vehicles is essential to detect potential problems in electrical systems. By observing wires, connectors and components for visible damage such as cuts or corrosion, and listening for unusual sounds that could indicate faults, key indications of electrical problems can be identified. This thorough analysis provides an initial assessment that guides the diagnostic and maintenance process, enabling accurate and timely intervention to ensure optimal vehicle performance.

Two devices that can help us in this task are:

Endoscope with inspection camera. It allows us to see on a screen hidden areas that we cannot reach visually otherwise. For example, to see areas of the air conditioning system under the dashboard, or the inside of some air ducts, wiring behind the engine, etc.

Image 68

Stethoscope for automotive use. They have a probe with microphone, different adapters, amplifier and headphones. This device allows us to listen to certain parts of the car and hear noises that allow a diagnosis to be made. For example, noise from hatches when they are operated, fans, belts, vibrating metal sheets, mechanical actuation of relays, etc.

Image 69

Analysis of data and operating parameters:

Data analysis in electric vehicles relies on real-time interpretation of crucial parameters such as voltage, temperature and current, using specialised diagnostic tools. These indicators offer detailed insight into vehicle performance, providing information on battery health, possible overheating in key components and power flow through the system. This continuous monitoring enables early detection of potential problems, facilitating informed decisions regarding preventive maintenance or corrections needed to ensure optimal electric vehicle performance.

Simulation tests.

Electronic simulators are tools that reproduce specific operating conditions to evaluate the behaviour of vehicle systems in a controlled environment. They allow the recreation of operational situations, such as the generation of sensor or actuator signals, to test systems and detect possible faults or anomalies. These simulators are useful for evaluating the performance of electrical and electronic systems without the need to run tests on a real vehicle, thus reducing costs and associated risks.

For example, in the context of an electric vehicle, electronic simulators could be used to recreate specific battery charging and discharging conditions. This involves generating signals that emulate the typical usage patterns of a battery during driving, making it possible to assess how the battery responds and whether there are any anomalies in its operation. Similarly, signals from sensors monitoring the temperature of the electric motor could be simulated to verify its thermal regulation capability under different simulated conditions. These simulators provide a controlled environment to evaluate and improve the performance of vehicle electrical and electronic systems.

Functional tests.

Functional testing in the context of electric vehicles is an essential process to ensure that all vehicle systems operate correctly. These tests include both actuated and real-world tests, and are essential to ensure the overall functionality of the vehicle. During live testing, the various vehicle systems are manually activated, verifying their response and operation under controlled conditions. This process may include the activation of lights, climate control systems and other electrical functions to assess their operability.

On the other hand, real-world testing involves running the vehicle under normal driving conditions to assess its overall performance after repairs or maintenance. These tests verify the behaviour of the electric motor, the efficiency of the regenerative braking system and other key aspects. Specific tests, such as acceleration and deceleration, can also be performed to assess the vehicle's dynamic response.

Advanced diagnostic tools.

Logic analysers are fundamental tools in the advanced diagnosis of complex electrical systems, as they allow the analysis of the time sequence of digital electrical signals. These tools capture and visualise the temporal relationship between different electrical signals, which facilitates the identification of communication, synchronisation or sequencing problems in complex electronic systems, such as those present in electric vehicles.

These analysers can record and display the precise temporal relationship between different digital signals, such as electrical pulses, control signals or data transmitted between different electronic components. For example, in an electric vehicle, they could be used to analyse the communication between the engine management system and the battery controller. If there are synchronisation or data transmission problems, the logic analyser will show time discrepancies between the signals, allowing potential faults in the communication of these systems to be quickly identified and resolved. This tool is crucial in the identification of complex communication problems in electronic systems and in the efficient troubleshooting of faults in electric vehicles and other advanced electronic systems.

Access to specific technical data and manuals.

Access to specific technical data and manuals in the context of electric vehicles refers to the availability of technical documentation provided by the manufacturer, including detailed and accurate information on vehicle operation and maintenance. This documentation includes accurate and comprehensive wiring diagrams as well as specific data for each component of the vehicle's electrical system. There are companies that provide this type of technical information to whoever needs it, usually workshops and professionals, but also vocational training schools, by purchasing or renting their application. This is the case of "Autodata" and other similar companies.

Image 70

As we have seen above, detailed electrical diagrams present a graphical representation of the configuration and connection of the vehicle's electrical components. These diagrams show the layout of circuits, wiring, connectors and the various electrical elements in the system, allowing technicians to understand the interconnection and operation of the electrical system as a whole.

For example, in an electrical schematic of an electric vehicle, it is possible to visualise how the various systems are interconnected, such as the battery, electric motor, inverter, electronic management systems and other components. This makes it possible to precisely identify the current path, connection points and control devices, making it easier to locate and troubleshoot electrical problems or connection faults.

In addition to wiring diagrams, this technical documentation also provides specific data for each component, such as technical specifications, tolerances, resistance values, capacitance, voltage, among other details. This access to detailed information is crucial for carrying out accurate diagnostics and proper maintenance on electric vehicles, ensuring optimal operation and efficient repair of electrical systems.

REPAIR AND MAINTENANCE PROCEDURES

Repair and maintenance procedures for electrical and electronic systems in electric vehicles are crucial to ensure optimum performance and prolong the service life of these systems. Here is an overview of the necessary technical procedures.

Replacement of defective components:

Using the diagnostic techniques mentioned above, defective components are located and determined.

A specific protocol is followed to disassemble the failed components and replace them with new units according to the manufacturer's specifications. In this way, once the faulty component is identified, a root cause analysis is performed to understand why it failed. This step is essential to address not only the obvious symptom, but also the underlying conditions that may have contributed to the failure. This may include factors such as overloads, adverse environmental conditions or normal wear and tear.

A clarifying example would be: When faced with a blown fuse, it is not enough to diagnose and determine that the malfunction of a system is due to a blown fuse and its subsequent replacement. It is essential to know what has caused the fuse to blow, since, if this is not done, it is likely that the problem may occur again, with the consequent inconvenience for the customer and it may affect confidence in the electromechanical technician and the workshop.

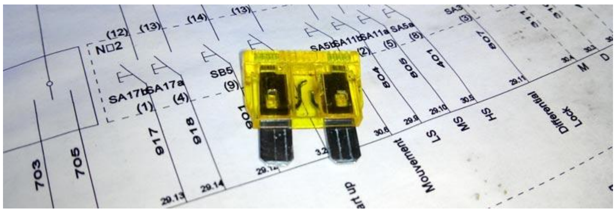


Image 71 (https://fidestec.com/blog/al-final-la-cago-con-un-simple-fusible/)

Replacement Compatibility. Before proceeding with the replacement, the compatibility of the replacement component is checked. It is crucial to ensure that the new unit is compatible with the specific vehicle model, complies with safety regulations and is aligned with the manufacturer's recommendations. This avoids integration problems and ensures optimal performance.

Disassembly of defective components is carried out according to a controlled protocol. Each step is carefully documented to ensure that the operation is carried out efficiently and that any risk of further damage is minimised. During this process, specialised tools may be used and attention is paid to electrical and mechanical connections.

In the case of electric vehicles, battery management is a critical aspect. If a battery problem is identified, specific procedures are followed to safely disconnect and replace the battery. This involves measures to avoid short circuits and to ensure safety when handling high voltage components.

Every phase of the process, from diagnosis to replacement and final testing, is recorded and documented in detail. This information is valuable for future maintenance and provides a complete vehicle maintenance history.

Adjustments and Calibrations:

After repairs or replacements, necessary adjustments and calibrations are carried out to ensure that the systems function correctly.

In some cases, the use of specific equipment is required to make precise adjustments to sensors, actuators or other components.

Preventive maintenance:

Regular inspection programmes are established to detect and prevent possible future problems.

Cleaning and lubrication actions are carried out on connections, components and electrical mechanisms to maintain their good condition, avoiding oxidation and, consequently, unwanted voltage drops.

Software and firmware updates:

Software and firmware upgrades provided by the manufacturer are applied to improve the performance, efficiency or security of electronic units that require it.

Image 72 (https://www.motorpasion.com/tecnologia/sistemas-operativos-en-el-coche-el-futuro-del-automovil)

Functional Tests:

After any kind of repair or maintenance, extensive tests are carried out to verify the correct functioning of the electrical and electronic systems.

These technical procedures in the repair and maintenance of electrical and electronic systems in electric vehicles ensure efficient, reliable and safe service. Rigorous application of these processes helps to maintain system integrity and prevent future problems.

2. LECTURE NOTES (FOR EACH LEARNING UNIT)

2.1 LEARNING UNIT 1: DC VEHICLE ELECTRIC CIRCUITS: PRINCIPLES AND PROPERTIES OF MAGNETISM APPLIED TO VEHICLE CIRCUIT DEVICES

BASIC CONCEPTS OF ELECTRICITY AND MAGNETISM

Electricity & Electric Current:

- Electric current, the flow of negative charges (electrons) through a conductor, is measured in amperes (A).
- Electromotive force (EMF), in volts (V), is required to induce this charge movement.
- The direction of electric current is from a region with excess charges (negative terminal) to a region with a deficit of charges (positive terminal), conventionally represented as positive to negative.

Magnetism & Magnetic Fields:

- Magnetism involves the interaction of magnetic materials, where magnets exhibit north and south poles.
- Measurement units for magnetic fields are Gauss (G) or Tesla (T).
- Magnetic force can induce motion in charged particles, known as the Lorentz force, pivotal in electric motor operations.

OHM'S LAW

- Ohm's Law (V = IR) defines the relationship between voltage (V), current (I), and resistance (R) in electric circuits.
- Useful equations include V = IR and R = V/I.
- Power (P) in watts (W) is defined as V multiplied by I (P = VI).

FARADAY'S LAW

- Faraday's Law underlines how changing magnetic flux induces electromotive force (EMF) in circuits.
- This induction of electricity from a changing magnetic field powers various vehicle components like the alternator.

PRINCIPLES OF OPERATION OF ELECTRICAL DEVICES USED IN DC VEHICLE CIRCUITS

DC ELECTRIC MOTORS

- DC motors convert electrical energy into mechanical energy, utilizing the interaction between magnetic fields and conductors carrying electric current.

- Starter motors and generators in vehicles operate on similar principles, essential for engine operation and battery charging.

MAGNETIC PROPERTIES OF MATERIALS USED IN DC VEHICLE CIRCUIT DEVICES

- Magnetic permeability, susceptibility, hysteresis, and electrical conductivity define the behavior of magnetic materials.
- Proper selection of materials is crucial for efficient design and operation of vehicle electrical systems.

APPLICATION OF MAGNETIC MATERIALS IN RELAYS, INDUCTORS, TRANSFORMERS, AND ELECTRIC MOTORS

- Magnetic materials, such as ferromagnetic substances, are critical in optimizing the performance of these devices in vehicles.
- Relays, inductors, transformers, and electric motors benefit from these materials to enhance efficiency and reliability.

APPLICATION OF THE PRINCIPLES OF MAGNETISM TO SENSORS USED IN DC VEHICLE CIRCUITS

- Magnetic field sensors, like Hall effect sensors, are pivotal in ABS, engine systems, and safety features in vehicles.
- Hall effect sensors and current sensors are essential in monitoring and controlling vehicle systems for optimal performance and safety.

Note: For visual clarity, some equations, illustrations, and diagrams are excluded here.

Estos apuntes cubren los conceptos clave de la Unidad 1.1 relacionados con los circuitos eléctricos de vehículos y las propiedades del magnetismo.

2.2 LEARNING UNIT 2: Interpretation of Wiring Diagrams

Basic Electrical Units

1. Potential Difference

- **Volt (V):** Difference in potential between two points in a circuit; named after Alessandro Volta.
- **1 Volt (V):** Difference between two points on a conductor carrying a current of 1 ampere (A).

2. Current Intensity

- **Ampere (A):** Measures electric current flow; named after André Marie Ampére.
- **1 Ampere (A):** Flow of 1 Coulomb per second.

3. Electrical Resistance

- **Ohm (Ω):** Measures resistance; named after Georg Simon Ohm.
- **1 Ohm (Ω):** Resistance of a conductor with a potential difference of 1 Volt producing a current of 1 Ampere.

4. Electrical Power

- **Watt:** Measures power consumption; named after James Watt.
- **1 Watt:** Power consumed by a device absorbing a current of 1 Ampere at a potential difference of 1 Volt.
- **1 horsepower (hp):** Equals 736 watts.

Basic Elements in a Circuit

Energy Sources

- **Batteries:** Convert chemical energy into electrical energy.
- **Accumulators:** Store electrical energy and transform it back when needed.
- **Generators:** Convert mechanical energy into electrical energy.
- Automobiles typically use direct current (DC) with a voltage supply of 12 or 24 volts.

Drivers

- Wires carry electric current and are bundled into harnesses in vehicles.
- Cables should have appropriate cross-sections to carry current without overheating.
- Conductors are designated by their normal cross-section in square millimeters.

Recipients and Consumers

- Circuits need elements that consume energy like bulbs, motors, or regulators.
- Switches open and close circuits to activate or deactivate elements.
- Various switch types serve different operational needs.

Types of Circuits

1. Simple Electrical Circuit

- Demonstrates behavior during short circuit or open circuit faults.
- Resistance breakdown leads to specific current flow changes.

2. Electric Circuit in Series

- Multiple devices in a single line; same current flows through all.
- Total resistance and consumed power are cumulative.

3. Parallel Circuit

- Multiple branches; each branch has its current flow.
- Voltage remains constant; current distribution varies based on resistance.

4. Mixed Circuit

- Combination of series and parallel associations.

Main Electrical Components

1. Resistors

- Offer opposition to current flow; conductors exhibit resistivity.
- Variable resistors include potentiometers, temperature-dependent, and light-dependent resistors.

2. Switches

- Manually operated, motion, pressure, temperature, and level switches serve specific purposes in circuits.

3. Relays

- Act as electrical switches; control high currents without overloading switches or buttons.

4. Motors and Generators

- Utilize electromagnetic principles to convert electrical energy into mechanical motion or vice versa.

5. Fuses

- Protect electrical systems; melt when current exceeds the preset limit, causing an open circuit.

Electrical Symbology

- Elements in an installation are assigned letters and numbers for identification.
- DIN 40719 assigns specific letters to different electrical elements.

Interpretation of Automotive Wiring Diagrams

- Wiring diagram interpretation is crucial for diagnosing and repairing vehicle electrical systems.
- Standard symbols and conventions exist, but manufacturers may have their own codes.
- Component identification, current direction, legend and colour codes, grounding and feeding points, circuit tracking, fuse, and relay identification are essential aspects of interpreting wiring diagrams.

2.3 LEARNING UNIT 3: CIRCUIT PROTECTION DEVICES

FUSES: Types, Classification, and Their Role in Overcurrent Protection

Fuses play a crucial role in safeguarding automotive and electric vehicle (EV) electrical systems, protecting electronic components, and preventing damage due to overcurrents. The most common fuse types, their classification, and their specific protective function in the automotive context are discussed here.

Types of Fuses

Blade Fuses: Extensively used in automobiles, these fuses have a flat shape and are inserted into fuse blocks allowing for easy visual inspection. They come in various amperage ratings and are common in both conventional and electric vehicles.

Tube Fuses: Though less common in modern automobiles, some vehicles still use tube fuses, especially in specific applications. These fuses consist of a glass or ceramic tube containing a conductive filament.

Mini and Micro Fuses: Designed to occupy less space, mini and micro fuses are utilized in vehicles where space is limited, commonly found in more compact electrical systems such as those in electric vehicles.

Classification of Fuses Based on:

Rated Current: Each fuse has a current rating representing the maximum current it can carry before opening the circuit. Choosing fuses with appropriate current ratings is crucial based on the specific electrical requirements of each vehicle circuit.

Nominal Voltage: The fuse's voltage rating indicates the maximum voltage for which it's designed. It must match the system's voltage to ensure safe performance.

Response Time: Some fuses are designed to respond more rapidly to overcurrents, while others offer slower response times. The choice depends on the application and sensitivity of the vehicle electronics.

LOCATION AND DISTRIBUTION OF PROTECTIVE DEVICES IN VEHICLE ELECTRICAL CIRCUITS

Fuses are strategically placed in the electrical system to protect specific components. For instance, one fuse might safeguard the lighting system, while another might protect the engine control system.

In the event of an overload or short circuit, the fuse blows, interrupting the current flow, thus preventing damage to expensive and sensitive electrical and electronic components.

High Voltage Fuses: As electric vehicles operate on high voltage systems, specific fuses are designed to handle these conditions, providing effective protection in higher power environments.

Electronic Fuses: In more modern electric vehicles, electronic fuses or smart fuses are used. These devices not only interrupt the current but can also send fault information to onboard diagnostic (OBD) systems.

2.4 LEARNING UNIT 4: Earthing Principles and Methods

Electric and hybrid vehicles rely significantly on proper grounding for safety and operational efficiency. This lecture delves into the vital principles and methods associated with grounding in these vehicles, ensuring safety against electric shocks and protecting occupants and vehicle electronics.

Key Grounding Principles:

- **Potential Reference:** Establishing a common potential reference between vehicle electrical components and earth prevents hazardous potential differences during system operation.
- **Disconnection Protocols:** Manufacturers adhere to specific protocols for disconnecting high-voltage electrical systems in vehicles. This process, often involving a disconnecting device or electrical connector, is crucial for safe operations and maintenance.
- **Visual Identification:** High-voltage cables are mandated to have an orange outer sheath, simplifying the detection of these conductors for safety reasons, especially during accidents or emergency interventions.

Direct Grounding Method:

- **Purpose:** Physically connecting vehicle electrical component blocks to earth via suitable grounding points on the chassis ensures a safe path for current.
- **Shunt Effect:** Illustrations demonstrate how a negative shunt prevents current flow through a person, while a positive shunt, preceded by a negative shunt, allows current flow.

Insulation Verification for EVs:

- **Importance:** Regular insulation resistance testing is crucial for preventing electric shocks in EVs, especially with increasing EV voltages over time. The test ensures proper insulation against high voltages.
- **Test Procedure:** Detailed steps for insulation measurement involving disconnection of the high-voltage system, safety procedures, test voltage application, resistance value judgment, and testing both battery and inverter connectors against the vehicle chassis ground.
- **Safety Note:** Removal of high-voltage components requires qualified personnel trained in EV operations due to the associated hazards.

Insulation Verification Instruments:

- **Megohmmeters:** These instruments apply a DC voltage to assess insulation resistance in cables, connections, and system components, aiding preventive maintenance by identifying potential issues.
- **Insulation Analyzers:** Assess insulation resistance, capacitance, and leakage current, offering detailed information on insulation quality and possible defects.

- **Insulation Fault Locators:** Essential for corrective maintenance, these instruments locate and repair specific areas of insulation failure, using techniques to pinpoint faults or short circuits.
- **Partial Discharge Testing:** Controlled test voltages to cause partial discharges in insulation, crucial for assessing insulation integrity, especially in high-voltage systems in hybrid vehicles.

Insulation Verification Instruments in Practice:

- **Chroma 19501-K Partial Discharge Tester:** A specific instrument designed for testing high-voltage semiconductor components and insulation materials, equipped with partial discharge detection and AC hipot test functions.
- **Other Tools:** Ohmmeters like Hioki's IR4057-50 and verification devices like Launch ES200 contribute to effective insulation resistance testing.

2.5 LEARNING UNIT 5: Diagnosis, Repair & Maintenance of Electric & Electronic Systems

Electric and electronic systems in vehicles demand specialized diagnostic techniques for effective troubleshooting, repair, and maintenance. These procedures involve various methods to ensure optimal functionality, prolong system life, and secure safe operations.

Diagnostic Fault-Finding Techniques in Electric and Electronic Vehicle Systems:

1. **Scan and Error Code Analysis:**
    - **Specialized Diagnostic Software:** Utilization of specific programs to scan and read error codes stored in vehicle electronic modules. Examples include Tesla Diagnostic Tool, Nissan Consult, BMW ISTA, GM Global Diagnostic System (GDS2), Ford Integrated Diagnostic System (IDS), and Volvo VIDA. These tools enable diagnostics, component testing, and software updates tailored to different vehicle models.
2. **Component Testing:**
    - **Multimeters:** Versatile devices for precise measurements in electrical systems, encompassing voltage, current, and resistance measurements. They aid in detecting faulty components, open circuits, or short circuits.
    - **Oscilloscopes:** Instruments analyzing electrical signals over time, assisting in waveform analysis, frequency measurement, electronic system diagnosis, and identification of intermittent issues.
3. **Visual and Audible Inspection:**
    - **Visual Examination:** Essential for detecting visible issues such as cable damage, connector issues, or corrosion.

- **Audible Inspection:** Listening for unusual sounds indicating potential faults in the electrical systems.

4. **Data Analysis and Operational Parameters:**
    - Real-time interpretation of crucial parameters like voltage, temperature, and current using specialized diagnostic tools. Monitoring these indicators helps detect early system issues for preventive maintenance.
5. **Simulation Testing:**
    - Electronic simulators replicate specific operational conditions, enabling evaluation of system behavior under controlled environments without using an actual vehicle. These simulate scenarios like battery charge-discharge cycles or sensor signal generation to assess system responses.
6. **Functional Testing:**
    - Crucial for ensuring all vehicle systems operate correctly, including manual activation of different vehicle functions under controlled conditions or actual driving tests after repairs.
7. **Advanced Diagnostic Tools:**
    - Logic analyzers aid in analyzing digital electrical signals' temporal sequence, crucial in diagnosing complex electronic system communication or synchronization issues.
8. **Access to Technical Data and Specific Manuals:**
    - Detailed technical documentation from manufacturers includes precise electrical schematics and specific data for each component, aiding in understanding and diagnosing complex electrical systems.

Repair and Maintenance Procedures for Electric and Electronic Systems:

1. **Component Replacement:**
    - Identification and replacement of faulty components following a specific protocol and manufacturer specifications.
2. **Soldering and Electronic Board Repair:**
    - Thorough inspection and advanced repairs on electronic boards if possible, ensuring optimal functionality.
3. **Adjustments and Calibrations:**
    - Necessary adjustments and calibrations post-repair to ensure proper system functionality.
4. **Preventive Maintenance:**

- Scheduled inspections, cleaning, and lubrication to prevent future issues and maintain system health.

5. **Software and Firmware Updates:**
    - Implementation of updates to enhance system performance, efficiency, and security.
6. **Post-Repair Functional Testing:**
    - Comprehensive testing to confirm the correct operation of electrical and electronic systems after maintenance or repairs.

These meticulous diagnostic and repair techniques ensure efficient, reliable, and secure service for electric and electronic vehicle systems, preserving system integrity and preventing future issues.

3. QUESTIONS AND ANSWERS (FOR THE ENTIRE MODULE)

1. **Why is it important to establish a potential reference in electric vehicles?**

Answer**:** Learning Unit 1

Establishing a potential reference is critical in electric vehicles as it ensures a common voltage level between the vehicle's electrical components and the ground. This mitigates the risk of hazardous potential differences that could cause electrical shocks or damage to sensitive components. By creating this reference, it helps maintain a stable and safe electrical environment within the vehicle's system.

2. **What is the purpose of insulation resistance inspection in electric vehicles?**

Answer**:** Learning Unit 1

Insulation resistance inspection is integral to ensuring the safety and reliability of electric vehicles. This test assesses the insulation integrity within the vehicle's high-voltage system, protecting against potentially dangerous voltages. It verifies that the insulation is effective in preventing current leakage and potential electrical hazards, a crucial aspect for maintaining the safety of occupants and the vehicle's electronic systems.

3. **What function do inverters serve in electric vehicles?**

Answer**:** Learning Unit 2

Inverters play a vital role in electric vehicles by converting direct current (DC) from the vehicle's batteries into alternating current (AC) that powers the electric motor. This transformation is essential as electric motors typically operate on AC power. Inverters control the speed and torque of the motor by managing the frequency and amplitude of the AC power supplied.

4. **Why is periodic inspection of high-voltage cables in electric vehicles crucial?**

Answer**:** Learning Unit 2

Periodic inspection of high-voltage cables is crucial to maintain the safety and reliability of electric vehicles. These inspections ensure the integrity of the cables, preventing potential risks of short circuits, insulation degradation, or electrical failures. Regular checks help identify early signs of wear, damage, or degradation, allowing for timely maintenance or replacement, reducing the likelihood of system failures or safety hazards.

5. **What is the main difference between Level 1 charging and Level 2 charging?**

Answer**:** Learning Unit 3

The primary distinction between Level 1 and Level 2 charging lies in the charging speed and power delivery. Level 1 charging involves using a standard household electrical outlet and delivers a lower charging power, typically at a rate of about 2-5 miles of range per hour of charging. Conversely, Level

2 charging requires a dedicated charging station, delivering a higher power output, typically around 10-60 miles of range per hour of charging, significantly reducing charging times compared to Level 1.

6. What advantages does V2G technology offer in the context of electric vehicle charging infrastructure?

Answer: Learning Unit 3

Vehicle-to-Grid (V2G) technology allows electric vehicles not only to draw power from the grid for charging but also to supply excess energy back to the grid when needed. This bidirectional flow of electricity supports grid stability, especially during peak demand periods. V2G technology enables vehicles to function as energy storage units, contributing to grid balancing, potentially reducing energy costs, and enhancing grid reliability.

9. What is the significance of marking the location of high-voltage disconnection devices in electric vehicles?

Answer: Learning Unit 4

Marking the location of high-voltage disconnection devices in electric vehicles is crucial for emergency situations, such as accidents or rescue operations. Emergency responders or technicians need clear identification of these devices to safely disconnect the high-voltage systems, reducing the risk of electrical hazards. Marking these locations aids in swift and safe extraction of occupants and informs personnel about potential high-voltage areas, minimizing the risk of accidental contact or damage during rescue procedures.

10. How do insulation verification instruments contribute to the safety of high-voltage systems in electric vehicles?

Answer: Learning Unit 4

Insulation verification instruments play a critical role in ensuring the safety and reliability of high-voltage systems in electric vehicles. These instruments, such as megometers and insulation analyzers, assess the insulation resistance and integrity of electrical components. By detecting potential faults, moisture, or damage in the insulation, these tools enable proactive maintenance, preventing electrical hazards and ensuring the safety and optimal performance of high-voltage systems in electric vehicles.

Learning Unit 5: Diagnosis, Repair & Maintenance of Electric & Electronic Systems

9. Why is the utilization of specialized diagnostic software crucial in diagnosing electric vehicle systems?

Answer**:** Learning Unit 5

Specialized diagnostic software provides detailed insights into the complex electronic systems of electric vehicles. These tools, tailored to specific vehicle brands or models, enable technicians to scan and interpret error codes stored in vehicle modules. This information helps identify problematic areas, enabling precise diagnosis and targeted repairs. Utilizing such software ensures accurate fault detection and efficient troubleshooting of electric and electronic systems in vehicles.

10. **How does visual and audible inspection aid in diagnosing electrical problems in electric vehicles?**

Answer: Learning Unit 5

Visual and audible inspections are essential diagnostic techniques in identifying potential electrical issues in electric vehicles. Visual inspection involves scrutinizing cables, connectors, and components for visible damages like cuts, corrosion, or anomalies. Simultaneously, listening for unusual sounds provides clues about potential electrical failures. These meticulous inspections serve as an initial assessment, guiding further diagnostic processes, ensuring timely interventions, and guaranteeing optimal operation of electric vehicle systems.

4. CASE STUDIES (FOR THE ENTIRE MODULE)

4.1 CASE STUDY 1: Insulation Testing Protocol Enhancement

Background:

An electric vehicle (EV) manufacturing company has been experiencing sporadic issues with the insulation of high-voltage systems in their vehicles. Despite following standard insulation testing protocols, occasional faults are detected post-production, leading to concerns about the reliability and safety of their EVs.

Scenario:

Several EVs have been recalled due to insulation-related problems, resulting in inconvenience to customers and a negative impact on the company's reputation. The current insulation testing procedure involves using traditional megometers and insulation analysers, but these tools haven't been fully effective in detecting underlying faults in the high-voltage systems.

Analysis:

Upon detailed analysis, it was found that the existing insulation testing procedure lacks the capability to identify subtle defects in the insulation of high-voltage components. The traditional tools used in the process have limitations in detecting intermittent faults and do not provide a comprehensive evaluation of the insulation's integrity.

Recommendation:

To address these concerns, the company should consider upgrading their insulation testing protocol. Implementing advanced partial discharge testing equipment, such as the Chroma 19501-K partial discharge tester, alongside existing tools, could enhance the efficacy of insulation testing. This approach allows for a more nuanced assessment of insulation quality and can detect subtle faults that might go unnoticed during routine tests. Furthermore, additional measures like incorporating insulation fault locators into the testing process can pinpoint precise locations of insulation defects, enabling targeted repairs or replacements.

4.2 CASE STUDY 2: Diagnostic Software Integration for Enhanced Vehicle Analysis

Background:

A service center specializing in electric vehicle maintenance and repair has been facing challenges in effectively diagnosing faults in various EV models due to the lack of comprehensive diagnostic software.

Scenario:

Technicians at the service center have been struggling to address specific issues in different EVs because the diagnostic software they currently use is limited to basic fault code reading. This limitation has resulted in longer repair times, increased customer dissatisfaction, and a backlog of unresolved issues.

Analysis:

Upon careful examination, it's evident that the diagnostic software available to the technicians lacks compatibility with newer EV models and doesn't offer in-depth analysis beyond error code interpretation. The absence of manufacturer-specific diagnostic tools has hindered the accurate identification of complex electrical and electronic system faults.

Recommendation:

To improve diagnostic accuracy and efficiency, the service center should invest in specialized manufacturer-centric diagnostic software. Introducing Tesla Diagnostic Tool, Nissan Consult, BMW ISTA, and other manufacturer-specific software can significantly enhance the capability of technicians to perform comprehensive diagnostics. Additionally, offering training sessions for technicians to familiarize themselves with these tools and their functionalities will empower them to diagnose and resolve intricate issues more efficiently. Integrating these advanced diagnostic software solutions will streamline the repair process, reduce turnaround time, and elevate customer satisfaction levels significantly.

5. MULTIPLE CHOICE QUESTIONS (FOR THE ENTIRE MODULE)

1. When talking about the movement of charges in electricity:

Select one:

a. It refers to a movement of resistances, which is measured in Ohms.

b. It refers to a movement of positive charges or free electrons, which is measured in Coulombs.

c. Refers to a movement of negative charges or free electrons, which is measured in Coulombs.

2. Which of the following is true regarding the term potential difference:

Select one:

a. 1 Volt (V) is the difference in potential between two points on a conductor, regardless of the current flowing.

b. 1 Volt (W) is the difference in potential between two points on a conductor carrying a current of 0.5 amperes (A).

c. 1 Volt (V) is the potential difference between two points on a conductor carrying a current of 1 ampere (A).

3. The Law of Ohm

Select one:

a. Refers to the safety regulations for the operation of a multimeter.

b. It establishes a relationship between potential difference, current and resistance.

c. It establishes a relationship between current and operating temperature.

4. They receive electrical energy which they transform into chemical energy, keeping it stored, to later undo the transformation and return electrical energy again.

Select one:

a. Refers to the operation of a pressure switch

b. None of the other options

c. Corresponds to the definition of a battery

5. The maximum current that a cable can carry depends on the cross-section and length of the cable.

Select one:

a. The current that a cable can carry never depends on its cross-section.

b. This statement is true

c. The current that a cable can carry never depends on its length.

6. A series circuit:

Select one:

a. Is composed of two or more branches, each of which contains at least one electrical device.

b. It consists of a single line where there are two or more electrical devices, connected together.

c. It is an association of elements without any criteria when connecting them.

7. A parallel circuit:

Select one:

a. Is not used in automobile electrics

b. It consists of a single line where two or more electrical devices are connected to each other.

c. It consists of two or more branches, each of which contains at least one electrical device.

8. The relay is an electrical component that functions as a switch.

Please select one:

a. A relay is not a switch

b. True. It is composed of an electromagnetic coil that when excited causes a magnetic field that causes the contacts of the interrupter to close.

c. Yes, it is. It is always actuated by the effect of the pressure of a fluid.

9. A fuse is a protection element.

Please select one:

a. None of the other options is correct

b. Composed of a conductive wire or sheet of a given cross-section, when the current in a circuit exceeds the preset limit, the conductive wire or sheet of the fuse melts causing an "open circuit" situation.

c. Composed of a conductor wire of a given cross-section, when the current in a circuit is less than the preset limit, the conductor wire of the fuse blows causing an "open circuit" situation.

10. During the inspection of an electrical vehicle:

Select one:

a. The test voltage applied during the insulation measurement must be higher than the vehicle battery voltage.

b. The test voltage applied during the insulation measurement must be less than the voltage of the vehicle's battery.

c. The test voltage applied during the insulation measurement must be equal to the voltage of the vehicle's battery.

Correct answer:

1	2	3	4	5	6	7	8	9	10
C	C	B	B	B	B	C	B	B	C

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MODULE 2

VEHICLE ELECTRICAL AND ELECTRONIC

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1 LECTURE NOTES (FOR EACH LEARNING UNIT)

1.1 LEARNING UNIT 1: DC VEHICLE ELECTRIC CIRCUITS - PRINCIPLES AND PROPERTIES OF MAGNETISM APPLIED TO VEHICLE CIRCUIT DEVICES

Electricity and Magnetism form the backbone of DC Vehicle Electric Circuits. Electricity involves the movement of negative electric charges (electrons) through conductive materials, generating work, such as powering lights or motors. The concept of charge movement quantifies in Coulombs (C), with electric current measured in Amperes (A), depicting the flow of free charges within a conductor.

The generation of this movement requires Electromotive Force (EMF) measured in volts (V), often supplied by batteries or alternators. Electric current direction, conventionally from positive to negative, simplifies circuit analysis, even though the actual movement is from regions of excess to deficit charges.

Magnetism delves into magnetic materials' behaviour, their interaction, and the strength of magnetic fields measured in Gauss (G) or Tesla (T). Understanding magnetisation, measured in amperes per meter (A/m), elucidates the alignment of magnetic dipoles under an external magnetic field.

Electric currents create magnetic fields around conductors they flow through, essential in comprehending natural phenomena and designing technological devices like generators and motors.

Ohm's Law

The foundational electrical circuit comprises a generator (battery) and a receiver (load with a resistor R, e.g., a lamp). Ohm's Law—$V = IR$—establishes the relationship between voltage (V), current (I), and resistance (R), pivotal in understanding power equations like $P = VI$.

In vehicles, the ground terminal isn't directly linked to receivers. Instead, the negative battery terminal connects to the body, acting as the ground. Faraday's Law and electromagnetic induction are pivotal in understanding how electric currents are generated by changing magnetic fields.

Principles of Operation of Electrical Devices used in DC Vehicle Circuits

Electric motors, pivotal in vehicle propulsion, convert electrical energy into mechanical energy. A conductor passing current through a magnetic field creates movement due to the interaction between magnetic fields. This principle is leveraged in starter motors, where coils create magnetic fields to generate torque essential for starting the engine.

The battery powers the starter motor, but continuous power draw depletes it. Hence, a charging system recharges the battery by reversing the generator's principle. All electric motors operate through electromagnetic induction, creating a rotating force through a variable magnetic field.

Magnetic Properties of Materials in DC Vehicle Circuit Devices

Materials like iron and steel with high magnetic permeability allow magnetic flux lines to pass through. Ferromagnetic materials intensify magnetic fields and retain some magnetisation even after the field is removed. Electrical conductivity of materials, like copper and aluminium, also influences device efficiency.

Application of Magnetic Materials in Relays, Inductors, Transformers, and Electric Motors

Magnetic materials optimise the performance of these devices. In relays, ferromagnetic cores concentrate magnetic flux, ensuring reliable switch operation. Inductors and transformers use ferromagnetic cores to increase inductance and improve efficiency. Electric motors utilise permanent magnets or ferromagnetic rotors for enhanced efficiency and performance.

Application of Magnetism Principles in Sensors used in DC Vehicle Circuits

Sensors leverage magnetism for precise measurements and control in various vehicle functions. Speed sensors in Anti-lock Braking Systems (ABS) detect wheel rotations using Hall effect or magnetic reluctance sensors, crucial in dynamically adjusting brake pressure. Crankshaft position sensors track engine position and speed, optimising fuel injection and spark synchronisation.

Hall Effect Sensors and their Performance in Detecting Magnetic Fields

Hall effect sensors, relying on semiconductor foils, generate voltage proportional to the surrounding magnetic field. Widely used in position and velocity sensing in motors, these sensors provide fast and accurate measurements.

Current Sensors and their Use in Measuring Current in Circuits

Current sensors, based on Hall effect or resistance, accurately measure electrical current flow. In electric vehicle Battery Module Blocks (BMDs), these sensors play a crucial role in precise current monitoring. They aid in thermal management, optimising battery life, ensuring system safety, and enhancing energy efficiency.

This comprehensive overview emphasises the fundamental role of electricity, magnetism, and their application in vehicle circuitry, elucidating their importance in optimising performance, efficiency, and safety in automotive electrical systems.

1.2 LEARNING UNIT 2: Interpretation of Wiring Diagrams

Understanding Electrical Systems in Automobiles

Electricity is the lifeblood of modern vehicles, powering essential functions from engine ignition to interior electronics. To comprehend the intricacies of automotive electrical systems, one must grasp the fundamental units, basic circuit elements, circuit types, main components, electrical symbology, and the interpretation of wiring diagrams.

Basic Electrical Units and Circuit Elements

The concept of electrical potential difference, measured in volts (V), signifies the distinction in potential between two points in a circuit. Alessandro Volta's contributions are honoured by this unit, wherein 1 Volt denotes the potential difference between two points on a conductor carrying a current of 1 ampere (A).

Electric current, quantified in Amperes (A), represents the flow of electrons within a circuit. André Marie Ampère's work established that 1 Ampere corresponds to a flow of 1 Coulomb per second.

Electrical resistance, measured in Ohms (Ω), characterizes the opposition encountered by a conductor to the flow of current. Georg Simon Ohm's insights led to defining one ohm as the resistance when a potential difference of one Volt generates a current of 1 Ampere.

Electrical power consumption is defined in Watts, highlighting the power consumed by a device drawing one ampere under a one-volt potential difference. James Watt's contributions led to the definition of this unit.

Basic Elements in a Circuit

Vehicles rely on diverse energy sources, such as batteries, accumulators, and generators, to convert energy into electrical power. In automobiles, direct current (DC) with a voltage of 12 or 24 volts is prevalent, usually supplied by batteries.

Wires, acting as conductors encased in insulators, facilitate the transmission of electric current. Bundled into harnesses, these wires form intricate pathways, identified by their color codes.

Recipients and consumers in vehicle electrical systems utilize this energy. Switches play a pivotal role in controlling circuit connectivity, activating or deactivating various vehicle components.

Types of Circuits

Electrical circuits come in various configurations:

- **Simple Electrical Circuit**: Comprising a battery, resistor, and interconnecting wires, a fault (short or open circuit) can impede current flow.
- **Series Circuit:** Devices in a single line share the same current; the total resistance is the sum of individual resistances.

- **Parallel Circuit**: Branches allow different currents based on device consumption; if one device fails, others continue functioning.
- **Mixed Circuit**: Combining elements of series and parallel circuits, it blends their characteristics.

Main Electrical Components

Resistors, fixed or variable, regulate current flow by altering resistance values. Variable resistors like potentiometers allow manual or automatic resistance adjustment.

Switches, available in diverse types, respond to different stimuli. Manual, motion, pressure, temperature, and level switches serve specific purposes within a vehicle's electrical system.

Relays act as electrical switches powered by an electromagnetic coil. They regulate high electrical currents without overloading control switches.

Motors and generators transform electrical energy into mechanical power, crucial for various vehicle components such as starter motors.

Fuses safeguard circuits; if the current exceeds a present limit, the fuse wire melts, breaking the circuit to prevent damage.

Electrical Symbology and Wiring Diagram Interpretation

Understanding electrical schematics is critical for diagnosing and repairing vehicle electrical systems. Each component is represented by a unique symbol. These symbols aid in identifying actual components within the vehicle.

Diagrams provide information on wire colours, circuit directions, grounding, feeding points, and the identification of fuses and relays. Technicians interpret these diagrams to trace circuits, identify component locations, and understand current flow.

The interpretation of automotive wiring diagrams demands an understanding of standard symbols, colour codes, and specific manufacturer conventions. This involves recognizing components, following circuit paths, and comprehending electrical system behaviour for effective diagnosis and repair.

In summary, comprehending the nuances of automotive electrical systems involves an understanding of fundamental units, circuit elements, circuit types, main components, electrical symbology, and interpreting wiring diagrams. This knowledge is crucial for ensuring the optimal functioning of vehicle electrical systems.

1.3 LEARNING UNIT 3: CIRCUIT PROTECTION DEVICES

FUSES: Types, Classification, and Their Role in Overcurrent Protection

Fuses play a crucial role in safeguarding automotive and electric vehicle (EV) electrical systems, protecting electronic components, and preventing damage due to overcurrents. The most common fuse types, their classification, and their specific protective function in the automotive context are discussed here.

Types of Fuses

Blade Fuses: Extensively used in automobiles, these fuses have a flat shape and are inserted into fuse blocks allowing for easy visual inspection. They come in various amperage ratings and are common in both conventional and electric vehicles.

Tube Fuses: Though less common in modern automobiles, some vehicles still use tube fuses, especially in specific applications. These fuses consist of a glass or ceramic tube containing a conductive filament.

Mini and Micro Fuses: Designed to occupy less space, mini and micro fuses are utilised in vehicles where space is limited, commonly found in more compact electrical systems such as those in electric vehicles.

Classification of Fuses Based on:

- **Rated Current:** Each fuse has a current rating representing the maximum current it can carry before opening the circuit. Choosing fuses with appropriate current ratings is crucial based on the specific electrical requirements of each vehicle circuit.
- **Nominal Voltage:** The fuse's voltage rating indicates the maximum voltage for which it's designed. It must match the system's voltage to ensure safe performance.
- **Response Time:** Some fuses are designed to respond more rapidly to overcurrents, while others offer slower response times. The choice depends on the application and sensitivity of the vehicle electronics.

LOCATION AND DISTRIBUTION OF PROTECTIVE DEVICES IN VEHICLE ELECTRICAL CIRCUITS

Fuses are strategically placed in the electrical system to protect specific components. For instance, one fuse might safeguard the lighting system, while another might protect the engine control system.

In the event of an overload or short circuit, the fuse blows, interrupting the current flow, thus preventing damage to expensive and sensitive electrical and electronic components.

High Voltage Fuses: As electric vehicles operate on high voltage systems, specific fuses are designed to handle these conditions, providing effective protection in higher power environments.

Electronic Fuses: In more modern electric vehicles, electronic fuses or smart fuses are used. These devices not only interrupt the current but can also send fault information to onboard diagnostic (OBD) systems.

Strategic Placement and Functions of Fuses

Strategically placed within the electrical system, fuses act as sentinels, shielding critical components such as lighting systems and engine controls. Upon encountering overloads or short circuits, fuses blow, halting current flow to prevent extensive damage to sensitive electronic parts. Visual identification through specific colours and codes aids in swift replacement, maintaining operational integrity.

Specialised Fuses for Electric Vehicles

Electric vehicles, with their intricate high-voltage systems, require specialised fuses to safeguard batteries and manage high-power circuits. Modern electric vehicles incorporate electronic or smart fuses that not only interrupt current flow but also relay fault data to onboard diagnostic systems, enhancing diagnostic capabilities and overall system safety.

Circuit-Breakers: Characteristics and Roles in Overload and Short-Circuit Protection

Circuit breakers, essential in automotive, residential, and industrial electrical setups, protect against overloads and short circuits by interrupting current flow under abnormal conditions. Their features, interruption capacities, response times, and functions in diverse scenarios unfold their crucial role in maintaining system integrity.

Characteristics and Responses of Circuit Breakers

Circuit breakers are defined by their interruption capacities and response times. The former indicates the maximum current they can safely interrupt, aligning with specific circuit requirements, while the latter defines their reaction speed to current changes.

Roles in Overloads and Short Circuits

During overloads, thermal elements within circuit breakers activate, causing circuit interruption and preventing prolonged overloads. For short circuits, the magnetic elements rapidly open the circuit, averting equipment damage. Positioned strategically, compact circuit breakers withstand demanding conditions, safeguarding sensitive electronic components, especially in electric vehicles.

Protective Relays in Electric Vehicles: Principles and Applications

Protective relays are pivotal in ensuring safety and performance within EV electrical systems. Operating on specific principles, these devices detect and mitigate adverse conditions, covering internal and external factors affecting the safety and performance of EVs.

Operating Principles of Protective Relays

Relays continuously monitor electrical conditions in EVs, detecting anomalies like overcurrents, overvoltages, short circuits, and external factors such as temperature fluctuations during charging. Their adaptability to rapid changes in load and driving conditions ensures an effective response, emphasising comprehensive protection.

Roles in Battery and Charging System Protection

Protective relays ensure battery safety by detecting and responding to overcharging, overheating, and short circuits. During the charging process, they prevent overvoltage situations, optimising safety for both the infrastructure and the vehicle's energy storage system.

Integration with Control Systems and Differential Protection

Integration with vehicle control systems enables a coordinated response to adverse conditions, optimizing real-time electrical protection. Additionally, relays play a critical role in differential protection, safeguarding motors and power systems in electric vehicles.

Location and Distribution of Protective Devices in Vehicle Circuits

Strategic placement of protective devices is crucial in ensuring the safety, efficiency, and reliable performance of vehicle electrical systems. Factors like proximity to critical components, accessibility for maintenance, and distribution at different circuit levels drive effective implementation.

Key Location Factors and Distribution Strategies

Protective devices are placed proximately to critical components like batteries and charging systems, ensuring rapid response to electrical events. Accessibility for maintenance minimises downtime, and careful distribution at different circuit levels enhances overall system protection.

Strategic Distribution and Safe Placement

Protective devices are strategically placed to isolate sensitive components from adverse electrical events, safeguarding against damage. Special attention is given to high-voltage system protection and safe placement away from potential risks like impacts or exposure to liquids, mitigating physical damage or short circuits caused by external conditions.

1.4 LEARNING UNIT 4: Earthing Principles and Methods

The grounding of electric and hybrid vehicles is paramount for their safe operation and to mitigate potential electrical hazards. Specific principles and methods are integral in establishing effective grounding, reducing the risk of electric shock, and ensuring the safety of both passengers and vehicle electronics. This unit delves into the fundamental grounding principles and methodologies relevant to this context.

Foundations of Grounding Principles

Electric vehicle grounding primarily establishes a common potential reference between the vehicle's electrical components and the earth. This connection prevents hazardous potential differences that might arise during electrical system operation. Disconnection of the vehicle's high-voltage electrical system is a critical operation that manufacturers plan meticulously to ensure safety. This process involves physically separating the vehicle's electrical circuit from the battery pack, adhering to safety specifications outlined in UNECE Regulation 100.

Safety Measures and Disconnection Protocols

In scenarios beyond repair, such as traffic accidents, emergency responders like the fire brigade might need to extract passengers, necessitating clear marking and accessibility to high voltage disconnection devices. Manufacturers often design guidelines indicating the disconnector's position and areas for potential extraction, typically locating high voltage circuits beneath the occupant compartment or within designated compartments in the vehicle.

Direct Grounding and Its Mechanism

Direct grounding involves a physical connection between the vehicle's electrical component blocks and the earth through suitable grounding points on the vehicle chassis. This method ensures a safe pathway for electrical current and minimises potential risks to individuals. Illustrative diagrams demonstrate the impact of negative and positive shunts on current flow through a person, highlighting safety considerations.

Insulation Verification and Testing

Insulation resistance testing is crucial maintenance for EVs, as it safeguards against electric shock, especially considering the increasingly high voltages used in modern EVs. Testing procedures necessitate proper disconnection, confirmation of zero voltage, and subsequent insulation tests with voltages higher than the vehicle's battery voltage. Insulation resistance values specified by the manufacturer determine the quality of insulation, tested at various high-voltage system points.

Insulation Verification Instruments

A suite of instruments ensures accurate assessment and maintenance of electrical insulation in high voltage systems. megohmmetres apply DC voltage to evaluate insulation resistance; insulation analysers assess resistance, capacitance, and leakage current, while insulation fault locators pinpoint faults or short circuits. Partial discharge testing, using instruments like the Chroma 19501-

K partial discharge tester, provides critical insight into insulation integrity, especially in hybrid vehicles operating on high-voltage systems.

Importance of Insulation Verification Tools

Instruments like ohmmeters and devices such as Launch ES200 complement the suite of insulation verification tools, ensuring comprehensive and effective testing of insulation resistance. Each instrument, from megohmmetres to fault locators, plays a specific role in assessing and maintaining electrical insulation, vital for the safe and reliable operation of electric and hybrid vehicles.

Effective grounding, meticulous disconnection protocols, and comprehensive insulation verification through specialised instruments form the cornerstone of safety measures in electric and hybrid vehicles. These practices ensure safe operations, mitigate electrical risks, and preserve the integrity of both vehicle occupants and electronic systems.

1.5 LEARNING UNIT 5: Diagnosis, Repair & Maintenance of Electric & Electronic Systems

Techniques for diagnosing faults in electrical and electronic systems in electric vehicles.

In diagnosing electrical faults in vehicles, specific devices and software are essential alongside conventional tools. They read stored error codes in the vehicle's electronic modules and offer extensive data on system operations, wiring diagrams, repair procedures, and actuator checks. Major vehicle brands recommend or offer their diagnostic devices and software.

Specialised Diagnostic Software

Distinct software like Tesla's Diagnostic Tool, Nissan Consult, BMW ISTA, GM Global Diagnostic System, Ford Integrated Diagnostic System, and Volvo VIDA, tailored for specific vehicle brands, aid in error code reading, system monitoring, and reprogramming of modules, ensuring accurate diagnostics.

Component and Wiring Tests

Multimetres play a versatile role in electric vehicle diagnostics:

- Voltage Measurement: Evaluates voltage across vehicle circuits.
- Current Intensity Measurement: Measures current flow through circuits/components.
- Resistance Measurement: Assesses component integrity.
- Short Circuit Detection: Identifies short circuits by measuring resistance between points.

Oscilloscopes analyse electrical signals over time:

- Waveform Analysis: Visualises signal waveforms, identifying issues like fluctuations or distortions.

- Frequency Measurement: Identifies frequency irregularities in signals.
- Electronic Systems Diagnostics: Helps analyse sensor and actuator signals.

Visual and Auditory Inspection

Visual inspection detects visible damage in wires, connectors, and components. Auditory inspection detects unusual sounds indicating faults, providing initial indicators for diagnostics. Devices like endoscopes and automotive stethoscopes aid in assessing hidden areas and diagnosing specific noises.

Analysis of Data and Operating Parameters

Real-time interpretation of voltage, temperature, and current reveals vehicle performance details, facilitating early problem detection and informed maintenance decisions.

Simulation Tests

Electronic simulators recreate operating conditions, evaluating system behaviour in controlled environments. They test systems without using real vehicles, reducing costs and risks.

Functional Tests

Tests, both actuated and real-world, ensure proper system functionality and assess vehicle performance under various conditions.

Advanced Diagnostic Tools

Logic analysers assist in complex electronic system diagnosis by analysing the temporal relationship between digital electrical signals, identifying communication or synchronisation problems efficiently.

Access to Specific Technical Data and Manuals

Technical documentation provides detailed wiring diagrams and component-specific data, crucial for accurate diagnostics and proper maintenance.

Repair and Maintenance Procedures

Replacing defective components follows a specific protocol, addressing root causes for optimal repair. Ensuring compatibility and controlled disassembly are integral steps.

Adjustments, preventive maintenance, software updates, and functional tests complete the repair and maintenance procedures, ensuring efficient, reliable, and safe service for electric vehicles.

M2 VEHICLE ELECTRICAL AND ELECTRONIC PRINCIPLES

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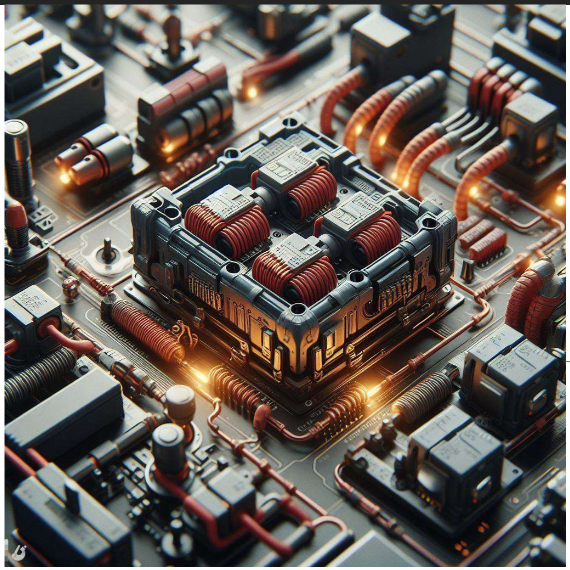
Presentation Flow



LEARNING UNITS

- 2.1 Direct Current motor vehicle electrical circuits: principles and properties of magnetism as applied to motor vehicle circuit devices
- 2.2 Interpretation of wiring diagrams
- 2.3 Circuit protection devices
- 2.4 Earthing principles and methods
- 2.5 Diagnosis, repair & maintenance of electric & electronic systems

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Introduction

INTRODUCTION

The objectives aim to provide a comprehensive understanding of electrical principles in the context of direct current vehicles. This encompasses gaining familiarity with fundamental concepts like voltage, current, and resistance. Moreover, the significance of protection devices in electrical circuits is emphasized, elucidating their vital role in averting overcurrents and short circuits. Grounding in electrical systems is highlighted for its critical role in ensuring safety and guarding against electric shock hazards. Additionally, the importance of diagnostic procedures for identifying faults in both electrical and electronic systems is underscored, recognizing their pivotal role in vehicle maintenance and repair efforts.

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KEY DEFINITIONS

1. Understand the basic concepts of electricity and magnetism and their application in electrical circuits of direct current vehicles.
2. Become familiar with the basic concepts of electricity, including voltage, current and resistance.
3. Understand the importance of protection devices in electrical circuits and their role in preventing overcurrent and short circuits.
4. Understand the importance of grounding in electrical systems and its role in safety and protection against electric shock.
5. Understand the diagnostic procedures for faults in electrical and electronic systems, as well as their importance for the maintenance and repair of vehicles.

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Learning Unit 1: D.C. VEHICLE ELECTRIC CIRCUITS: PRINCIPLES AND PROPERTIES OF MAGNETISM APPLIED TO VEHICLE CIRCUIT DEVICES

05

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Basic Concepts of Electricity and Magnetism

- Presentation of basic concepts of electricity and magnetism.
- Definition of electric current, electromagnetism, and their relationship with the movement of charges.
  - ✓ **Electric Current:** It's the flow of charged particles (typically electrons) through a conductor, creating energy for various applications.
  - ✓ **Electromagnetism:** This involves the interaction between electric currents and magnetic fields, enabling the creation of magnetic fields through flowing currents.
  - ✓ **Relationship:** Electric currents are generated by the movement of charged particles through conductors, essential for powering devices and creating magnetic fields in systems like motors and generators. Understanding these concepts is vital for comprehending how electricity and magnetism work together in various applications, including vehicle electrical systems.

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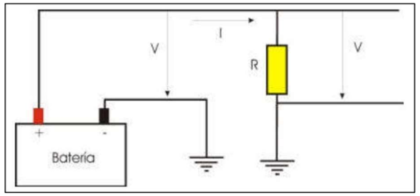
PRACTICAL APPLICATIONS

Ohm's law

- Voltage (V) is directly proportional to Current (I) when Resistance (R) is constant.
- The formula: $V = I \times R$
- It helps predict how changes in voltage, current, or resistance affect each other in an electrical circuit.
- Crucial for designing, analyzing, and ensuring the safety of electrical systems.
- Enables engineers to calculate values like current flow or required resistance in a circuit.



Faraday's Law

- Detailed description of Faraday's Law and electromagnetic induction.
- Examples of application in vehicular devices like the alternator and its role in electricity generation.
- Emphasizing the importance of this law in generating electrical energy from the vehicle's mechanical motion.

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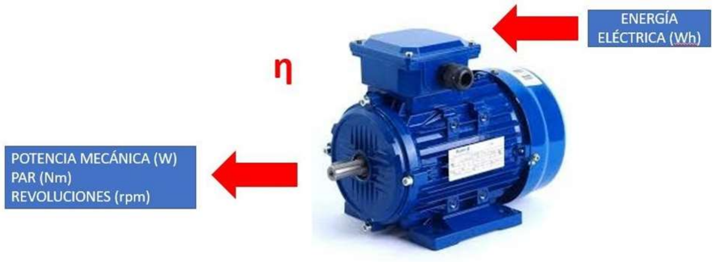
Principles of Operation of Electrical Devices used in DC Vehicle Circuits: DC Electric Motors and their Application in the Propulsion System

- Explanation of the functioning of electric motors in vehicles.
- Details on how they convert electrical energy into mechanical energy to propel the vehicle.
- Highlighting the significance of these motors in the context of electric vehicle propulsion systems.



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Magnetic Properties of Materials used in DC Vehicle Circuit Devices

- Analysis of magnetic properties of materials used in vehicle circuit devices.
- Emphasis on concepts like magnetic permeability, magnetic susceptibility, and magnetic hysteresis.
- Stressing the influence of these properties on the efficiency and performance of vehicle electrical systems.

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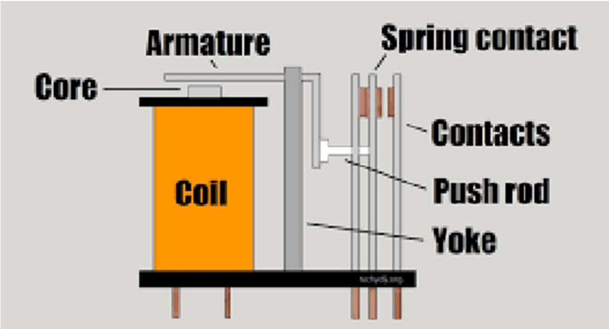
Application of Magnetic Materials in Relays, Inductors, Transformers, and Electric Motors

- Details on the application of magnetic materials in relays, inductors, transformers, and electric motors.
- Specific examples of how magnetic materials enhance the efficiency and performance of these devices in vehicles.
- Emphasizing the importance of proper selection of magnetic materials to enhance the reliability of electrical systems in vehicles.



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BACKGROUND

key concepts presented in the preceding slides.

Emphasis on the importance of understanding the principles of electricity and magnetism in designing and operating electrical systems in vehicles.

Highlighting how these principles are fundamental for the efficiency, performance, and safety of modern vehicles.

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Learning Unit 2: Interpretation of wiring diagrams

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Basic Electrical Units

- Definition of potential difference (volt) and current intensity (ampere).
- Relationship between potential difference, current intensity, and electrical resistance (ohm).
- Explanation of electrical power (watt) and its significance.
- Historical background: Alessandro Volta, André Marie Ampère, Georg Simon Ohm, James Watt.

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LEARNING UNIT2: Interpretation of wiring diagrams

Basic Elements in a Circuit

- Types of energy sources: batteries, accumulators, generators.
- Role of conductors (wires) and factors influencing cable selection (cross-section, length).
- Cable connections and considerations for effective connections.
- Overview of recipients and consumers in circuits: light bulbs, motors, switches..

n° Wires/mm	Amper
14/0,25	6
14/0,30	8,75
28/0,30	17,5
44/0,30	27,5
65/0,30	35
84/0,30	45
97/0,30	50
120/0,30	60

Minimum cross-section = Resistivity x cable length / Resistance

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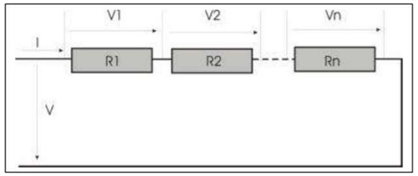
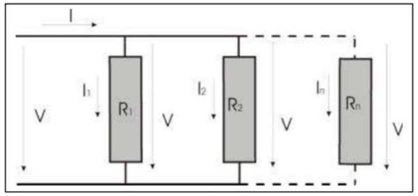
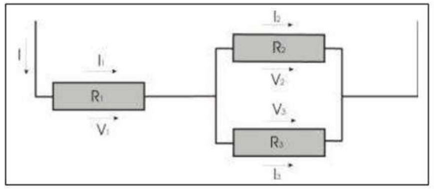
Types of Circuits

- Explanation of simple circuits and their behavior in the event of faults (short circuit, open circuit).
- Characteristics of series circuits: current distribution, total resistance, and power consumption.
- Features of parallel circuits: current distribution, total resistance, and power consumption.
- Mixed circuits: Combination of series and parallel associations.







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Main Electrical Components

- Overview of resistors: fixed, variable, temperature-dependent, light-dependent.
- Types of switches: manually operated, motion, pressure, temperature.
- Explanation of relays, motors, generators, and their functions in automotive systems.
- Role and importance of fuses as protection elements in electrical systems.

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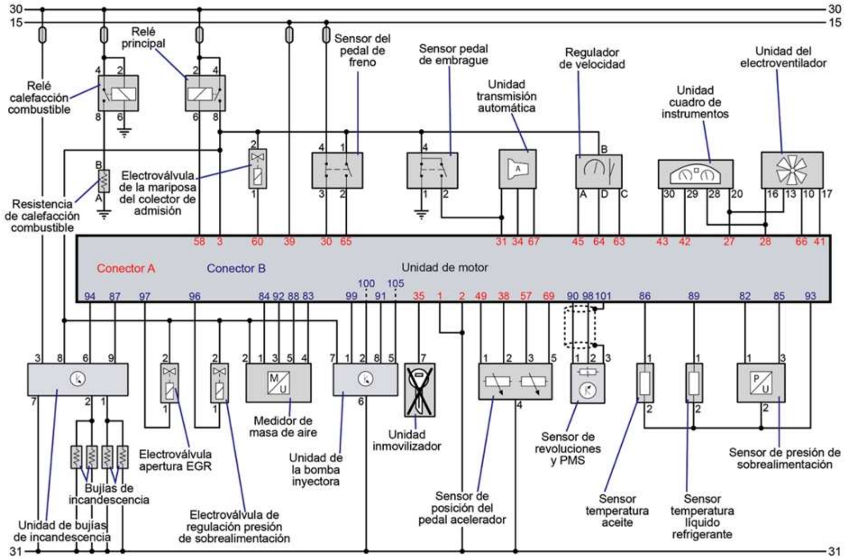
Electrical Symbology and Interpretation



- Explanation of electrical symbols in wiring diagrams.
- Conventions used in wiring diagrams and their importance in vehicle diagnosis.
- Component identification and their representation in diagrams.
- Understanding current direction, legend, color codes, and circuit tracking in diagrams.

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BACKGROUND

- ✓ **Fundamental Base**: Understanding basic electrical units is essential for interpreting complex systems and conducting maintenance safely.
- ✓ **Circuit Configurations**: Series, parallel, and mixed circuit configurations directly impact current flow and the efficiency of an electrical system.
- ✓ **Role of Key Components**: Grasping resistors, switches, relays, and fuses is critical for proper functioning and preventing electrical system failures.
- ✓ **Interpretation and Adaptation**: Mastering the interpretation of diagrams and manufacturer-specific conventions is vital for precise identification and effective troubleshooting of electrical issues.
- ✓ **Continuous Learning**: Given the constant evolution of technology, staying updated and being willing to learn and adapt to new electrical system advancements is crucial.
- ✓ **Focus on Safety and Efficiency**: Priority should always be on safety, along with the proper selection of components to ensure electrical system efficiency.

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Learning Unit 3: Circuit protection devices

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Electrical Symbology and Interpretation

- Blade Fuses: Commonly used in automobiles, flat-shaped and easily visually inspected in fuse blocks.

- Tube Fuses: Less common but still used in specific applications, consisting of glass or ceramic tubes with a conductive filament.

- Mini and Micro Fuses: Compact fuses ideal for limited-space electrical systems, prevalent in electric vehicles.

- Classification Criteria:
  1. Rated Current,
  2. Nominal Voltage,
  3. Response Time.

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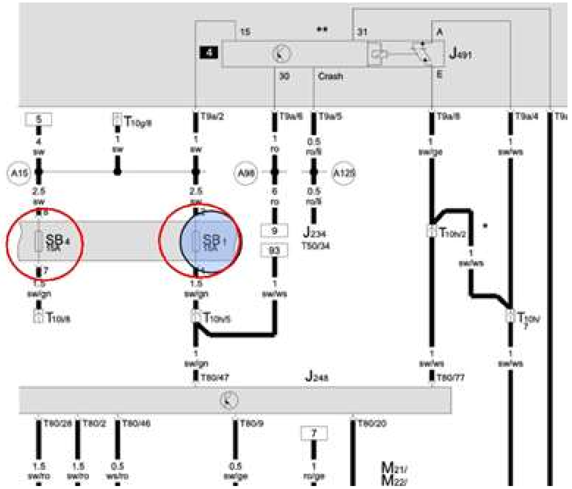
Location and Distribution of Protective Devices

- Strategic Placement: Fuses placed to safeguard specific components like lighting, engine control, etc.
- Identification: Fuses color-coded for amperage, facilitating quick replacement and system integrity.
- Battery System Protection: EVs equipped with fuses to safeguard the battery and high voltage circuits.

LOCATION AND DISTRIBUTION OF PROTECTIVE DEVICES IN VEHICLE ELECTRICAL CIRCUITS



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Circuit Breakers - Essential Features

- Interrupting Capacity: The maximum current safely interrupted, tailored to circuit requirements.
- Response Time & Trip Curve: Defines the time taken for the circuit breaker to trip in response to current changes.
- Overload and Short Circuit Protection: Thermal elements activate during overloads, while magnetic elements respond to short circuits.

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Protection Relays in Electric Vehicles

- Anomaly Detection: Constant monitoring for overcurrents, overvoltages, and adverse conditions.
- Battery and Charging System Protection: Relays intervene to prevent battery damage and ensure safe charging.
- Integration with Vehicle Control Systems: Ensures fast and coordinated responses to adverse conditions.
- Differential Protection in Motors: Essential for safeguarding critical components.

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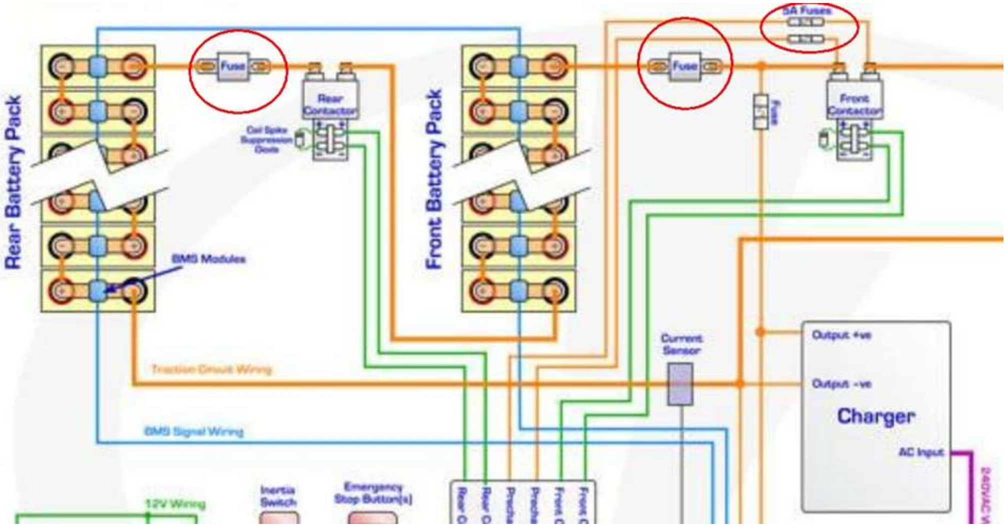
Location and Distribution of Protective Devices



- Key Location Factors: Proximity to critical components, accessibility for maintenance, isolation of sensitive parts.
- Distribution at Different Circuit Levels: Protection in main panels, critical points, high voltage systems.
- Location in Safe Zones: Devices placed away from impact or liquid-prone areas to minimize risks.

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BACKGROUND

- ✓ **Fuse Types & Functions**: Varied fuse types cater to different automotive needs, ensuring overcurrent protection.
- ✓ **Circuit Breakers' Role**: Vital in protecting against overloads and short circuits in vehicle electrical systems.
- ✓ **Relays' Importance**: Crucial for detecting and responding to adverse conditions in EVs, ensuring safety.
- ✓ **Strategic Placement**: Protective devices carefully positioned to secure vital vehicle components.
- ✓ **Essential for Electric Mobility**: The integration of protection devices ensures safe and efficient EV operation.

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Learning Unit 4: Earthing principles and methods

The grounding of electric and hybrid vehicles is a crucial aspect to ensure safe operation and prevent electrical hazards. The application of specific principles and methods ensures effective grounding, reducing the likelihood of electric shock and protecting both occupants and vehicle electronics. The fundamentals of grounding principles and methods are explored below in this context.

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LEARNING UNIT 4:
Earthing principles and methods

Introduction to Vehicle High-Voltage Disconnection

- Overview of disconnecting high-voltage electrical systems in EVs
- Importance of protocols and safety measures
- UNECE Regulation 100 requirements for disconnecting devices
- Visual aid: Image 50 showcasing high-voltage cables' orange sheath for visibility

06

05 - 15

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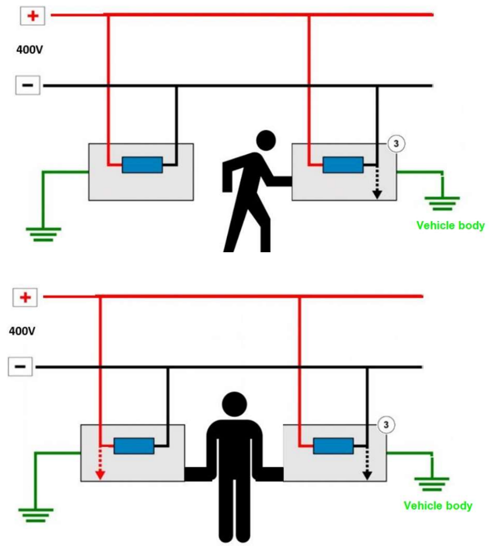
Safety Considerations and Disconnection Devices Location

- Safety concerns beyond repair shops: emergency situations and extraction
- Strategies to mark high-voltage disconnection devices
- Placement: Under occupant compartment, engine compartment, or luggage compartment floor
- Visual aids: Image 51 and Image 52 depicting scenarios of contact and flow of current



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Grounding Methods in Electric Vehicles

- Explanation of direct grounding method and its role in providing a safe path
- Illustration: Visual aid depicting the concept of direct grounding in EVs

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EV Insulation Verification: Importance and Procedure

- Significance of insulation resistance testing in EV maintenance
- Step-by-step procedure for insulation measurement
- Safety precautions and qualified personnel necessity
- Visual aid: Image 53 displaying insulation tests on the HV battery and inverter sides

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Instruments for High Voltage Insulation Verification

- Overview of key instruments: Megmeters, Insulation Analyzers, Fault Locators
- Role of each instrument in identifying insulation issues
- Visual aids: Images 56, 57, 58 showcasing examples of insulation verification instruments

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BACKGROUND

- ✓ Recap of the critical role of insulation verification in ensuring vehicle safety
- ✓ Mention of additional verification tools: Ohmmeter IR4057-50, Launch ES200
- ✓ Emphasis on the collective importance of these instruments for safe operation

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Learning Unit 5: Diagnosis, repair & maintenance of electric & electronic systems

In Learning Unit, we delve into fundamental techniques for diagnosing faults in electrical and electronic systems in electric vehicles. From employing specialized tools to real-time data analysis, we explore precise methods to identify and resolve issues within these complex systems. This knowledge is not only critical for automotive professionals but also drives the reliability and performance of electric mobility, being foundational for a more efficient and sustainable industry.

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Introduction to Diagnostic Tools for Electric Vehicles

- Overview of diagnostic software for different manufacturers
- Mention of Tesla Diagnostic Tool, Nissan Consult, BMW ISTA, GM Global Diagnostic System, Ford IDS, Volvo VIDA
- Visual: Image 60 showcasing a diagnostic tool for Tesla vehicles

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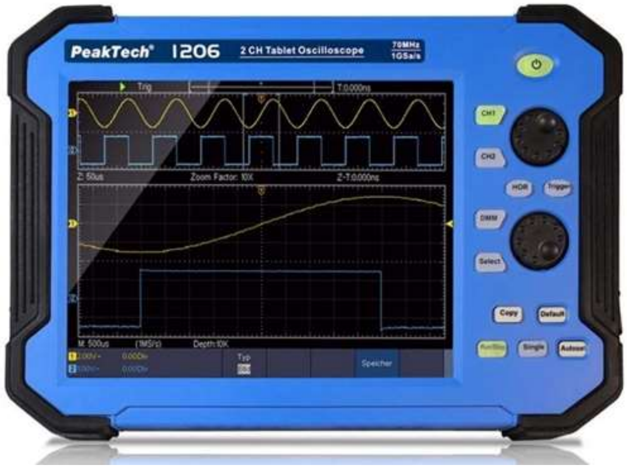
Diagnostic Techniques: Multimeters and Oscilloscopes



- Explanation of multimeters and their applications in EVs
- Oscilloscope's role in analysing electrical signals
- Visual: Image 66 displaying multimeter and oscilloscope functionalities

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Visual and Audible Inspection Tools

- Importance of visual and auditory inspection in identifying electrical problems
- Introduction of endoscopes and stethoscopes for automotive use

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LEARNING UNIT 5: Diagnosis, repair & maintenance of electric & electronic systems

Data Analysis, Simulation Tests, and Functional Testing

- Data analysis importance for real-time interpretation
- Electronic simulators' role in controlled environment testing
- Details about functional tests and their significance
- Visual: Image 70 depicting data analysis and simulation

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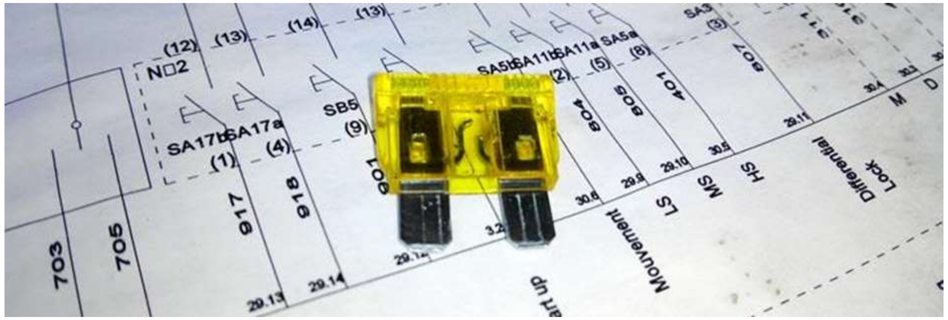
Advanced Diagnostic Tools and Repair Procedures

- Explanation of logic analyzers and access to technical data
- Overview of repair procedures: component replacement, compatibility checks, adjustments, and calibrations
- Visual: Image 71 highlighting component replacement procedure



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BACKGROUND

- ✓ Recap of the importance of diagnostic tools for EV maintenance
- ✓ Emphasis on rigorous testing, repair, and maintenance procedures for system integrity
- ✓ Visual: Image 72 showcasing the significance of software updates in EVs

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KEY POINTS

1. Safety in Electrical Systems: Prioritizing safety measures is fundamental in electrical systems, particularly in EVs. Grounding, disconnection protocols, and specialized diagnostic tools are paramount for handling high-voltage systems safely.
2. Circuit Protection Devices: Understanding fuse types, locations, and classifications is vital. Properly placed fuses and circuit breakers ensure the protection of critical components, facilitating quick repairs and maintaining system integrity.
3. Diagnosis of Electrical Faults: Utilizing advanced diagnostic tools such as multimeters, oscilloscopes, and specialized software enables efficient fault diagnosis. Real-time data analysis, simulation tests, and access to technical data enhance diagnostic accuracy and repair effectiveness.
4. Insulation Verification: The use of insulation verification instruments is crucial for maintaining the integrity of high-voltage systems. Megmeters, insulation analysers, and fault locators aid in assessing insulation resistance, identifying faults, and ensuring safe operation.
5. Repair & Maintenance Procedures: Methodical procedures for component replacement, adjustments, and preventive maintenance are vital. Conducting functional tests post-repairs ensures the reliability and safety of electrical and electronic systems in electric vehicles.

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REFERENCES

Journals and Publications

- SAE International: SAE Technical Papers: SAE's library contains technical papers covering a wide range of automotive engineering topics.
- IEEE Xplore: IEEE Xplore Digital Library: A database offering articles, conferences, and journals on electrical engineering, electronics, and vehicle systems.
- National Highway Traffic Safety Administration (NHTSA): NHTSA Technical Publications: Provides technical reports, guides, and safety standards related to vehicles.
- Journals: Search for specialized journals like "Electric Vehicle Research and Technology": This journal covers research and technological advancements in electric vehicles.
- Vehicle Manufacturer Websites: Many manufacturers offer online service manuals and technical resources for their electric vehicle models. For instance, Tesla Service Manuals.
- Online Forums and Communities: Platforms like Reddit - Electric Vehicles or forums dedicated to electric vehicles often contain discussions and shared technical resources by enthusiasts and industry professionals.

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MODULE 2

VEHICLE ELECTRICAL AND ELECTRONIC

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1 QUESTIONS AND ANSWERS (FOR THE ENTIRE MODULE)

1.1 Why is it important to establish a potential reference in electric vehicles?

Answer**:** Learning Unit 1

Establishing a potential reference is critical in electric vehicles as it ensures a common voltage level between the vehicle's electrical components and the ground. This mitigates the risk of hazardous potential differences that could cause electrical shocks or damage to sensitive components. By creating this reference, it helps maintain a stable and safe electrical environment within the vehicle's system.

1.2 What is the purpose of insulation resistance inspection in electric vehicles?

Answer**:** Learning Unit 1

Insulation resistance inspection is integral to ensuring the safety and reliability of electric vehicles. This test assesses the insulation integrity within the vehicle's high-voltage system, protecting against potentially dangerous voltages. It verifies that the insulation is effective in preventing current leakage and potential electrical hazards, a crucial aspect for maintaining the safety of passengers and the vehicle's electronic systems.

1.3 What function do inverters serve in electric vehicles?

Answer**:** Learning Unit 2

Inverters play a vital role in electric vehicles by converting direct current (DC) from the vehicle's batteries into alternating current (AC) that powers the electric motor. This transformation is essential as electric motors typically operate on AC power. Inverters control the speed and torque of the motor by managing the frequency and amplitude of the AC power supplied.

1.4 Why is periodic inspection of high-voltage cables in electric vehicles crucial?

Answer**:** Learning Unit 2

Periodic inspection of high-voltage cables is crucial to maintain the safety and reliability of electric vehicles. These inspections ensure the integrity of the cables, preventing potential risks of short circuits, insulation degradation, or electrical failures. Regular checks help identify early signs of wear, damage, or degradation, allowing for timely maintenance or replacement, reducing the likelihood of system failures or safety hazards.

1.5 What is the main difference between Level 1 charging and Level 2 charging?

Answer**:** Learning Unit 3

The primary distinction between Level 1 and Level 2 charging lies in the charging speed and power delivery. Level 1 charging involves using a standard household electrical outlet and delivers a lower charging power, typically at a rate of about 2-5 miles of range per hour of charging. Conversely, Level 2 charging requires a dedicated charging station, delivering a higher power output, typically around 10-60 miles of range per hour of charging, significantly reducing charging times compared to Level 1.

1.6 What advantages does V2G technology offer in the context of electric vehicle charging infrastructure?

Answer: Learning Unit 3

Vehicle-to-Grid (V2G) technology allows electric vehicles not only to draw power from the grid for charging but also to supply excess energy back to the grid when needed. This bidirectional flow of electricity supports grid stability, especially during peak demand periods. V2G technology enables vehicles to function as energy storage units, contributing to grid balancing, potentially reducing energy costs, and enhancing grid reliability.

1.7 What is the primary function of protective relays in electric vehicles, and how do they contribute to the safety of these vehicles' electrical systems?

Answer: Learning Unit 3

The primary function of protective relays in electric vehicles is to monitor electrical conditions constantly, detecting anomalies like overcurrents, overvoltages, short circuits, and temperature fluctuations during charging. They ensure safety by responding effectively to these adverse conditions, safeguarding the vehicle's electrical systems and optimising battery protection. Additionally, they integrate with control systems for coordinated responses and play a critical role in differential protection, securing motors and power systems within electric vehicles.

1.8 List three different types of fuses used in automotive and electric vehicle systems, discussing their distinguishing features and applications in vehicle circuits.

Answer: Learning Unit 3

Fuses are indispensable components in safeguarding electrical systems within automotive and electric vehicles. Three primary types include:

1. **Blade Fuses:** These are prevalent in automobiles due to their flat shape and ease of visual inspection when inserted into fuse blocks. Available in various amperage ratings, they are commonly found in both conventional and electric vehicles, protecting critical systems like lighting and engine controls. Their distinct flat design allows for quick identification and replacement.
2. **Tube Fuses:** Though less common in modern automobiles, some vehicles still utilise tube fuses, comprising glass or ceramic tubes containing conductive filaments. These fuses cater to specific applications within vehicle systems and offer their unique method of protection against overcurrent situations.
3. **Mini and Micro Fuses:** Designed to occupy minimal space, these fuses find utility in compact electrical systems, particularly in electric vehicles where space is limited. Their smaller form factor allows for installation in more confined areas within the vehicle, ensuring protection without compromising available space.

1.9 What is the significance of marking the location of high-voltage disconnection devices in electric vehicles?

Answer: Learning Unit 4

Marking the location of high-voltage disconnection devices in electric vehicles is crucial for emergency situations, such as accidents or rescue operations. Emergency responders or technicians need clear identification of these devices to safely disconnect the high-voltage systems, reducing the risk of electrical hazards. Marking these locations aids in swift and safe extraction of occupants and informs personnel about potential high-voltage areas, minimizing the risk of accidental contact or damage during rescue procedures.

1.10 What's the primary purpose of insulation resistance testing in electric vehicles?

Answer: Learning Unit 4

Insulation resistance testing serves to safeguard against electric shock and ensures the integrity of insulation, critical as modern EVs use increasingly higher voltages.

1.11 How do insulation verification instruments contribute to the safety of high-voltage systems in electric vehicles?

Answer: Learning Unit 4

Insulation verification instruments play a critical role in ensuring the safety and reliability of high-voltage systems in electric vehicles. These instruments, such as megohmmeter and insulation analysers, assess the insulation resistance and integrity of electrical components. By detecting potential faults, moisture, or damage in the insulation, these tools enable proactive maintenance, preventing electrical hazards and ensuring the safety and optimal performance of high-voltage systems in electric vehicles.

1.12 What are the key safety measures outlined to manage high-voltage disconnection in electric vehicles?

Answer: Learning Unit 4

Manufacturers focus on clear marking and accessible positioning of disconnection devices, especially in scenarios like traffic accidents, allowing emergency responders to extract occupants safely.

1.13 Why is the utilisation of specialised diagnostic software crucial in diagnosing electric vehicle systems?

Answer**:** Learning Unit 5

Specialised diagnostic software provides detailed insights into the complex electronic systems of electric vehicles. These tools, tailored to specific vehicle brands or models, enable technicians to scan and interpret error codes stored in vehicle modules. This information helps identify problematic areas, enabling precise diagnosis and targeted repairs. Using such software ensures accurate fault detection and efficient troubleshooting of electric and electronic systems in vehicles.

1.14 How does visual and audible inspection aid in diagnosing electrical problems in electric vehicles?

Answer: Learning Unit 5

Visual and audible inspections are essential diagnostic techniques in identifying potential electrical issues in electric vehicles. Visual inspection involves scrutinising cables, connectors, and components for visible damages like cuts, corrosion, or anomalies. Simultaneously, listening for unusual sounds provides clues about potential electrical failures. These meticulous inspections serve as an initial assessment, guiding further diagnostic processes, ensuring timely interventions, and guaranteeing optimal operation of electric vehicle systems.

1.15 What specialised role do oscilloscopes play in diagnosing faults in electric vehicles?

Answer: Learning Unit 5

Oscilloscopes analyse electrical signals over time, providing visualisations of signal waveforms, identifying issues like fluctuations or distortions. They also facilitate frequency measurement, highlighting irregularities in signals, and aid in electronic systems diagnostics by analysing sensor and actuator signals.

2 CASE STUDIES (FOR THE ENTIRE MODULE)

2.1 CASE STUDY 1: Insulation Testing Protocol Enhancement

Background:

An electric vehicle (EV) manufacturing company has been experiencing sporadic issues with the insulation of high-voltage systems in their vehicles. Despite following standard insulation testing protocols, occasional faults are detected post-production, leading to concerns about the reliability and safety of their EVs.

Scenario:

Several EVs have been recalled due to insulation-related problems, resulting in inconvenience to customers and a negative impact on the company's reputation. The current insulation testing procedure involves using traditional megohmmeters and insulation analysers, but these tools haven't been fully effective in detecting underlying faults in the high-voltage systems.

Analysis:

Upon detailed analysis, it was found that the existing insulation testing procedure lacks the capability to identify subtle defects in the insulation of high-voltage components. The traditional tools used in the process have limitations in detecting intermittent faults and do not provide a comprehensive evaluation of the insulation's integrity.

Recommendation:

To address these concerns, the company should consider upgrading their insulation testing protocol. Implementing advanced partial discharge testing equipment, such as the Chroma 19501-K partial discharge tester, alongside existing tools, could enhance the efficacy of insulation testing. This approach allows for a more nuanced assessment of insulation quality and can detect subtle faults that might go unnoticed during routine tests. Furthermore, additional measures like incorporating insulation fault locators into the testing process can pinpoint precise locations of insulation defects, enabling targeted repairs or replacements.

2.2 CASE STUDY 2: Diagnostic Software Integration for Enhanced Vehicle Analysis

Background:

A service centre specialising in electric vehicle maintenance and repair has been facing challenges in effectively diagnosing faults in various EV models due to the lack of comprehensive diagnostic software.

Scenario:

Technicians at the service centre have been struggling to address specific issues in different EVs because the diagnostic software they currently use is limited to basic fault code reading. This limitation has resulted in longer repair times, increased customer dissatisfaction, and a backlog of unresolved issues.

Analysis:

Upon careful examination, it's evident that the diagnostic software available to the technicians lacks compatibility with newer EV models and doesn't offer in-depth analysis beyond error code interpretation. The absence of manufacturer-specific diagnostic tools has hindered the accurate identification of complex electrical and electronic system faults.

Recommendation:

To improve diagnostic accuracy and efficiency, the service centre should invest in specialised manufacturer-centric diagnostic software. Introducing Tesla Diagnostic Tool, Nissan Consult, BMW ISTA, and other manufacturer-specific software can significantly enhance the capability of technicians to perform comprehensive diagnostics. Additionally, offering training sessions for technicians to familiarise themselves with these tools and their functionalities will empower them to diagnose and resolve intricate issues more efficiently. Integrating these advanced diagnostic software solutions will streamline the repair process, reduce turnaround time, and elevate customer satisfaction levels significantly.

3 MULTIPLE CHOICE QUESTIONS (FOR THE ENTIRE MODULE)

3.1 When talking about the movement of charges in electricity:

Select one:

a. It refers to a movement of resistances, which is measured in Ohms.

b. It refers to a movement of positive charges or free electrons, which is measured in Coulombs.

c. Refers to a movement of negative charges or free electrons, which is measured in Coulombs.

3.2 Which of the following is true regarding the term potential difference:

Select one:

a. 1 Volt (V) is the difference in potential between two points on a conductor, regardless of the current flowing.

b. 1 Volt (W) is the difference in potential between two points on a conductor carrying a current of 0.5 amperes (A).

c. 1 Volt (V) is the potential difference between two points on a conductor carrying a current of 1 ampere (A).

3.3 The Law of Ohm

Select one:

a. Refers to the safety regulations for the operation of a multimeter.

b. It establishes a relationship between potential difference, current and resistance.

c. It establishes a relationship between current and operating temperature.

3.4 They receive electrical energy which they transform into chemical energy, keeping it stored, to later undo the transformation and return electrical energy again.

Select one:

a. Refers to the operation of a pressure switch.

b. None of the other options

c. Corresponds to the definition of a battery.

3.5 The maximum current that a cable can carry depends on the cross-section and length of the cable.

Select one:

a. The current that a cable can carry never depends on its cross-section.

b. This statement is true.

c. The current that a cable can carry never depends on its length.

3.6 A series circuit:

Select one:

a. Is composed of two or more branches, each of which contains at least one electrical device.

b. It consists of a single line where there are two or more electrical devices, connected together.

c. It is an association of elements without any criteria when connecting them.

3.7 A parallel circuit:

Select one:

a. Is not used in automobile electrics.

b. It consists of a single line where two or more electrical devices are connected to each other.

c. It consists of two or more branches, each of which contains at least one electrical device.

3.8 The relay is an electrical component that functions as a switch.

Please select one:

a. A relay is not a switch.

b. True. It is composed of an electromagnetic coil that when excited causes a magnetic field that causes the contacts of the interrupter to close.

c. Yes, it is. It is always actuated by the effect of the pressure of a fluid.

3.9 A fuse is a protection element.

Please select one:

a. None of the other options is correct.

b. Composed of a conductive wire or sheet of a given cross-section, when the current in a circuit exceeds the preset limit, the conductive wire or sheet of the fuse melts causing an "open circuit" situation.

c. Composed of a conductor wire of a given cross-section, when the current in a circuit is less than the preset limit, the conductor wire of the fuse blows causing an "open circuit" situation.

3.10 During the inspection of an electrical vehicle:

Select one:

a. The test voltage applied during the insulation measurement must be higher than the vehicle battery voltage.

b. The test voltage applied during the insulation measurement must be less than the voltage of the vehicle's battery.

c. The test voltage applied during the insulation measurement must be equal to the voltage of the vehicle's battery.

Correct answer:

1	2	3	4	5	6	7	8	9	10
C	C	B	B	B	B	C	B	B	C

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MODULE 3

Practical application of EV technologies and measuring on HV systems

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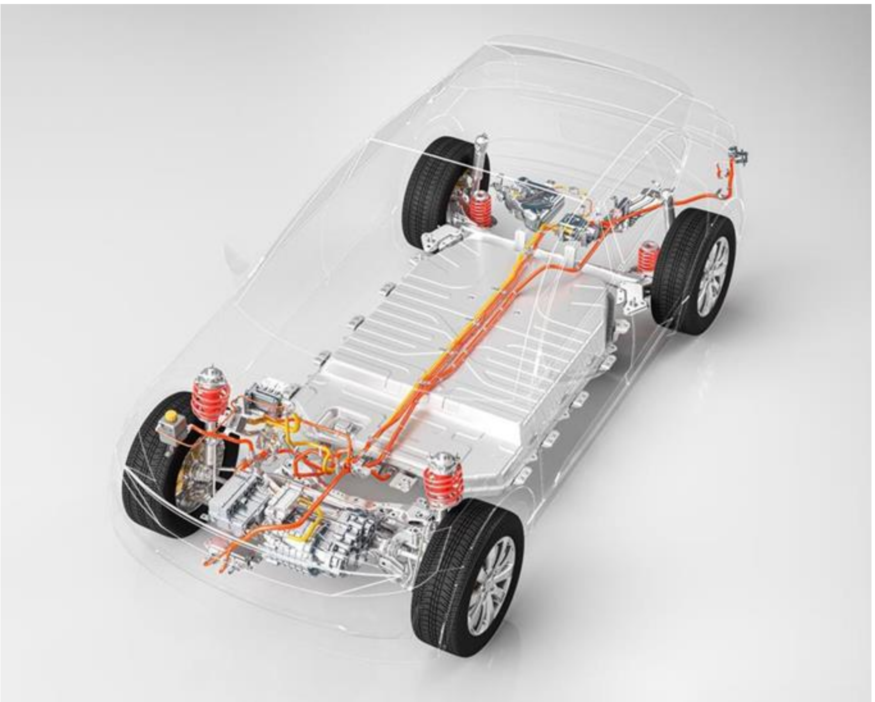
1 LECTURE NOTES (FOR EACH LEARNING UNIT)



1.1 LEARNING UNIT 1 - Basic High Voltage system explained - Full Hybrid

Slide 1:

This presentation is about the Basic High Voltage system for a Toyota Yaris Hybrid and some fundamental functions of the High Voltage system on this vehicle.

Slide 2:

What we have here is a 1.5 Littre Toyota Yaris Hybrid.

This vehicle has no charging socket, which means it can only recharge its batteries using regenerative charging.

So, when braking or when the combustion engine is running, one of the 2 motor generators generate electricity that is then stored on the High Voltage battery.

Slide 3:

When dealing with vehicles that have High Voltage batteries, in this case the Toyota Yaris Hybrid, the Voltage is around 140.

That does not mean we do not have other levels of Voltage in the vehicle, it is only the High Voltage component that is around the 140 mark.

Most of the electronic components in the vehicle are still using 12 Volts.

If you therefore remove the backseat of the vehicle, you will find a normal 12 Volt battery on the rights side – which is what you see on the first picture.

Right next to the 12 Volt battery, you will see the battery pack which is located in the middle under the seat. And if we look at the left side of the vehicle, we have a small fan that draws in air from the area where the backseat passengers on the left side have their feet.

The air travels in through the metal housing and helps cool down the battery if necessary.

This little orange service plug seen on picture 3, is the same as here on picture 2.

It has a 2-step function, so if you want to disconnect power to the battery, you will first pull the lever down and in doing so you will break the interlock switch line.

Secondly, you want to pull the lever forward and remove the service plug. Doing so will divide the High Voltage battery, so you now have 2 units of approximately 70 Volts each. Inside the service plug there is a safety fuse, in the unlikely case of short-circuiting.

Slide 4:

This is our battery pack and on the left side we have the service plug, that we can pull down and then pull out, so we can disconnect the battery pack.

Furthermore, there are 3 temperature sensors located over the battery pack, that allow control of any cooling necessary.

The battery pack is a Nickel metal hydride battery, which is a very stable and durable battery, and it will often last between 10 and 20 years without any issues.

Of course, the capacity of the battery can change a little over time. This is known as SOH, State of Health.

Over time we will see that the starting and stopping periods will be shortened, as the capacity of the battery decreases.

Here we have a measuring component where you have a sensor unit that measures how many Amps are added or removed from the battery. This is known as SOC, State of Charge.

And here we have the battery cells which, when connected, will reach a total of 140 Volt.

Here we have a temperature sensor that measures the temperature of the air coming in from the fan. Finally, we have a small relay sitting here and we will talk more about that later.

EU regulations state that a battery pack may only lose 30% of its capacity over a period of 8 years or after 160.000 km, otherwise the consumer warranty must cover it.

Slide 5:

The battery pack consists of these 20 battery modules that, combined, reach 140 Volt and from there it is a simple division that will tell you what each module contains.

Here you see the service plug and when we use it to disconnect the battery pack, we split the modules into 2 of almost similar sizes. So, to make it easier, we can say that we now have 2 x 70 Volt batteries instead of 1 of 140 Volt.

Slide 6:

Again, you see the battery pack here with several temperature and voltage sensors.

We have our service plug here and we have 3 electrical relays here. They are open until they receive Voltage and that means they need to activate before you can use the electricity from the battery.

Now, since it is the High Voltage battery that ignites our combustion engine, we need to have access to High Voltage to start the vehicle.

The upper 2 electrical relays are on the same circuit, and as you see, it connects to the battery pack.

One of them goes through a resistor and one goes directly to the inverter/converter. The second circuit comes from the opposite side of the battery pack and runs through this electrical relay, through a current sensor that measures how much power is used.

So, when we start the ignition system, we get 2 clicks. The first is both the main relay 2 and the precharge relay that connects through the resistor and charges the capacitor. There is enough current going to the inverter, situated in the engine bay, to charge the capacitor up there.

Whenever they are charged, the main relay 1 connects and that is why we hear 2 clicks before it can engage the starter and ignite the engine.

Slide 7:

This diagram shows the same as before, just from a different perspective.

Here are the 2 electrical relays that work together, one with a resistor and one without. And the electrical relay on the other side of the High Voltage battery.

We have the service plug and then here, the interlock switches. Here on the first interlock switch, you can see that it disconnects when we pull down the lever on the service plug.

When the Interlock switches are disconnected, the electrical relays cannot activate. You can also see a specific interlock switch for the power cables between the battery pack and the inverter, so the battery pack automatically disconnects if these are disassembled.

There is also a specific interlock switch for the cover of the inverter terminal, so at the removal of the cover it will automatically disconnect the battery pack.

This is of course a safety measure to ensure any vehicle owners or auto technicians aren't electrocuted.

Slide 8:

Here we have our High Voltage control unit. This unit has both an inverter and a converter.

A converter is mainly known from our mobile phone chargers, the little block at the end. It converts the alternating current into direct current, from AC to DC.

That means from around 220 Volt to 3.7 or whatever our mobile phone needs.

As this unit is also an inverter, it can also take DC and change it to AC.

The powerful cable seen here has 2 poles, the minus and the plus pole from our High Voltage battery that slides into the housing here.

It is necessary to charge the High Voltage battery occasionally as without a charged battery the vehicle won't start. When the vehicle brakes, we get electricity from the engine and that comes through these 3 cables.

This is 3 phased AC electricity.

But as AC cannot come directly to the DC battery, we need it to go through diodes to rectify the current and then store it on the battery.

If the vehicle does not get enough electricity from the braking alone, then there are 2 motor generators located in the- transmission. And when the combustion engine is running it pulls AC from the motor generator up though these cables here.

The electricity is then rectified and stored on the battery.

Behind this cover, which we can remove via this metal frame here and the cover bolts, we find a small plastic component with a switch. When removing the cover, the interlock switch- disconnects the High Voltage battery.

This is NOT the correct procedure to disconnect the battery pack. Using the service plug is mandatory and then waiting a few minutes before taking the next step.

When you have removed the terminal cover, you can see the cables from the motor generator, and you can see the 3 mounting points where you can measure if there still is Voltage in the capacitors.

Afterwards you can remove the larger cover and start measuring on the motor generator and the 2 mounting points that come from the battery pack.

On this side there are some connections that have to do with the air conditioning compressor and they run out through the side.

This component also has to keep the 12 Volt battery charged, as there is no 12 Volt generator in the vehicle. So over here, on the right of the inverter/converter, you find a connection that leads to the fuse box and then this circuit runs along with the High Voltage cables back to the 12 Volt battery.

This large cable here, which goes to the battery pack, will always be direct current (DC) as the battery only can work with DC.

However, the cable here, that goes to the air condition compressor, motor generator 1 and motor generator 2, that will always be alternating current (AC).

Either going out to drive the electric engine, or coming back with AC, that has to be rectified and stored on the battery.

Slide 9:

Here we can see the connections and the cable from the battery pack and here we have a set of connections to motor generator 1.

Up here, we can see underneath all the covers and when you do your measuring with a multimeter you should only have between 0 to 0.50 Millivolts.

After that you may start any repairs on the vehicle.

Slide 10:

These are the motor generators located inside the transmission. The unit is known as E-CVT (Electronically controlled Continuously Variable Transmission).

On the left side we have the clutch part, pulled by the engine, followed by the motor generator 1 which is the smallest of them.

Here on the right, we have motor generator 2.

This part, here, is kept still in the transmission and this gear propels the vehicle.

If we want to start the vehicle, then motor generator 1 runs the engine counterclockwise and that is how we get our combustion engine started.

Once the vehicle is running and we want to change into electric propulsion, well then, the combustion engine stops and our electric engine, here, takes over the propulsion up to a speed of 50 to 60 km/h.

This picture is from a YouTube video that explains more details and the link is seen here.

So, when the vehicle brakes, the motor generator spins and sends electricity to the inverter. The Inverter then rectifies it into direct current and when the vehicle needs electric propulsion it can then pull the electricity from the inverter.

All this is controlled electronically by the ECU.

Slide 11:

We do not have a lot of comfort systems in this vehicle, but we do have an air conditioning compressor that runs on electricity.

We no longer have a belt connected to a combustion engine, instead we have connector to the electrical engine that pulls the compressor if cooling is needed.

If you need the system to generate heat, then the combustion engine will start and provide the heat.

I hope that this explained a few fundamentals about the Toyota Yaris Hybrid.

Thank you for your attention.

1.2 LEARNING UNIT 2 - Basic High Voltage system Explained - Plug in Hybrid

Slide 1:

This video is about the Basic High Voltage system for a Hyundai Ioniq Plug In Hybrid and some fundamental functions of the High Voltage system on this vehicle.

Slide 2:

What we have here is a 1.6 Litre Hyundai Ioniq Plug In Hybrid 2021 model.

This vehicle has a charging socket, which means it can recharge the batteries. The charging socket can connect to a standard 220volt wall socket or a charging station. When braking the vehicle, the electric motor/generator generates alternating current, that will be rectified and then stored on the High Voltage battery, and also if the combustion engine is running, the starter/generator can charge the high voltage battery. The difference between motor/generator and starter/generator will be explained later.

Slide 3:

When dealing with vehicles that have High Voltage batteries, in this case the Hyundai Ioniq Plug In Hybrid, the Voltage is around 400.

That does not mean we do not have other levels of Voltage in the vehicle, it is only the High Voltage component that is around the 400 mark.

Most of the electronic components in the vehicle are still using 12 Volts.

The 12volt battery is located on the right hand of the trunk, behind a cover.

If you remove the backseat cushion of the vehicle, you will find the primary 400-volt battery pack and the secondary 400 volt battery pack is placed in the trunk, under some covers, in the same location you would normally find the spare wheel.

Both battery packs have a small fan that cools down the battery packs if necessary. The air travels in through the plastic housing and controls the temperature of the battery.

Slide 4:

If you want to disconnect power to the battery, you will first have to make sure that the ignition is switched off and the charging plug is removed. Then disconnect the 12volt battery ground cable and isolate it.

Slide 5:

Secondly you have to locate and remove a small metal plate that is attached with 2 plastic clips, located in this area.

You must not mistake this fuse for the service plug, which is located here, this fuse is only installed in case a short circuit should occur.

Remember that before you remove the safety plug, you must put on your PPE (your personal protective equipment) for safety reasons.

This little orange service plug has a 2-step function, first pull up the green part and press it backwards so that the orange handle can be opened, and in doing so you will break the interlock switch line.

Secondly, you want to pull the lever up and remove the service plug. Doing so will divide the High Voltage battery packs.

Slide 6:

After removing the service plug, you must wait 5 minutes before continuing.

By doing so, the capacitors will be discharged. They are located in the inverter /converter in the engine compartment.

Slide 7:

After having waited for 5 minutes, and still wearing your PPE, you will continue by disconnecting this plug. The plug is located in the engine compartment just next to the inverter/converter. It is quite easy to see because of the yellow clip on the top. The first part is to move the clip upwards, after that you can press the yellow part and then flip the handle. When the handle is all the way down, you will be able to remove the plug.

It can be quite hard to get to the plug, so it may be a good idea to remove the plate which is covering the engine- This may give you a little more room to work with, but it is still quite difficult.

Slide 8:

When it is removed, you need a measuring tool recommended for High Voltage use. In the inverter/ converter you will find these 2 contacts seen here, and you have to make sure that your tool is connected to both of them simultaneously to measure back into the inverter. You are not measuring in the cable going to the battery, you are measuring the inverter to make sure the capacitors are discharged, and you have to have less than 40 millivolts. If that is the case, you may remove your PPE and continue working without it.

Slide 9:

The high voltage wiring is in the bright orange housing that you see here in the engine compartment.

On this little label here it says motor, so that is actually the wiring down to the motor which is propelling the vehicle and sending power from braking the vehicle back to the converter and afterwards back to the battery.

This part here goes to the high voltage starter generator. This upper part is where we disconnected the battery and measured into the inverter/ converter. These cables below go to the onboard charging unit, and as you can see on the photo to the left, it continues underneath the vehicle, coming up underneath the backseat and into the battery pack.

Slide 10:

The onboard charger is located here, that is actually the left front tire, and here we have removed a plastic fender panel for visibility.

So, when you have the charging plug in, the Alternating current goes down to this part and is then rectified and stored on the battery. So, this is actually an AC/DC rectifier for the battery.

Another way to charge the battery is when the vehicle is running, and the starter generator is active. It can then make Alternating current, which is then rectified in the inverter/converter. As you see here it's attached with coolant hoses for temperature regulation, this is necessary as the starter / generator is able to produce high amounts of electricity.

This part is also the starter, so when we want to start the combustion engine, we will get high voltage from the inverter/converter. It cannot propel the vehicle, that energy comes from the electric engine placed between the combustion engine and the transaxle.

Slide 11:

So, this part is the inverter/converter.

It distributes the electricity to several components in the vehicle as well as rectifying high voltage when needed. This includes the air conditioning pump, the starter generator as well as the electric engine.

It is water cooled for temperature regulation.

It also converts the high voltage electricity to 12 volts over to this side here.

Then the wire goes back to the 12-volt battery which is located in the back of the vehicle.

Slide 12

This inverter / converter is what we could call the heart of the high voltage system in the vehicle.

It uses coolant to regulate the temperature. When the combustion engine starts, it is powered from this part here into the starter generator.

And if it needs to charge while the vehicle is running, the electricity returns here as well, to be rectified and sent to the battery for storage.

The motor part, here, is for the motor propelling the vehicle and it is controlled by this unit. And when the vehicle brakes, the electricity generated goes back as Alternating current and rectifies in the inverter/ converter and again back to the battery.

Slide 13

The comfort system only has this one part which is the air conditioning pump. It runs on high voltage coming from the inverter / converter when needed. Please note that if you want cabin heat in the vehicle you must have the combustion engine running.

I hope this gave some clarity on where parts are located and how they function together.

Thank you for your attention.

1.3 LEARNING UNIT 3 - High voltage system basic explanation – Full Electric Vehicle

Slide 1:

This is a video about the Basic High Voltage system for the Volkswagen E-up, This vehicle is what is known as an EV (an electric vehicle)

Slide 2:

This Volkswagen E-up is from the year 2015. That means that it is the first version of the E-up.

In this video we will not talk much about batteries, but we will talk about the charging plug, and we will talk about the electric engine.

Slide 3:

Here we have the Charging socket and there are a few wires behind the socket. 2 of them are going directly to the battery and these two wires contain only direct current and they are for fast charging of the battery.

The other high voltage wires from the Charging socket are going along the right-hand side of the battery to the inverter converter.

Those wires contain alternating current which is then rectified in the inverter converter into direct current and then it goes back to be stored on the battery.

So, this vehicle has no onboard charger, but the inverter converter does the job of rectifying the alternating current, so it can be stored on the battery for later use.

An EV has quite a large battery pack because it's the only power source for the electric motor, and the EV is dependent on electricity to go as far as possible for the consumer.

The Volkswagen E-up has a battery pack that, when fully charged, can reach around 150 km. A lot of EV’s have even larger battery packs so they can go even further, therefore the battery packs always take up so much room in the EV’s.

This orange wire in the engine compartment is going from the inverter/ converter to the battery. Another orange wire goes from the inverter/ converter to the air condition compressor. A third wire goes to a water heating element, placed under the electric engine, in the engine compartment. This heating element is for heating up the cabin and keeping the windscreen defrosted. And finally, we have an additional 3 wires that go from the inverter/converter to the electric engine which is propelling the vehicle.

Slide 4:

When we are looking at the charging socket, we have these two large connectors down below. They can charge the battery using direct current, and that is the fastest way of charging the vehicle.

Moving over to the photo on the left, these two small connectors on the top of the charging plug are for communicating with the charging station and the cable going from the charging station to the charging socket.

It is the control unit in the vehicle that decides how fast the charger can charge the battery, therefore all the information from the cable and the charging station will be stored in the control unit. This includes information about the battery temperature and the voltage on each module in the battery pack. This way the ECU can provide a safe and fast charge in all possible conditions.

We will talk some more about this later.

These other five connectors are all for alternating current, so you can put the household plug into a wall socket in your home or use a charging station with alternating current.

They will be three phases: phase 1, phase 2, and phase 3, and then we have the N1 which is the neutral one and ground in the middle.

As you can see here, this one has been damaged. That means they have been running more electricity than the connector has been able to handle, and it has melted.

This vehicle can be connected either with one phase or three phases, depending on how fast you want to be able to charge the battery.

Slide 5:

What we see here is the charging plug on the vehicle. This is a mirror image where the socket placements are swapped. You still have the 2 communication connectors on the top. They are known as the control pilot and the proximity pilot. These two wires are shown in this little diagram we have on the right-hand side, we have the supply station and we have the vehicle, In the vehicle we have a control unit that decides how much current is able to go into the battery.

This is based on outside temperature, what temperature is inside the batteries, and what the voltage is on each battery cell.

The charging station can be a proper charging station or a cable with a box on - a so called EVSE (Electric vehicle supply equipment), this diagram fits both scenarios.

When you are using an ohmmeter, from the PP connector in the charging cable and to the ground, you'll get different measurements that shows how much current can go through the cable. When the control unit has to decide how much current the battery can be charged with, it has to have information on how much current can be sent through the cable, so it will not be overloaded and melted.

In this right-hand corner, we have a little table showing how many ohms compared to how many amps the cables are able to handle.

The way the control unit signals the charging station how many amps can go to the battery, is by a PWM (Pulse Width Modulation) signal. The term duty cycle is used to describe the amount of time the signal is on, this can be between 0 and 100 %.

The PWM signal is measured between the CP connector and ground and it's only active while it's charging, so you have to put the charging plug into a charging station and then measure it with an oscilloscope.

Slide 6:

This slide is about how the control unit in the car can tell the charging station how fast it can charge the battery.

If the battery is charging using only 1 phase and the need for electricity is 1.4 kW/h, that means that the control will tell the charging station, using a PWM signal, that the duty cycle is on 10%. If it's charging with all 3 phases, then it will get 4.2 kW/h.

If the vehicle demands faster charging, then the PWM signal will be on for a longer time, if the duty cycle goes all the way to 90% then it means that it's alright to charge it using direct current using the two bottom connectors of the charging plug.

Slide 7:

What we have here is the electric engine from a Volkswagen Up.

It is made up of different parts, we have the housing which has an inlet and an outlet port for water cooling. This is the stator, the stator is connected to the 3 phased alternating current, into a number of coils, and we will talk more about those coils later.

Then we have the rotor made of permanent magnets which are very powerful. These permanent magnets are quite sensitive to heat and if they get too hot, they will lose their efficiency.

It is the Magnetic Fields in the coils of the stator, and the Magnetic Fields from the permanent magnets that determines how much torque the engine is going to produce, so therefore these two Magnetic Fields are very important, and needs to be as strong as possible, otherwise the vehicle will lose torque.

It is the rotor that is connected to the gears and propels the vehicle through the differential.

Slide 8:

What we have here is the power supply meaning that's our battery with direct current, and to have it transformed into alternating current, we need the inverter/converter part, which is this one.

Here we have some capacitors, the capacitors help stabilise the voltage.

Inside the inverter/converter we have 6 transistors, 3 of them on the positive side, and 3 of them on the negative side, meaning that when the T1, here, is active the current flows from the plus side and into a coil in the stator, that propels the rotor.

If the T1 is active, the negative current will go through the same coil and therefore the magnetic field will change and it will propel the rotor in the same direction or the opposite direction, depending on where the rotor is placed in comparison with the coils in the stator.

These coils can both be magnetised with a north pole and a south pole at the same coil.

We have a sensor unit – here - measuring how many amps are passing to the motor, and we have a resolver which can detect the rotor placement both when it is standing still and when it is rotating. Therefore, at all times the inverter/converter can send electricity to the coils in the stator and make the rotor rotate in the direction that is wanted.

Slide 9:

This is a drawing of an electric engine, and what we have here is transistors and power supply, and you can see the current going through the coils.

On this coil the current is creating a South Pole and therefore the North Pole, here - is attracted towards the South Pole here, and that makes the rotor rotate.

Exactly the same is happening on the other side here, the South Pole attracts the North Pole, but as well as this, the South Pole is also pushing the South Pole away, and that makes the rotor move in the right direction.

After this, the rotor movement will continue as the other coils will be magnetized as well.

Slide 10:

We would like to have the alternating current going like this - in a nice waveform, but the transistors are not able to do that.

They can turn the electricity on and off, so if you have 400 volts here, the transistors can turn the electricity on and off a number of times, to create a waveform. This means that if the electricity is on for a long time period, the coil in the stator, will be very magnetised and therefore will provide a lot of torque to the engine. That means full throttle for the vehicle.

If the electricity is only on for a shorter period of time, the engine will only be able to sustain the speed of the vehicle.

If the electric engine is running faster, the Hz are increasing which means if the engine is going faster the waveform, will be shortened so there will be more waveforms and therefore more Hz.

Slide 11:

So, let’s talk about disconnecting the high-voltage battery on a Volkswagen E-up.

A trained mechanic is able to disconnect the high voltage batteries and make repairs on a Volkswagen E-up.

Please note that you are only allowed to work with these repairs if you are certified mechanic.

The first thing you need to do is to unplug the charging plug and turning the ignition off.

Slide 12:

You will open the left front door and remove a panel on the dashboard to get to the fuses. Now we remove this fuse with the big yellow label. This is the first time you will disconnect the interlock line.

Now we open the engine compartment, and take off the engine cover, and you'll find this green connector. Press the red clip - here - out and down and then you can extract it. Now you must put on a padlock, this is the second time you have disconnected the interlock line.

Slide 13:

Then you will go unscrew this cover, located on top of the inverter converter.

You can unscrew all the bolts without your PPE (your safety gear) but when you disconnect this middle wire you must put on your PPE, meaning glasses and gloves for high voltage.

By removing this little electric connector, this is now the third time you are disconnecting the interlock line, therefore the vehicle should be safe to work on, but you need to check if there are any voltage first.

Slide 14:

Using a multimeter you are measuring for safety reasons, to make sure that are no voltage on the Poles, and you can work safely.

You start measuring with 1 probe (ground) on the metal housing and the other probe on the 5 connectors on the inverter / converter, one at a time.

After that you measure the 5 connectors again, starting with the bottom 2 for the battery, then the top 3 in the following sequence: 1 & 2, 1 & 3, and 2 & 3

If every measurement is below 1 volt, you are now certain there are no voltage in the capacitors and the battery is disconnected.

Slide 15:

This is the inverter converter part. We can see the inlets from the battery here on the left, and the three outlets to the electric engine here on the right.

We can just see that there is an inlet for water-cooling in this inverter / converter.

Slide 16:

The Comfort System is quite simple for the Volkswagen E-up.

The vehicle has a small water heating element which, supplied with high voltage, can heat up water in a reservoir which is then transported by a little 12-volt pump, into the heating element in the cabin, which not only provides heat in the cabin but also defrosts the windscreen.

The vehicle is also fitted with a high voltage air conditioning compressor, so when cooling is needed, that can be turned on and you will have a nice temperature in the cabin.

I hope this gives some clarity on where parts are located and how they function together.

Thank you for your attention.

M3 - Practical application of EV technologies and measuring on an EV

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EVTECH

Presentation Flow

LEARNING UNITS

- 3.1 Basic High Voltage system explained – Full Hybrid
- 3.2 Basic High Voltage system Explained – Plug in Hybrid
- 3.3 High voltage system basic explanation – Full Electric Vehicle

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Introduction

INTRODUCTION

The purpose of this module is to give the learner the necessary knowledge, skill and competencies regarding high voltage batteries and Battery Management System (BMS) to act as a car mechanic/technician in the era of electric and hybrid electric car technologies.

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Learning Unit 1: Basic High Voltage System Explained - Full Hybrid

1

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Basic High Voltage system explained: Toyota Yaris Hybrid

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Basic High Voltage system explained

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Battery

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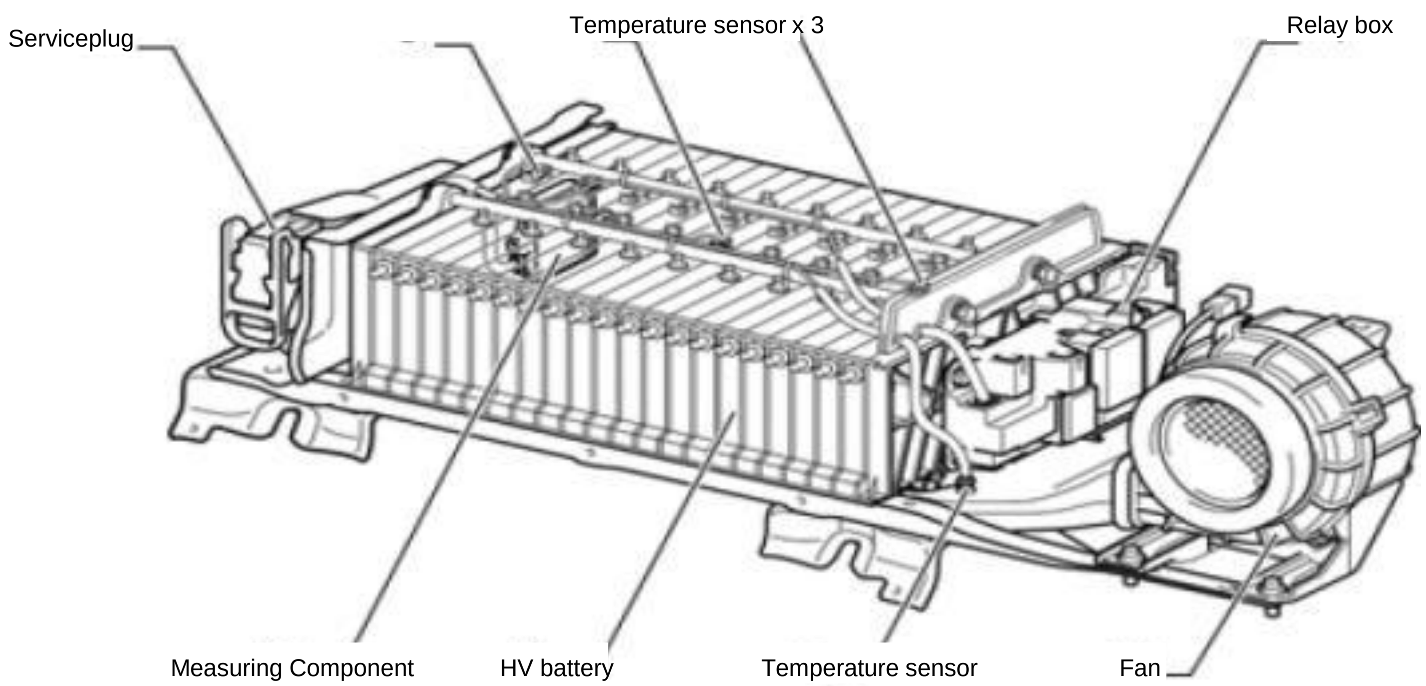
Battery



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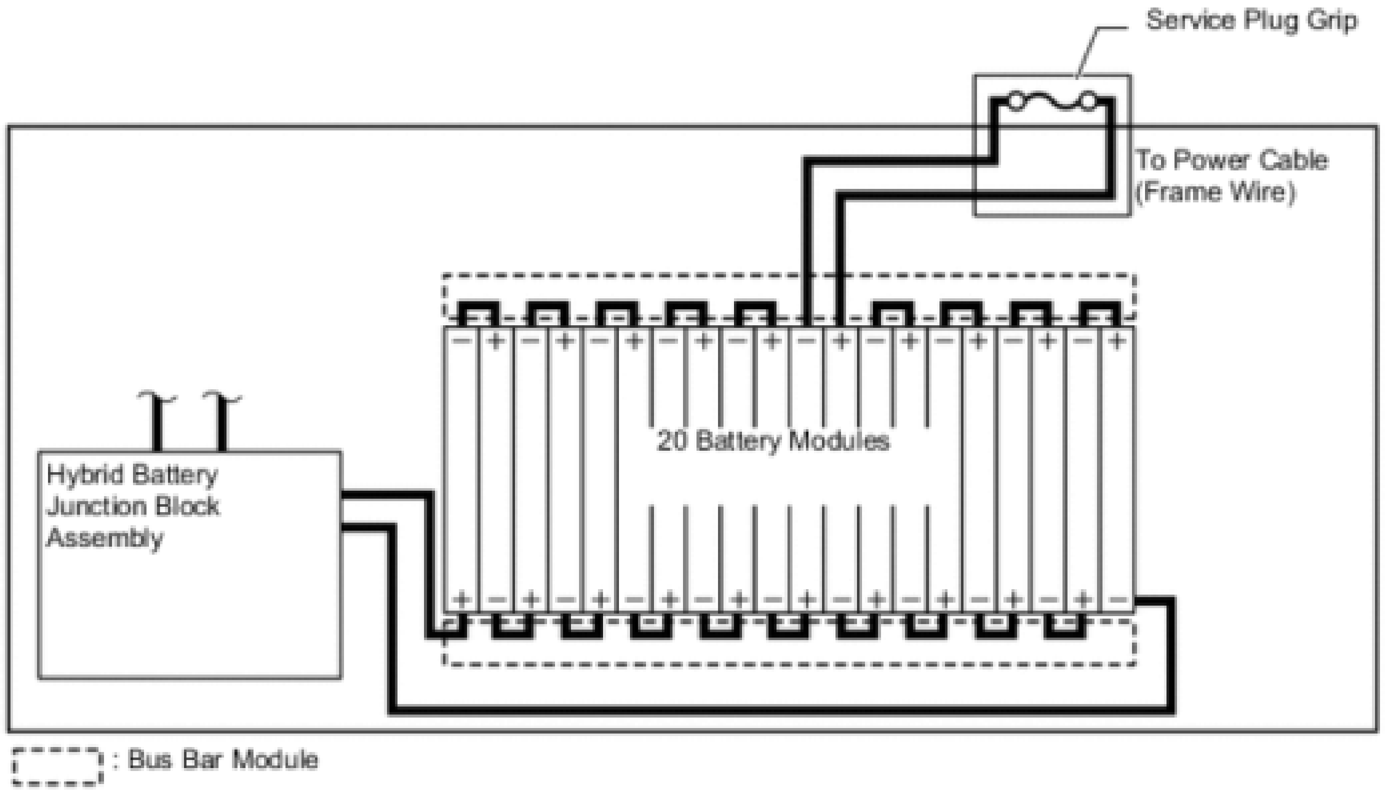
Battery



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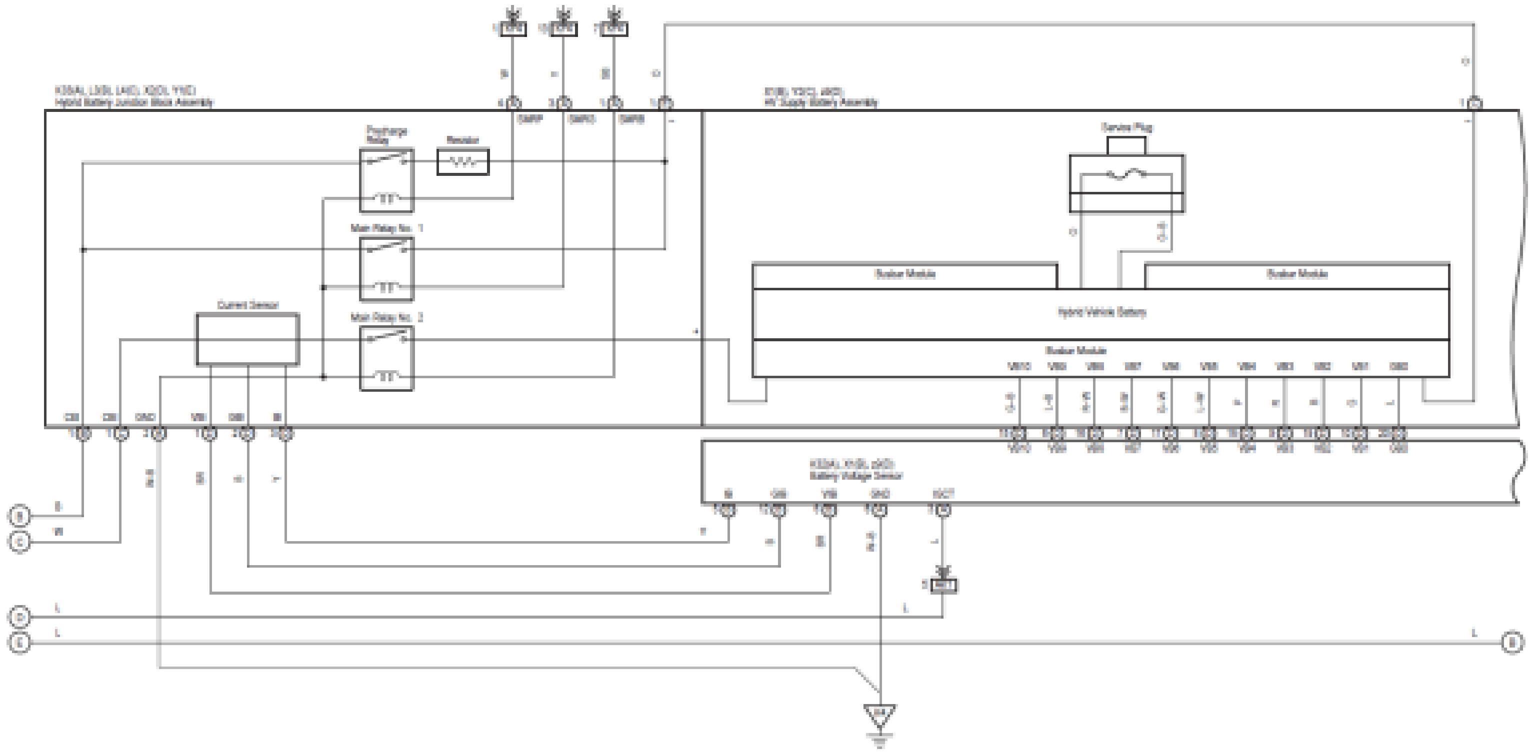
Battery



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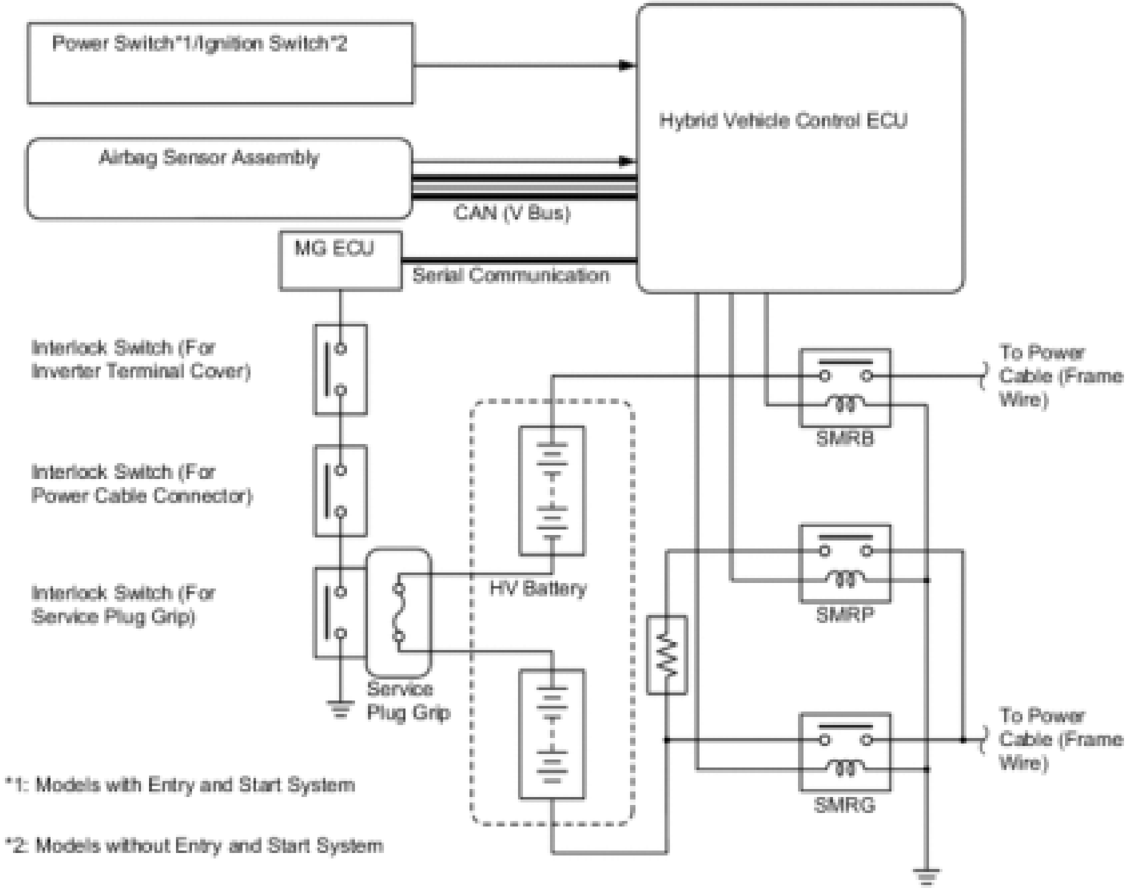
Battery



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Inverter - Converter

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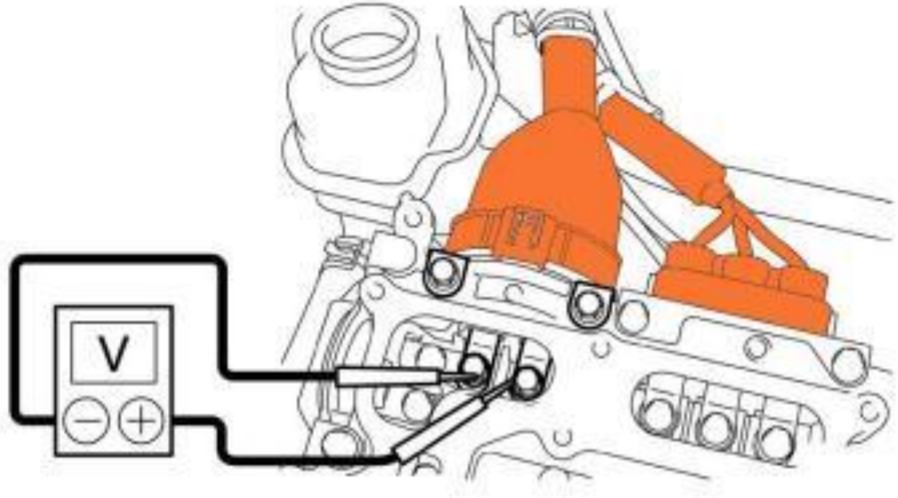
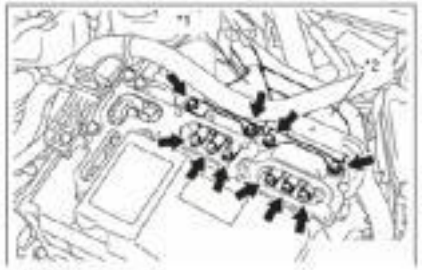
Inverter - Converter



h. **Using a megohmmeter set to 500 V, measure the resistance according to the value(s) in the table below.**

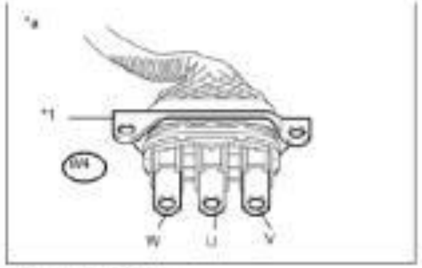
Note

- Carefully perform this inspection as motor (MG2) may generate current when the front wheels are rotated by hand.
- Be sure to set the megohmmeter to 500 V when performing this test. Using a setting higher than 500 V can result in damage to the component being inspected.



Text in Illustration

*1	Motor Cable (MG1)
*2	Motor Cable (MG2)



Text in Illustration

*1	Shield Ground
*a	Motor Cable (for MG2) (Inverter with Converter Assembly Side)

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Electric motor-generators

https://www.youtube.com/watch?v=dLNDGUISTYM

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Comfort system

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Learning Unit 2: Basic High Voltage System Explained - Plug in Hybrid

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Basic High Voltage system Explained -
Hyundai Ioniq Plug in Hybrid

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Basic High Voltage system explained

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Battery

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How to disconnect the High Voltage battery

EVTECH

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High Voltage battery



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How to disconnect the High Voltage battery

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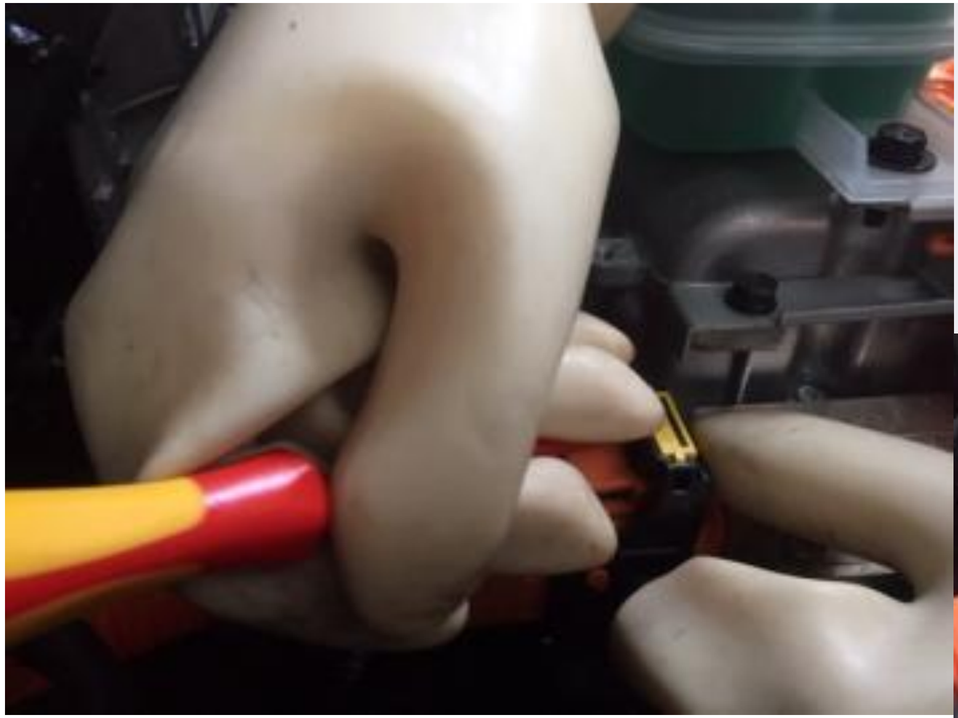
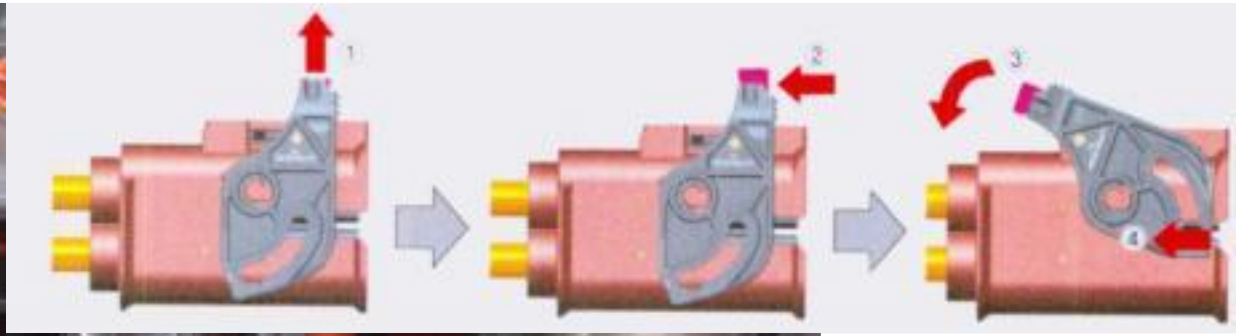
How to disconnect the High Voltage battery





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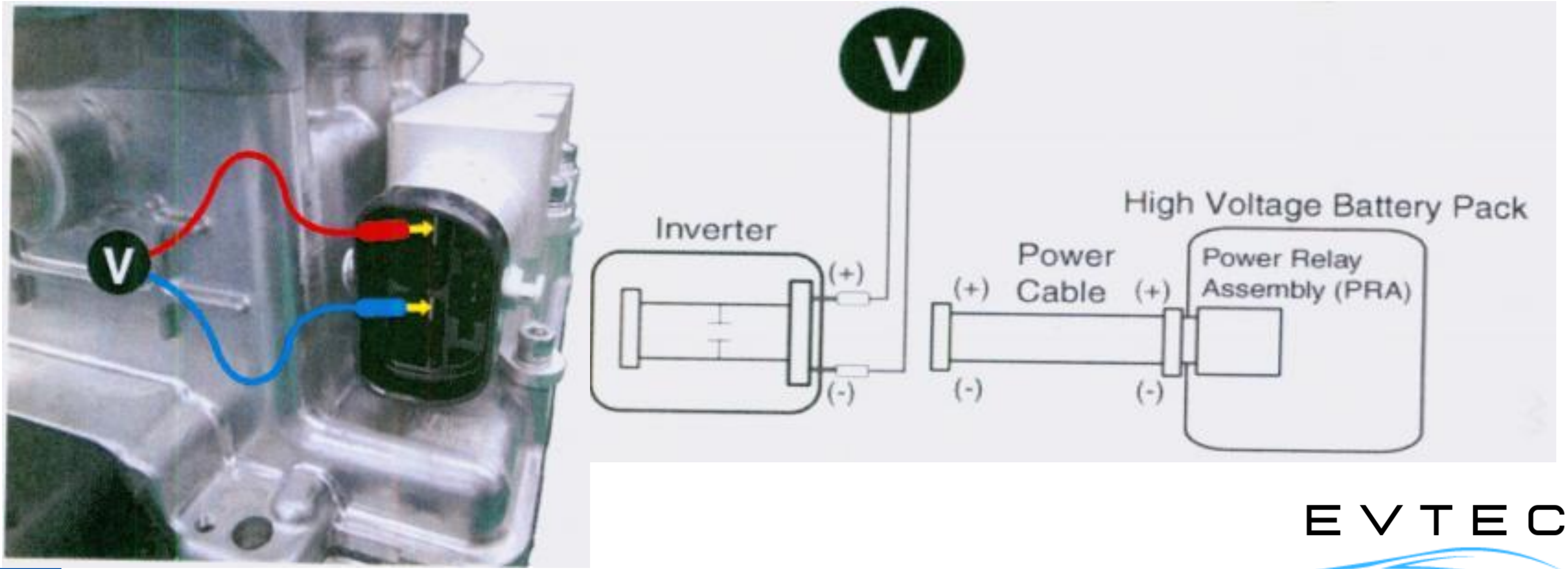
How to disconnect the High Voltage battery



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Wiring

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Charging

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Charging

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Learning Unit 3: High Voltage System Basic Explanation – Full Electric Vehicle

3

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High voltage system basic explanation WV E-up Electric car

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High voltage system basic explanation

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Battery - Wiring

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Charging

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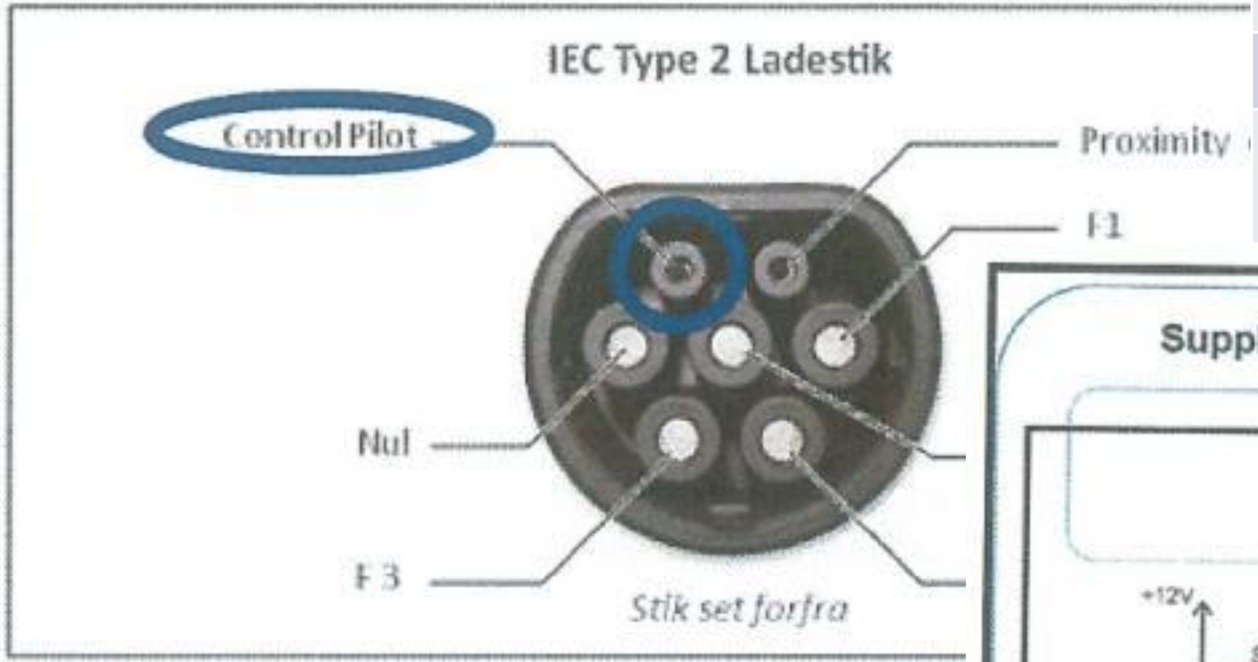
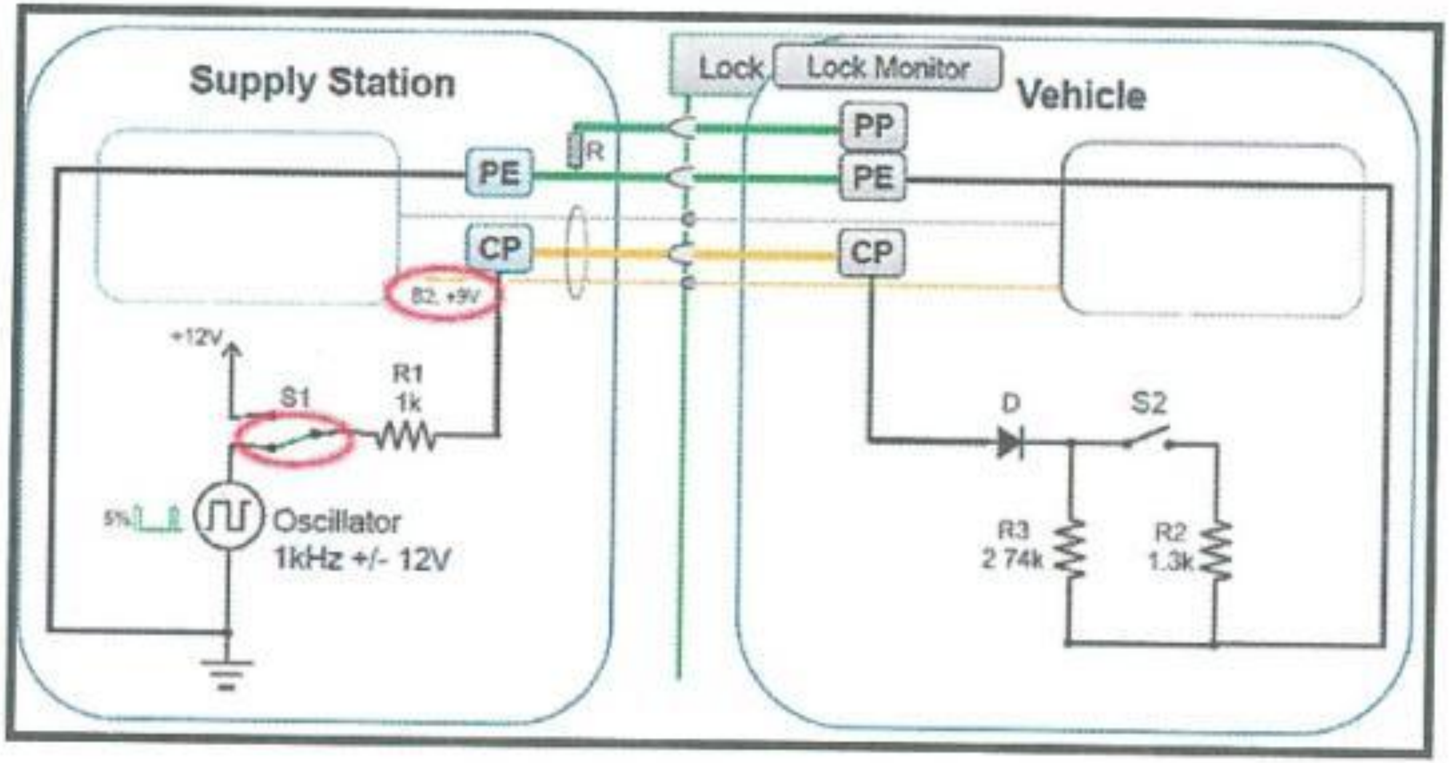
Charging

13A	1,5 kΩ	1 kΩ - 2,7 kΩ
20A	680 Ω	330 Ω - 1 kΩ
32A	220 Ω	150 Ω - 330 Ω
70A one phases 62A tree phases	100 Ω	50 Ω - 150 Ω





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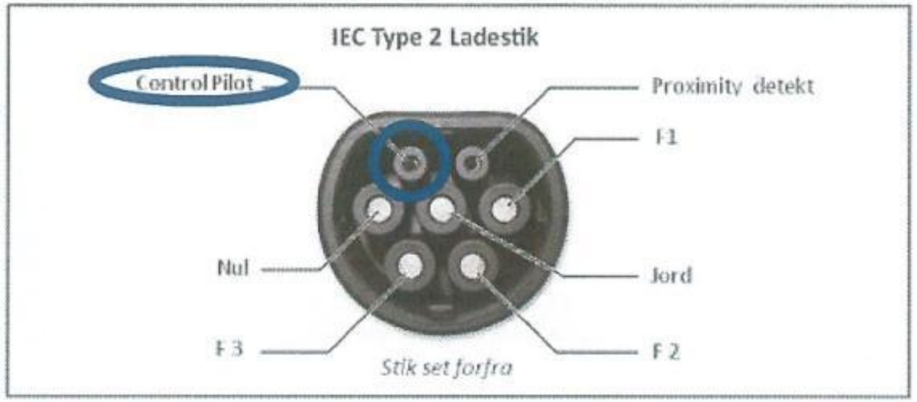
Charging



PWM	SAE Kontinuerlig	SAE Kort sigt	Lade Effekt KW/ 1 fase	Lade Effekt KW/ 3 fase
10 %	6 A		1.4 KW/h	4.2 KW/h
16 %	9.6 A		2.3 KW/h	6.9 KW/h
25 %	15 A	20 A	3.4 KW/h	10.2 KW/h
30 %	18 A	22 A	4.1 KW/h	12.3 KW/h
40 %	24 A	30 A	5.5 KW/h	16.5 KW/h
50 %	30 A	36 A	6.9 KW/h	20.7 KW/h
90 %	DC		350 KW/h 2025	

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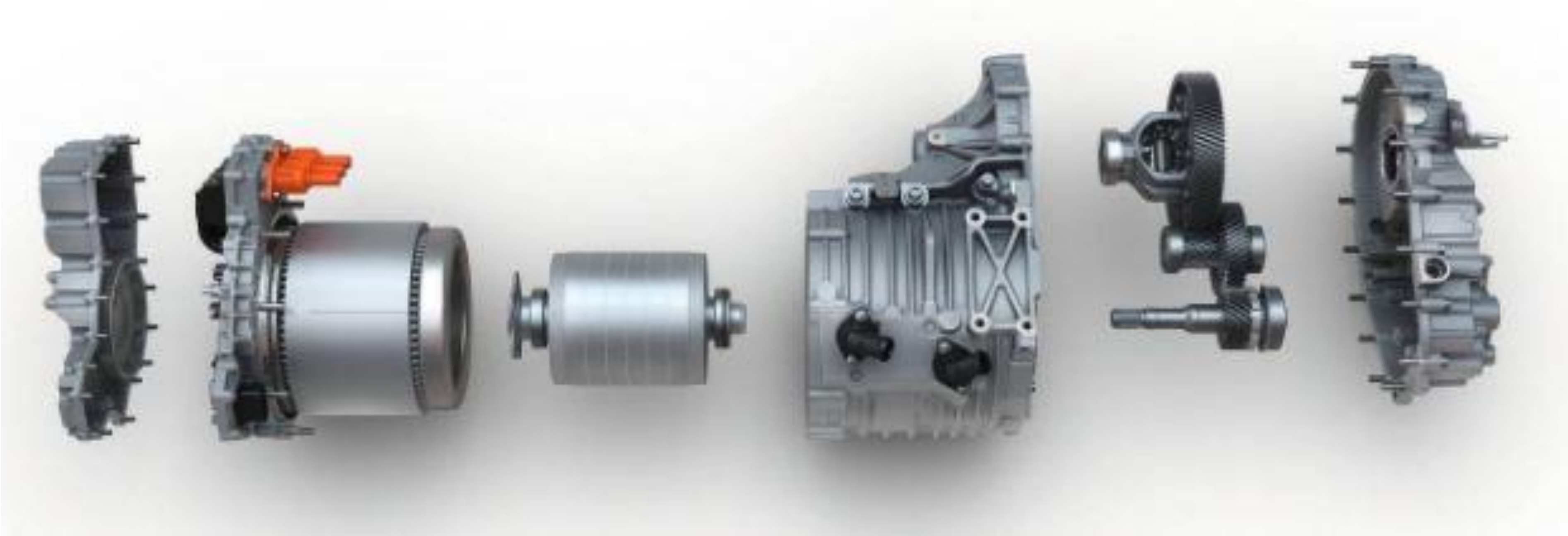
Electric engine



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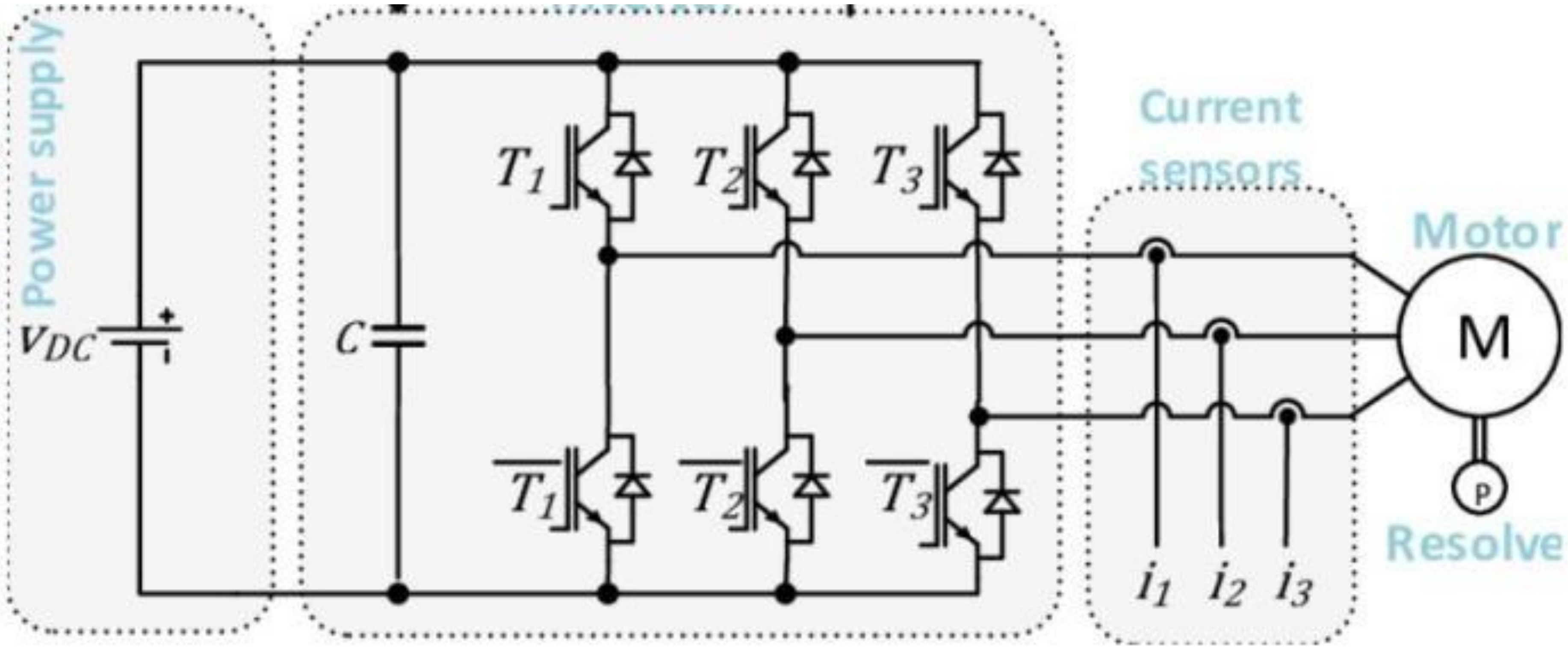
Electric engine



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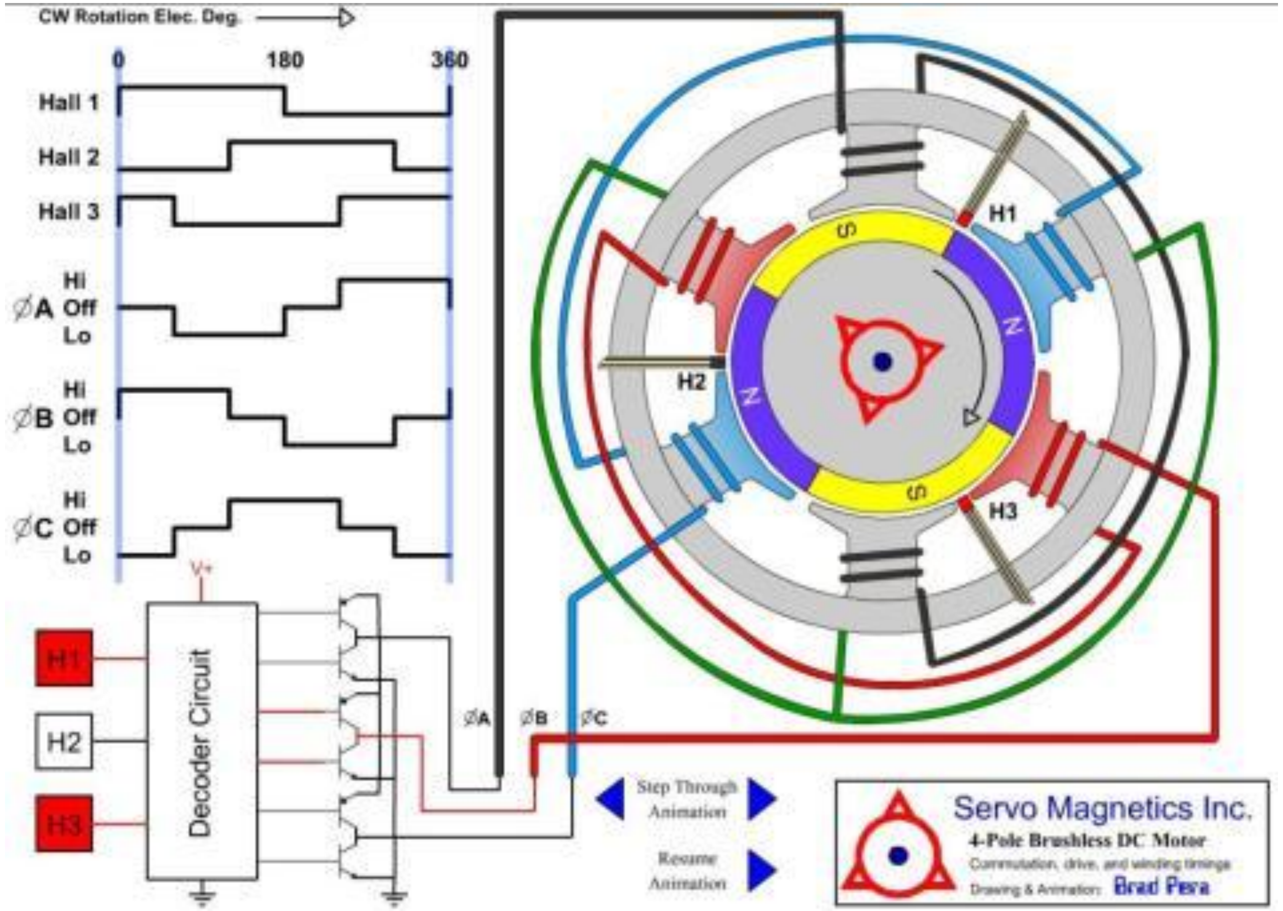
Electric engine



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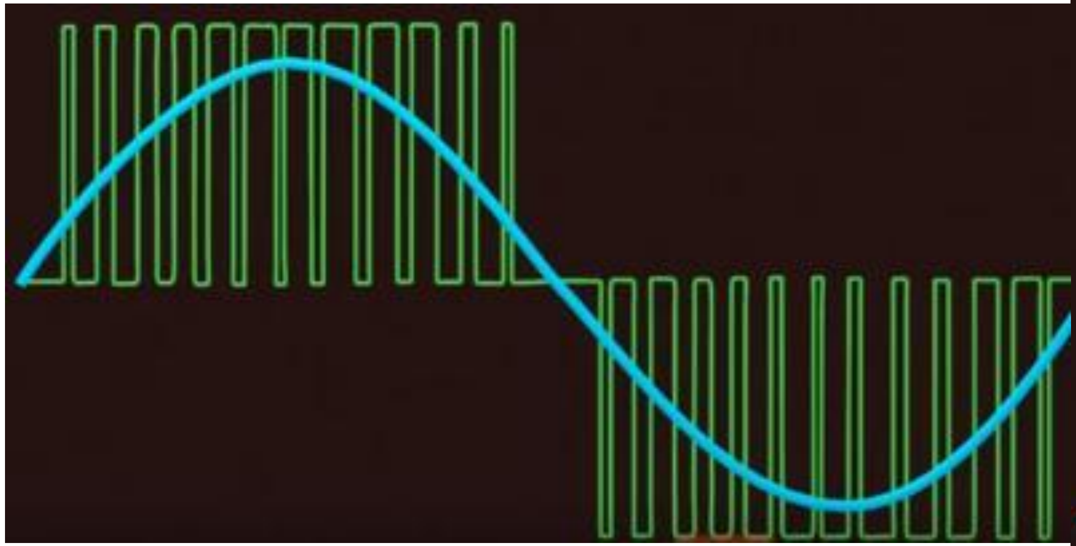
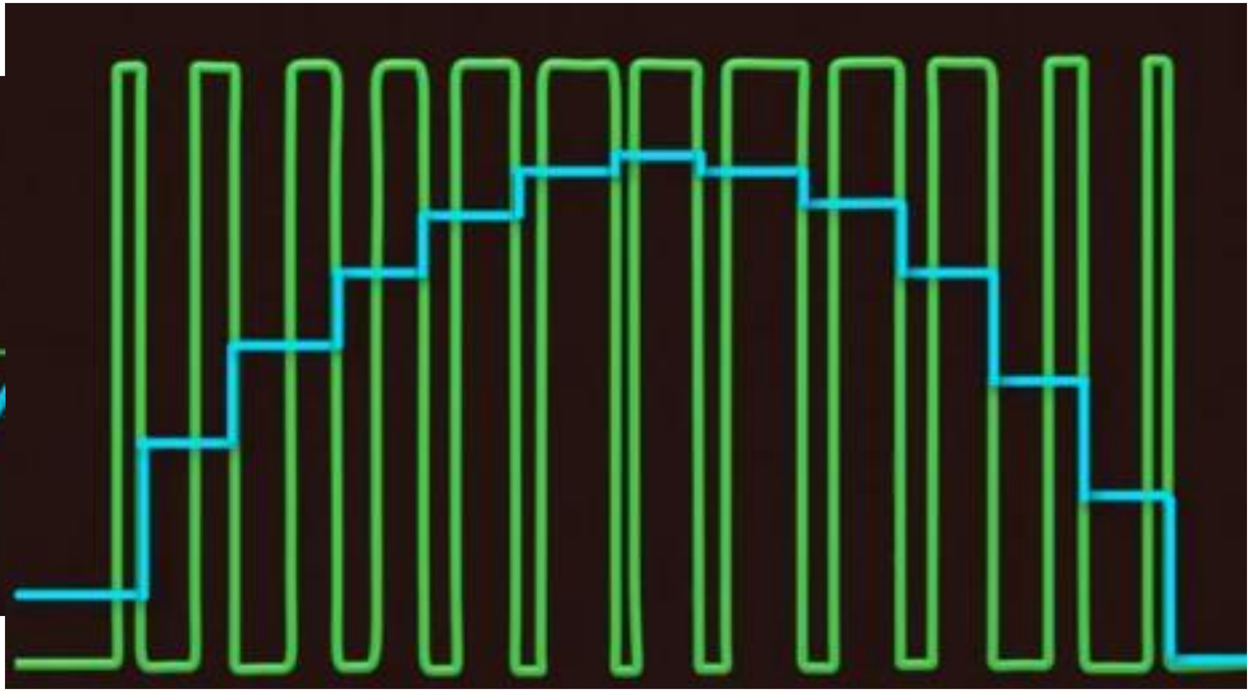
Electric engine





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How to disconnect high voltage battery

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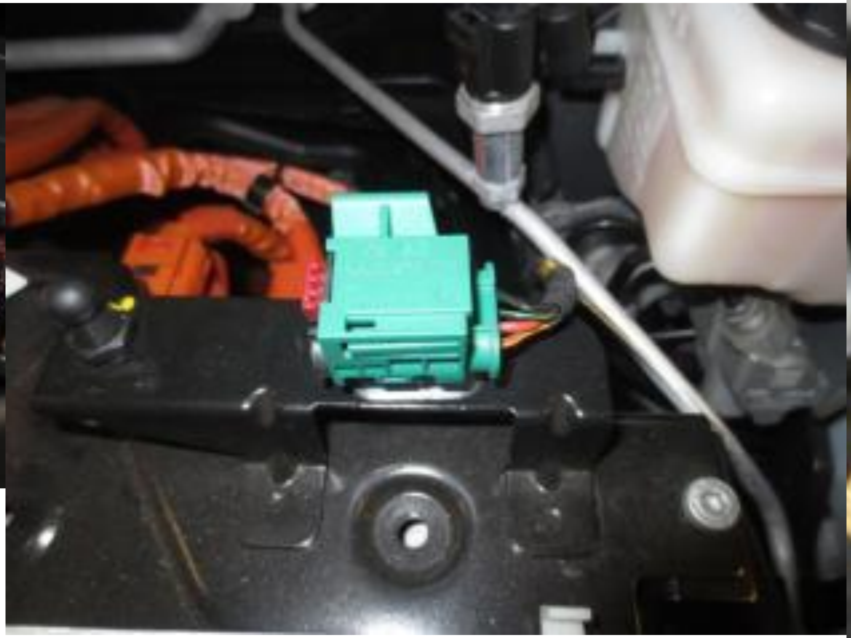
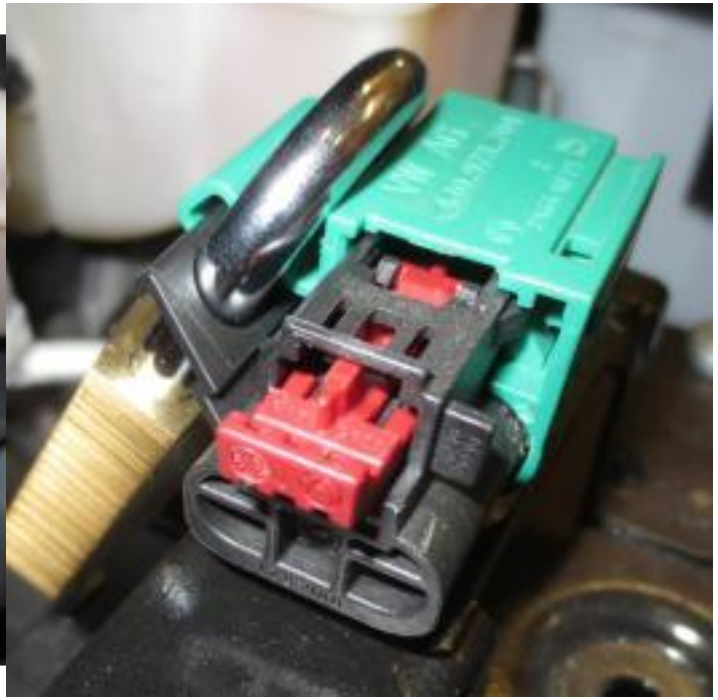
How to disconnect high voltage battery





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How to disconnect high voltage battery

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How to disconnect high voltage battery

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Inverter converter

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MODULE 3

Practical application of EV technologies and measuring on HV systems

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1 ASSIGNMENT CASE STUDIES (FOR THE ENTIRE MODULE)

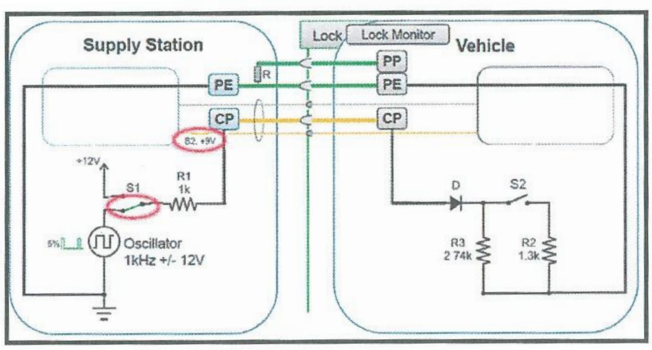
1.1 Assignment 1 - Measurement of charging cable and the commutation between charging wire and charge control

VW E-Up – EV

Measure the Ohmic resistance between the 2 wires (PP and Earth) in the charging cable connector.

The charging cable: ________Ω

The charging cable must be without power for the measurement to be reliable.



This resistance is an expression of how much current (A) the cable can conduct without damage. This resistance is converted into a voltage measurement (V) when the cable is mounted in the plug/charging station and in the vehicle.

Now measure PP (Proximity Pilot) measuring point in the trunk, without charge connected (without charging cable connected), and with charge connected and record the 2 measurements in the diagram below, describe which ones are with charging connectors and which ones are without charging connectors.

Set the Scoopmeter to the same voltage on both measurements.

Value									

Value Per tern		Time						Value Per tern	

What is the difference between the measurements and what does the charge controller use this measurement for:

____

____

Measure CP (Control Pilot) measuring point in the trunk, with charge connected and without charge connected, record the 2 measurements in the diagram below, describe which ones are with charge connected and which are without charge connected.

Set the Scoopmeter to the same voltage on both measurements.

Value									

Value Per tern		Time						Value Per tern	

PWM	SAE Kontinuerlig	SAE Kort sigt	Lade Effekt KW/ 1 fase	Lade Effekt KW/ 3 fase
10 %	6 A		1.4 KW/h	4.2 KW/h
16 %	9.6 A		2.3 KW/h	6.9 KW/h
25 %	15 A	20 A	3.4 KW/h	10.2 KW/h
30 %	18 A	22 A	4.1 KW/h	12.3 KW/h
40 %	24 A	30 A	5.5 KW/h	16.5 KW/h
50 %	30 A	36 A	6.9 KW/h	20.7 KW/h
90 %	DC		350 KW/h 2025	

What is the difference between the measurements and what does the charge controller use this measurement for:

Hyundai Ioniq Plug in hybrid - PHEV

Measure the Ohmic resistance between the 2 wires (PP and Earth) in the charging cable connector.

The charging cable: ________Ω

The charging cable must be without power for the measurement to be reliable.

This resistance is an expression of how much current (A) the cable can conduct without damage. This resistance is converted into a voltage measurement (V) when the cable is mounted in the plug/charging station and in the vehicle.

Now measure PP (Proximity Pilot) measuring point in the trunk, without charge connected (without charging cable connected), and with charge connected and record the 2 measurements in the diagram below, describe which ones are with charging connectors and which ones are without charging connectors.

Value									

Value Per tern		Time						Value Per tern	

What the difference between the measurements and what does the charge controller use this measurement for:

Measure CP (Control Pilot) measuring point in the trunk, with charge connected and without charge connected, record the 2 measurements in the diagram below, describe which ones are with charge connected and which are without charge connected.

Set the Scoopmeter to the same voltage on both measurements.

Value

Value Per tern		Time						Value Per tern	

What the difference between the measurements and what does the charge controller use this measurement for:

____
____

____
____

____
____

1.2 Assignment 2 - Measurement of rotation sensor

VW E-Up – EV

To do these exercises, you must have completed basic high-voltage and safety training, in the field of electric and hybrid vehicles.

Remember safety precautions. The pulling wheels should be free from under the layers!

You need to measure the signals from the electric motor, not the orange ones that are high voltage cables, the wires you need to measure are all on the 12volt system.

Breakout connectors are made with contact points.

You will need an electric diagram of the electric motor.

No.	What are these wiring signals for	Measurement
1		
2		

3		
4		
5		
6		
7		
8		
9		
10		

Set the Scoopmeter so that the time on a phase can be read.
Plot the signal in chart.

Value									

Value Per tern		Time						Value Per tern	

What is the max voltage___________: Volts What is the minimum voltage: Volts________

This type of current is called: ____________________

A phase takes: _____________ms and it gives a Hz of: Hz__________

Now you turn the scoop into 4 channel and measure on all 3signals.

Set the Scoopmeter to the same voltage on all channels.
Plot the signals in schema.

Value									
Value Per tern		Time						Value Per tern	

Only needs to be answered at the first assignment.

What is the difference of this sensor compared to other rotation sensors:

____
____

____
____

____
____

____
____

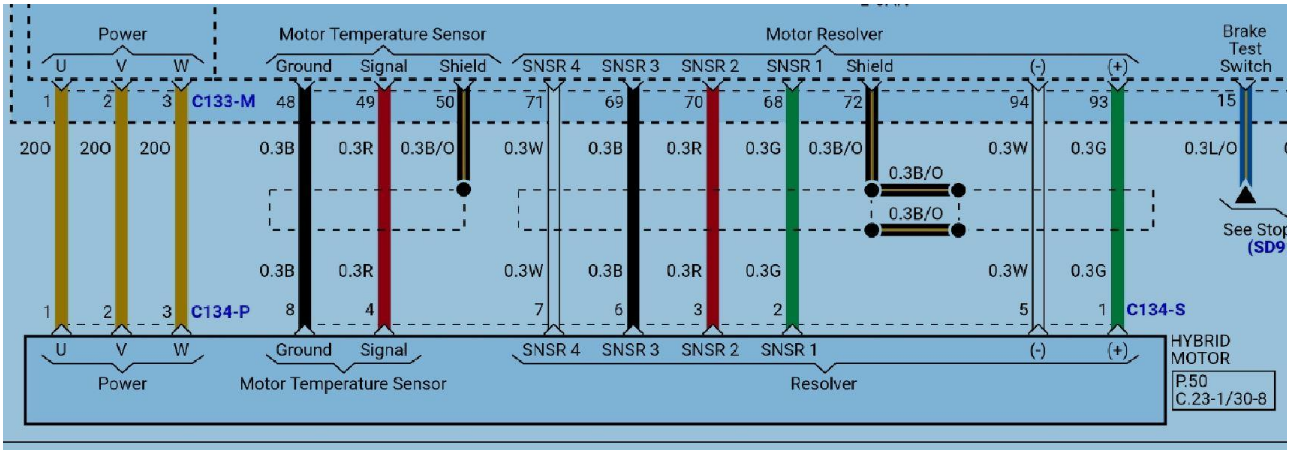
Hyundai Ioniq Plug in hybrid - PHEV

To do these exercises, you must have completed basic high-voltage and safety training, in the field of electric and hybrid vehicles.

Remember safety precautions. The pulling wheels should be free from under the layers!

You need to measure the signals from the electric motor, **not the orange ones that are high voltage cables, the wires you need to measure are all on the 12volt system.**

Break-out connectors with contact points have been made**.**
You will need wiring diagrams, this is the Electric motor.



The yellow wire on the left side is high voltage and is not in the socket, it is the 8 wires in the socket that must be periphery measured.

No.	What are these wiring signals for	Measurement
1		
2		
3		
4		
5		
6		
7		
8		

Voltage supply to the giver at 1 am and 5 am
Set the Scoopmeter so that the time on a phase can be read.
Draw signal one in chart.

Value									

Value Per tern		Time						Value Per tern	

What is the max voltage: Volts ___________ What is the minimum voltage: Volts _ ______

This type of current is called: ___________________

A phase takes: ____________ms and it gives a Hz of: Hz _________

Now you turn the scoop into 3 channel and measure all 3 signals

1. Channel 2 – 3 2. Channel 6 – 7 and 3. Channel 1 – 5

Set the Scoopmeter to the same voltage on both channels.
Plot the signals in schema and write values in the bottom.

Value									

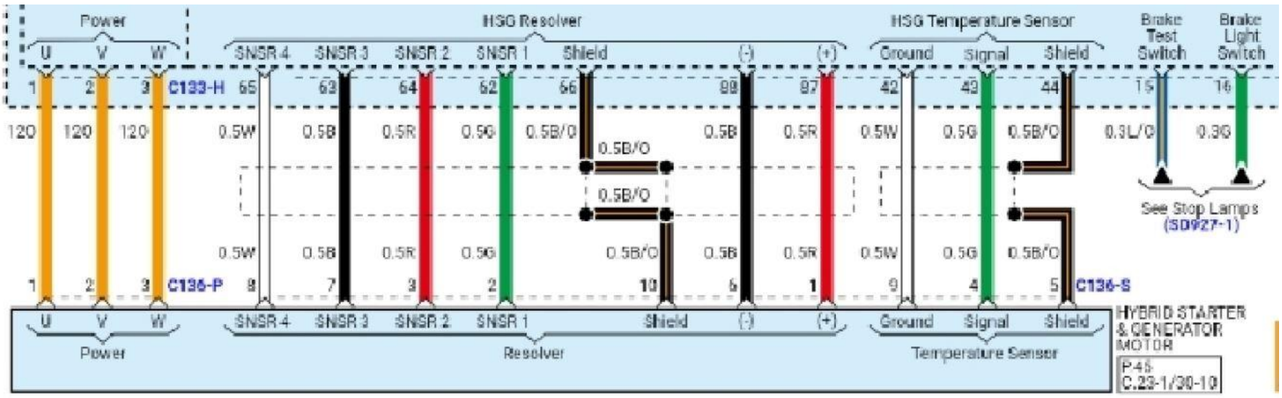
Value Per tern		Time						Value Per tern	

Only needs to be answered at the first assignment.

What is the difference of this sensor compared to other rotation sensors:

Break-out connectors are made with chrome sleeves.

You will need wiring diagrams; this is High Voltage generator/starter.



The yellow wire on the left side is high voltage and is not in the socket, it is the 10 wires in the socket that must be periphery measured.

No.	What are these wiring signals for	Measurement
1		
2		
3		
4		
5		
6		
7		
8		
10		
11		

Voltage supply to the giver at 1 am and 6 am
Set the Scoopmeter so that the time on a phase can be read.
Plot the signal in chart.

Value									

Value Per tern		Time						Value Per tern	

What is the max voltage: Volts ___________ What is the minimum voltage: Volts ______

This type of voltage is called: ___________________

A phase takes: ____________ms and it gives a Hz on: Hz ________

Now you turn the scoop into 3 channel and measure on 3 signal wires

Read the current diagram and find out which coils are connected the, you can do this with an ohm meter, write down the ohmic measurements.
Write down the clamp no. on the different coils.

1.clamp no. ______________________ Ω

2.clamp no. ______________________ Ω

3.clamp no. ______________________ Ω

Set the Scoopmeter to the same voltage on all channels.
Plot the signals in schema.

Value									

Value Per tern		Time						Value Per tern	

1.3 Questions and Answers (Q&As)

1. Q: What distinguishes a hybrid vehicle from a traditional gasoline-powered car?
   A: Hybrid vehicles utilise both a gasoline engine and an electric motor for propulsion, whereas traditional cars solely rely on gasoline engines.

2. Q: How does regenerative braking work in hybrid and electric vehicles?
   A: Regenerative braking harnesses kinetic energy during braking, converting it into electricity to recharge the vehicle's battery.

3. Q: What are the main benefits of owning a plug-in hybrid vehicle?
   A: Plug-in hybrids offer increased fuel efficiency, reduced emissions, and the flexibility to operate in electric-only mode for short distances.

4. Q: Can hybrid vehicles be charged externally like electric cars?
   A: No, hybrid vehicles do not have the capability for external charging; they rely on their internal combustion engine and regenerative braking to recharge the battery.

5. Q: How does the range of a plug-in hybrid differ from that of a full electric vehicle?
   A: Plug-in hybrids typically have a shorter electric-only range compared to full electric vehicles due to their smaller battery capacity and reliance on gasoline backup.

6. Q: What factors should be considered when selecting between a hybrid, plug-in hybrid, or full electric vehicle?
   A: Consider factors such as driving habits, commuting distance, access to charging infrastructure, and environmental concerns when choosing the right type of vehicle.

7. Q: How do you maintain the battery health in hybrid and electric vehicles?
   A: Maintaining battery health involves avoiding deep discharges, minimising exposure to extreme temperatures, and following manufacturer-recommended maintenance schedules.

8. Q: Can hybrid and electric vehicles be serviced at traditional auto repair shops?
   A: Yes, many traditional auto repair shops are equipped to service hybrid and electric vehicles, although specialised training and equipment may be required for certain repairs.

9. Q: What are the potential challenges of owning a full electric vehicle?
   A: Challenges may include limited charging infrastructure, longer charging times compared to refuelling with gasoline, and concerns about range anxiety on long trips.

10. Q: How does the driving experience differ between a hybrid and a full electric vehicle?

A: Full electric vehicles offer smoother and quieter driving experiences due to their lack of internal combustion engines, while hybrids may still produce some engine noise.

11. Q: Are there any government incentives or tax credits available for purchasing hybrid or electric vehicles?
    A: Yes, many governments offer incentives such as tax credits, rebates, or special access to HOV lanes to encourage the adoption of hybrid and electric vehicles.

12. Q: How does cold weather affect the performance of hybrid and electric vehicles?
    A: Cold weather can reduce battery efficiency and range in hybrid and electric vehicles, although advancements in battery technology have mitigated some of these effects.

13. Q: Can hybrid and electric vehicles be charged using renewable energy sources?
    A: Yes, owners of hybrid and electric vehicles can choose to charge their vehicles using renewable energy sources such as solar or wind power if available.

14. Q: What are the differences in maintenance costs between hybrid, plug-in hybrid, and full electric vehicles?
    A: Maintenance costs for hybrid and electric vehicles are generally lower than those for traditional gasoline vehicles due to fewer moving parts and less frequent maintenance requirements.

15. Q: Are there any safety considerations specific to hybrid and electric vehicles that mechanics should be aware of?
    A: Mechanics should be trained to handle high-voltage systems safely and should follow manufacturer guidelines for disabling and servicing hybrid and electric vehicle components. Additionally, proper insulation and personal protective equipment should be used when working on these vehicles.

1.4 MULTIPLE CHOICE QUESTIONS (FOR THE ENTIRE MODULE)

1. The status of the capacity of the battery is known as:
    a. State Of Capacity
    b. State Of Health
    c. State Of Charge
2. The status of the remaining quantity of electricity available in the battery is known as:
    a. State Of Capacity
    b. State Of Health
    c. State Of Charge
3. What is the name of the High Voltage control unit?
    a. The generator
    b. The inverter/converter
    c. The carburetor

4. What characterises a hybrid car?
    a. This vehicle has no charging socket
    b. The vehicle has no High Voltage battery
    c. The vehicle has no inverter/converter
5. According to EU regulations the state that a battery pack over a period of 8 years or after 160.000 km may only lose
    a. 20 % of its capacity
    b. 30 % of its capacity
    c. 40 % of its capacity
6. When you are measuring the inverter in the plugin hybrid to make sure the capacitors are discharged. What is the max voltage you may measure?
    a. 0 millivolts
    b. 40 millivolts
    c. 100 millivolts
7. Can you heat the cabin of hybrid and plugin hybrid without the combustion engine?
    a. No
    b. Yes
    c. Only the plugin hybrid
8. What kind of current is the High Voltage battery on?
    a. Alternating Current
    b. Direct Current
9. How do you charge your battery the fastest?
    a. Using Direct Current
    b. Using Alternating Current
    c. It's the same
10. How is the high voltage wiring colored on HV vehicle?
    a. Yellow and Black
    b. Red
    c. Orange

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
b.	c.	b.	a.	b.	b.	a.	b.	a.	c.

MODULE 4

Batteries and BMS

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1 INTRODUCTORY PARAGRAPH (FOR EACH LESSON)

The purpose of this module is to give the learner the necessary knowledge, skill and competencies in regard to high voltage batteries and Battery Management System (BMS) to act as a car mechanic/technician in the era of electric and hybrid electric car technologies.

1.1 LEARNING UNIT 1 - Introduction to battery technology – Electricity

In this learning unit you will be introduced to the fundamentals of understanding battery technology, namely electricity.

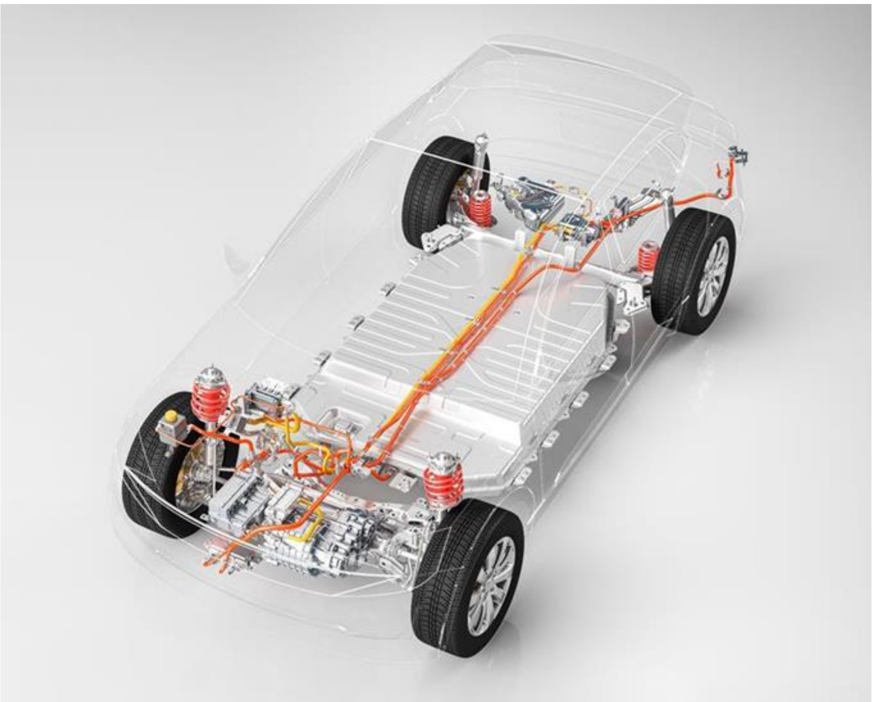
1.2 LEARNING UNIT 2 - The application of High Voltage batteries

In this learning unit you will learn about high-voltage batteries, their chemical composition and functionality, as well as the pros and cons of Li-ion batteries.

1.3 LEARNING UNIT 3 - Batteries including the BMS in Electric and Hybrid Electric vehicles.

In this learning unit you will learn about how Li-ion high-voltage batteries are managed through the Battery Management System.

2 LECTURE NOTES (FOR EACH LEARNING UNIT)



2.1 LEARNING UNIT 1 - Introduction to battery technology – Electricity

What is Electricity?

Electricity is a form of energy resulting from the movement of charged particles, primarily electrons. It is a versatile energy source that powers various devices, from light bulbs and appliances in our homes to the intricate circuits in our electronic devices.

At the heart of electricity are atoms, the building blocks of matter. Atoms consist of a central nucleus composed of positively charged protons and neutral neutrons, surrounded by negatively charged electrons orbiting in energy levels or shells.

Electrons carry a negative electrical charge, while protons have a positive charge. Neutrons have no net charge and are neutral. An atom is electrically neutral when the number of electrons equals the number of protons.

An atom is electrical neutral and consists of 3 smaller particles, negatively charged electrons orbiting and in the core positively charged protons and neutral neutrons, which again are made of even smaller particles called quarks and gluons.

Sometimes, electrons can be transferred from one object to another through friction or contact, causing one object to become negatively charged (extra electrons) and the other to become positively charged (missing electrons). This phenomenon is known as static electricity, and it can result in attractions or repulsions between charged objects.

Electricity really gets interesting when we talk about electric current. Electric current is the flow of electrons through a conductor (usually a material that allows electrons to move freely, like metal). This flow of electrons constitutes an electric current, which can be harnessed to do work.

Three fundamental concepts in electricity are:

Voltage (V): Voltage is like the "push" that causes electrons to move. It's measured in volts (V) and represents the electrical potential difference between two points in a circuit.

Current (I): Current is the rate of flow of electrons through a conductor. It's measured in amperes (A) and tells you how many electrons pass through a point in a circuit per second.

Resistance (R): Resistance is the opposition to the flow of electric current in a material. It's measured in ohms (Ω) and depends on the material's properties and shape.

Ohm's Law, formulated by Georg Simon Ohm, relates these three concepts: V (Voltage) = I (Current) × R (Resistance). This law helps us understand how these factors are interrelated in electrical circuits.

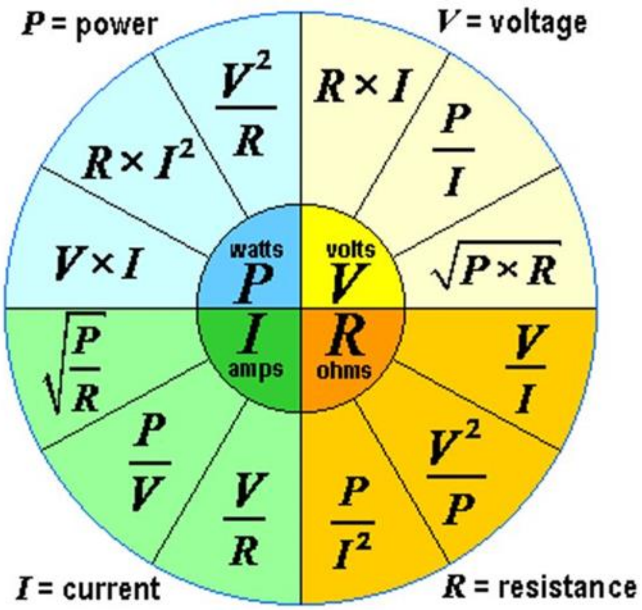
The formula for electric power, expressed as $P=A\times V$, relates power (P) to current (A, in amperes) and voltage (V, in volts). Here's a breakdown of the formula:

P (Power): Measured in watts (W), power is the rate at which electrical energy is transferred by an electric circuit. In this formula, it's the product of the current and voltage.

A (Current): Current, measured in amperes (or amps), represents the flow of electric charge through a conductor. It indicates how many coulombs of charge pass through a point in the circuit per second.

V (Voltage): Voltage, measured in volts, is the electrical potential difference between two points in a circuit. It's a measure of the electric force that drives the current around the circuit.

The formula $P=A\times V$ essentially states that the power (in watts) in an electrical system is equal to the current (in amperes) flowing through it multiplied by the voltage (in volts) across it. This formula is fundamental in electrical engineering and is used to calculate the power consumption or generation in any electrical device or system.



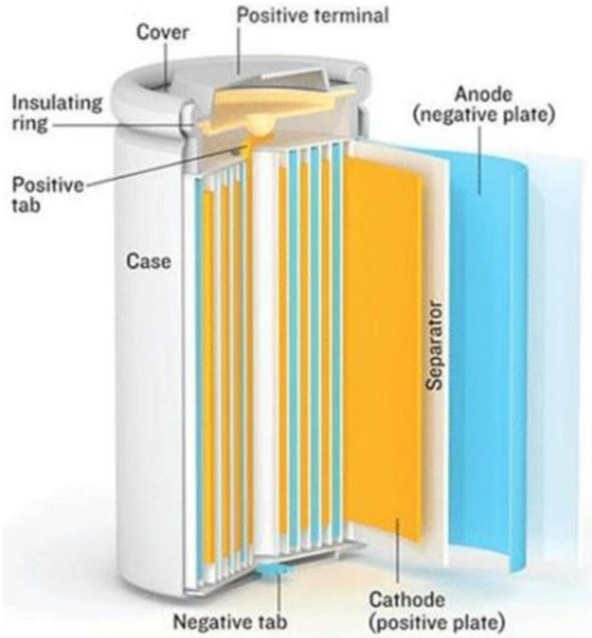
Electrical components (like resistors, capacitors, and transistors) are connected in various ways to form electrical circuits. Circuits allow us to control the flow of electricity and create the functions we need, from powering devices to sending information.

In summary, electricity is the flow of electrons through conductors, and it can be harnessed for various purposes in our modern world.

Understanding the basics of voltage, current, resistance, and how they relate to each other is essential for working with electricity effectively and safely.

2.2 LEARNING UNIT 2 - The application of High Voltage batteries

Lithium-ion (Li-ion) batteries are a type of rechargeable battery that has become ubiquitous in modern electric vehicles due to their high energy density, low self- discharge, and long cycle life. The chemistry and functionality of lithium-ion batteries involve several key components and processes.



1. Cathode (Positive Electrode): The cathode is typically made from a lithium metal oxide compound (like LiCoO2, LiMn2O4, LiFePO4, etc.). It determines the battery's voltage and capacity.
2. Anode (Negative Electrode): The anode is usually made from graphite, which serves as a host for lithium ions. When the battery is charged, lithium ions are stored in the anode.
3. Electrolyte: The electrolyte is a lithium salt dissolved in an organic solvent. It conducts lithium ions between the cathode and anode.
4. Separator: This is a porous membrane that keeps the cathode and anode from directly contacting each other, preventing short circuits while allowing lithium ions to pass through.

Chemistry and Operation

Charging:

During charging, lithium ions move from the cathode to the anode through the electrolyte. Electrons flow from the cathode to the anode through the external circuit, providing the electric energy needed to charge the battery.

Discharging:

When the battery is in use (discharging), lithium ions move back from the anode to the cathode, and electrons flow through the external circuit from the anode to the cathode, powering the connected device.

Advantages of Li-ion Batteries:

High Energy Density: Lithium-ion batteries can store a large amount of energy in a small volume and weight, making them ideal for electric vehicles where weight and space are critical.

Low Self-Discharge: They have a much lower self-discharge rate compared to other rechargeable batteries, like Ni-Cd or Ni-MH, which means they retain their charge longer when not in use.

No Memory Effect: Li-ion batteries don't suffer from the memory effect (a condition that reduces the longevity of a battery due to incomplete discharge cycles), making them more user-friendly.

Long Lifespan: They can endure hundreds to thousands of charge/discharge cycles before their capacity falls significantly.

Challenges and Safety

Thermal Stability: Li-ion batteries can be sensitive to high temperatures, which can lead to thermal runaway – a condition where the battery overheats and potentially catches fire or explodes.

Aging: They degrade over time, even when not in use, due to chemical reactions occurring within the battery.

Cost: The materials and manufacturing process can be more expensive compared to other types of batteries.

Sensitive to Overcharging: Overcharging can lead to damage, reducing lifespan and possibly causing safety issues.

To mitigate these challenges, most Li-ion batteries come with a built-in battery management system (BMS) that monitors and regulates charging and discharging to ensure safety and prolong the battery's life. Advances in technology continue to improve the performance, safety, and cost-effectiveness of lithium-ion batteries.

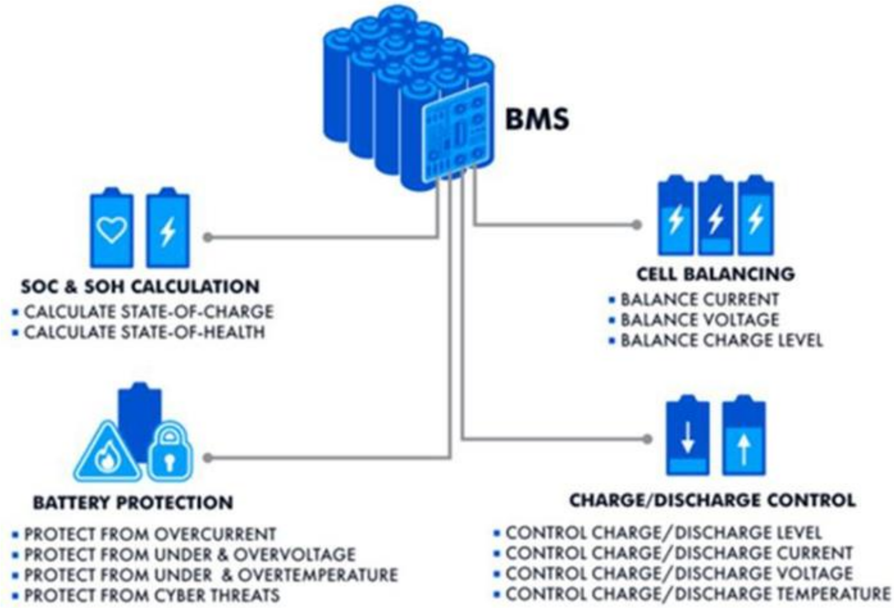
2.3 LEARNING UNIT 3 - Batteries including the BMS in Electric and Hybrid Electric vehicles.

A Battery Management System (BMS) is a critical component in lithium-ion battery technology, designed to ensure safe and efficient operation of the battery pack.

Lithium-ion batteries are used in a wide range of applications, from small electronic devices to large-scale energy storage, and electric vehicles.

The BMS plays several key roles:

1. Cell Monitoring and Balancing
2. Temperature Management
3. State of Charge (SoC) and State of Health (SoH) Calculation
4. Charge and Discharge Control
5. Protection
6. Communication



Lithium-ion battery packs are made up of multiple cells. Each cell has slightly different characteristics, and over time, these differences can become more pronounced, affecting the performance and lifespan of the battery. The BMS monitors the voltage and temperature of each cell to detect any anomalies. It also balances the cells by ensuring all cells in the pack have the same charge level, either by discharging cells that are fully charged or charging those that are undercharged.

Lithium-ion batteries are sensitive to temperature extremes. The BMS monitors the temperature and can take corrective actions like reducing the charging rate or even shutting down the battery if temperatures move outside of a safe range.

The BMS calculates the State of Charge, which is a measure of the current energy level of the battery as a percentage of its full capacity. It also assesses the State of Health, indicating the overall condition of the battery and how much its capacity has degraded over time.

To prevent damage, the BMS controls the charging and discharging processes. It ensures the battery doesn't overcharge or discharge below a certain level, as both can harm the battery's lifespan and performance.

The BMS provides protection against over-voltage, under-voltage, over-current, and short circuit conditions. This helps in preventing situations that could lead to battery damage or safety hazards like thermal runaway, where excessive heat in one cell can propagate to adjacent cells.

The BMS is essential for maximising performance, longevity, and safety of lithium-ion battery packs. It achieves this through sophisticated monitoring and control strategies, ensuring the battery operates within its safe operating area.

M4 Batteries and BMS

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Presentation Flow

LEARNING UNITS

- 4.1 Introduction to battery technology - Electricity
- 4.2 The application of High Voltage batteries
- 4.3 Batteries including the BMS in Electric and Hybrid Electric vehicles

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Introduction

INTRODUCTION

The purpose of this module is to give the learner the necessary knowledge, skill and competencies regarding high voltage batteries and Battery Management System (BMS) to act as a car mechanic/technician in the era of electric and hybrid electric car technologies

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Learning Unit 1: Introduction to Battery Technology - Electricity

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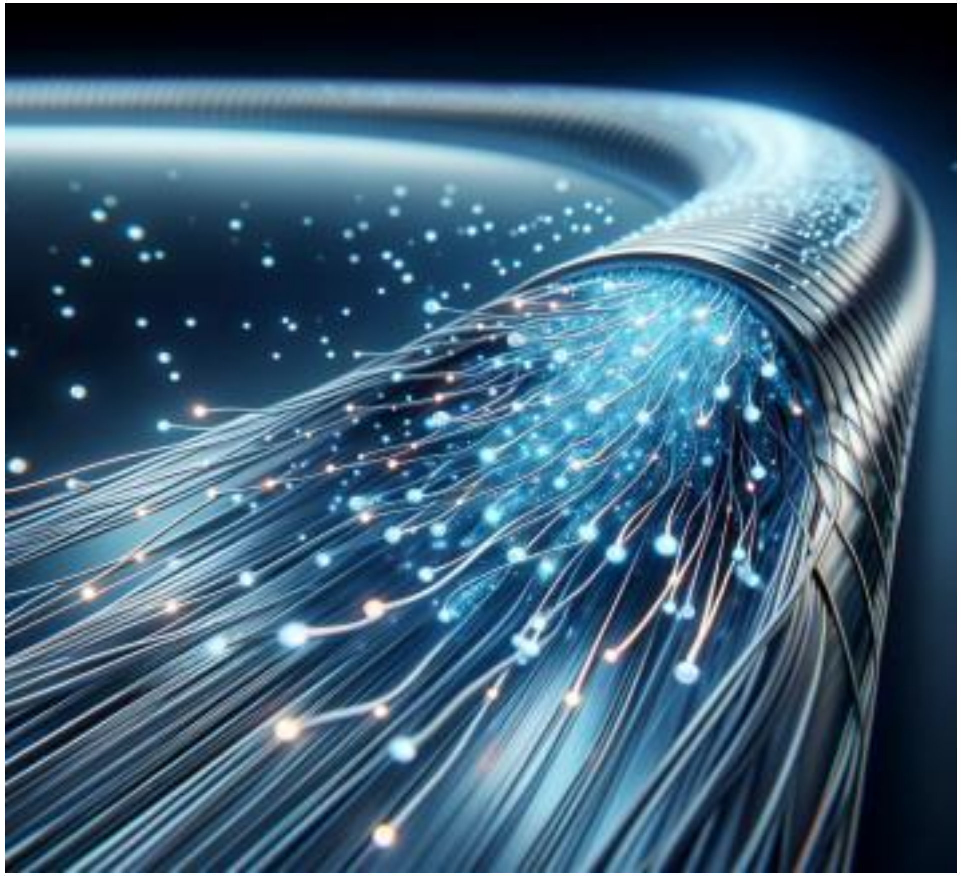
Electricity



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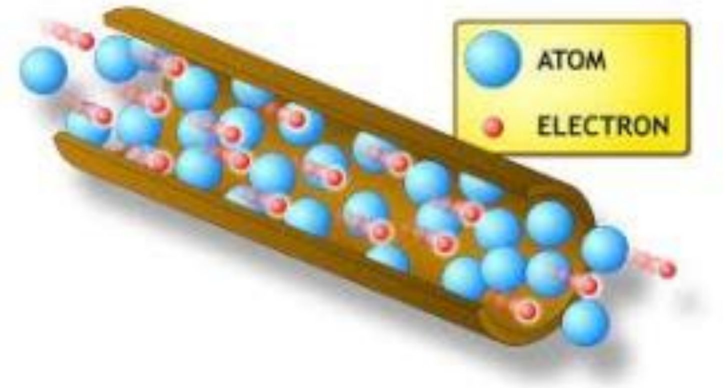
What is Electricity?

Electricity is a form of energy resulting from the movement of charged particles, primarily electrons. It is a versatile energy source that powers various devices, from light bulbs and appliances in our homes to the intricate circuits in our electronic devices



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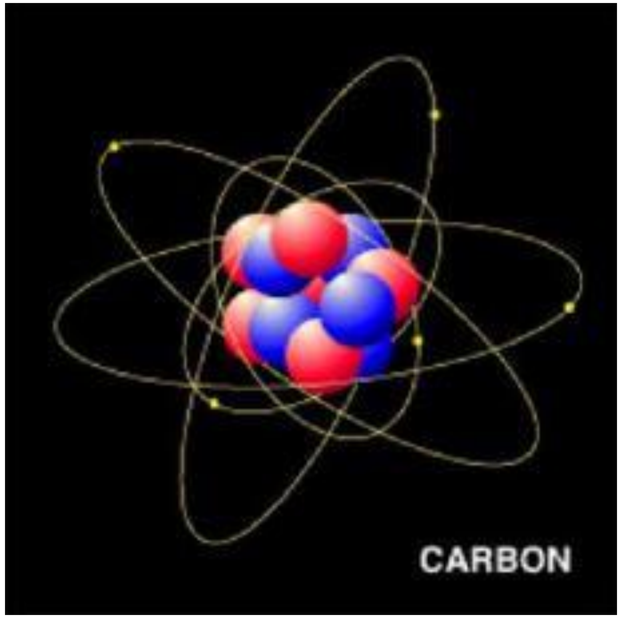
Atoms and Electrons

At the heart of electricity are atoms, the building blocks of matter. Atoms consist of a central nucleus composed of positively charged protons and neutral neutrons, surrounded by negatively charged electrons orbiting in energy levels or shells



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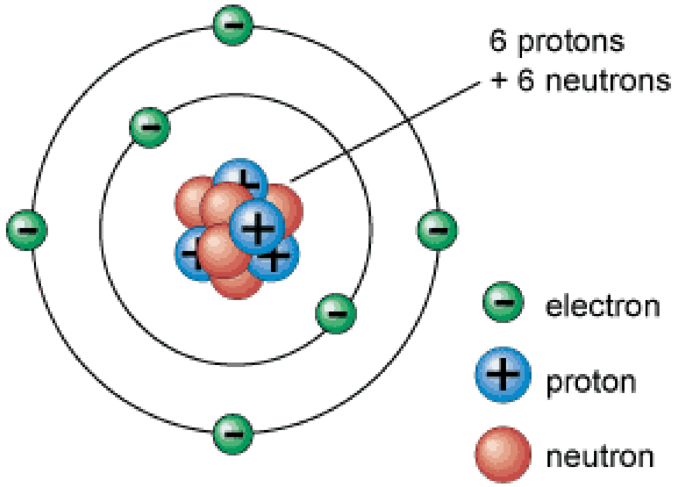
Charge and Electrons

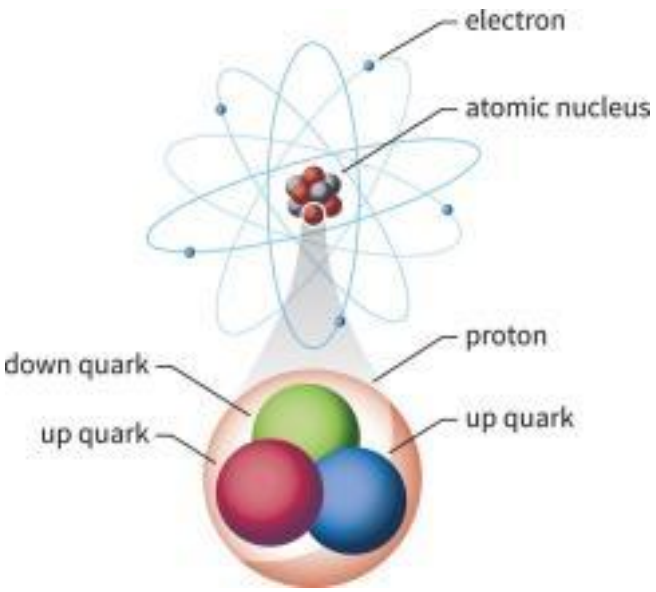
Electrons carry a negative electrical charge, while protons have a positive charge. Neutrons have no net charge and are neutral. An atom is electrically neutral when the number of electrons equals the number of protons



Carbon atom

Electrons

An atom is electrical neutral and consists of 3 smaller particles, negatively charged Electrons orbiting and in the core positively charged protons and neutral neutrons, which again is made of even smaller particles called quarks and gluons



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Static Electricity

Sometimes, electrons can be transferred from one object to another through friction or contact, causing one object to become negatively charged (extra electrons) and the other to become positively charged (missing electrons). This phenomenon is known as static electricity, and it can result in attractions or repulsions between charged objects.

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Electric Current

Electricity really gets interesting when we talk about electric current. Electric current is the flow of electrons through a conductor (usually a material that allows electrons to move freely, like metal). This flow of electrons constitutes an electric current, which can be harnessed to do work.

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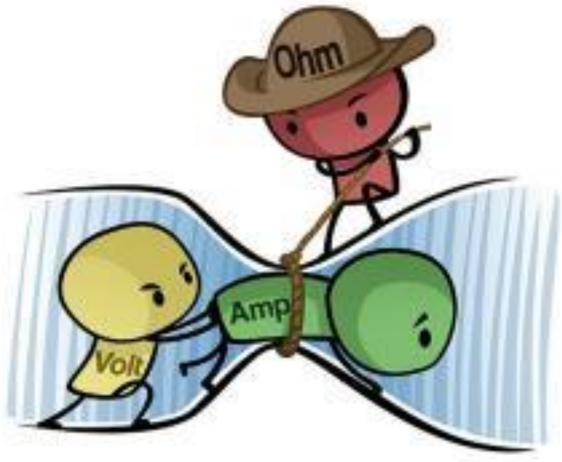
Voltage, Current, and Resistance

Three fundamental concepts in electricity are:

1. Voltage (V): Voltage is like the "push" that causes electrons to move. It's measured in volts (V) and represents the electrical potential difference between two points in a circuit.

2. Current (I): Current is the rate of flow of electrons through a conductor. It's measured in amperes (A) and tells you how many electrons pass through a point in a circuit per second.

3. Resistance (R): Resistance is the opposition to the flow of electric current in a material. It's measured in ohms (Ω) and depends on the material's properties and shape.



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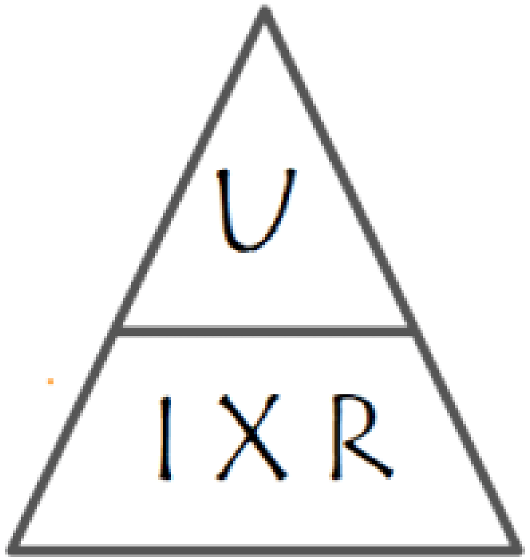
Ohm's Law

Ohm's Law, formulated by Georg Simon Ohm, relates these three concepts: V (Voltage) = I (Current) × R (Resistance). This law helps us understand how these factors are interrelated in electrical circuits.



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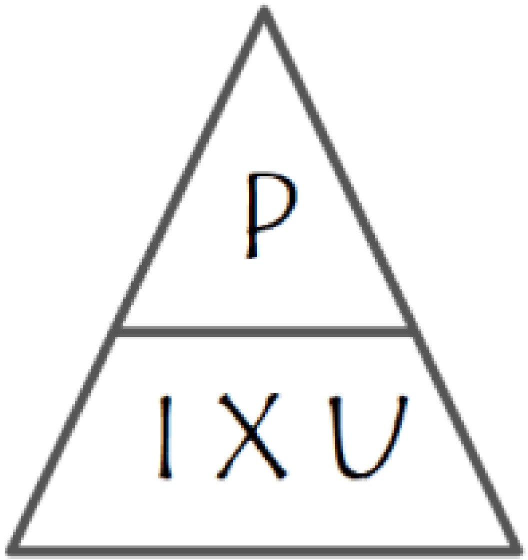
Electric power

The formula for electric power, expressed as P=A×V, relates power (P) to current (A, in amperes) and voltage (V, in volts). Here's a breakdown of the formula:

1. P (Power): Measured in watts (W), power is the rate at which electrical energy is transferred by an electric circuit. In this formula, it's the product of the current and voltage.

2. A (Current): Current, measured in amperes (or amps), represents the flow of electric charge through a conductor. It indicates how many coulombs of charge pass through a point in the circuit per second.

3. V (Voltage): Voltage, measured in volts, is the electrical potential difference between two points in a circuit. It's a measure of the electric force that drives the current around the circuit.



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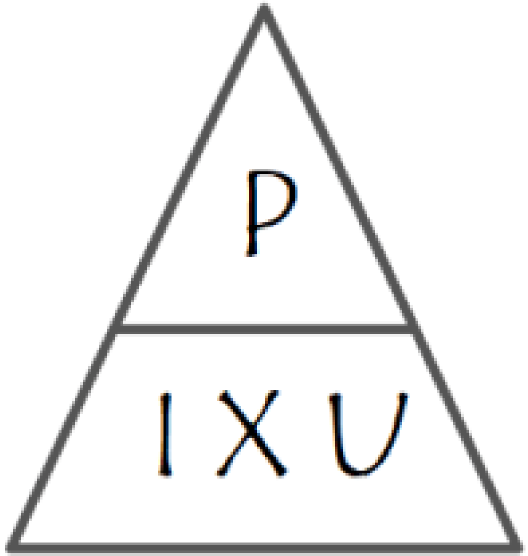
Electric power

The formula P=A×V essentially states that the power (in watts) in an electrical system is equal to the current (in amperes) flowing through it multiplied by the voltage (in volts) across it. This formula is fundamental in electrical engineering and is used to calculate the power consumption or generation in any electrical device or system.



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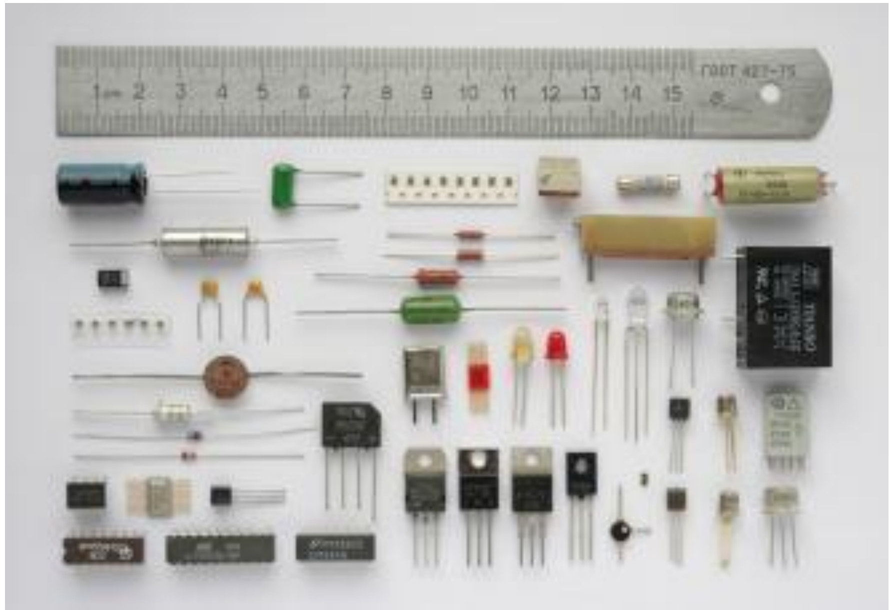
Electrical components

Electrical components (like resistors, capacitors, and transistors) are connected in various ways to form electrical circuits. Circuits allow us to control the flow of electricity and create the functions we need, from powering devices to sending information.



In summary, electricity is the flow of electrons through conductors, and it can be harnessed for various purposes in our modern world. Understanding the basics of voltage, current, resistance, and how they relate to each other is essential for working with electricity effectively and safely.

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Learning Unit 2: The Application of High Voltage Batteries in Electric and Hybrid Electric Vehicles

2

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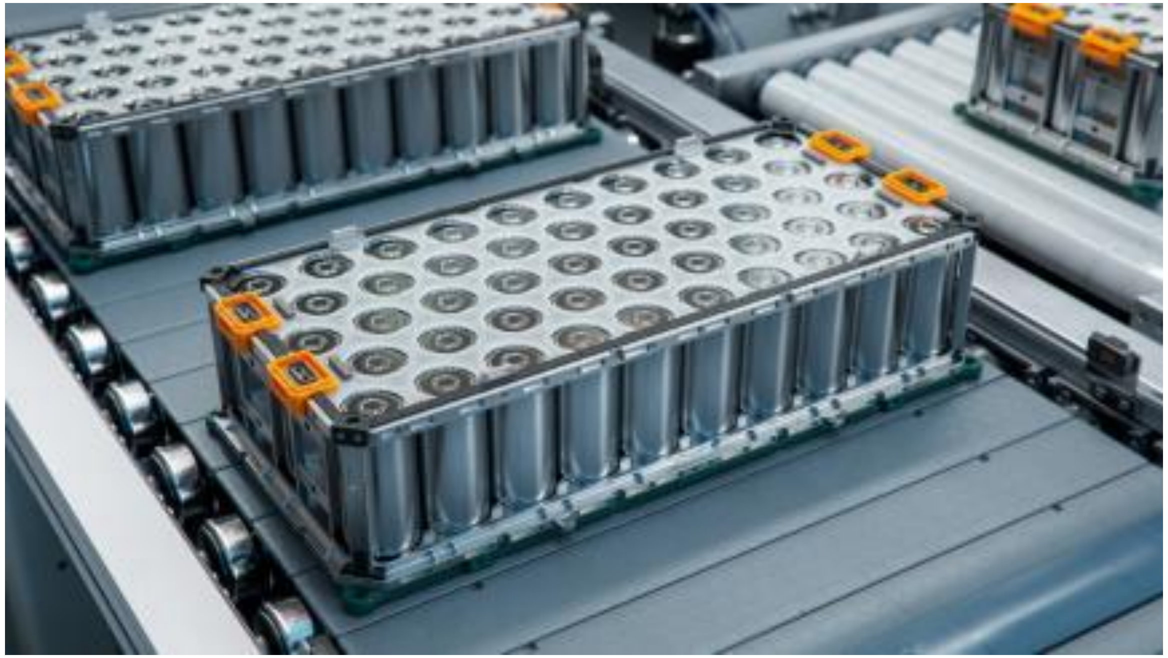
Lithium-ion Batteries



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Lithium-ion Batteries

Lithium-ion (Li-ion) batteries are a type of rechargeable battery that has become ubiquitous in modern electric vehicles due to their high energy density, low self-discharge, and long cycle life. The chemistry and functionality of lithium-ion batteries involve several key components and processes

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Key Components

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2. Anode (Negative Electrode): The anode is usually made from graphite, which serves as a host for lithium ions. When the battery is charged, lithium ions are stored in the anode.

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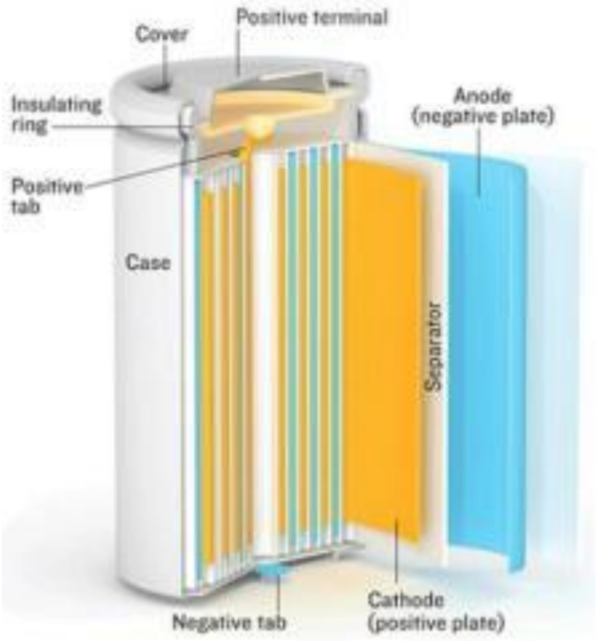

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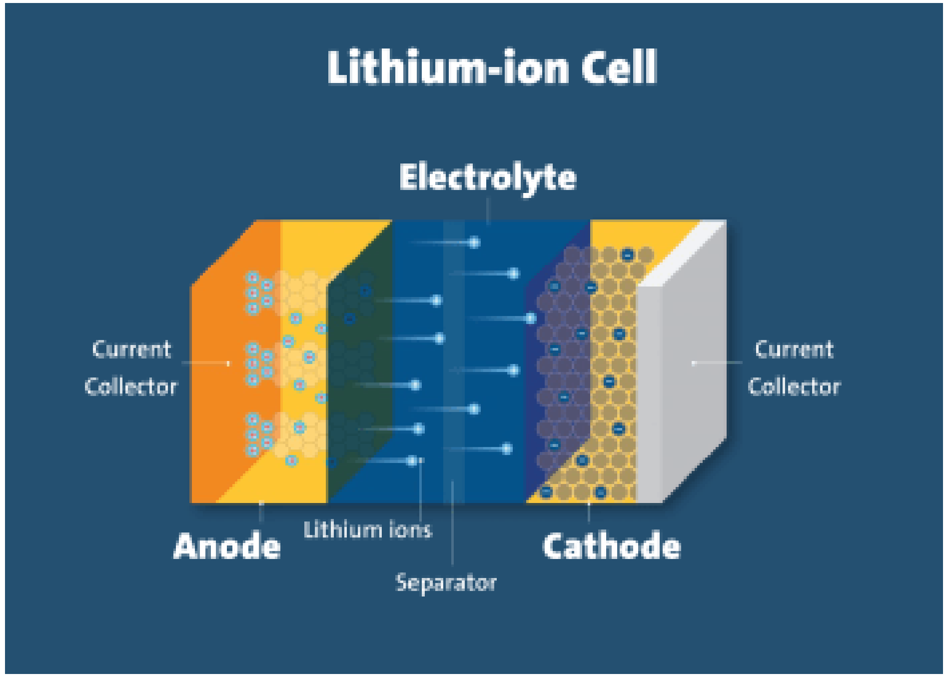
Chemistry and Operation

1. Charging: During charging, lithium ions move from the cathode to the anode through the electrolyte. Electrons flow from the cathode to the anode through the external circuit, providing the electric energy needed to charge the battery.



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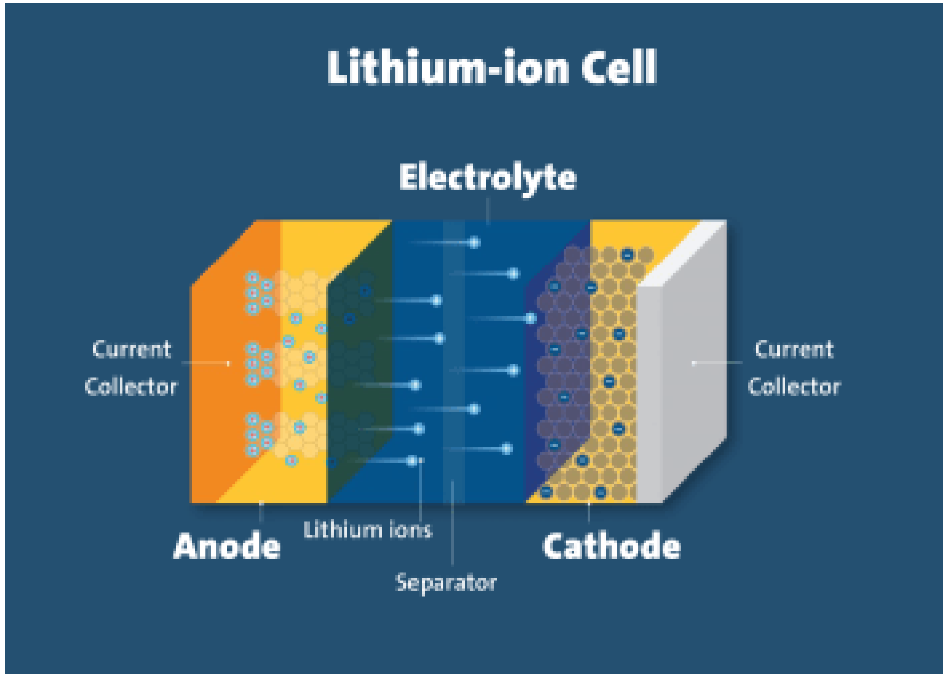
Chemistry and Operation

2. Discharging: When the battery is in use (discharging), lithium ions move back from the anode to the cathode, and electrons flow through the external circuit from the anode to the cathode, powering the connected device.



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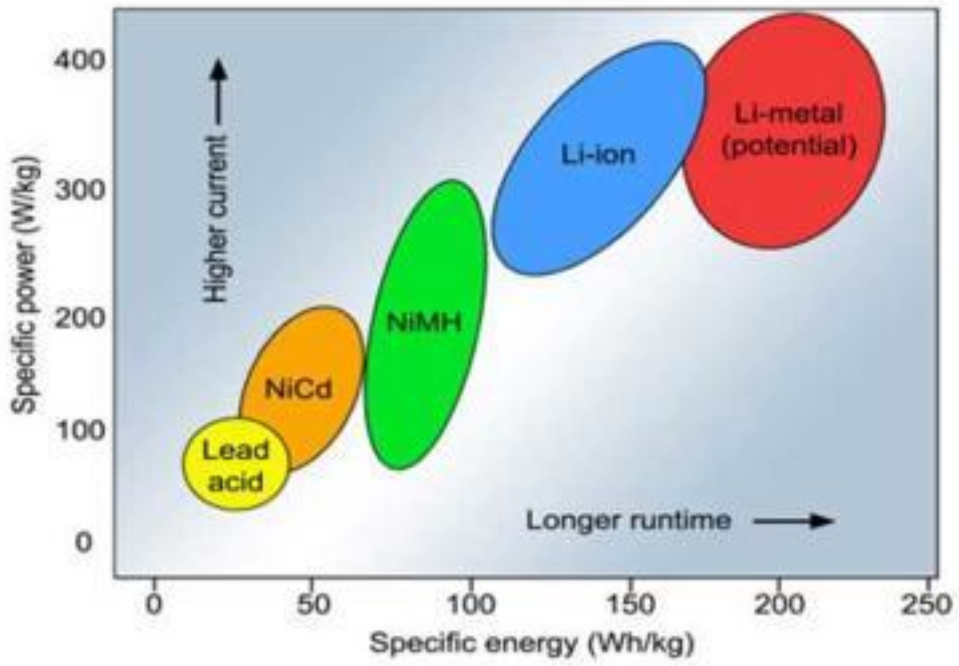
Advantages of Li-ion Batteries

1. High Energy Density: Lithium-ion batteries can store a large amount of energy in a small volume and weight, making them ideal for electric vehicles where weight and space are critical.

2. Low Self-Discharge: They have a much lower self-discharge rate compared to other rechargeable batteries, like Ni-Cd or Ni-MH, which means they retain their charge longer when not in use.



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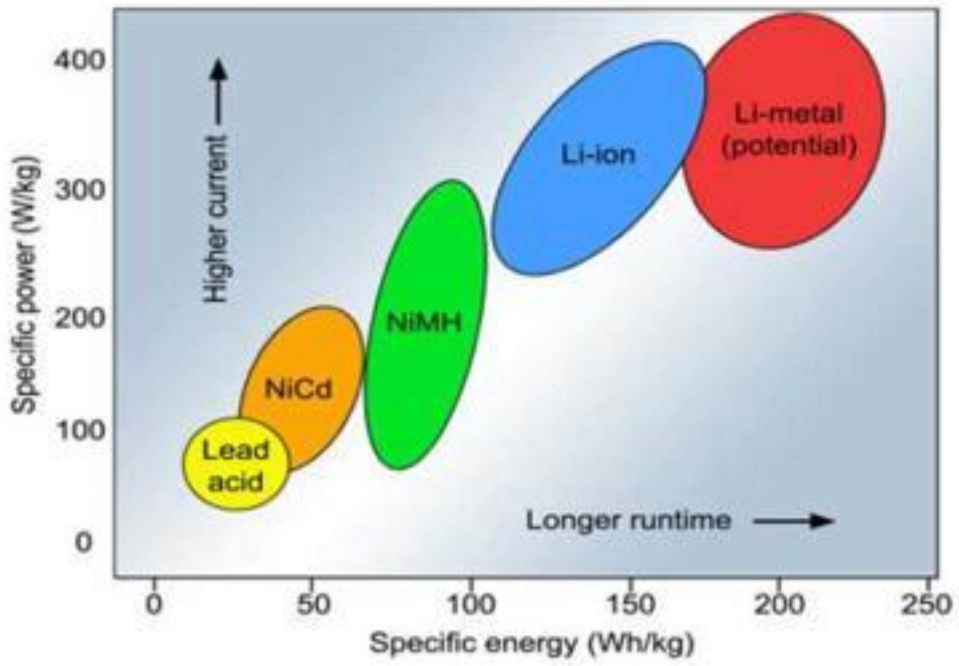
Advantages of Li-ion Batteries

3. No Memory Effect: Li-ion batteries don't suffer from the memory effect (a condition that reduces the longevity of a battery due to incomplete discharge cycles), making them more user-friendly.

4. Long Lifespan: They can endure hundreds to thousands of charge/discharge cycles before their capacity falls significantly.



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Challenges and Safety

1. Thermal Stability: Li-ion batteries can be sensitive to high temperatures, which can lead to thermal runaway – a condition where the battery overheats and potentially catches fire or explodes.

2. Aging: They degrade over time, even when not in use, due to chemical reactions occurring within the battery.

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Challenges and Safety

3. Cost: The materials and manufacturing process can be more expensive compared to other types of batteries.

4. Sensitive to Overcharging: Overcharging can lead to damage, reducing lifespan and possibly causing safety issues.

Battery Management System

To mitigate these challenges, most Li-ion batteries come with a built-in battery management system (BMS) that monitors and regulates charging and discharging to ensure safety and prolong the battery's life. Advances in technology continue to improve the performance, safety, and cost-effectiveness of lithium-ion batteries.

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Learning Unit 3: Batteries Including the BMS in Electric and Hybrid Electric Vehicles

3

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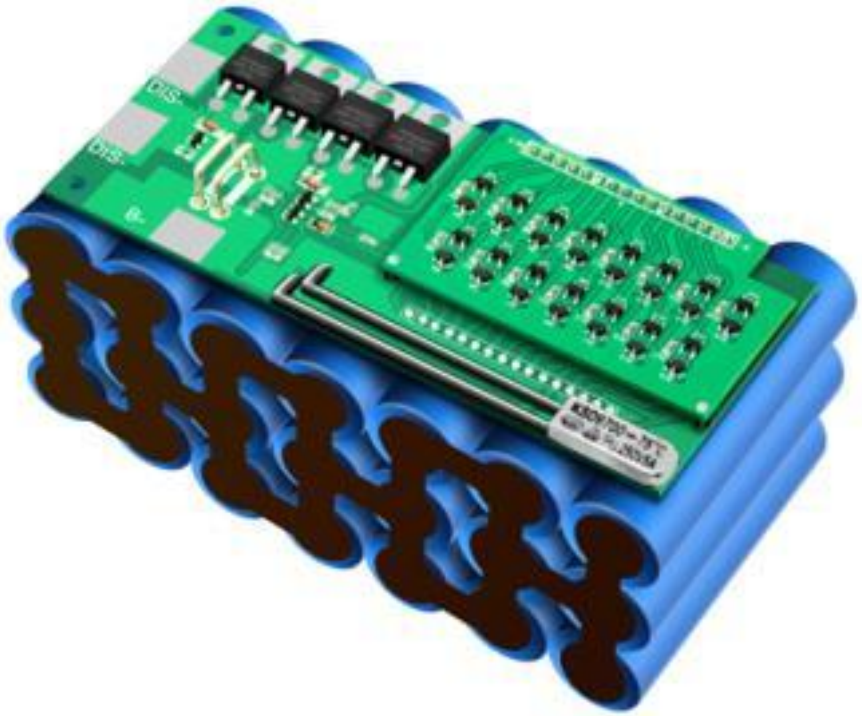
Battery Management System



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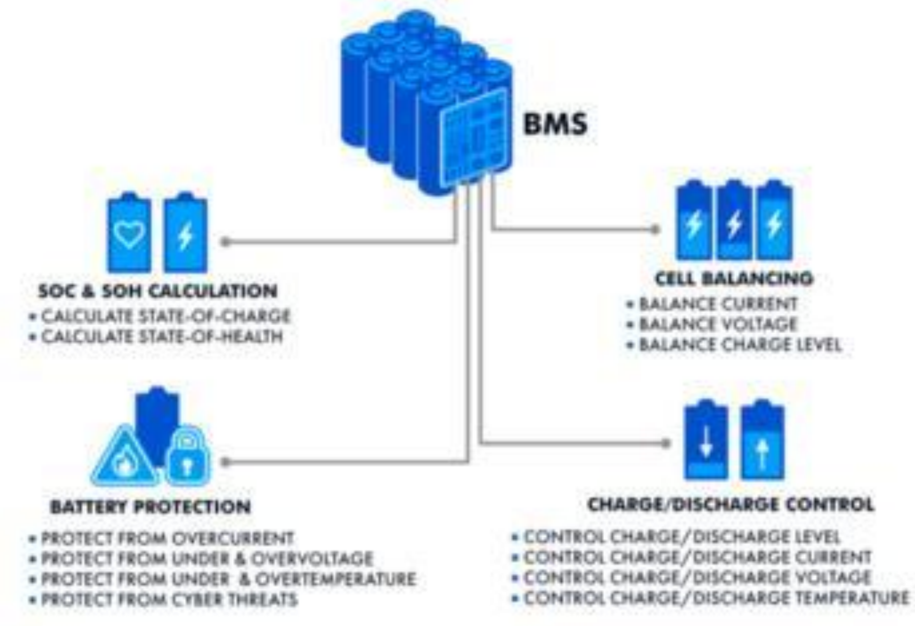
Battery Management System

A Battery Management System (BMS) is a critical component in lithium-ion battery technology, designed to ensure safe and efficient operation of the battery pack. Lithium-ion batteries are used in a wide range of applications, from small electronic devices to large-scale energy storage, and electric vehicles.



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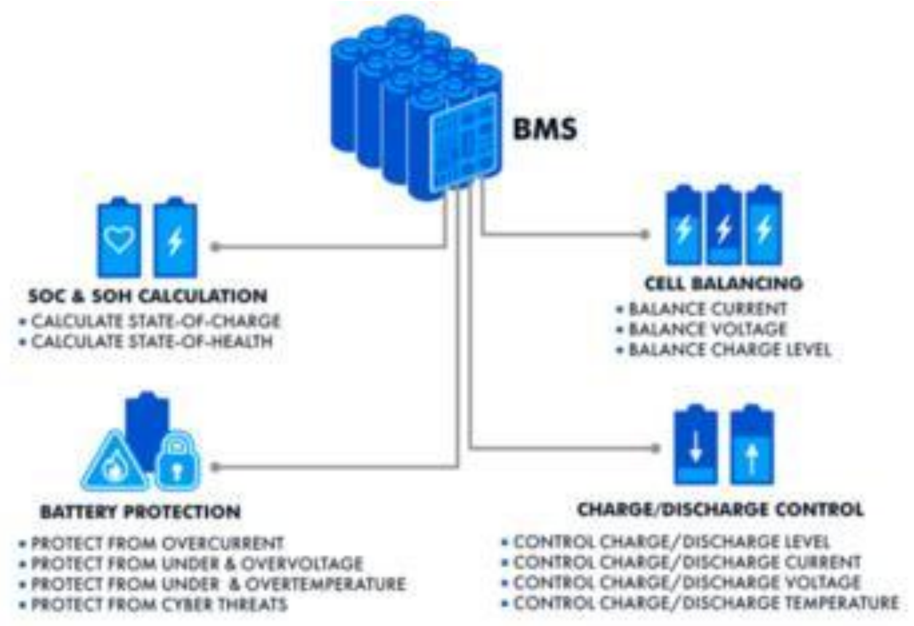
Battery Management System

The BMS plays several key roles:

1. **Cell Monitoring and Balancing**
2. **Temperature Management**
3. **State of Charge (SoC) and State of Health (SoH) Calculation**
4. **Charge and Discharge Control**
5. **Protection**
6. **Communication**



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Cell Monitoring and Balancing

Lithium-ion battery packs are made up of multiple cells. Each cell has slightly different characteristics, and over time, these differences can become more pronounced, affecting the performance and lifespan of the battery. The BMS monitors the voltage and temperature of each cell to detect any anomalies. It also balances the cells by ensuring all cells in the pack have the same charge level, either by discharging cells that are fully charged or charging those that are undercharged.

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Temperature Management

Lithium-ion batteries are sensitive to temperature extremes. The BMS monitors the temperature and can take corrective actions like reducing the charging rate or even shutting down the battery if temperatures move outside of a safe range.

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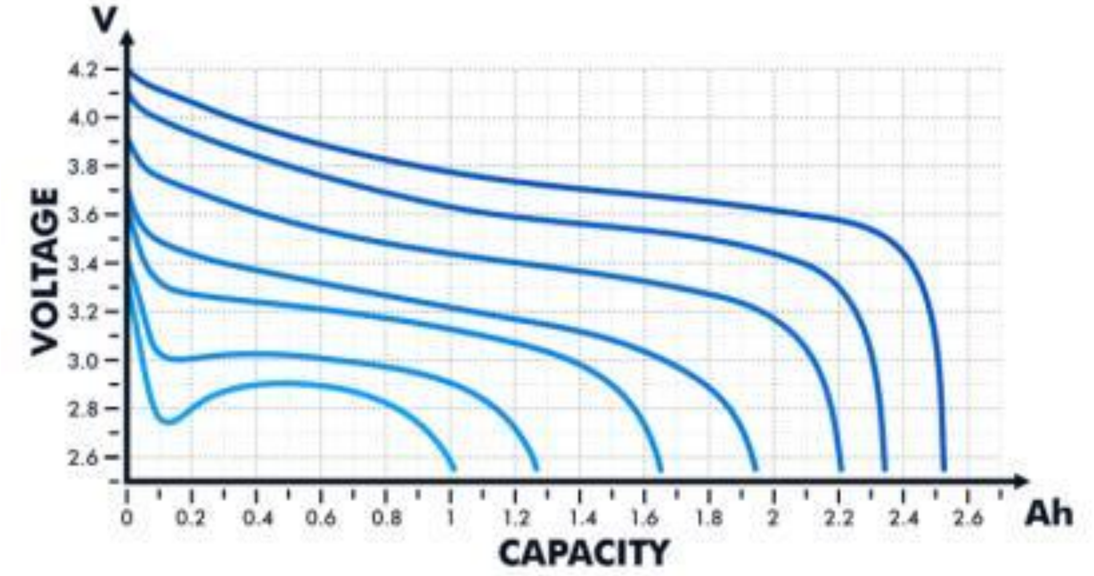
State of Charge (SoC) and State of Health (SoH) Calculation

The BMS calculates the State of Charge, which is a measure of the current energy level of the battery as a percentage of its full capacity. It also assesses the State of Health, indicating the overall condition of the battery and how much its capacity has degraded over time.



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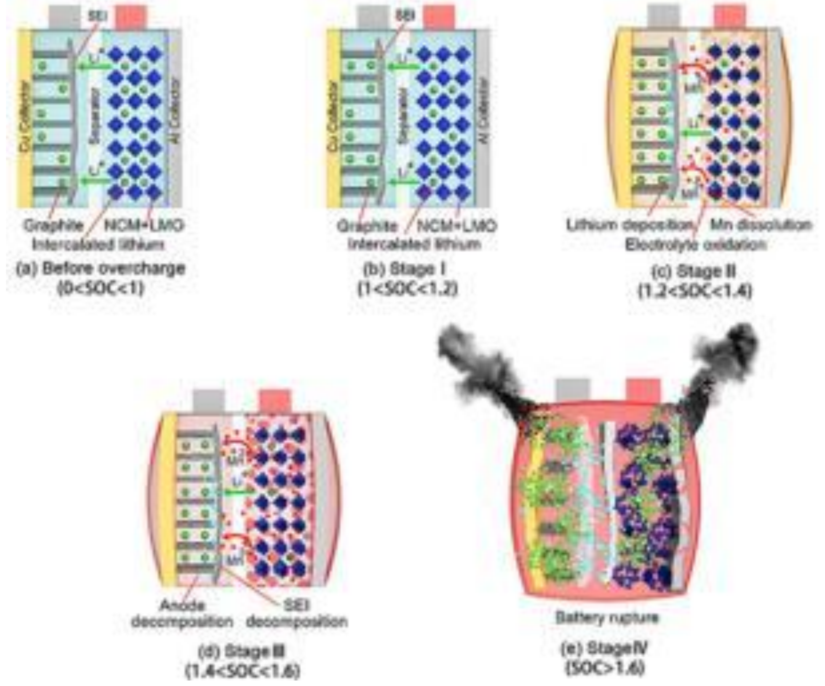
Charge and Discharge Control

To prevent damage, the BMS controls the charging and discharging processes. It ensures the battery doesn't overcharge or discharge below a certain level, as both can harm the battery's lifespan and performance.

Protection

The BMS provides protection against over-voltage, under-voltage, over-current, and short circuit conditions. This helps in preventing situations that could lead to battery damage or safety hazards like thermal runaway, where excessive heat in one cell can propagate to adjacent cells.



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Summary

The BMS is essential for maximising performance, longevity, and safety of lithium-ion battery packs. It achieves this through sophisticated monitoring and control strategies, ensuring the battery operates within its safe operating area.

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MODULE 4

Batteries and BMS

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1 ASSIGNMENT CASE STUDIES (FOR THE ENTIRE MODULE)

The trainees shall...

- Learn about the basics of electricity.
- Know the terminology of electricity and the definition of potential difference; current; resistance, and power.
- Know about different types of electricity.
- Have a basic understanding of battery technology used in electric vehicles.
- Have the ability to measure and calculate voltage on low voltage batteries, in a safe manner.
- Calculate potential difference; current; resistance, and power.
- Learn about the safety and handling of Lithium ion batteries.

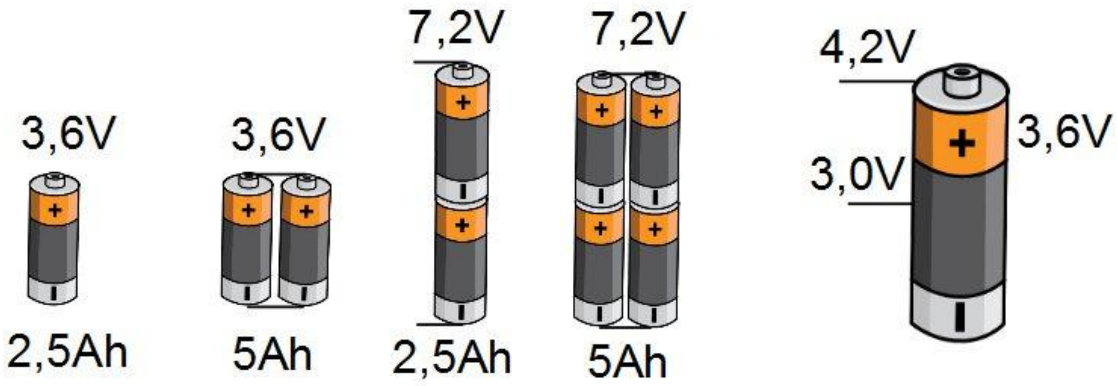
Methodological Skills („Suitcase of Methods“)

The trainees shall...

- Read and understand technical phrases.
- Independently make technical electrical calculations.
- Safely disassemble measure and reassemble a low voltage battery.
- Assess the calculations and measurements of the assignment.

1.1 Battery Assignment

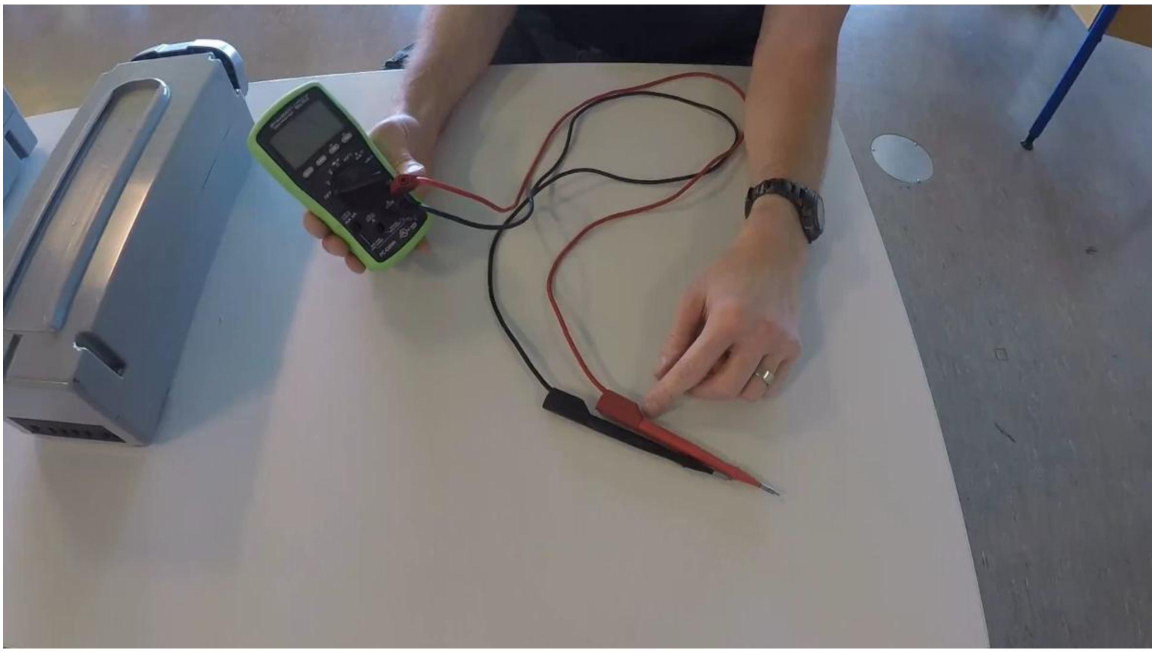
Serial & parallel connection in Li Ion batteries :



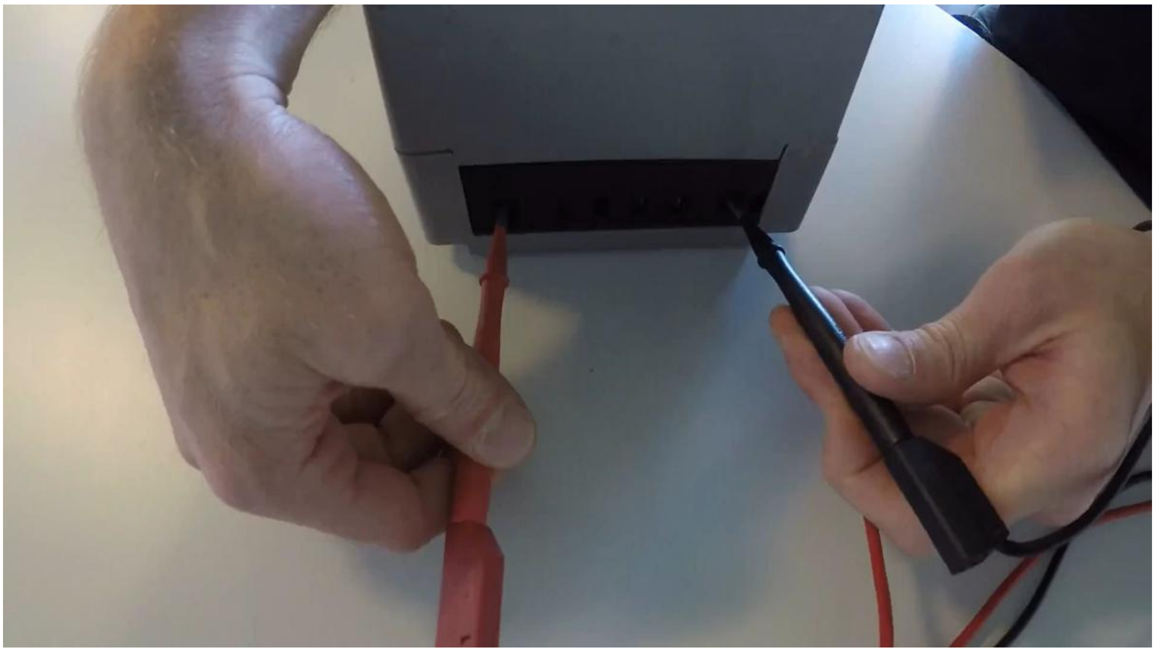
Assignment - Step by Step:

Introducing the assignment

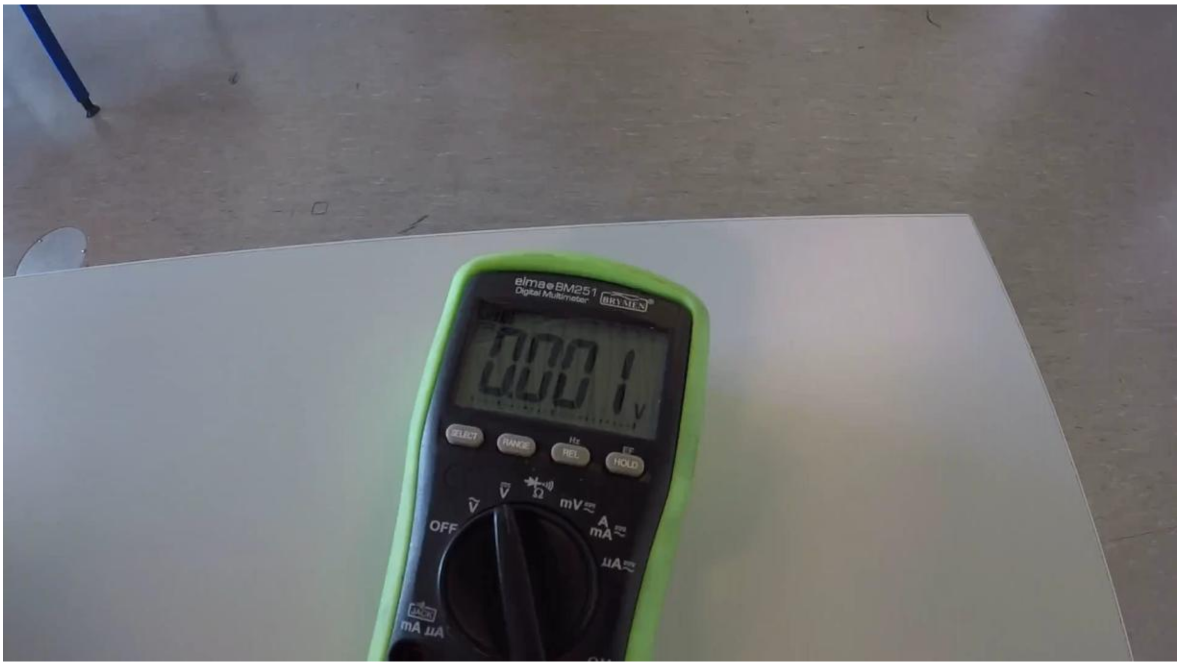
Using the multimeter



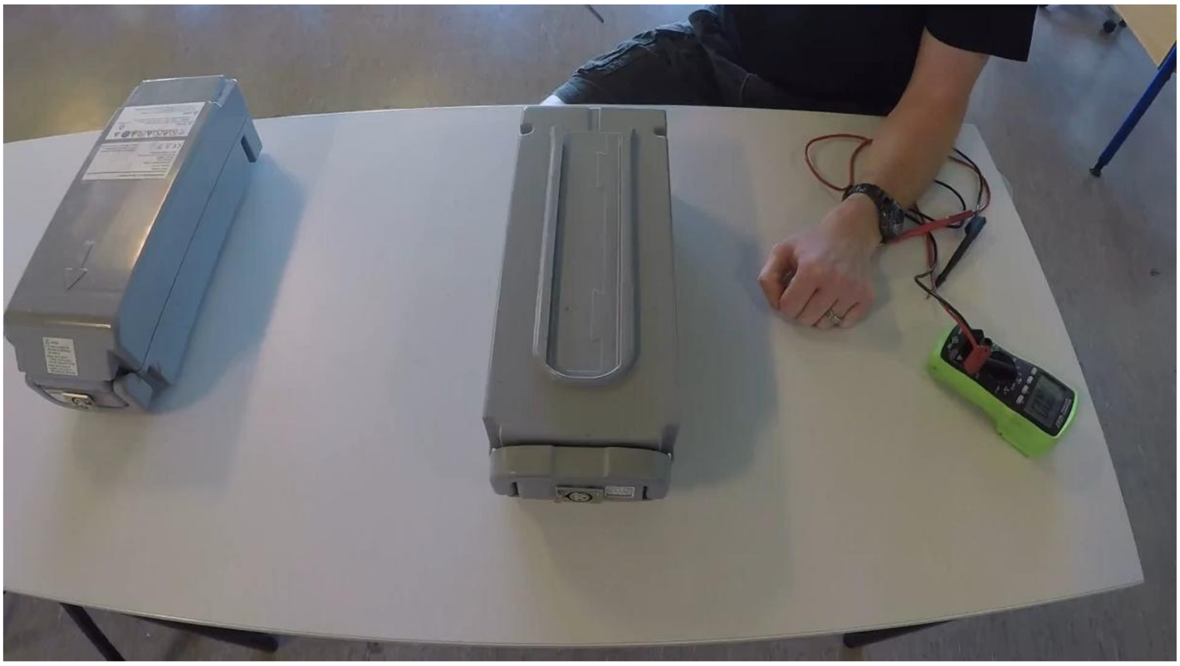
Measuring the different socket combinations



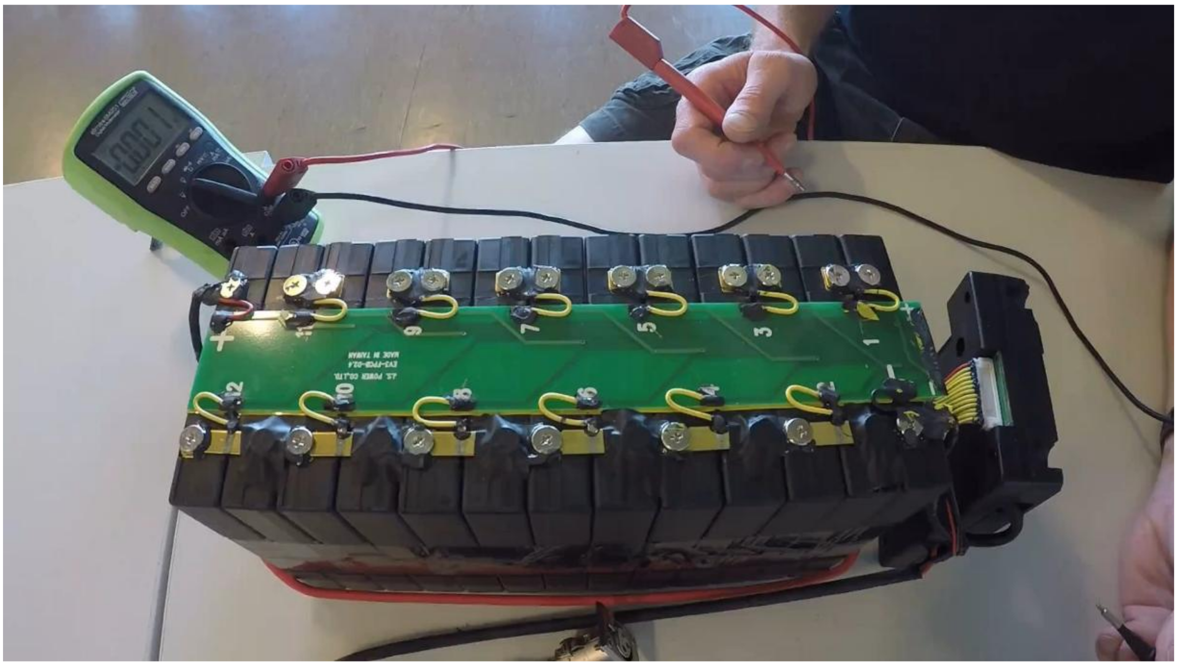
The resulting voltage measurements



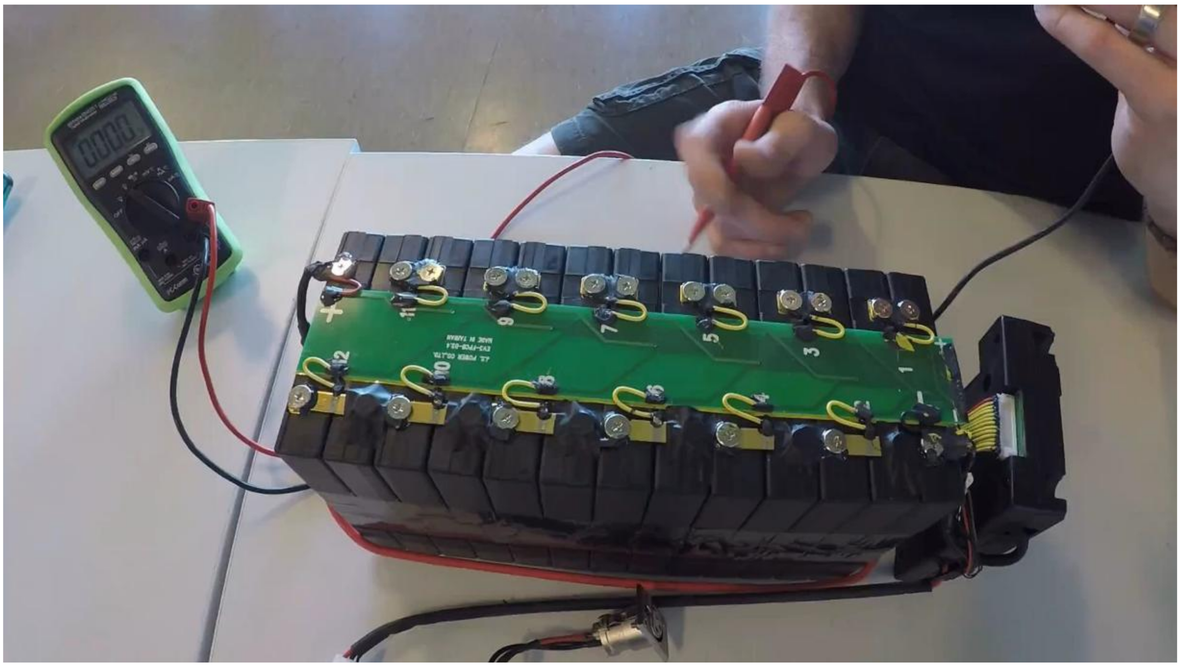
Disassembly of the battery



Measuring the potential difference and the sum of the individual cells



Measuring each individual cell



The results of measuring each individual cell

Please find the Link to the Assignment Power Point here.

1.2 Hand up to the Learner:

In the table below fill in the results of the measurements done in the sockets of the Battery

+					-
Voltage					

Here is some space for comments of your findings:

Accumulative cell measurement table

Description	Voltage
First Cell	
Between Cell 1 and 2	
Between Cell 1 and 3	
Between Cell 1 and 4	
Between Cell 1 and 5	
Between Cell 1 and 6	
Between Cell 1 and 7	
Between Cell 1 and 8	
Between Cell 1 and 9	
Between Cell 1 and 10	
Between Cell 1 and 11	
Between Cell 1 and 12	
Between Cell 1 and 13	

Here is some space for comments of your findings:

Individual cell measurement table

Description	Voltage
First Cell	
Cell 2	

Cell 3	
Cell 4	
Cell 5	
Cell 6	
Cell 7	
Cell 8	
Cell 9	
Cell 10	
Cell 11	
Cell 12	
Cell 13	

Here is some space for comments of your findings:

2 QUESTIONS AND ANSWERS (Q&A)

1. Q: What is electricity?
   A: Electricity is the flow of electrons through a conductor, typically in the form of a closed circuit.

2. Q: What is voltage?
   A: Voltage, measured in volts (V), is the electrical potential difference between two points in a circuit, representing the force that drives electrons to flow.

3. Q: What is current?
   A: Current, measured in amperes (A), is the rate of flow of electric charge through a conductor, indicating the number of electrons passing through a point in a circuit per unit of time.

4. Q: What is resistance?
   A: Resistance, measured in ohms (Ω), is the opposition to the flow of electric current in a circuit, caused by materials that impede the flow of electrons.
5. Q: What is the relationship between voltage, current, and resistance in a circuit?
   A: According to Ohm's Law, voltage (V) equals the product of current (I) and resistance (R) in a circuit ($V = I * R$). This relationship describes how changes in voltage, current, and resistance affect each other within an electrical system.

6. Q: What is a lithium-ion (Li-ion) battery?
   A: A lithium-ion battery is a type of rechargeable battery that uses lithium ions to generate electrical energy. It is commonly used in various applications, including electric vehicles, consumer electronics, and renewable energy storage systems.

7. Q: What are the advantages of Li-ion batteries over other types of batteries?
   A: Li-ion batteries offer high energy density, lightweight design, and longer lifespan compared to traditional battery technologies like lead-acid batteries. They also have a lower self-discharge rate and do not suffer from the memory effect.

8. Q: How do Li-ion batteries work?
   A: Li-ion batteries consist of positive and negative electrodes separated by an electrolyte. During charging, lithium ions move from the positive electrode (cathode) to the negative electrode (anode), where they are stored. During discharge, the ions move back to the cathode, generating electrical energy.

9. Q: What are the safety considerations associated with Li-ion batteries?
   A: Safety concerns with Li-ion batteries include overheating, short circuits, and potential thermal runaway leading to fires or explosions. Proper handling, monitoring, and thermal management systems are essential to mitigate these risks.

10. Q: How does the lifespan of Li-ion batteries vary depending on usage and maintenance?

A: The lifespan of Li-ion batteries can be affected by factors such as depth of discharge, charging/discharging rates, temperature, and overall usage patterns. Proper maintenance practices, such as avoiding deep discharges and extreme temperatures, can help prolong battery life.

11. Q: What role does a Battery Management System (BMS) play in electric vehicles with Li-ion batteries?
    A: The Battery Management System (BMS) in electric vehicles monitors and manages the performance, health, and safety of the Li-ion battery pack. It regulates charging and discharging, balances cell voltages, and protects against overcharging, over-discharging, and overheating.

12. Q: How does the BMS help optimise the performance and longevity of Li-ion batteries in electric vehicles?
    A: The BMS optimises battery performance by ensuring each cell operates within safe voltage and temperature ranges, preventing premature degradation. It also balances cell voltages to maximise energy storage capacity and maintains state-of-charge (SOC) accuracy for accurate range estimation.

13. Q: What are some common challenges associated with managing Li-ion batteries in electric vehicles, and how does the BMS address them?
    A: Challenges include cell degradation, thermal management, and maintaining battery health over time. The BMS addresses these challenges by implementing strategies such as cell balancing, temperature monitoring, and adaptive charging algorithms to extend battery life and ensure safe operation.

14. Q: How does the BMS communicate with other vehicle systems to optimise performance and efficiency?
    A: The BMS communicates critical battery data, such as SOC, temperature, and voltage, to the vehicle's powertrain and energy management systems. This data enables real-time adjustments to power delivery, regenerative braking, and thermal management to maximise efficiency and performance.

15. Q: What are the safety features integrated into the BMS to protect against potential battery-related hazards in electric vehicles?
    A: The BMS includes safety features such as overvoltage protection, undervoltage protection, short circuit detection, and thermal management controls to prevent hazardous conditions like overheating, overcharging, and over-discharging. Additionally, the BMS can initiate rapid shutdown procedures in emergency situations to mitigate risks.

3 MULTIPLE CHOICE QUESTIONS (FOR THE ENTIRE MODULE)

1. Electrons carry?
    a. no net charge
    b. a negative charge
    c. a positive charge
2. An atom is
    a. electrically negative
    b. electrically positive
    c. electrically neutral
3. Electrical Current is measured in
    a. Volt (V)
    b. Amperes (A)
    c. Ohms (Ω)
4. P=
    a. IxR
    b. VxR
    c. AxV
5. The Cathode is
    a. The positive electrode
    b. The negative electrode
    c. The Electrolyte
6. What is the advantage of a li-ion Battery?
    a. High Energy Density
    b. No Memory Effect
    c. All of the above
7. What is the challenge with a li-ion battery?
    a. High Self-Discharge
    b. Thermal Stability
    c. Short lifespan
8. What are the main tasks of the Battery Management System (BMS)
    a. Cell Monitoring and Balancing; Temperature Management; State of Charge (SoC) and State of Health (SoH) Calculation
    b. Charge and Discharge Control; Protection and Communication
    c. All of the above
9. A typical li-ion battery pack is made up of
    a. Multiple battery cells
    b. One large battery cell
10. Li-ion batteries are used in
    a. small electronic devices
    b. large-scale energy storage and electric vehicles
    c. a wide range of applications, from small electronic devices to large-scale energy storage, and electric vehicles.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
b.	c.	b.	c.	a.	c.	b.	c.	a.	c.

EVTECH

MODULE 5

EV WORKPLACE SAFETY

Co-funded by
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Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them.

1. INTRODUCTORY PARAGRAPH

The aim of this module is to provide the learner with the necessary knowledge, skills and competences in the safe operation, maintenance and repair of electric cars. The learner will be able to mark the car and workplace in a safe way. In addition to the risks arising from the maintenance and repair of electric and hybrid vehicles. The learner will be able to select appropriate personal protective equipment and tools needed to perform maintenance and repair of the vehicle. The learner will know the effects of electric current on the human body.

1.1 POTENTIAL RISKS AND CHALANGES DURING REPARING, OPERATING AND MAINTAINING ELECTRIC VEHICLES.

Transport of electric vehicles

Towing electric cars is very similar to conventional cars with automatic transmission. Manufacturers prohibit towing them, even over a short distance. Hooking an electric car on a tow rope means, among other things, problems with battery operation. And this is one of the most expensive elements in the entire electric vehicle. Electric cars should be transported on a trailer.

Guidelines for carriers

Warning

The vehicle must not be transported with the wheels in a position that allows them to rotate, as this may result in the vehicle overheating and causing serious damage. In rare cases, extreme overheating of the vehicle may result in a fire.

Authorized methods of transport

ATTENTION

When being pulled onto a tow truck or being pulled out of a parking space for relocation, the wheels may rotate slowly (at a speed of less than 5 km/h) if the maximum permissible distance is less than 10 meters and the transport mode is activated. Exceeding the stated limits may lead to overheating and serious damage which is not covered by the warranty.

It is best to transport the vehicle on a trailer or similar means of transport. The direction in which the vehicle is placed on the tow truck does not matter.

If it is necessary to transport the vehicle without using a tow truck, a lift and dollies should be used to prevent the wheels from contacting the road surface. When transporting a vehicle using this method, you must not exceed the distance of 55 km or the speed specified by the truck manufacturer. Tesla recommends that when using this transportation method, the vehicle must be facing forward, with the front wheels raised and the rear wheels resting on the carts.

ATTENTION

It is not recommended to transport the vehicle with the front wheels resting on the bogies, but it is permissible if an external steering lock is used and it is ensured that the front wheels do not rotate. DO NOT TRANSPORT THE VEHICLE IF THE FRONT WHEELS ARE NOT COMPLETELY PROTECTED FROM ROTATING.

ATTENTION

Transport mode must be engaged before pulling the Model S onto the tow truck. Transport mode or touchscreen is not available, it is necessary to use self-loading wheel dollies or wheel rollers to place the vehicle in a position where it can be transported. Tesla is not responsible for any damages caused by or occurring during transportation of the Model S vehicle, including damage to personal property or damage caused by the use of self-loading carts or wheel rollers.

Warning

The Model S is equipped with high-voltage parts that may be damaged in a collision. Before transporting Model S vehicle, it is important to assume that these parts are energized. Until qualified roadside assistance personnel have confirmed that all high-voltage systems are disabled, the precautions applicable to high-voltage systems must be followed, which includes the use of personal protective equipment. Otherwise, serious injuries may occur.

Disabling the self-levelling air suspension

Model S vehicles equipped with air suspension self-level even when the power is turned off. To prevent damage to the vehicle, activate the car jack mode, which disables self-leveling:

1. On the touchscreen, select Controls > Suspension.
2. Press the brake pedal and select Very High to raise the suspension to its maximum height.
3. Select Controls > Service > Jack Mode.

ATTENTION

Jack mode is cancelled when the vehicle accelerates to a speed of over 7 km/h.

Warning

Transporting a vehicle with air suspension without the jack mode engaged may cause the vehicle to come loose, resulting in serious damage.

Turning on transport mode

Transport mode ensures that the parking brake remains disabled while the Model S is being pulled onto a tow truck. After activating transport mode, information appears on the screen that the vehicle will roll freely. The following conditions must be met to enable transport mode:

- Low voltage power supply must be available. If your Model S vehicle is not powered, you cannot use the touchscreen to enter transport mode.

- Model S must detect the remote control. Transport mode is only available when the vehicle is detected by the remote control.

Turning on transport mode:

1. Engage Park Mode.
2. Chock the wheels or otherwise immobilize the Model S vehicle.
3. Press and hold the brake pedal, then select Controls > Service > Towing on the touchscreen. A message will appear on the touch screen reminding you how to properly transport your Model S vehicle.
4. Press and hold the Transport Mode button until it turns blue. The Model S now rolls freely and can be slowly rolled (at the pace of a walking person) or pulled with a winch

ATTENTION

If low voltage power is cut off after the Model S vehicle is engaged in Transport Mode, Transport Mode is cancelled.

ATTENTION

If the vehicle's electrical system is not working and you cannot use the touchscreen to activate transport mode, use wheel loaders or wheel rollers. Before doing so, please read the technical data provided by the manufacturer and the suggested load capacity.

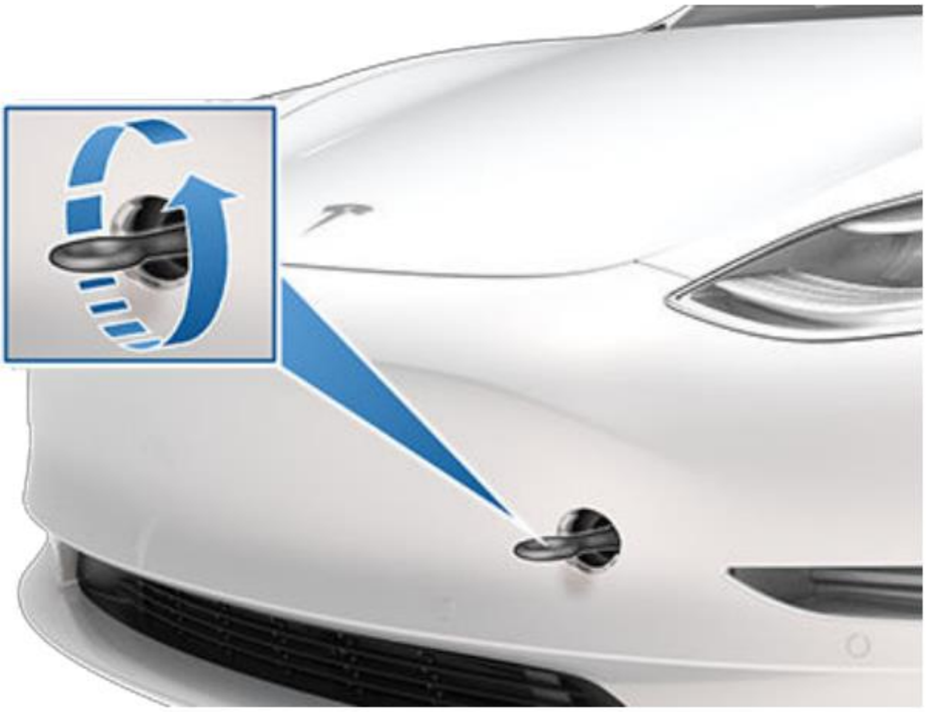
Pulling onto a trailer using a towing eye:

1. Find a towing eye.
2. Remove the tow eye cover by inserting a small flat-blade screwdriver into the slot along the top edge of the cover and gently prying it away from the top latch.

Attention

Store the cover in a safe place so that you can reinstall it after towing.

3. Insert the towing eye fully into the hole, then rotate it counterclockwise until it is secure.



4. Attach the tow rope to the eye.

ATTENTION

Before you start retracting, check that the eyelet is securely installed.

5. Enable transport mode via Controls > Service > Towing.
6. Slowly pull the Model S onto the tow truck.

Pulling onto a trailer without using a towing eye

ATTENTION

To avoid damage, always use a properly installed towing eye when pulling your vehicle onto a tow truck. Pulling a vehicle hitched by the chassis, frame or suspension may result in damage to the vehicle.

Warning

If the vehicle is towed onto a tow truck without a tow hitch, all suspension mountings should be checked for proper torque and all components should be visually inspected for damage before restarting the vehicle. If any of the fasteners are loose or if any damage is found, the defective element should be replaced.

The use of a winch and towing eye is strongly recommended. However, if the towing eye is unavailable for some reason (e.g. lost), the instructions below describe how to attach the towing straps.

1. The belts should be attached to the lower suspension arms of the front wheels on both sides of the vehicle.

- To protect the bottom of the vehicle against damage, place something under the seat belts, for example a piece of wood.

- Enable Transport Mode via Controls > Service > Towing
- Slowly pull the Model S onto the tow truck.

Tire protection

The wheels of a vehicle transported on a trailer should be immobilized using the eight-point attachment method.

- None of the metal parts of the belts may come into contact with painted surfaces or touch the surfaces of the wheels.
- Do not thread belts over body panels or through wheels.

ATTENTION

The vehicle may be damaged if the belts are attached to the chassis, suspension or body.

To protect the underside of the vehicle from damage, place something under the seat belts - such as a piece of wood.

- Enable transport mode via Controls > Service > Towing.

- Slowly pull the Model S onto the tow truck.

https://www.tesla.com/ownersmanual/2012_2020_models/pl_pl/GUID-AF2A18C5-77CA-4FB3-A965-3C88D38B8979.html

Safely lifting electric vehicles

Electric cars are usually much heavier than typical cars with combustion engines. They also have a completely (or almost completely) flat floor. There are lithium-ion batteries under the passenger compartment of the car, with a cooling and heating system (using a glycol-based fluid). Theoretically, the batteries are well protected by the car's structure. They have to be, because damaging one cell would cause a chain reaction and the battery would catch fire. However, it must be taken into account that a car that is several or a dozen years old will be brought to the workshop. The car may be seriously damaged by corrosion. Or – previously damaged in an accident.

Features that a lift intended for servicing hybrid and electric cars:

- should enable the lift arms to lift the car by the wheels. This is to ensure adequate access to the batteries, which are placed flat in the floor of the car.
- should allow for lifting cars by the chassis to enable repairs to the suspension, steering or braking system.
- Appropriate stabilization of the vehicle on the lift is important, with level differences greater than 10 - 15 mm.
- Some lifts use asymmetric arms with columns designed in such a way that they allow easy entry and exit from the car.

- The standard lifting capacity for passenger cars is usually from 3.2 to 3.5 tons.

Floor jack with wheel holders

Floor lift

Battery lift

When working on the disassembly and assembly of electric car batteries, a battery lift is needed due to its weight. The weight of electric car batteries is several hundred kilograms. The flat working surface of the lift is designed to support the battery so that the battery is not damaged..

https://www.youtube.com/watch?v=K9BR0fYt7LI&t=127s

https://italcom.com.pl/kategoria-produktu/elektromobilnosc

https://motofocus.pl/wyposazenie-warsztatowe/91603/podnosnik-do-obslugi-samochodow-elektrycznych-i-hybrydowych-czym-sie-rozni-od-standardowego

Using the technical manual for electric vehicles

The vehicle's technical manual contains information that defines the rules for the transport and parking of vehicles involved in collisions and road accidents.
The State Fire Service has also developed rules on what to do if an electric vehicle was involved in a collision or accident, which are as follows:

I. Reconnaissance and protective actions

1. External and design features may be helpful in identifying a car. In addition, information from the owner or user of the vehicle (if present) and rescue cards with a description of the car may be a source of knowledge.
Main identifying features:

1) characteristic markings on external body elements or "green license plates" (in Poland)
2) markings on the plastic engine cover (under the hood);
3) charging socket or sockets, which may be located in different places depending on the manufacturer and model;
4) orange covers of components, especially high-voltage cables;
5) no exhaust pipe – in fully electric vehicles;
6) markings on the dashboard indicating the activity of the electrical power system;
7) lack of fuel level indicator - in fully electric vehicles;
8) QR code, VIN number or other types of markings used by car manufacturers,

2. During reconnaissance, the area of operations should be secured by:

1) positioning vehicles at a safe distance to provide protection from road traffic;
2) fencing off the operation area using available means, such as road signs, flashing lights, warning tape, etc.;
3) conducting reconnaissance 3600
a) obtain as much information as possible about the circumstances from participants or witnesses of the event
and causes of the event;
b) identify the main hazards: mechanical, electrical, thermal and chemical;
c) assess the number and condition of injured persons and assess whether there are any trapped persons;
d) if the car is connected to a charging station, make every effort to safely disconnect the plug or external power supply (e.g. a safety switch within the charging station). If it is not possible to use the above-mentioned safety switch, try to contact the charging station dispatcher and ask to remotely disconnect its power supply, providing the number on the charging station and/or its location.

Consider the risk of explosion.

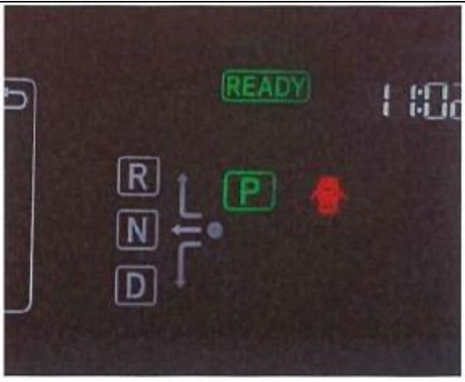
The process of thermal decomposition of the traction battery may result in the release of flammable and toxic gases, including hydrogen or carbon monoxide - monitor the explosive atmosphere inside and near the vehicle using a multi-gas sensor. This is particularly important when operating in closed spaces (garages, workshops, etc.).

4. If possible, proceed to deactivate and secure the car. Once you have identified your car's make and model, obtain a vehicle rescue card. Use the card as an aid, especially when deactivating the car and making further decisions and locating critical components. You can obtain a rescue card, among others: from the following sources: RescueCode, Euro Rescue, Crash Recovery System applications, QR codes placed on various elements of the vehicle body, physical rescue cards in the vehicle, the Internet, etc.
5. Assess the degree of car damage in the event of a traffic accident. A high degree of damage may mean that the battery is damaged. Follow card Z1.
6. In the event of a car fire, follow the Z2 card**.**
7. For a car completely or partially submerged in water, follow the Z3 chart**.**

Until full identification, we should always assume that we may be dealing with an electric vehicle. Do not interfere with the elements of batteries, cables and high-voltage equipment - do not disassemble them, do not cut them, do not crush them, do not open the casing

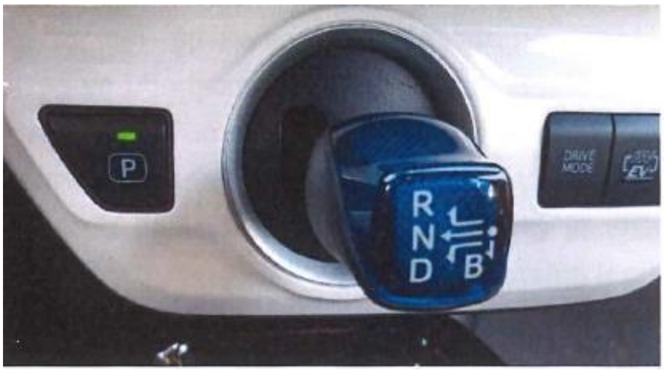
I. Vehicle deactivation and security

Vehicle deactivation and security	
Mandatory activities (for every car)	
1. Secure the car as soon as possible to prevent it from moving (locking). forward and backward movement). Use chocks and/or wheel chocks and/or other equipment for this purpose. For additional protection before the car starts moving, insert the plug of the vehicle charging cable into the car's power socket, which is not connected to the power source. The vehicle's charging cable may be located in the trunk.	**Attention** ✓ You cannot hear the electric motor running. ✓ Before eliminating forward and backward movement, rescuers should not be in front of or behind the vehicle. ✓ The charging cable plug placed in the vehicle's power socket is recognized as being connected to the charger - the vehicle cannot be moved.
2. Check your car's dashboard to see if any indicators indicating that the electric motor is running or ready to run are on (e.g. blue LEDs, blue or green pictogram and the words "READY", "READY TO GO" or "POWER" HE"). If so, turn off the electric engine with the ignition key. If you have any doubts, use the emergency card or the ignition button in the case of a vehicle. An example of the READY inscription indicating the operation of the electric motor:	**ATTENTION!** 1. Some car manufacturers allow or recommend carrying the key or card away from the car at a certain minimum distance, usually 5 m. This prevents possibility of turning on the electric motor. Information on whether this action can be performed is obtained from the card rescue vehicle. 2. If you are not sure that you can safely return your car key or card, refrain from

<table>
<tr>
<td>

Sample ignition button

</td>
<td>taking the risk of failing to recognize the presence of the key or card in your car. There is that car as a result
closes the doors, raises the windows, closes the sunroof (hands-free systems). This may be dangerous for working rescuers. Just returning the key or only
turning on the electric motor.</td>
</tr>
<tr>
<td>3. Move the operating mode control ("gear shift") lever to the neutral "N" position or to the PARKING position. Sometimes it is the peripheral "P" button, but it is always located close to the "gear shift" lever.

Example of an operating mode control lever with a neutral "N" position and a peripheral "P" button


4. Apply the car's parking brake. It may take the form of: a handbrake, a footbrake near the gas and brake pedals or a button on the dashboard..</td>
<td>ATTENTION!

1. Disconnecting the 12V battery too early carries a high risk: inability to move the lever to the PARKING position or press the "P" button - these are electrically assisted systems.</td>
</tr>
</table>

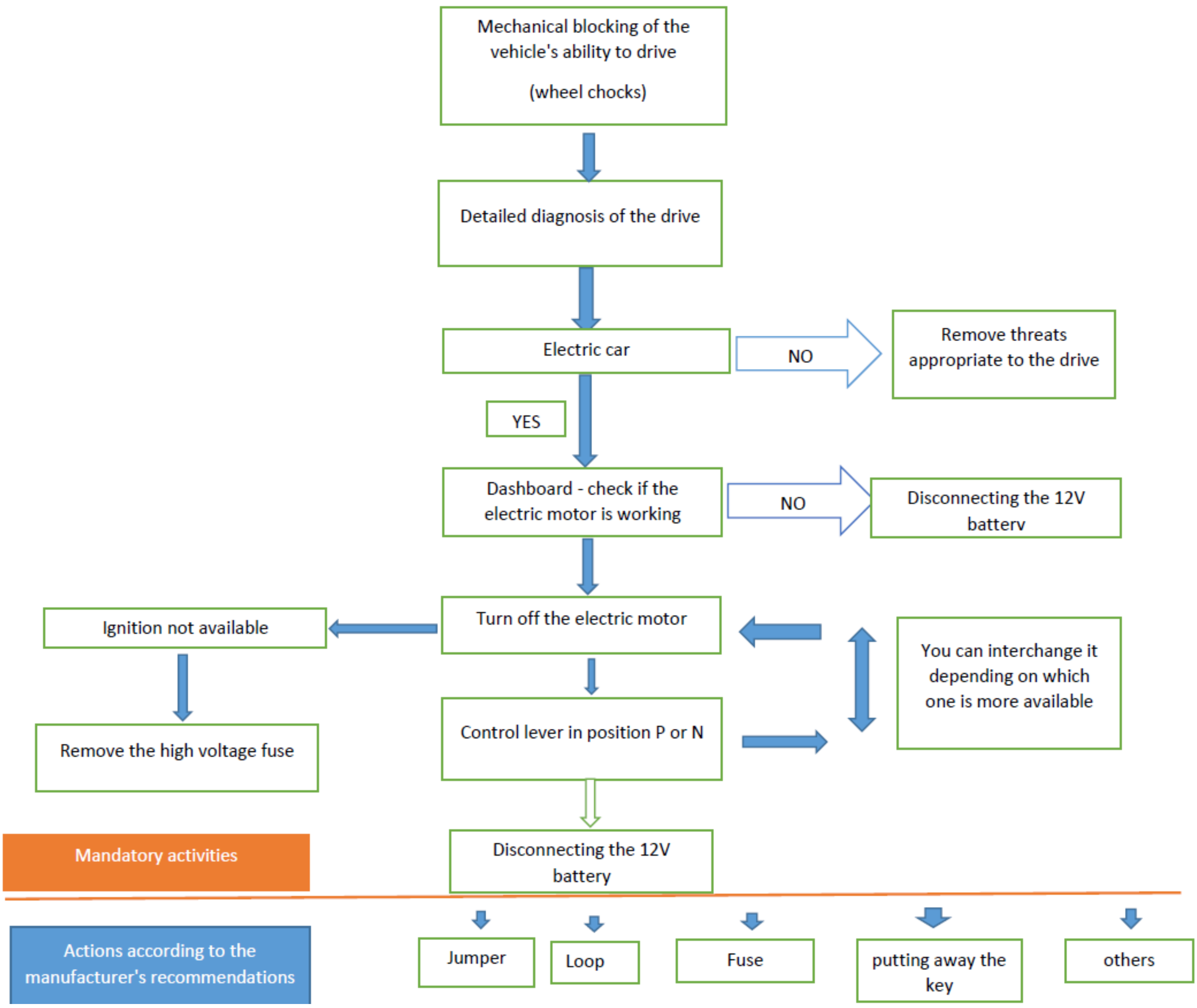
5. Disconnect the 12V battery. Disconnect the negative battery clamp (black cable) or both clamps (always in the order: negative and positive). Secure wires (and any metal objects nearby) so that there is no automatic short circuit.	**ATTENTION!** 1. In the vast majority of cars, disconnection 12V battery deactivation of the high voltage system (at this point). Some manufacturers do not require further action to be taken to turn off the high voltage system. 2. Disconnecting the 12 V battery too early (before turning off the electric motor) does not cause deactivation. There are known cases of this happening electric movement after disconnecting the 12 V battery.
Alternative actions (in accordance with the rescue card)	
	ATTENTION! 1. When turning off the high voltage system via emergency stop switch, be especially careful, because there is a risk of an electric arc. At this one operations, it is necessary to use a helmet visor. It is also essential to use protective measures individual - dielectric gloves. 2. Do not confuse high-voltage wires marked in orange with the special loop indicated for cutting. 3. When the high voltage system is turned off, it may turn off keep it in the electrical installation for a few to several more minutes.

<table>
<tr>
<td>
2. Remove the high voltage fuse.
3. The location of the fuse is indicated in the vehicle's rescue card. If there is no information regarding the location of the high voltage fuse, remove all fuses.
4. The places where the high voltage system fuse is installed are marked with a symbol on the vehicle's rescue card:

Example location of the high voltage fuse:

</td>
<td>
ATTENTION!
1. Fuses can be located in several places!
Check the vehicle's rescue card!
</td>
</tr>
</table>

Algorithm – deactivation and security of the car



Hazards occurring during operation, maintenance and repair of electric vehicles

1. High electrical voltage

Electric and hybrid vehicles are equipped with high-voltage electrical installations. As defined in UNECE Regulation No. 100, the term high voltage in vehicles refers to the classification of electrical components or circuits which operate at an operating voltage exceeding 60V and not more than 1500V direct current (DC) or exceeding 30V and not more than 1000V rms current. alternating current (AC).

There is a threat to people who come into contact with electrical devices:

- the occurrence of high voltages and high currents, and these at the values:
- 5mA – cause tingling
- 10mA – cause cramps, difficulties in putting down tools
- 50mA – cause ventricular fibrillation and apnea
- 80mA – cause fatal threats
- • occurrence of an electric arc (burns, eyesight)
- • occurrence of toxic vapours (respiratory tract hazard)
- • secondary threats such as cuts, limb injuries, etc.

2. **Mechanical hazards**

When servicing, maintaining and repairing electric cars, mechanics work with a heavy assembly such as the battery. An electric car battery can weigh up to 700 kg. Which constitutes direct threats related to pressing body parts of people operating electric vehicles.

3. **Thermal hazards**

The electric battery can reach high temperatures (the allowable operating temperature for most batteries is 500). When the temperature of the lithium-ion battery reaches 700C, a reaction occurs between the electrolyte and the anode in the cell, at a temperature of approximately 1300C the separator begins to melt, which causes an internal short circuit. However, at a temperature of approximately 1500C, the safety valve in the battery opens and flammable gases escape. Black smoke and flames are released.

Security protocol

In the case of electric cars, we have a different service procedure compared to combustion models. Before operating a vehicle equipped with a high-voltage network, an employee authorized to operate high-voltage vehicles must follow the procedure of performing the following steps:

General procedure for turning off high voltage in an electric vehicle

1. Disconnection of the high voltage system
   - Turn off the ignition and wait 1 minute
   - Disconnect the negative terminal of the 12V battery
   - Disconnect the high voltage service switch connector
   - Wait 10 minutes (or more according to the vehicle manual)

2. Protection against accidental switching on of high voltage
   - Removing the key from the ignition (if present), securing the key
   - Protection of the service switch against unauthorized access

3. Confirmation of the absence of high voltage in the system
   - Wait the time specified by the manufacturer (time needed to discharge the capacitors)
   - Check the correct operation of voltage measuring devices

The correct operation of the device should be checked in accordance with the recommendations of the measuring device manufacturer. The operation of the device can be checked by testing the voltage of the 12 V battery

   - Check the lack of voltage at the measurement points (according to the vehicle manual)

No voltage at all points - you can start servicing the vehicle.

Attention

The measurement of the lack of voltage should be carried out with a tester compliant with DIN VDE 0682-401 (in Poland PN-EN 61243).

Pojazdy hybrydowe i elektryczne w praktyce warsztatowej – Torsten Schmidt WKŁ
https://italcom.com.pl/produkt/przyrzady-kontrolno-pomiarowe/

Sample Nissan Leaf procedure

- To prevent serious injury or death
- NEVER touch high voltage components without wearing appropriate personal protection.
- Personal protective equipment should always be worn when touching or working with high voltage components.
- If the charging connector is connected to the vehicle, remove it. Check the destamping method for your specific vehicle.
- The vehicle contains parts containing magnets with a very large magnetic field. Persons with a pacemaker must not perform any work in the vehicle.
- Make sure the READY indicator is off and the high voltage system is turned off
- After turning off the high voltage system, wait at least 10 minutes for the high voltage capacitor to completely discharge. Do not operate any vehicle while waiting.

Attention
Full discharge of the high voltage system takes 10 minutes. After 5 minutes, the electrical voltage drops below 60 V

• After turning off the high voltage, remove the (-) 12V battery terminal
• Wait at least 3 minutes to discharge the SRS capacitors. Even if there is a fault in the 12V battery system/circuit (-), the gas bag controller maintains voltage for at least 3 minutes, which may result in the activation of pyrotechnic elements.
• Always extinguish the high voltage system before disconnecting the 12V battery
• The 12V system remains active even after disconnecting the 12V battery if the high voltage system is connected.
• The high voltage system is active when:
The charging indicator is on
The READY indicator is on

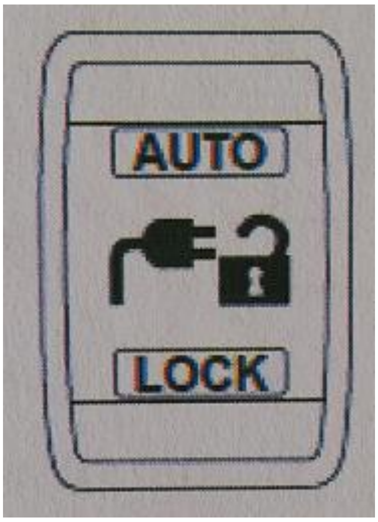
Attention
If the DC/DC converter is turned on and does not turn off, power will be supplied to the 12V system from the high voltage system continuously.

ATTENTION
The fast charger must be turned off to release the charging connector lock

1. Release the quick charge lock and pull to remove it. Please refer to the quick charging instructions.
2. Press the fast charging connector release button on the fast charging connector and pull to remove.

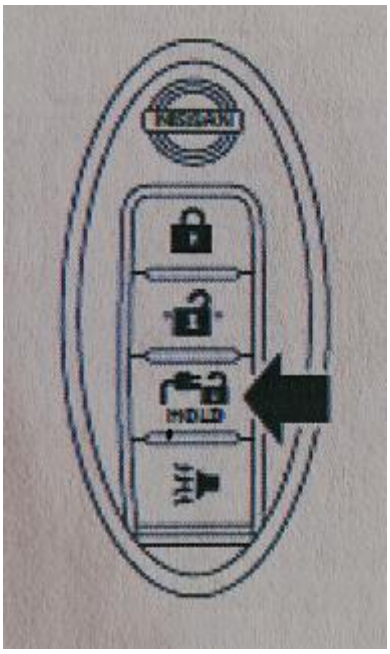
ATTENTION
If the charging connector cannot be removed, the electric lock is activated. Follow the next steps to turn it off

- To enable the electric charging connector lock, place the lock switch in the UNLOCK mode (middle position).
- The charging connector can be unlocked by pressing the charging connector unlock button

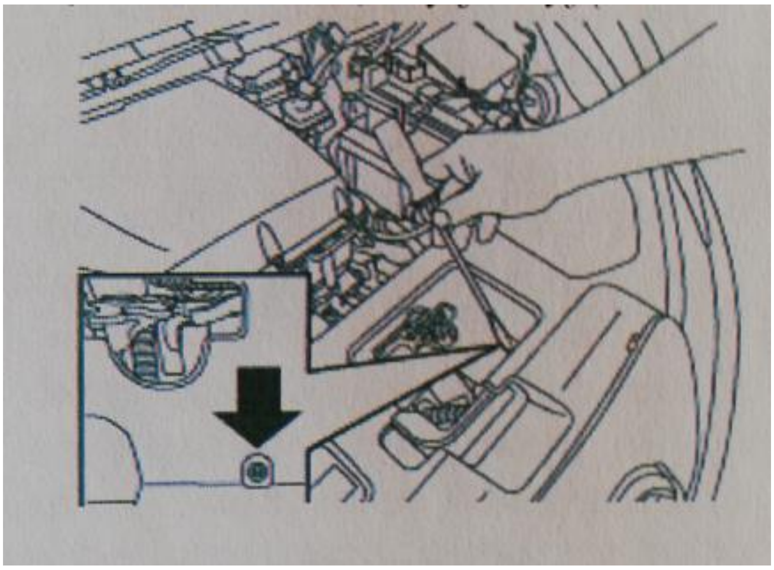


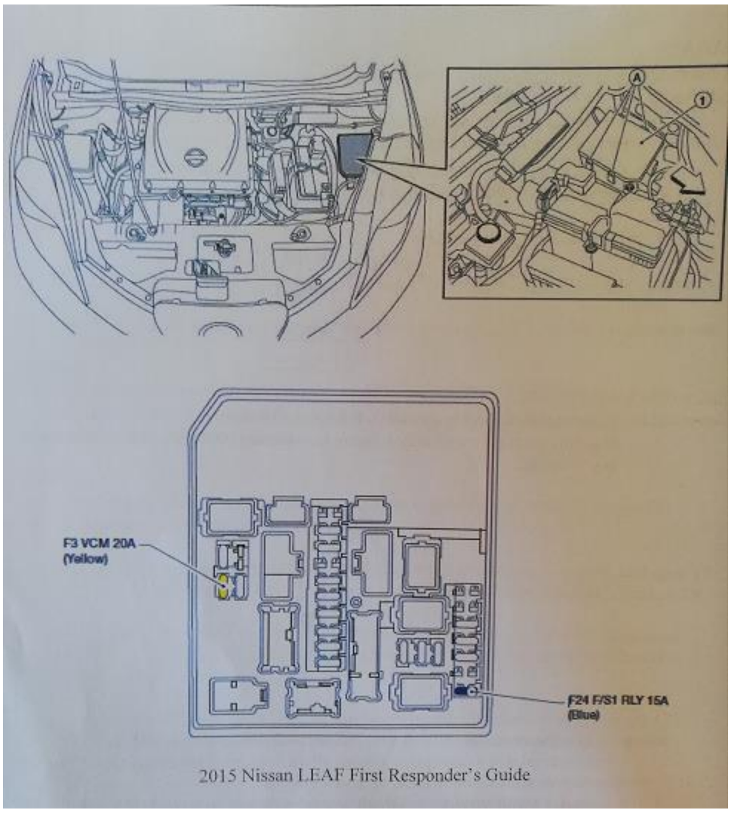
- Temporarily unlock the charging connector for 30 seconds

Press it to release the charging connector and pull the charging connector to remove it



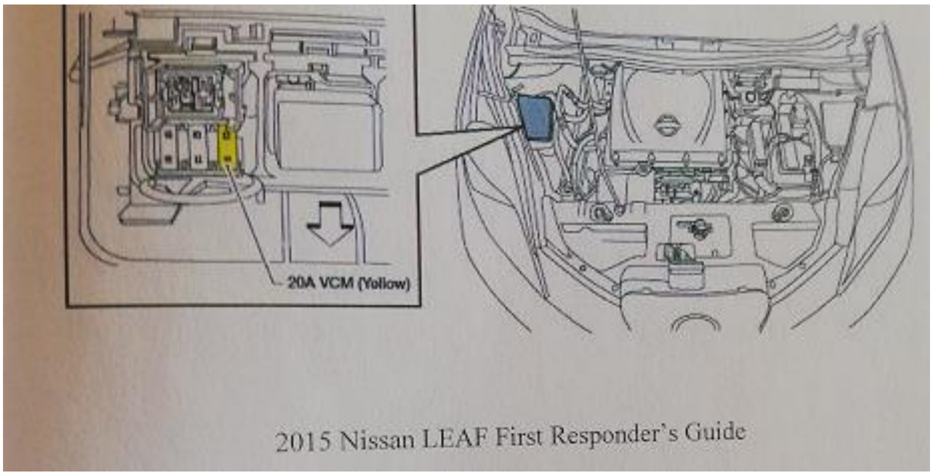
- Using a flat-head screwdriver (or appropriate tool), insert into the screw located through the hole near the front of the inverter compartment cover lock
- Turn the screwdriver clockwise to release the charge lock connector. Press the charging connector release button and pull the charging connector to remove it.





To avoid inadvertent reconnection of power and the risk of electric shock, which could result in serious personal injury or death, the person who removed the fuse should carry it with them. Fuses cannot be left next to the vehicle. The fuse box should be covered with insulated mat.

- Remove the fuse box cover and remove the VCM 20A fuse



Alternative procedure
If you have any doubts about the precise location of the fuses required by the procedure, replace all of them

- Disconnect the negative (-) 12V battery cable.
- Insulate the negative (-) battery terminal with insulating tape.
- After removing the fuses, wait at least 10 minutes for the high voltage capacitor to fully discharge.

Do not remove the service plug without wearing appropriate personal protective equipment (PPE), which helps protect the employee from serious injury and death by electrical shock. Lithium-ion batteries maintain high power even when the service plug is removed. To avoid electric shock, NEVER touch the terminals in the socket.

Marking the electric vehicle and its surroundings

When servicing electric cars, the car equipped with a high-voltage system and its surroundings should be marked appropriately.

- **Marking of the space in which a car equipped with a high-voltage system is operated (no unauthorized persons are allowed)**

The environment in which the operated electric vehicle is located should be separated in a visible manner in order to inform third parties that they are prohibited from entering the designated area.

- **The environment in which the operated electric vehicle is located should be separated in a visible manner in order to inform third parties that they are prohibited from entering the designated area.**

Maintenance tools and equipment needed for electric vehicle maintenance and repair services

- **Electrical insulating gloves**

ELSEC electrically insulating gloves - are five-finger gloves with an anatomical shape, made of high-quality natural latex. Each ELSEC electrical insulating glove has its own individual number and is electrically tested on a computer-controlled measuring station. A report on the tests carried out is attached to each ELSEC electrical insulating glove. The ergonomic shape and flexibility of the ELSEC electrical insulating glove allows you to work freely with anti-sweat inserts and protective leather gloves. ELSEC electrical insulating gloves are intended for use exclusively for electrical purposes as basic personal protective equipment for work at voltages up to 1 kV or as additional protective equipment at voltages higher than 1 kV.

RECOMMENDATIONS AND RESTRICTIONS OF USE

• The voltages at which gloves are used must not exceed the limit value appropriate for a given class of gloves.

• Do not use gloves, including stored gloves, if more than 6 months have passed since the date of the last examination.

• Do not use damaged or leaking gloves. If there is any doubt as to the condition of the gloves, they should not be used and should be subjected to inspection. If the gloves get wet or damp, they should be carefully dried at a temperature not exceeding 65 ºC and covered with talcum powder.

• Glove inspection tests should be performed in accordance with the PN-EN 60903:2006 standard. Class 1, 2 and 3 gloves should be electrically tested, while Class 00 and 0 gloves should be inspected by visual inspection to detect damage and cracks. It is recommended to examine gloves that are used intensively every 3 months.

TRANSPORT/STORAGE
Gloves should be transported and stored in their original packaging. Gloves should be stored in a dark, dry room with a temperature of 5°-35°C, away from light sources and ozone-generating devices, not folded or bent.

CHECKS BEFORE USE
Before use, check the condition of the gloves inside and out by visual inspection and check their tightness by inflating them. Do not use damaged or leaking gloves. If there is any doubt about the condition of the gloves, they should be inspected before use. If the gloves become wet or damp, they should be carefully dried at a temperature not exceeding 65°C and covered with talcum powder. The voltages at which gloves are used must not exceed the limit value appropriate for a given class of gloves, given in the EN 60903:2006 standard. Gloves should not be used if more than 6 months have passed since the date of their last examination, and in the case of new and stored unused gloves, if more than 12 months have passed since the date of the last examination.

CLEANING
If the gloves become dirty with substances such as tar or paint, the parts covered with them should be immediately wiped with an appropriate solvent, avoiding excess solvent, but without using a brush, sandpaper or sharp tools. Do not use kerosene, gasoline, liquid paraffin, toluene or xylene to remove these substances. Then the gloves should be washed with soap and water at a temperature not exceeding 25°C, and after washing they should be dried.

PERIODIC CHECKS
Glove inspection tests should be performed in accordance with the EN 60903:2006 standard. Class 1, 2 and 3 gloves should be subjected to electrical tests, while Class 00 and 0 gloves should be inspected by inflation to check for leaks and by visual inspection to detect damage or cracks. Electrical tests can be performed optionally. It is recommended to examine gloves that are used intensively every 3 months.

- **Protective helmet**

PRZEZNACZENIE
The helmet is designed to protect the head against injuries caused by falling objects, and also provides protection against electric shock by preventing the flow of shock current through the head, protection

against electric arc and molten metal spatters. Particularly recommended for use as personal protective equipment when working under voltage, working at heights and when performing switching activities. The helmet must be properly adjusted before use. The user should adjust the helmet to the head circumference, set the wearing height and the length of the chinstrap. The helmet has a head circumference step adjustment, every 1 mm in the range from 53 cm to 63 cm, and a two-position wearing height adjustment.

REGULATIONS

The helmet's useful life is 60 months from the production date. AFTER ANY IMPACT, CRACKS OR DAMAGES, THE HELMET MUST BE REMOVED FROM USE. Do not modify or eliminate original helmet components. Do not use paints, acids or self-adhesive labels without the manufacturer's consent.

STORAGE AND TRANSPORT

Store and transport the helmet in a separate transport bag or container. The helmet should not be squeezed. Place away from heat sources. Protect against mechanical damage and sunlight (UV). Do not place the helmet directly next to room windows or car windows. It is recommended to store at a temperature of (20±15) 0C

CLEANING

Clean the helmet only with soap and water. After washing, dry thoroughly. Do not use solvents or detergents for cleaning. Replace sweatbands with new ones if they are heavily worn.

PERIODIC TESTS AND PRIOR USE INSPECTION

A visual inspection should be performed before each start of work. The inspection includes checking: no visible defects in the helmet shell; o the correct functioning of the head circumference regulation; o the correct operation of the chin strap attachment; about the period of use. A helmet that is damaged (mechanical damage to the shell, or faulty operation of the head circumference adjustment or chinstrap attachment) or dirty cannot be used in live work. If the helmet becomes damp, dry it thoroughly before use. Pay attention to the helmet's service life, which is 60 months from the production date. After this period, the helmet should be withdrawn from use and disposed of. Helmet production in accordance with EN 397:2012 and EN 50365:2002

signage

on the helmet shell:

symbol of working under voltage;

50365:2002 reference standard "Electro-insulating helmets for low-voltage installations"

class 0 electrical class for installations with rated voltage up to 1000V alternating voltage and 1500V direct voltage;

e.g. 003 series number;

CE 1437 marking of compliance with Directive 89/686/EEC and notified body number - CIOP-PIB, ul. Czerniakowska 16, 00-701 Warsaw; SECRA symbol (name) of the product; EN 397:2012+A1:2012 reference standard "Industrial protective helmets"; 53-63cm head circumference adjustment range;

HUBIX manufacturer's name;

-30°C very low temperature (up to –30°C);

440Vac electrical insulation;

MM molten metal spatters

LD deformation

- insulating mats

The electrical insulating mat is a means of collective protection. Protects against electric shock when working under voltage. Electrical insulating mats meet the requirements of the IEC 61111:2009 standard.

The mats should be used at temperatures of -40°C to +55°C. Avoid contact with concentrated acids and greases. Place the mats on a clean and smooth surface free from sand, gravel, metal particles, etc. When working, place your feet in the centre of the mat.

Electrical insulating mats are subject to periodic testing no later than 12 months from the date of the last test. The mat to be tested must be clean and dry, after visual inspection by a person authorized to perform this type of testing. The user or testing laboratory is responsible for entering the date of the electrical test in the table on the underside of the mat. Marking with the test date should be safe for rubber and should not change the electrical insulating properties of the mat.

Class of electrical insulating mat	Test type (periodic)	
	Test voltage kV	Test time
2	20	1 minute
Tested in accordance with the requirements of the IEC 61111:2009 standard		

- Electrical insulating shoes

Electrical insulating properties – threats and effectiveness

In order to ensure electrical insulating properties that reduce the risk of electric shock, the footwear is made in accordance with the requirements of the PN-EN 50321-1:2018 standard. Each new shoe is subjected to an inspection by the manufacturer - an electrical voltage test using a test voltage of 20 kV. As a result of a positive inspection result, the device is marked with a serial number and production date (month and year). The footwear is marked with a double triangle symbol (symbol of electrical insulating properties) with the marking Class 2 (control - voltage testing with an alternating voltage of 20 kV, use in conditions with voltage up to 17 kV alternating voltage (AC). Footwear with electrical insulating properties is used as an additional protective measure and in situations of risk of electric shock, it cannot be used as the only protective measure. In conditions of risk of electric shock, other basic protective equipment should be additionally used, resulting from the risk assessment. The electrical insulating properties of footwear should be confirmed by carrying out periodic inspections. This test should be carried out by an appropriate testing laboratory at intervals no longer than 12 months. The interval between periodic inspections should be adapted to the intensity and conditions of use of the footwear based on the risk assessment. Also, if it is suspected that the conditions of use, inappropriate cleaning or storage may have caused the loss of electrical insulating properties of the footwear, they should be subjected to periodic inspection before being put back into use. A positive result of the periodic inspection should be confirmed by issuing an appropriate certificate and recording the deadline for the next periodic inspection of footwear. The footwear has a space for entering the dates of periodic inspections and the date of entry into use, printed on the outside of the upper.

STORAGE AND PACKAGING

Storage conditions are an important factor in maintaining the electrical and mechanical properties of electrically insulating footwear. Before first use and between subsequent uses, footwear should be stored in the factory packaging, dry, clean, at a temperature of (20±15) ºC. It should not be bent, compressed, placed near a heat source, exposed to sunlight or strong artificial light, ozone or other substances harmful to rubber. Shoes that are properly stored and maintained experience slower aging processes. Shoes are packed in plastic bags with a unit label (unit packaging) and then in a cardboard box with a collective label containing 5 pairs of shoes of one size (collective packaging).

PRECAUTIONS BEFORE AND AFTER USE

Before using the footwear for the first time, check: whether it has suffered any transport damage, whether no more than 12 months have passed since the date of production and enter the date of introduction into use (day/month/year) in the appropriate table located on the inside of the upper of each shoe (left and right leg). If transport damage is suspected or the 12-month period from the production date has been exceeded, a periodic inspection should be carried out before the footwear is put into use. Periodic inspections and tests may only be performed by formally trained and qualified personnel. In this case, the first date of periodic inspection should be recorded on the plate. The footwear should be carefully visually inspected before each use. Check whether the properties of the footwear specified by the manufacturer are appropriate for the expected working conditions on electrical equipment. Before use, check by visual inspection whether the footwear is not mechanically, thermally or chemically damaged or worn, and whether the periodic inspection period confirming compliance with the requirements regarding electrical insulating properties has not expired. The dates of periodic inspections should be recorded on the inside of the upper on a plate intended for this purpose. Footwear that is damaged or worn out, or that has exceeded the periodic inspection deadline, should be withdrawn from use. .Footwear is considered unfit for use when:

• the top layer of rubber is cracked above half of its thickness
• the top is cracked or burnt
• there is severe wear of the rubber on the nose
• there are cracks on the soles
• the sole is detaching from the upper
• there is a puncture, cut or other mechanical damage
• there is wear of the protrusions of the bottom carving

Electrically insulating footwear should not be used in situations where there is a risk of cutting, perforating or mechanical or chemical exposure, which may partially reduce its insulating properties. In doubtful cases, footwear should be subjected to electrical product tests. The user should always check before use and ensure that the uppers of the footwear are dry (footwear whose uppers get wet loses its insulating properties partially or completely). NOTE: If footwear is exposed to wet uppers (over 90 mm according to Table 4, EN 50321), the footwear loses its insulating properties, partially or completely. Always check whether the class of footwear corresponds to the rated values of the voltages involved. Where there is a risk of cuts, perforations, getting wet or exposures leading to reduced electrical insulating properties, the use of additional protective measures should be considered. After use, shoes should be cleaned with soap and water using a delicate sponge and dried away from heating devices. Lubrication with silicone emulsion delays the aging of the rubber. It is advisable to avoid contact with gasoline, paraffin, oils and solvents.

CLEANING AND MAINTENANCE
Footwear should be washed with soap and water using a sponge or soft cloth. Dry away from heating devices. Lubricate with silicone emulsion or glycerin. Avoid contact with gasoline, paraffin, oils and solvents.

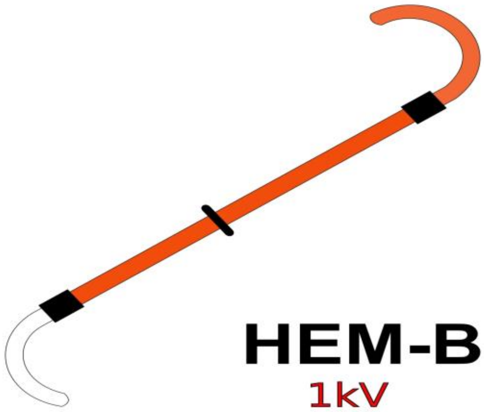
TRANSPORT
It should be carried out in clean means of transport, protected against weather conditions, chemical substances harmful to rubber and fabric, and against mechanical damage.

Marking

ANTYAMPER - trade name and article number CE - conformity mark 1439 - number of the notified body supervising ISO 20347 - standard for professional footwear OB - essential requirements for professional footwear SRA - slip resistance on ceramic surfaces Rubber - shoes made of natural rubber Handmade - handmade Made in EU – manufactured in Europe. ELECTRICAL EQUIPMENT – name and address DOUBLE TRIANGLE SYMBOL, CLASS 2 - indicates the electrical insulating properties of shoes used to work with devices with voltage up to 17 kV AC	

- tested voltage current, alternating current EN 50321-1 - standard for electrically insulating footwear PRODUCTION DATE - entered on the label on the shoe SERIAL NUMBER - entered on the label on the shoe PERIODIC TESTS - table for entering the deadlines for subsequent inspections - periodic tests DATE OF INTRODUCTION INTO USE - table for entering the date of commencement of use 4 L or 4 R - shoe size on sole - L - left leg, right leg (see sole)	

- **Emergency hook**



The HEM-B 1kV evacuation hook is designed to pull a person or their limbs away from a energized device, which makes it possible to undertake an immediate rescue action without having to wait for the device to be disconnected from the voltage.
The HEM-B 1kV evacuation hook is used to pull away limbs (arms or legs) and can be used with devices with a rated voltage of up to 1 kV.

The hook is made of a glass-epoxy pipe filled with polyurethane foam, commonly used in the production of UDI insulating rods. The length of the insulating part ensures effective isolation of the rescuer during evacuation activities. The limiter clearly divides the pipe into a gripping and insulating part. The hook-shaped tip protected with a layer of insulating plastic allows for appropriate gripping of the injured person's torso or limb. The handle in the gripping part facilitates manipulation of the hook and exerting appropriate axial force during a rescue operation.

WAY OF USAGE

HEM-B and HED-B hooks should be placed on the board together with other rescue equipment (bridges, insulating walkways, dielectric gloves) in an easily accessible place, close to places posing a risk of electric shock, e.g. switchboards, electrical stations, workplaces equipped with in electrical devices, and during work, evacuation hooks should be located in such a place that they are ready for use immediately after an electric shock occurs.

The responsible employee should regularly check and monitor the technical condition of the hooks:

- cleanliness and lack of mechanical damage to the hook - the plastic cover on the metal core of the hook must be of a uniform color,

- whether the insulating part shows no signs of mechanical damage, it should be smooth without any material losses, cracks and scratches,

- whether the validity of periodic voltage tests is current,

whether the hook has a legible nameplate/hook type, rated voltage, year of production, factory number, standard number PN-EN 60832-1:2010, WTO-7/02 number/.

NOTE: Any noticed damage causes the evacuation hook to be withdrawn from service.

NOTE: The use of the evacuation hook for devices with a rated voltage higher than the rated voltage of the hook is prohibited. In the event of an accident - electric shock (up to 1 kV~ for HEM-B and up to 30 kV~ for HED-B), the witness of this event should as quickly as possible grab the selected hook with one hand by the handle and with the other hand by the gripping part of the hook (part in front of the limiter) and approach the injured person, taking care not to get into the zone where paralysis may occur.

When the infected person is in a voltage zone up to 30 kV, use the HED-B hook. Hook the hook around the affected person's waist or chest and pull him or her away from this area.

When the infected person is in a low voltage zone, use the HEM-B hook as above. The HEM-B hook is used to pull the paralyzed person by the leg or arm away from the element on which the muscles contracted during the paralysis.

ATTENTION: IT IS PROHIBITED TO PULL OUT OF THE SHOOTED PERSON BY GRABBING THE NECK WITH A HOOK.

The operation of pulling away an infected person with HEM-B and HED-B hooks must be performed by holding the gripping parts of these hooks. The grip part is clearly distinguished by the grip stop.

After pulling the injured person to a safe place, immediately provide first aid and call for medical assistance.

It is recommended to practice expressing in stress-free conditions.

Notes on use, storage, transportation, maintenance and decommissioning of hooks:

- Hooks should always be ready for use, i.e. they should be placed in a visible and accessible place, they must be clean, dry and have valid operational tests. If there is any doubt as to the condition of the evacuation hook, it should be withdrawn from service and sent to the manufacturer for verification.
- If they are dirty, wipe them with a clean cloth moistened with anhydrous alcohol.

- Avoid storing hooks in sunny places and in rooms with high temperature and heavy dust.
- HEM-B, HED-B evacuation hooks should be transported protecting them against mechanical damage and dirt.
- HEM-B and HED-B evacuation hooks undergo product tests required by the WTO. This gives the user a guarantee of safe and failure-free operation throughout the entire period of operation, provided that the requirements of this manual are followed. Taking into account the stability of the electrical and mechanical parameters of the materials from which the hooks are made, the manufacturer provides for periodic operational tests every two years. They are to consist in a thorough visual inspection and a dry electrical strength test of the insulating part performed in accordance with PN-EN 60832-1:2010. The hook may be withdrawn from service in the event of wear or mechanical damage or a negative result of periodic tests. Of course, the above does not limit the right of the user, guided by his own operational experience, to confirm the ownership of the hook within periods set by him that are shorter than those recommended by the manufacturer.
- Any repairs to HEM and HED hooks may only be performed by the manufacturer.
- Failure to follow these instructions may pose a threat to the user's health or life as well as damage to the equipment and is unacceptable.

https://sklep.opa.pl/

1.2 ELECTRICAL INSTALLATON AND FUNCTIONAL SYSTEM SAFETY.

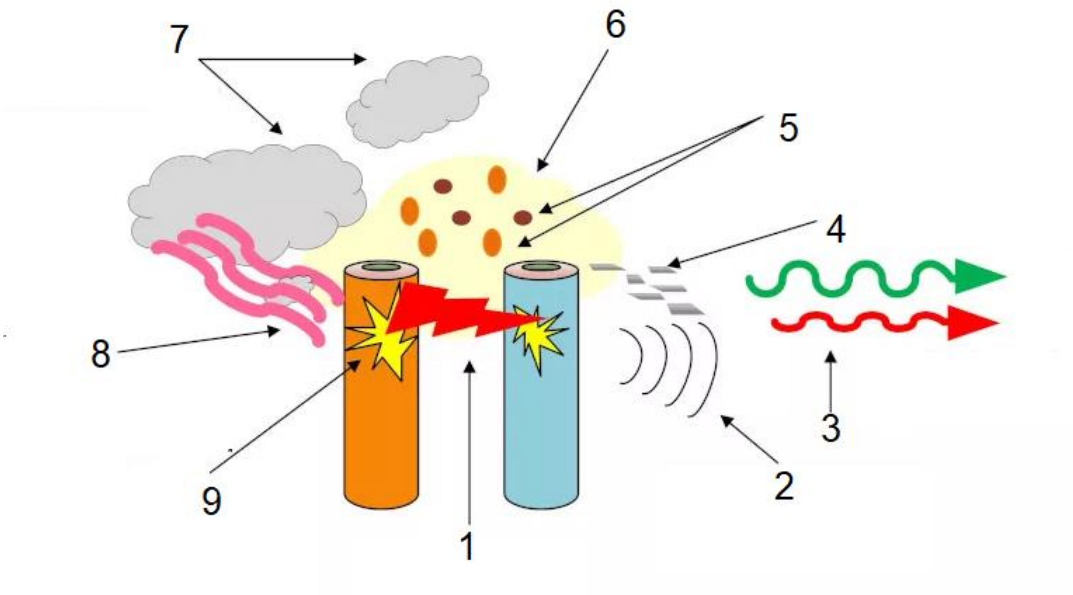
Electrical short circuit (danger and risk)

When repairing high-voltage systems in electric cars, the greatest threat is not only the risk of electric shock, which results in current flowing through the human body. Although such a situation is very dangerous, it rarely happens because the mechanic would have to make two mistakes at the same time: i.e. touch the positive and negative poles of the battery at the same time. Fortunately, this is difficult to achieve.

However, it should be borne in mind that the energy stored in traction batteries poses a very serious risk of electric shock. In addition, traction batteries and the high-voltage installation pose a daily challenge due to the potential occurrence of flash arcs. These are uncontrolled electrical discharges that can lead to dangerous situations and damage.

Arc fault

Mechanics must be aware of the potential hazards of arc flash when repairing high-voltage electrical systems. An electric arc most often occurs between two conductive elements with different potentials as a result of short circuits in the electrical installation. The causes of these short circuits may be damage to the wire insulation or human error.



Electric discharge where the insulation of two wires is damaged; *source: Raven Media*

1- electric arc
2- shock wave, sound wave
3- UV, IR radiation
4- accelerated charges
5- particles of molten metal and plastic
6- plasma at a temperature of 10,000 -20,000 0C
7- aggressive chemical fumes
8- thermal radiation
9- damaged insulation

An electrical discharge may occur where two electrical wires with a voltage difference exceeding 100 V DC are exposed. The result of the discharge is an arc flash, which is a dangerous phenomenon. It involves the movement of electric current through air between two exposed conductors. This may lead to an electrical explosion and the release of enormous amounts of energy in the form of heat, light, sound and pressure - which poses a potential threat to the mechanic's health and life.

According to research conducted by Oak Ridge National Laboratory, an electric arc causes air ionization, and the temperature then reached can be as high as 20,000°C. In such conditions, ordinary work clothes are burned and human skin is severely burned, all within a few seconds, within a range of up to several meters to the ionization site.

The heat can also ignite any nearby combustible materials. The high temperature resulting from the plasma discharge may also cause melting or literally vaporization of parts of wires made of copper or aluminum. The transformation of the solid state into vapor generates explosive pressure and acoustic energy. The blast of the resulting shock wave can cause permanent hearing damage. Molten metals can be sprayed by an explosion in the workplace. Optical radiation from the incident poses many hazards. Excessive exposure to optical radiation and the depth of its penetration causes permanent skin burns and damage to eyesight.

Personal protection

Only a small part of personal protective clothing provides adequate protection against the thermal impact of an electric arc. When performing work related to high-voltage systems in electric vehicles, it is extremely important that employees are provided with specialized clothing and protective equipment that meet stringent safety standards. This is important due to the potential dangers associated with an electric arc explosion.

The effects of this phenomenon, such as extreme temperatures, flash and energy emission in the form of heat, light, sound and pressure, may be dangerous to the health and life of employees performing repairs or maintenance of high-voltage systems. This type of protective clothing should meet stringent European standards such as IEC 61482-1-1:2009 or IEC 61482-1-2:2007, which specify requirements for protection against the thermal effects of an electric arc.

Such specialized clothing can be easily recognized thanks to the appropriate pictogram placed on the tag, next to the assigned value of the clothing's safety level coefficient in relation to the arch, expressed in inches/cm^2. Protective clothing minimizes the risk of burns and other injuries when working with electrical hazards. In addition, mechanics working on high-voltage vehicle systems should be equipped with the following personal protective equipment:

• **protective helmet with visor -** protects against thermal hazards caused by electric arc and against impacts of molten metal particles,

• **insulating gloves -** specialized electrical insulating gloves protect hands and hands against contact with live parts and against the thermal impact of an electric arc,

• **electrically insulating shoes -** shoes with appropriate electrical resistance on the soles minimize the risk of shock current flowing through the human body and feet.

Possible causes of an arc fault:

- connecting to battery-powered systems,
- changing components in the high voltage system,
- repair, service and relocation of traction batteries,
- performing measurements of electrical installations,
- testing and troubleshooting, replacement of electric motors,
- repair of the high voltage system after a vehicle accident,
- using inappropriate hand and power tools,
- damaged or poor insulation of wires and electrical components,
- lack of appropriate training of employees performing repairs,

- not having a license to work with electrical devices,
- weather conditions during the repair.

https://autoexpert.pl/artykuly/niekontrolowane-przeskoki-elektryczne

Extinguishing electric batteries

Before I move on to extinguishing batteries in smaller devices, such as scooters and bicycles, I will start with the best documented fires, i.e. car battery fires. Basically, whether the battery is smaller or larger, it doesn't matter because the ignition process is the same.

First of all, we need to realize when to put out a fire and when not to. Here, the battery itself can warn about it, just before the explosion, clouds of smoke and a hissing sound begin to emerge, but from the beginning.

Battery ignition is characterized by gray smoke emanating from the chassis area and the previously mentioned hissing sound. A reaction then occurs which will soon cause a fire to break out.

Examples of battery fire

https://www.youtube.com/watch?v=Le6KNI9YsH0&t=53s

https://www.youtube.com/watch?v=sAQlLu5ttOk&t=91s

Rules for extinguishing electric cars (batteries)

Start extinguishing the fire. The following extinguishing agents can be used to extinguish a fire or defend yourself: water and extinguishing powders.
1) small fires can be extinguished with water or using ABC or AB fire extinguishers - maintaining the distance indicated on
fire extinguisher label as when extinguishing electrical appliances;
2) a developed car fire should be extinguished with water;
3) visible fire in the vehicle battery should be extinguished with water and follow the manufacturer's recommendations included in the rescue card;
4) when dispensing water using distributed current, at any capacity (only PWT Ø 52 - "Turbo" nozzles), a minimum scattering angle of 30° and a minimum distance of 1 m from installation elements that may be under voltage must be maintained;
5) when dispensing water using short-circuit current (only PWT Ø 52 - "Turbo" nozzles) with a maximum capacity of 250 l/min, a minimum distance of 5 m must be maintained from installation elements that may be under voltage. When using capacities above 250 l/min, maintain a minimum distance of 10 m.

Classic heavy, medium or light foam should not be used - except in cases clearly indicating the need to use foam (e.g. fuel spill).

After extinguishing the fire in the vehicle's interior components, assess whether the vehicle's traction battery has been damaged and the process of "thermal instability" has begun. If the previously described symptoms indicating a battery fire do not occur, take measurements on the surface of the casing. Monitor the temperature for 30 minutes. If the temperature does not exceed 50°C and does not show an increasing tendency, there is no need to carry out further cooling activities.

If the temperature of the traction battery housing increases above 50°C or an increasing tendency in temperature is observed, the external elements of the battery should be cooled with water for 10 minutes (e.g. using distributed current or a water curtain). Stop water for 3 minutes and measure the temperature at multiple points. If the battery temperature has dropped below 50°C and does not rise, stop cooling. Monitor the temperature for 30 minutes and repeat cooling if it increases.

In the event of a battery fire, it is necessary to provide more water on site than in the case of a fire in a combustion-powered car. A stream of water should be administered directly onto the burning battery to effectively cool it. If holes are created in the battery housing during a fire, use them to pour water - keep a safe distance.

The battery cooling process, even after eliminating the signs of burning, may take from several to several hours! (on average it is about 7 hours, there are known cases of relapse of smoking after 20 hours). Cooling the battery is difficult due to its tight construction. Under no circumstances should you interfere with the structure of the battery, as this may result in electric shock. The effects of extinguishing and cooling the battery should be monitored using a thermal imaging camera or pyrometer. Apply cooling until the surface temperature drops below 50°C and there is no tendency for it to increase further. Monitor the temperature for 30 minutes and repeat cooling if it increases.

The use of a container to sink an electric car may only be used in justified cases (when the techniques described above prove ineffective). Do not fill the container with water higher than necessary, i.e. up to the upper edge of the battery. Preventive flooding of the vehicle is not recommended. The reasons for this include, among others: high logistical effort, high costs of disposing of contaminated water as special/hazardous waste and inevitable increase in overall damage. Use a container to extinguish electric vehicles only if you have recognized how to handle fire water, i.e. the possibility of transferring it to an appropriate entity. Consider using a dry containerized vehicle quarantine.

If a container is used and the vehicle is flooded with water, dispatch chemical units (readiness level B) to the site to collect water samples. Water samples need to be analyzed for the composition of the resulting waste.

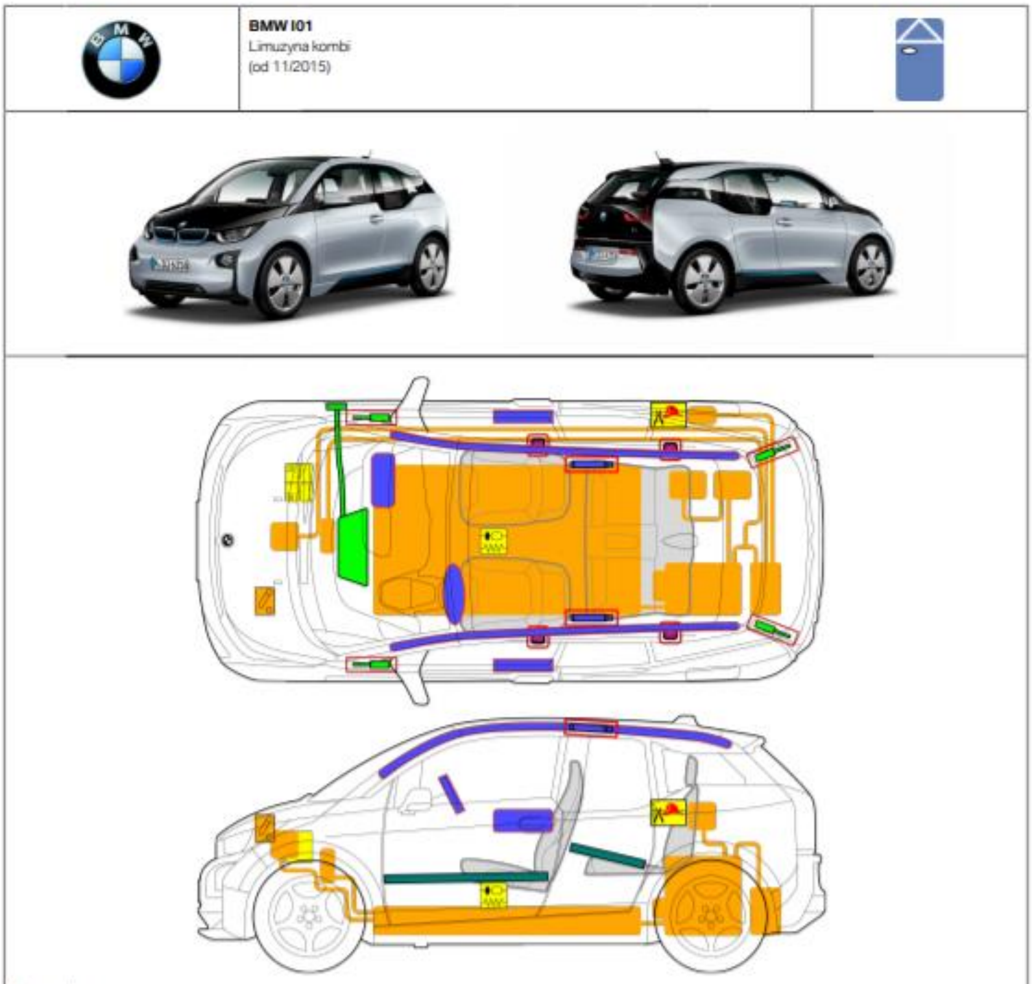
https://www.ppoz.pl/czytelnia/ratownictwo-i-ochrona-ludnosci/Pozary-elektrykow/idn:2985

The process of thermal decomposition of the traction battery may result in the release of flammable and toxic gases, including e.g. hydrogen or carbon monoxide - monitor the explosive atmosphere inside and near the vehicle using a multi-gas sensor.

Vehicle rescue card

The rescue card presents important information for emergency services. It marks key areas of the vehicle, such as body reinforcements, the location of the high-voltage cable, the location and number of safety airbags and seat belt tensioners (which may explode during a collision).

Example of an electric car rescue card.



BMW I01
Limuzyna kombi
(od 11/2015)

Legenda

Airbag	Generator gazowy	Napinacz pasa	Sterownik SRS	Aktywny system ochrony przechodniów
Automatyczny system ochrony przed zgnieceniem kabiny	Amortyzator gazowy / wstępnie napięta sprężyna	Wzmocnienie karoserii	Strefa niebezpieczna	Odłącznik układu wysokiego napięcia (rozwiązanie odcinające)
Akumulator niskonapięciowy	Kondensator niskonapięciowy	Zbiornik paliwa	Zbiornik gazu	Zawór bezpieczeństwa
Akumulator wysokonapięciowy	Komponent / kabel wysokonapięciowy	Odłącznik układu wysokiego napięcia	Bezpiecznik wysokonapięciowy	Kondensator wysokonapięciowy

W tym zestawieniu pokazane jest maksymalne wyposażenie pojazdu

Nr ID	Nr wersji	Data wersji	Strona
WBY-I01	1	11/2015	01

Ważne: dalsze informacje, patrz podręcznik dla służb ratowniczych.

https://www.autobaza.pl/page/wp-content/uploads/2020/10/karta-pojazdu-elektrycznego.png

Identification and familiarization with the operating systems of an electric vehicle

The presence of a high voltage electrical system, electric and hybrid cars are called high voltage vehicles. Series-produced vehicles should be built to ensure the electrical safety of high-voltage systems. To this end, they should protect against electric shock during normal use and ensure the safe use of the vehicle. During maintenance (e.g. when washing the vehicle) and operation, the high voltage system cannot pose a risk to the driver and operating staff, provided that everything works properly. This also applies to situations in which the high-voltage plug connectors would be disconnected (unintentionally by an unauthorized person).

In order to meet electrical safety requirements during normal use of high-voltage vehicles, manufacturers make the plug connectors and insulation of this system in such a way that contact does not pose an electrical hazard. The systems are equipped with an insulation resistance monitoring system and a circuit continuity monitoring system. The systems recognize damaged insulation and loose plug connections and automatically deactivate the high-voltage system if necessary.

Electrical safety must also be maintained in the event of a road accident. If the collision sensor detects an impact (airbags are activated), the high-voltage system will turn off. In the event of an accident caused by the high-voltage system, there should be no threat to passengers and rescuers. When the ignition is turned on or the 12V battery is disconnected, the high voltage system turns off.

In addition, high voltage systems have a so-called service switch, which must be disconnected before starting all maintenance activities.

Construction and operation of the high voltage system

The high voltage system usually operates when the conditions are met:

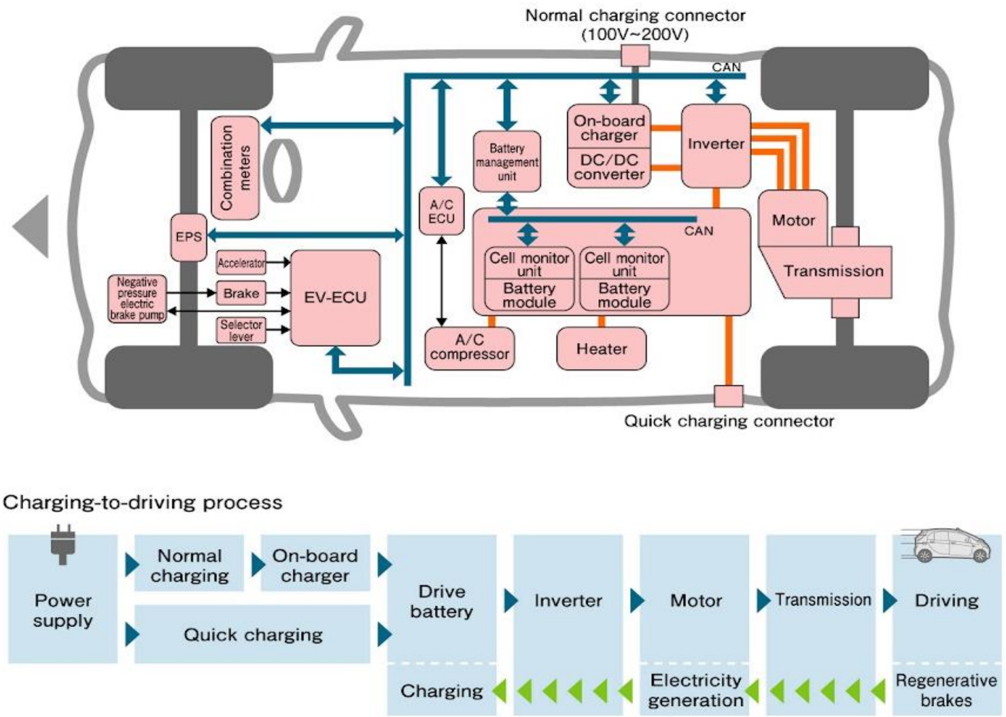
- a 12V calculator is connected to the car's installation,
- the ignition is on,
- the service switch or service plug of the high voltage system is turned on,
- the insulation of high-voltage system components and cables is efficient,
- all plug connections are functional,
- the collision sensor cannot signal a collision (no airbag can be activated).

If even one condition is not met, the high voltage system will not reach the ready state.
The conditions stated apply to all electric vehicles. Additional terms may apply to some models.

High-voltage installation of an electric car

The high-voltage system controller is powered by the on-board network voltage and is turned on and off by the electric ignition switch. The high-voltage controller is networked to the vehicle's traditional systems and critical high-voltage components.

Diagram of the high voltage system of an electric car (Mitsubishi)



source: https://forum.mitsumaniaki.pl/printview.php?t=32633&start=0

Part of the data exchange takes place via a data bus. Thanks to the received signals, the high-voltage system controller implements an appropriate operating strategy, e.g. determines when the electric machine operates as an electric motor and when as a generator. For this purpose, the controller primarily uses information received from the high-voltage battery controller, engine controller and braking system. The battery charge level and the current driving condition are the basis for determining the intensity of electricity produced by the electric machine when operating as a generator and the power to drive the vehicle in the electric motor mode. The relevant control variables are:

1. accelerator pedal position or load signal,
2. placing the brake pedal,
3. vehicle speed,
4. driving mode or gear currently engaged,
5. traction battery charge status

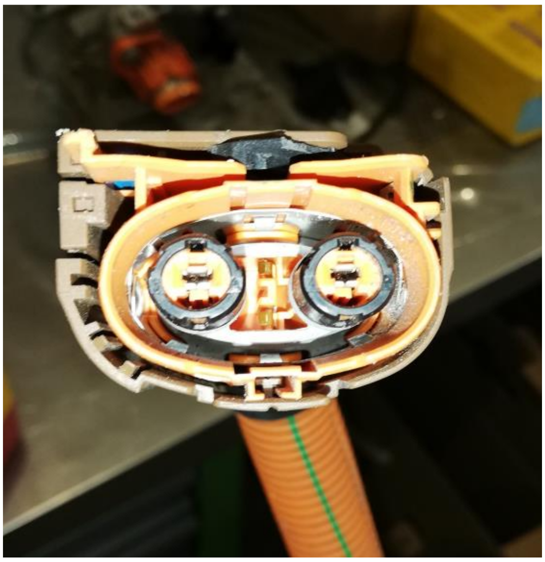
Input signals		Output signals
Ignition switch voltages	high voltage system controller	Signals controlling the main high voltage relay
high voltage battery sensor (battery temperature, battery voltage, current)		Drive status indication signals on the instrument panel
Electric motor phase sensor		DC/AC converter control signals
Various temperature sensors (e.g. on the inverter)		AC/DC converter control signals
Signals from voltage converters		Signals to the combustion engine controller
Pilot signal (high voltage circuit interlock)		Control signals for the high-voltage battery controller
Insulation monitoring signal		Signals to the braking system controller or energy recovery control
Brake pedal position		
Air conditioning switch on signal		
Vehicle speed signal		
Driving mode selector lever position		
Airbag signal		
A signal from the combustion engine controller, e.g.: accelerator pedal position		

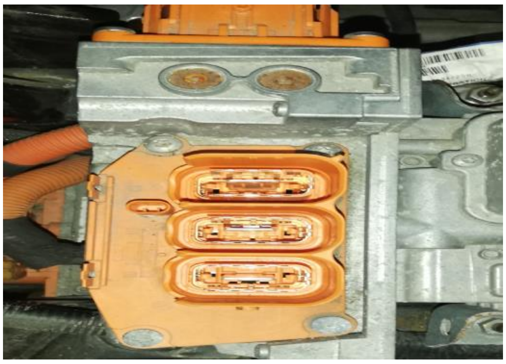
Construction of high voltage networks

A traditional 12 V network uses ground as a second wire. The car body cannot constitute a negative polarity due to high voltages and the associated risk of electric shock and the use of the body as a ground for a 12 V installation (technically it is not possible to use the same cable for a network with two different voltages).
Therefore, a two-wire IT type installation is used. All cables have double insulation and are protected against voltage polarization change. They are orange in color. The cables are terminated with special connectors that eliminate the possibility of accidental connection. The advantage of this solution is high resistance to failure. This means that if an error (insulation damage) occurs in one polarization or

phase (in one place) in the network, the system can continue to operate. There is no danger of a network short circuit provided that all other insulation is functional.

High voltage installation cables



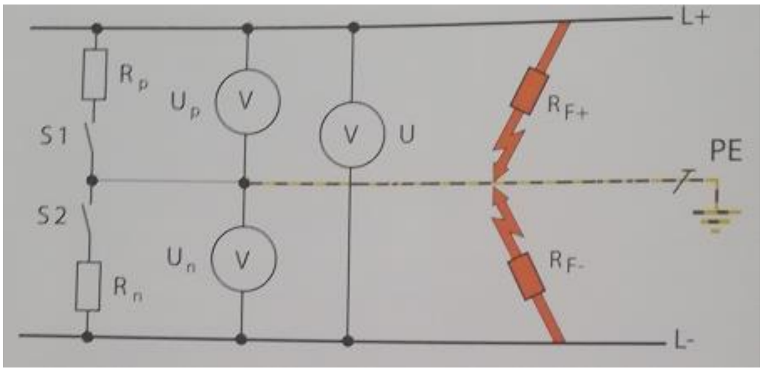


Onboard resistance monitoring

The on-board resistance monitoring system is called IMD and detects insulation faults by measuring residual currents. For this purpose, it measures the insulation resistance between high-voltage components and the vehicle body at regular intervals. The IMD module detects the resistance between the various high voltage phases and the body by applying a measurement voltage. This allows you to determine whether the insulation is still safe enough. \According to UNECE Regulation No. 100, which specifies technical requirements for the drive of road vehicles.
If the high-voltage AC buses and the high-voltage DC buses are insulated from each other, the insulation resistance between the high-voltage bus and the electrical ground must be at least 100 Ω/V operating voltage for the DC buses and at least 500 Ω/V for the AC pad buses. If the AC high voltage

buses and the DC high voltage buses are galvanically connected, the electrical resistance must be 100 Ω/V operating voltage.

Electrical connection diagram of the on-board insulation resistance monitoring system



Source: Pojazdy hybrydowe i elektryczne w praktyce warsztatowej Torsten Schmidt Rys 5.8

If the insulation is faulty, the active resistance monitoring system recognizes it by measuring the residual current flowing from the high-voltage phases..

The methods of taking measurements also have many variants. One of them is the 3VM three-voltmeter method. It is characterized by the following features:

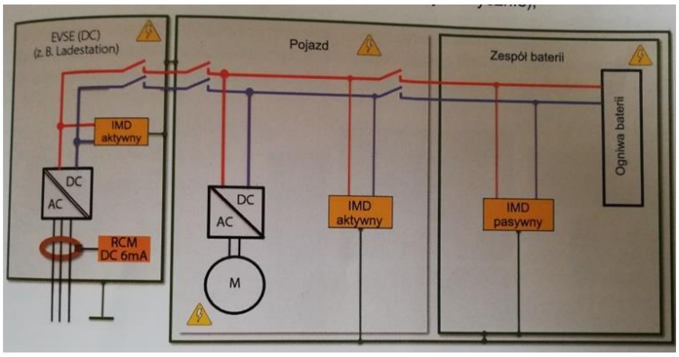
- enables accurate measurement in stable voltage conditions,
- recognizes symmetrical damage (short circuit between pole and ground, caused by aging due to uniform corrosion on both contacts or moisture) and asymmetrical damage (one-sided, e.g. negative pole to ground or positive pole to ground)m
- damage to the positive and negative poles can be detected separately.

Three voltmeter method for defects. The most important disadvantages are high measurement deviations in unstable conditions of fluctuating voltage and the dependence of the deviations on the voltage value. This method makes it impossible to monitor the insulation condition at 0V.

0V monitoring enables active monitoring of insulation resistance. By Daniel Wolfer. The measurement pulse generated by the IMD module is fed by the system through the electrical mass. The active method has advantages:

- measurement of systems under 0V voltage,
- recognition of symmetrical and asymmetrical damage, identification of the type of damage (to the positive pole to the negative pole of direct current or asymmetrically)
- early detection of system deterioration and its maintenance and repair before failure occurs

Possible configuration of passive and active IMD modules in a high voltage system



Source: Pojazdy hybrydowe i elektryczne w praktyce warsztatowej Torsten Schmidt Rys 5.9

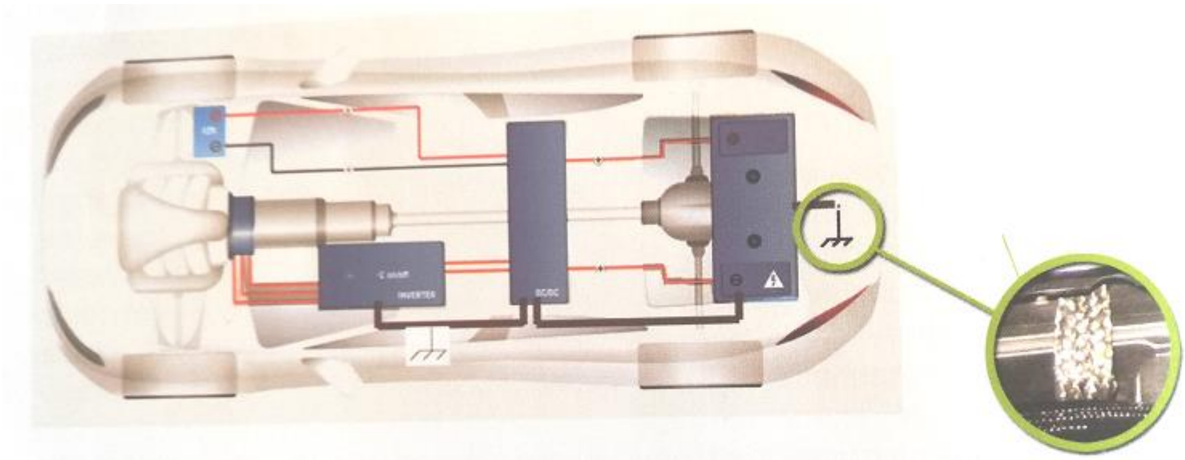
Signalling the disconnection of high-voltage connectors under voltage and how it works.

Connector disconnection signalling monitors proper connection of high-voltage cables to eliminate electrical hazards due to accidental disconnection of high-voltage contacts of active high-voltage systems. For this purpose, the system is equipped with a safety pilot cable. It is powered by a 12V mains cable running in series from one connector to the other. If the wire circuit is disconnected in one of the pilot contact plug connectors, the high voltage system controller will recognize this. Then the high voltage controller will open the high voltage relay and turn off the high voltage. Pilot contacts are present in all important plug connectors, including the main switch.

1- pilot connector

Potential equalization system

A potential equalization system in the on-board high-voltage network is necessary to reliably drive mass-produced high-voltage vehicles. In electrical installations, protection against electric shock in the event of a failure and failure of the high-voltage system's emergency stop switch by the insulation monitoring system is of fundamental importance. In the event of damage to the insulation of conductors of live high-voltage network elements, the risk of electrocution to vehicle passengers or employees is minimal thanks to potential equalization using a protective equipotential bonding, which enables equalization of different voltage levels between high-voltage elements and the body. For this purpose, all elements of the high-voltage network are connected to each other by a so-called equalizing bus (connected by a cable). In addition, high-voltage components must be electrically connected to the body via a single bonding cable or a bus mounted to the body. If there was no potential equalization system, in the event of a failure of the high voltage network (loss of wire insulation) it would pose a serious threat to life. If a person touched two elements with damaged insulation at the same time, or one part of the damaged insulation and the body, the potential equalization would occur through the flow of current through the person. However, in an installation equipped with a potential equalization system, in the event of damage, the equalizing current flows through the housing of the damaged part or through the equalizing cable. The potential difference is removed. In addition to this protective function, the potential equalization system contributes to the failure-free operation of the on-board insulation resistance monitoring system.



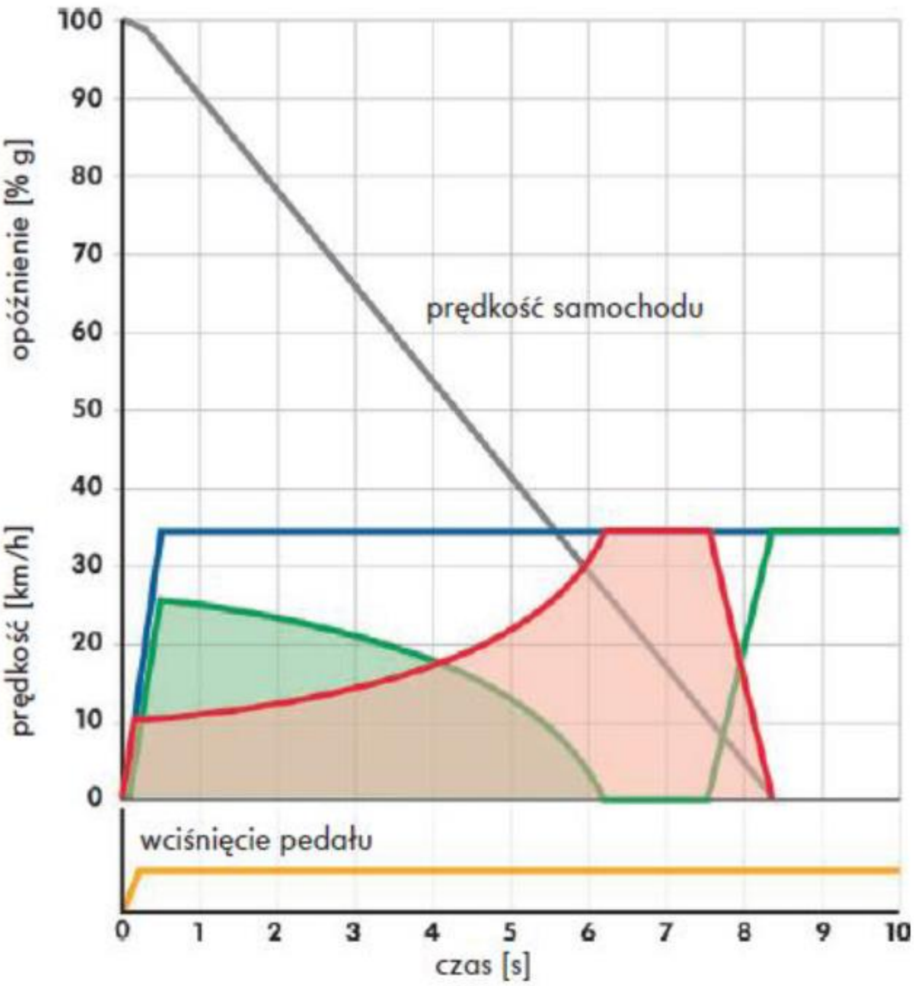
Źródło: Pojazdy hybrydowe i elektryczne w praktyce warsztatowej Torsten Schmidt Rys 5.13

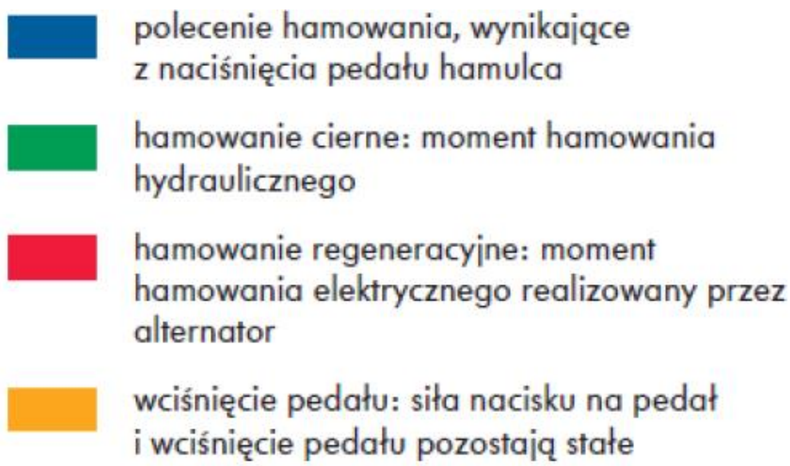
Regenerative braking system

In electric cars, supported by a vacuum actuator, the vacuum must be generated by an electric pump. The vacuum pump is powered by 12 V from the on-board network. In order for the pump to produce the appropriate vacuum, the braking system is equipped with an appropriate sensor that measures the pressure in the brake master cylinder. Depending on the pressure level, the pump is switched on or pumped out. Instead of a vacuum brake pump, manufacturers are increasingly using an electromechanical brake pump with electrical assistance. They include a dual-circuit tandem brake pump, a brake pedal sensor, an electronic controller and an electric motor with a gear that generates and transmits braking assistance. The electric motor then supports the driver's foot pressure on the brake pedal, replacing the classic vacuum device. The pedal position sensor installed in the pump detects its current position. Based on this signal, the controller calculates appropriate signals to control the electric motor, which activates the brake master cylinder with a set torque through the gear. Braking power assistance depends on the torque of the electric motor. An electromechanical brake pump enables regenerative braking. In the initial stage of regenerative braking operation, it can generate a pedal response force to foot pressure corresponding to the sensations of a driver equipped with a traditional braking system. The electric motor used for assistance is most often brushless. The use of an electric brake pump makes it possible to eliminate the vacuum pump and obtain a greater value of vehicle braking delay during regenerative braking, which contributes to the effective charging of the battery during energy recovery. In the event of damage to the electromechanical brake pump or a faulty electric motor, braking is still performed by maintaining the mechanical connection between the pedal and the pump. As in traditional braking systems, meeting the requirements for vehicle equipment regulations.

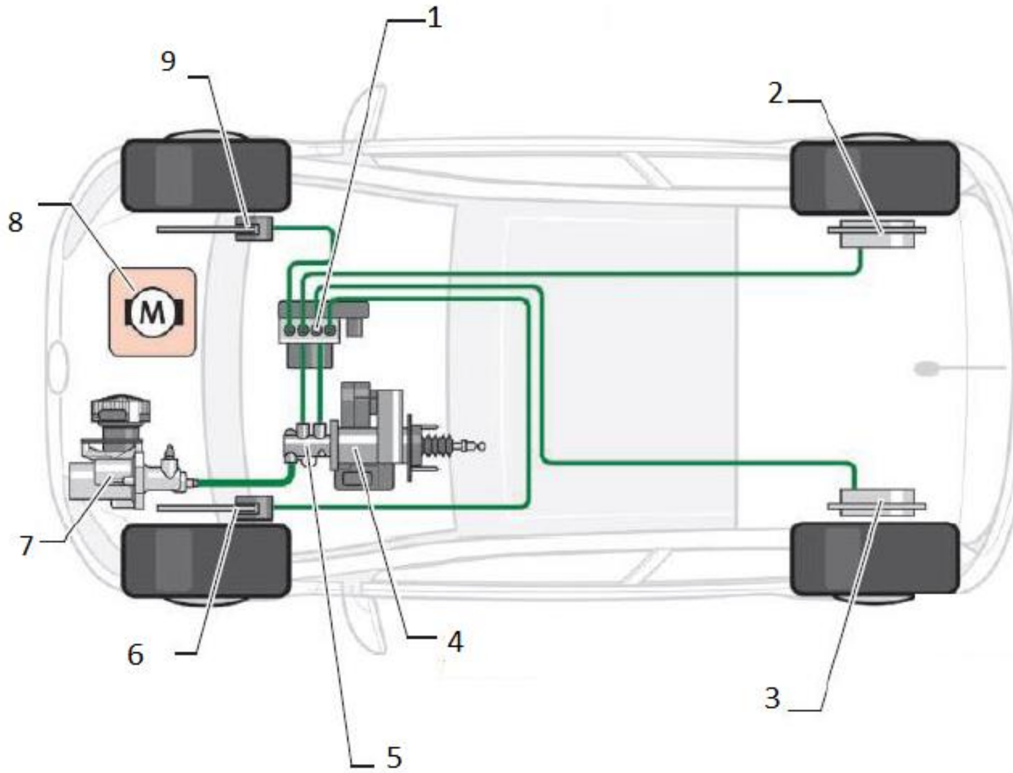
The braking process takes place in stages:

- ✓ regenerative braking, braking delay up to 3.5 m/s2
- ✓ friction braking, braking delay above 3.5 m/s2



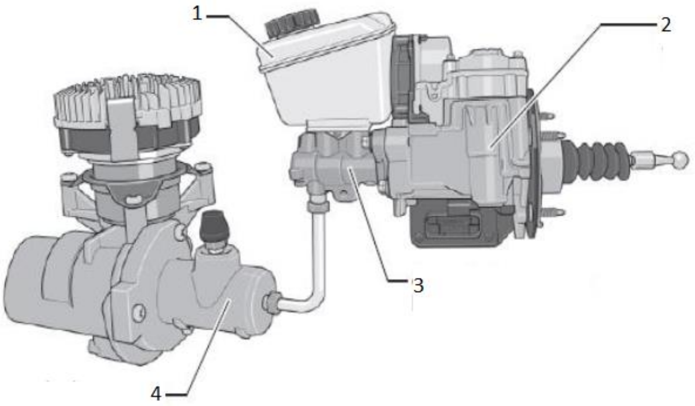


Construction of the electronic braking system – VW e-Up/ e-Golf

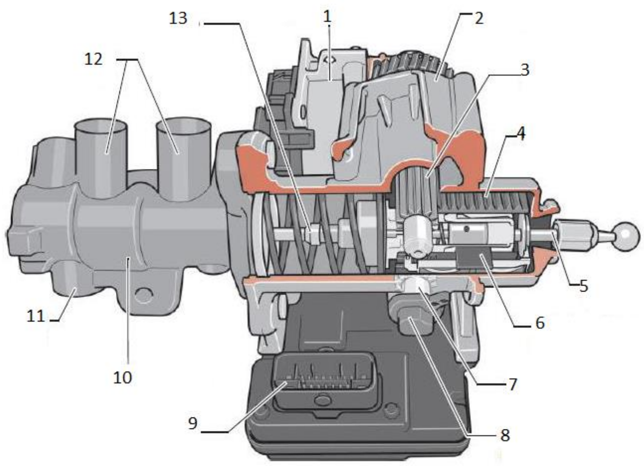


1 ESC/ABS system
2 rear wheel brake
3 rear wheel brake
4 electromechanical braking force amplifier
5 two-section brake pump

6 front wheel brake
7 pressure reservoir
8 three-phase drive unit and electronic power and control module of the electric drive
9 front wheel brake



1 brake fluid container
2 electromechanical braking force amplifier
3 two-section brake pump
4 pressure reservoir



1. amplifier motor position sensor
2. motor with gear
3. upper pinion
4. strengthening sleeve

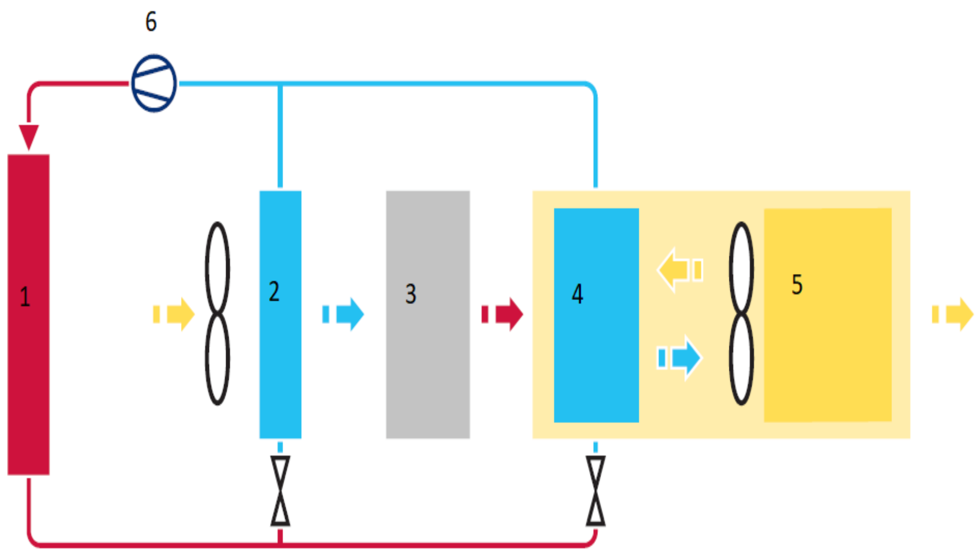
5. amplifier pusher
6. brake pedal position sensor
7. lower pinion
8. brake pedal sensor connector
9. amplifier force controller
10. wo-section brake pump
11. tank connector
12. brake fluid reservoir connector

Cooling and heating system

Lithium-ion and nickel-hydroxide batteries should be operated at a specific temperature to maintain optimal power and durability. The core temperature of a lithium-ion battery cell should not exceed 400C. If this limit is exceeded for a long time, the battery will age quickly. This applies to nickel-hydroxide batteries, which are slightly less sensitive to heat and can reach temperatures of 500C. Both types of batteries have the feature that at negative temperatures their ability to discharge and charge decreases. Manufacturers state that the readiness for operation is at a temperature of -15 0C or even -20 0C. Battery cells warm up automatically while drawing and storing electricity. Moreover, if necessary, in countries with a cold climate, manufacturers use battery heating during longer stops, e.g. using an electric heater in the battery cooling circuit. Unlike heating the battery, it is necessary to cool it. It's not only about its operation at high external temperatures, but also about the battery's automatic heating during operation and charging. Especially short-term high current loads causing cells to heat up. Various cooling methods are used to avoid battery overheating.

Method 1

In the first, theoretically simplest system, air is sucked in from the air-conditioned interior of the vehicle and used to cool the battery. The cool air sucked in from inside the vehicle has a temperature below 40°C. This air flows around the freely accessible surfaces of the battery. The disadvantage of this solution is low cooling efficiency. The air sucked in from inside the vehicle is not sufficient to reduce the temperature evenly. Safety is also a problem. The air ducts create a direct connection between the passenger compartment and the battery. This should be considered problematic due to, for example, the possibility of gas leaking from the battery. The air inside the vehicle contains dust and dust. Dust accumulates between the cells and, combined with condensed water from the air, creates an electrically conductive deposit. The sediment increases the possibility of creeping currents in the battery. To avoid this danger, the intake air is filtered. Alternatively, the air can also be cooled by a separate, small air conditioner, similar to the separate rear seat air conditioning systems in premium cars.



1- condenser

2- evaporator

3- cabin

4- battery evaporator

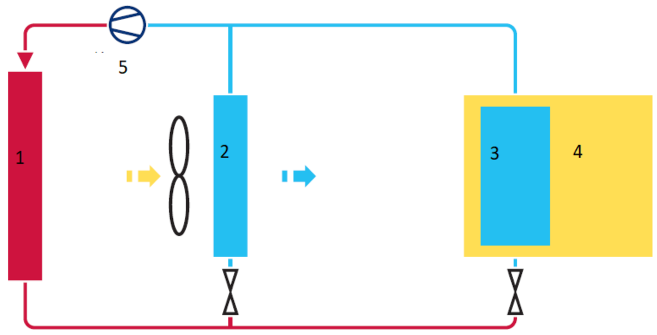
5 -battery

6 - compressor

Method 2

A special evaporator plate located in the battery cell is connected to the vehicle's air conditioning system. The so-called splitting method is used on the high- and low-pressure side through flexible conduits and an expansion valve. In this way, both the vehicle interior evaporator and the battery plate evaporator, which functions like a regular evaporator, are incorporated into one and the same circuit. The different tasks of the two evaporators result in correspondingly different refrigerant flow requirements. While the vehicle interior cooling system must meet the requirements of passengers, the high-voltage battery requires weaker or stronger cooling depending on driving conditions and ambient temperature. These requirements result in the need for complex regulation of the amount of evaporated refrigerant. The special design of the plate evaporator enables the integration of the component with the battery and provides a large heat exchange surface. This ensures that the temperature is kept below the critical value of 40°C. At very low outdoor temperatures, it is necessary to raise the temperature to the ideal value for the battery, which is at least 15°C. However, in this situation the plate evaporator is useless. A cold battery has lower efficiency than a battery at the appropriate temperature, and at very low temperatures below zero degrees it is practically impossible to charge it. In mild hybrid vehicles this is acceptable: in extreme situations the hybrid function is only available to a limited extent. However, driving on a combustion engine is possible. In a purely electric vehicle, it is necessary to heat the battery to enable the vehicle to be started and driven in any situation, even in winter..

1- condenser



2- evaporator

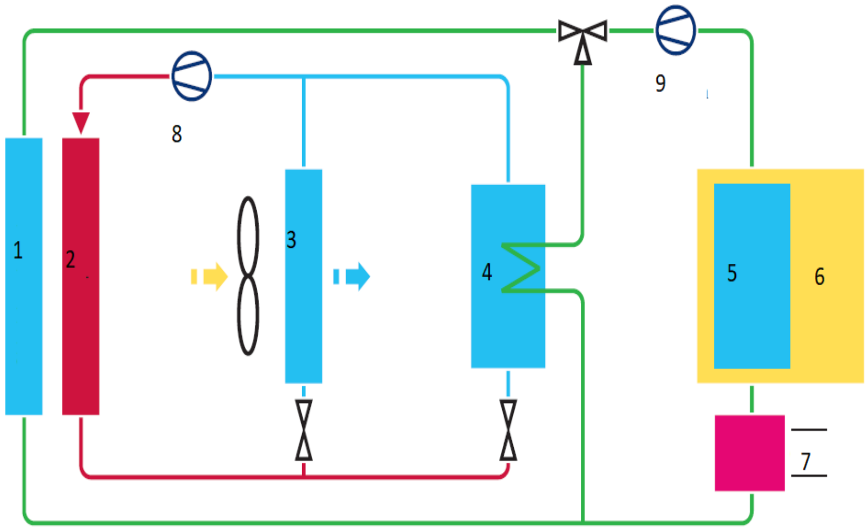
3- plate evaporator

4 – battery

5 – compressor

Method 3

In the case of larger capacity batteries, the correct temperature is of fundamental importance. Therefore, at very low temperatures, additional heating of the battery is required to maintain the temperature in the optimal range. This is the only way to achieve a satisfactory range in electric driving mode. To provide additional heating, the battery is integrated into the secondary circuit. This circuit ensures a constant, ideal operating temperature ranging from 15°C to 30°C. There is an integrated cooling plate in the battery block through which a coolant consisting of a mixture of water and glycol flows (green circuit in the figure). At low temperatures, the coolant can be quickly heated to the ideal temperature by the heating system. If the temperature in the battery increases while using the hybrid functions, the heating is turned off. The coolant can then be cooled by air flow in the battery cooler or low-temperature cooler located at the front of the vehicle. If the cooling power provided by the battery cooler is insufficient at high outside temperatures, the coolant flows through the cooler (chiller). In the refrigerator, the refrigerant from the air conditioning system evaporates. In addition, heat can be transferred from the secondary circuit to the evaporating refrigerant in a very compact manner and with a high-power density. Additional post-cooling of the coolant then occurs. Thanks to the use of a special heat exchanger, the battery can be operated in the optimal temperature range and with optimal efficiency.



1 - battery cooler

2 – condenser

3- evaporator

4- chiller

5- cooling plate

6- battery

7- heating

8 – air conditioning compressor

9- coolant circulation

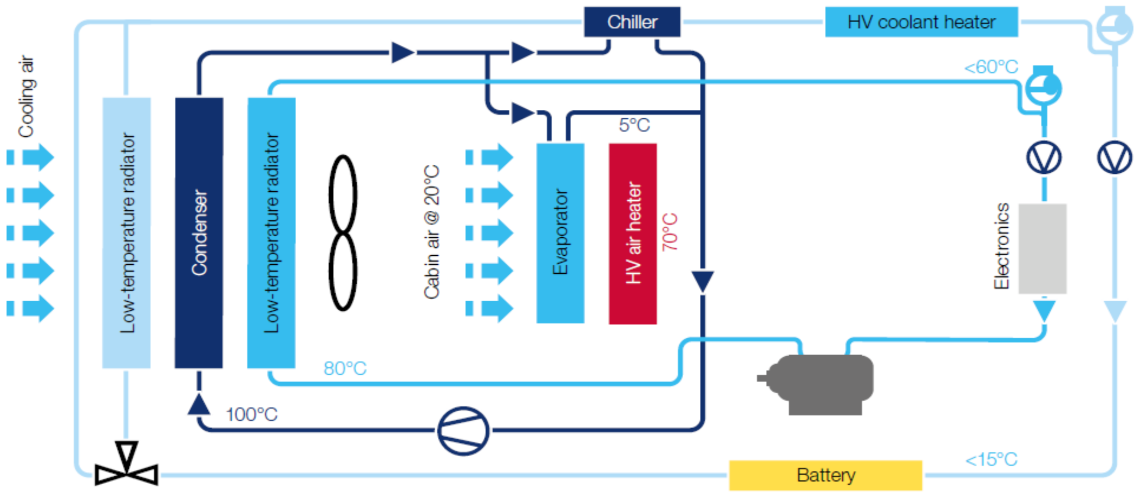
In the graphics above, you can see that there is a relationship between the amount of thermal energy generated and the complexity of the system aimed at maintaining the proper temperature of the batteries. In the simplest solutions, battery cooling is carried out by familiar elements that make up the air conditioning system. Advanced solutions enabling battery temperature control use a chiller, a combination of an evaporator, an expansion valve and a solenoid valve. – explains Grzegorz Jurczuk, technical specialist from MAHLE Polska. – Despite the use of a new element that increases the cost of vehicle production, solutions based on the chiller are extremely efficient and at the same time free from disadvantages, such as insufficient efficiency in various weather conditions, noise generated, or integration of plate evaporators with the battery, which in the event of evaporator failure requires replacing the entire battery module.

Cooling system in electric cars

In the case of fully electric cars, there is a need for even more stringent thermal regulation. In electric cars, the cooling system is divided into two circuits, each of which contains separate low-temperature radiators, a coolant pump, a thermostat and a valve cutting off the flow of coolant. The systems responsible for cooling the engine and battery, as well as the standard functions of the air conditioning system, are integrated through a special chiller.

The high-voltage heater provides sufficient battery temperature control at low outdoor temperatures. In this case, the temperature of the fluid to cool the engine and its accessories (internal circulation in the graphic below) must be less than 60 degrees Celsius. To achieve full performance while ensuring the longest possible life of the battery, engine and accessories, the coolant temperature should always be maintained. battery between approximately 15°C and 30°C. When the temperature becomes too low, the coolant is heated by a high-voltage heater. When the temperature becomes too high, the fluid is cooled by a low-temperature cooler. If this is not enough (e.g. in the middle of a hot summer), a "chiller" integrated in both the coolant circuit and the refrigerant (air conditioning) circuit further reduces the fluid temperature. The air conditioning refrigerant flows through the "chiller" and cools the coolant, which also flows through the chiller (the battery is indirectly cooled by the air conditioning system). All control is carried out using dedicated thermostats, sensors, pumps and valves.

Some electric cars use a passive battery cooling system, an example of this is the first-generation Nissan Leaf. However, keeping in mind that temperature affects the life and performance of batteries, the tendency is to use active cooling systems, for example those based on the previously mentioned "chiller", which is an element connecting the cooling system and the air conditioning system. Depending on the operating conditions of the electricity storage unit, the air conditioning system may reduce the temperature of the mixture of glycol and water cooling the battery

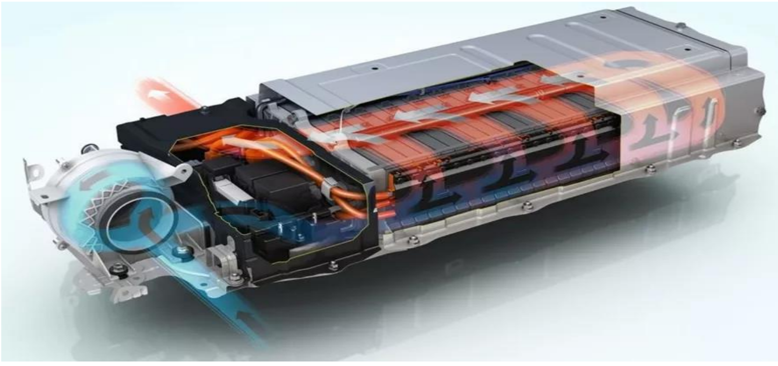


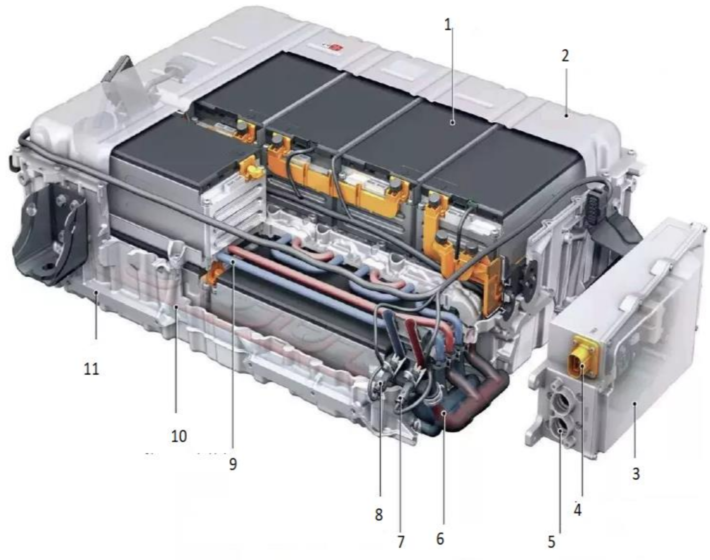
The principle of operation of the system can be seen here

https://www.youtube.com/watch?v=xFb57pG54OI&t=8s

source: https://motofocus.pl/producenci-czesci-i-dystrybutorzy/94449/uklad-chlodzenia-w-samochodach-elektrycznych-i-hybrydowych-jak-to-dziala

Examples of design solutions





1- battery cell module

2- upper body of the battery case

3- junction box

4- charger connector

5- high voltage connector

6- coolant distributor

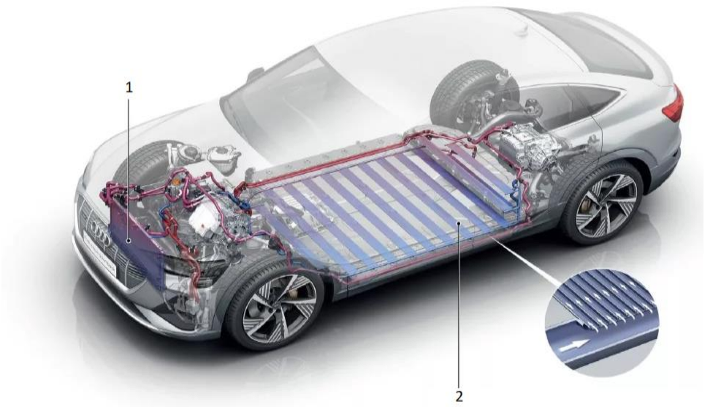
7- cooling inlet temperature sensor

8- cooling output temperature sensor

9- upper cooling pipes

10- lower cooling pipes

11- lower body of the battery case



1- low temperature chiller

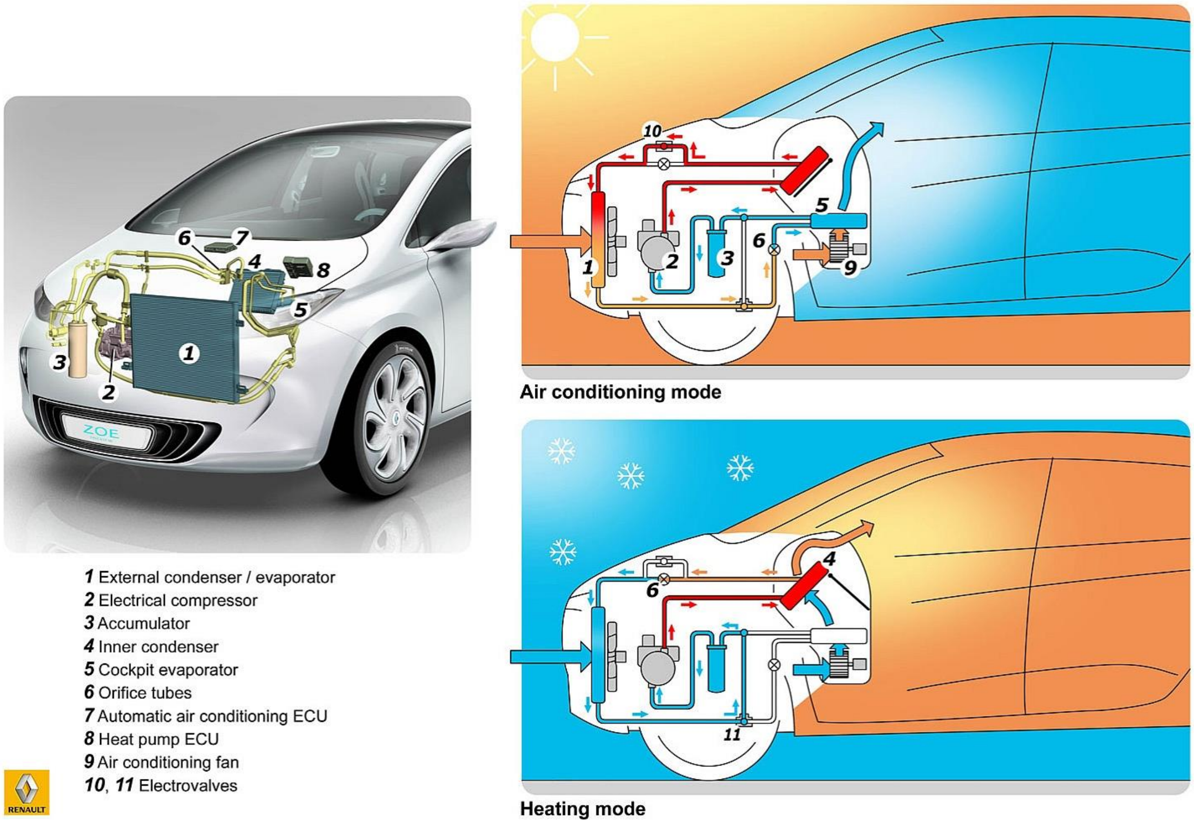
2- battery cooling by extruded aluminum profiles

source : https://autoexpert.pl/artykuly/elektryka-tez-trzeba-chlodzic

Ogrzewanie pojazdu

To ensure adequate comfort, the electric vehicle (the interior of the cabin) must be heated. Vehicle designers use high voltage by installing high-voltage heaters to heat air or coolant. PTC heating elements, i.e. with a positive temperature coefficient of resistance, are used in vehicles. Inside the heater, high voltage current flows through the heating elements, generating heat. Thanks to the positive coefficient, the resistance of the heating elements increases as the temperature increases. The current flow automatically increases, which limits the maximum heating power and reduces the risk of overheating. PTC elements have been used in vehicles for a long time, e.g. mirror heating. The high-voltage PTC heater can be used to heat the cooling liquid or air directly. Placing the heater in the cooling liquid is easy to install, while placing the heater to heat the air requires significant modifications, but is more efficient.

You can also heat the vehicle using the air conditioning system, which works as a heat pump. Reversing the refrigerant circulation.



source: https://elektrowoz.pl/porady/pompa-ciepla-w-samochodzie-elektrycznym-warto-doplacic-czy-nie-sprawdzamy/

Safe operation of electric cars

Without appropriate employee qualifications, car repair shops cannot perform work on hybrid and electric cars. Appropriate qualifications are required in individual countries.

Trained persons: May perform general work on the vehicle not directly related to the high voltage system. These include, for example, bodywork, oil and wheel changes, work on the conventional braking system near the wheel hub motors, work on high-voltage cables in the steering system, on the combustion engine, axles, etc., and work on the electrical installation. Qualifications for working in high-voltage systems in a voltage-free state: Thanks to this qualification, specialists can independently

work in high-voltage systems disconnected from the power supply. This includes, for example, work on switched off high-voltage systems and components and activities in the danger zone.
Qualifications for work on energized high-voltage systems: Activities during which workers may touch high-voltage components or parts with body parts or tools are considered to be work on energized high-voltage systems if a voltage-free condition is not ensured and cannot be exclude electrical hazards. Obtaining qualifications at this level enables a qualified person to work independently and safely in high voltage systems.

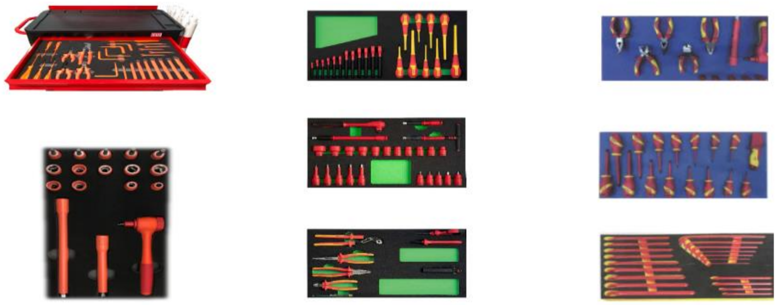
Tools for servicing electric vehicles

When servicing electric vehicles, the workshop station plays a huge role. In addition to the basic equipment, it should be adapted to operate electric and hybrid cars and have workplace instructions, also in the field of high voltage (HV). Safe work requires specialized insulated tools (VDE), appropriate measuring equipment and additional occupational health and safety equipment. All tools should be insulated (VDE). In addition, you should use insulating tapes and mats, as well as DC meters. You also need to ensure access to the sorbent in case of battery leakage. This is important because Lithium-Ion (Li-Ion) batteries contain an organic electrolyte which, if leaked, can be removed by workers with specialized equipment. Compliance with health and safety rules when servicing hybrids is even more important because an error may result in the car catching fire and, in extreme cases, causing severe burns to the mechanic.

Examples of specialized tools

source: https://italcom.com.pl/produkt/walizka-z-narzedziami/

Tool carts



https://italcom.com.pl/produkt/wozki-z-narzedziami/

Occupational health and safety cabinet

source : https://italcom.com.pl/produkt/ochrona-osobista/

https://italcom.com.pl/produkt/ochrona-osobista/

1.3 BATTERY SYSTEM SAFETY.

The safety of lithium-ion batteries has improved significantly since their development in the early 1990s, and each year brings progress in this field. Reduction in size, increasing service life and range, as well as rigorous research and testing aimed at minimizing the risk of fires and implementing new safeguards in this area make the batteries and their operation simply safe. According to the US National Highway Traffic Safety Administration (NHTSA), the three safest cars in the world are electric vehicles.

However, there is a risk of battery damage. Even though they are relatively rare, their spectacular nature and media nature give the impression of a problem on a much larger scale.

https://motopedia.otomoto.pl/_next/image?url=https%3A%2F%2Fapimotopedia.wpengine.com%2F wp-content%2Fuploads%2F2023%2F03%2Fpozar_akumulatora.jpg&w=992&q=95

Battery fire.

A lithium-ion battery consists of many tightly packed cells mounted in a waterproof and fireproof housing. When a single cell fails, the battery practically turns into a small explosive that produces a huge amount of gas and heat (up to 650C) in fractions of a second. An exothermic reaction then occurs, called "thermal runaway", which does not need oxygen from the atmosphere to be maintained. The heat obtained in a single cell is transferred to neighboring cells, causing the fire to spread dynamically.

A single cell that has failed cannot be extinguished. The chemical reaction taking place inside is too fast. The only way to stop the uncontrolled temperature increase is to directly cool the cells on fire.

There is no simple or effective tool to stop an electric car battery fire. Although direct cooling is the best method, the problem is that there is no access to the inside of the battery. Therefore, if the case has not been tampered with, the best solution is to simply wait until the battery burns out. Paying attention to ensure that the fire does not spread to the surrounding area.

An alternative method is to "dump" water onto the faucets for 6 to 8 hours. Providing water for such a long time requires providing it in large quantities (even over 10,000 l). However, it should be remembered that extinguishing a battery is similar to birthday candles - when it seems that they have all been blown out, there will almost always be one that is still smoldering.

It sometimes happens that even after theoretically extinguishing a battery fire, after a short while, a day, a week or a month, the fire breaks out again.

https://motopedia.otomoto.pl/pozar-akumulatora-auta-elektrycznego-jak-do-niego-dochodzi-i-dlaczego-tak-trudno-go-ugasic

Types of battery protection.

To minimize the risk of battery damage, technical solutions are used to protect against failure.

The security system consists of:

Cooling system that protects the battery from overheating.

Reinforced protective casing to prevent mechanical damage.

The firewall separates the battery modules, limits potential damage and protects other vehicle components from ignition.

The high voltage emergency shutdown system reduces the risk of ignition.

A circuit that separates the high voltage (HV) battery voltage from the rest of the vehicle's electrical system when parked significantly increases safety when the vehicle is not in use.

Safety systems in an electric vehicle are active regardless of the state the vehicle is in, i.e. when parked, while driving and while charging the battery. An electric vehicle battery failure is a situation that may be caused by extreme external factors:

Thermal factors.

Extremely low (as low as -15°C) and high (above 45°C) temperatures can have a negative impact on battery performance. Extremely high temperatures may cause undesirable chemical reactions to occur, causing it to overheat. If this results in thermal runaway, there is a risk of fire. In turn, at very low temperatures, the internal resistance of the battery increases, which can cause additional thermal effects, also increasing the chances of a fire occurring. Extreme temperatures alone will never be the sole cause of a BEV fire. Weather anomalies are a factor that slightly increases risk; For a fire to occur, many circumstances must coincide.

Mechanical factors.

Mechanical factors include road accidents. The modern design of lithium-ion cells, as well as the electric cars themselves, especially the integration of cell packages within reinforced vehicle parts, means that in the vast majority of such events, the battery will not be damaged. However, the unpredictability of accident situations creates the risk of mechanical damage, which even a reinforced structure will not adequately protect.

In a sense, mechanical factors include leaks of coolants and electrolytes. Liquid-cooled batteries contain coolant in their cooling system, leakage of which may damage the battery. Adding coolant to a burning cell can further strengthen the flame.

Electrolytes leaking from damaged high-voltage energy storage systems are typically irritating, flammable and potentially corrosive. Liquids leaking from high-voltage energy storage systems are generally coolants.

Electrical abuse.

Lithium-ion batteries are designed to receive and store a specific amount of energy over a specific period of time. Exceeding these limits due to charging or overcharging too quickly may degrade performance or result in premature failure. Internal chemical reactions caused by overcharging can theoretically result in a short circuit and, consequently, a fire. Importantly, in the case of many electric vehicles, "electrical abuse" is not possible at all, as long as their BMS is properly designed and works properly.

Thermal runaway.

A battery fire begins with thermal runaway, a process in which the temperature of lithium-ion cells increases uncontrollably above a certain threshold. This results in a sudden release of flammable gases and excessive heat. A failure involving an uncontrolled increase in temperature is usually accompanied by sparks and the production of large amounts of dark smoke. This process takes place in individual cells, so its potential risk increases when heat spreads, including in the form of fire and an uncontrolled temperature increase throughout the battery. Smoke, consisting of a mixture of flammable and toxic gases, is released from the safety valve or through cracks in the battery coating. Flammable gases may be ignited by nearby sources such as fire, sparks or may even spontaneously ignite due to poor condition of the cooling system. The resulting flame further heats the battery. If the gas release rate from the battery shell is lower than the internal gas production rate, the battery cell may rupture. The safety valve may release some of the accumulated gas that is typically produced during the pre-thermal runaway process, but may not be able to prevent external heating of the cell, for example from flame radiation or a nearby battery burning. If the released gas accumulates in a closed area and mixes with the surrounding oxygen, there is a risk of gas explosion when a source such as a spark and flame occurs.

OPRACOWANIE / Eksperci: Samochody elektryczne nie palą się ani częściej, ani groźniej niż samochody spalinowe 2021 PSPA.COM.PL

Safety of the battery removed from the vehicle.

The threats and ways to protect the battery from damage presented above concerned the situation of a battery installed in a vehicle. The period when the battery functions as an independent element is not taken into account. This mainly applies to a new battery not installed in the vehicle, a battery removed for repair or service purposes and a battery intended for disposal.

Batteries removed from the vehicle after initial assessment while still in the vehicle are transported to a specially equipped station where they are disassembled. From now on, service employees must be especially careful about safety. Batteries are often not discharged. There is a real risk of electric shock with higher voltage than in the socket.

When repairing batteries, for safety reasons, the work is performed by two employees at the same time. These employees must have the knowledge and authorization to open batteries. For safety reasons, everyone says out loud what they are doing at any given moment so that a colleague can react quickly in the event of an emergency. They are dressed in special protective clothing without metal elements, thick gloves and masks.

Authorized Repair Plant of Traction Batteries for Renault Electric and Hybrid Cars in Zabrze.

https://v.wpimg.pl/NmQwOTMzYQwwFTlnYgFsGXNNbT0kWGJPJFV1dmJMfFkpWCk9IR88CCEYYTM_Dz4MJgdhJCFVLx04WDllYh4nHiEbLi1iHyMPNBNgN3pKfFhnRHx5eht2WXxDKzV1Vy9dYUNiNXwcLVs1R3ZnfkJ7Tyw

The battery at the station is connected to the so-called vehicle simulator. This way, you can monitor the effect of the repair on an ongoing basis. The casing is removed with tools adapted to 1000 V.

The next step is to check for electrolyte leaks. The presence of water, corrosion and other leaks indicating a leaky battery are assessed. After detecting a faulty module, it is replaced with a functional one. After being tightly closed, the battery returns to its owner.

Batteries that cannot be reused or repaired are carefully checked and verified for suitability for use outside cars. They can be used in energy storage and other applications. In a situation where battery damage prevents its further use, the battery is recycled. Practice shows that over 90% of all battery components can be recovered and recycled.

The rules for handling batteries are set out in Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC. It specifies, among others: permissible content of mercury and cadmium in batteries.

In 2020, a regulation on batteries and waste batteries was proposed, repealing Directive 2006/66/EC and amending Regulation (EU) No. 2019/1020, modernizing EU legislation in this area in connection with the sustainable and smart mobility strategy, which aims to achieve by 2050, reduce transport-related greenhouse gas emissions by 90%. It sets performance and recycling standards that batteries must meet.

The latest regulations that EU officials are currently working on will include, among others: specify that batteries must be collected from users free of charge. Moreover, according to them, batteries for cars and light vehicles will have to be marked with stickers specifying how burdensome the production process of their cells is to the environment. They will also determine recycled content issues for new batteries. For example, when they come into force, new batteries will have to contain at least 16%. recycled cobalt, 85% recycled lead and 6% each recycled lithium and nickel.

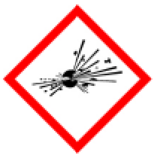
Batteries intended for recycling must be properly stored and secured. It is not necessary to mark them as hazardous materials if they are whole. First of all, the manufacturer's recommendations, general regulations and occupational health and safety regulations should be followed.

It is recommended to use a large metal container for transporting the high-voltage energy storage system or parts thereof when disconnected from the vehicle. Pay attention to the condition of the high-voltage energy storage system (e.g. presence of smoke, noise, sparking, heating) and prepare for the possibility of flooding the metal container. When transporting a lithium-ion battery, additional regulations regarding the transport of hazardous materials apply. Their transport takes place on the basis of a transport document and the driver must have safety instructions. Return transport of damaged high-voltage batteries should be in the original packaging.

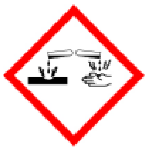
Symbols worth knowing when servicing and repairing electric vehicles.

flammable

poisonous



Danger of explosion



corrosive, irritating to the skin

dangerous to health

dangerous to the environment

Electric vehicle

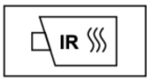
Attention: high voltage

Attention danger (type described next to the symbol)

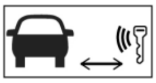
Rinse with plenty of water

LI ION lithium-ion

Dangerous voltage



Use a thermal imaging camera



Remove the key from the car

Safe disconnection and connection of batteries.

To safely disconnect or connect a battery in motor vehicles, follow procedures in accordance with the manufacturer's guidelines. Different vehicles have different technical solutions. The differences concern the location of the elements to be disconnected, their method and marking. Using procedures designed for a specific vehicle allows for professional and trouble-free operation of the electric vehicle.

Sample information from AUTODATA:

Inspection and service

Unless otherwise noted, isolation of high-voltage battery packs or electric vehicle powertrain components is not necessary for routine inspection and maintenance work.

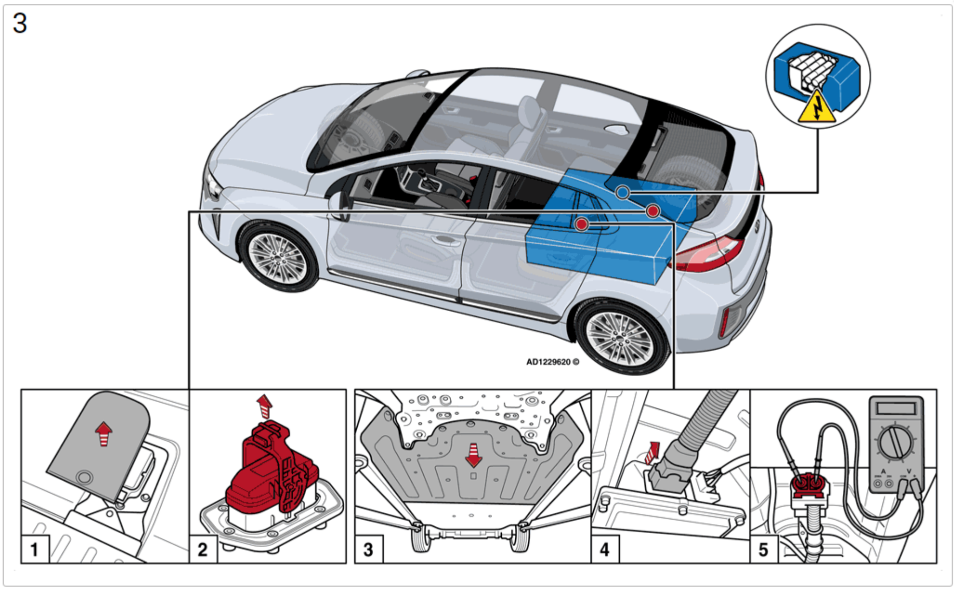
Security measures

When working on high voltage systems and components, the following safety measures must be observed:

- *Personnel working on high-voltage components of an electric vehicle's drive system must be properly trained to perform the necessary activities.*
- *Post high voltage warning signs to ensure the safety of personnel in the workplace.*
- *No high voltage systems or components must be accessible to untrained personnel.*
- *Always wear insulated gloves that comply with applicable local safety standards.*
- *Disconnect the high voltage battery pack.*
- *After disconnecting the high-voltage battery pack and before working on the electric vehicle's drivetrain, the recommended waiting time must have elapsed.*
- *Check whether the residual voltage value is lower than the recommended safety level.*
- *All tools and test equipment must be suitable for use on high voltage circuits.*

Note: For easier identification, the high voltage wiring harness for the electric drive may be covered with orange insulation.

Disconnecting/cutting off the electric drive batteries



- *Turn off the ignition and remove the keys from inside the vehicle.*
- *All electrical devices must be turned off.*

- *Disconnect the vehicle's main battery. See appropriate steps for vehicle main battery.*
- *Remove the trunk floor covering.*
- *Remove the access cover of the device that disconnects the voltage of the electric drive batteries, fig.3.1.*
- *Unlock the device that disconnects the voltage of the electric drive batteries, fig.3.2.*
- *Remove the device that disconnects the voltage of the electric drive batteries fig.3.2.*
- *Wait 5 minutes.*
- *Raise and support the vehicle.*
- *Remove the chassis protective covers to gain access to the inverter harness multi-pin connectors fig3.3.*
- *Disconnect the multi-pin connector of the inverter harness fig3.4.*
- *Before continuing operation, check whether the residual voltage at the inverter terminals is less than 30 V fig3.5.*

Connecting the electric drive batteries:

- *Turn off the ignition and remove the keys from inside the vehicle.*
- *Connect the multi-pin connector of the inverter harness fig3.4.*
- *Install the undercarriage cover fig3.3.*
- *Install a device that disconnects the voltage of the electric drive batteries, fig.3.2.*
- *Install the access cover of the device that disconnects the voltage of the electric drive batteries, fig.3.1.*
- *Install the trunk floor mat.*
- *Connect the vehicle's main battery.*

There are procedures for emergency disconnection of the HV described in the rescue cards. Using these procedures will allow you to cut off the high voltage, but it will not allow you to perform service work or service the vehicle and batteries in a professional manner. The use of an emergency procedure may also affect the durability of individual components. One way to disconnect HV on lifesaving cards is to cut the wires in specific places. This is not recommended for normal operation of an electric vehicle.

The seemingly simple disconnection of the 12V battery may have undesirable effects on the car. The key moment is the opening of the contactors in the high-voltage installation, which disconnects the traction battery from the remaining electrical areas of the vehicle in the SME module that manages the battery operation. These contactors usually open no more than a minute after turning off the car's ignition and are characterized by a quite loud knock coming from under the car. This is important because disconnecting the 12V battery is only allowed after opening the SME module contactors. When they are closed and we disconnect the 12V battery, the so-called hot opening of contactors.

They will open, but only when current flows through the contactors. In a PHEV or EV car, each opening of the contactors is counted by the battery management module. Few people realize that even turning the ignition on and off in the car opens the contactors, and such openings can only be made a limited number of times. If it is exceeded, it is necessary to replace the module. In BMW cars it is 250,000. openings, which means that if you do it 10 times every day, the module will be enough for 25,000. days, i.e. for almost 70 years. Opening the contactors while hot is another matter, as there are only five such openings in BMW cars. After the sixth time, the contactors will no longer close, which means it will not be possible to start the vehicle. Unfortunately, it is similar in cars of other brands.

To ensure that the contactors are open and the 12-volt battery can be disconnected, wait at least two minutes. If a characteristic clicking sound occurred during this time, we can assume that the contactors were opened. However, this does not always happen.

To be 100% sure, connect a multimeter (i.e. electrical meter) to the 12-volt battery and set it to measure voltage. After turning off the ignition, observe the multimeter readings - the voltage will drop. When the contactors open, the voltage will begin to increase to a value equivalent to the 12V battery voltage, and even slightly higher as the battery begins to power individual areas. This is the moment when it can be disconnected safely for the car.

1.4 TOOLS AND EQUIPMENT FOR ELECTRIC VEHICLE TECHNICIANS

Car repair and servicing is the domain of automotive services and the car repair shops that provide them. Cars, regardless of their drive type, require servicing, as repair and maintenance are essential elements of the operation of any technical facility.

Servicing an electric or hybrid car requires performing activities similar to those for a conventional vehicle. (does not apply to servicing the combustion engine in electric vehicles).

| Systems requiring servicing in electric cars:

- cooling system of the power conversion system
- cabin air conditioning system
- drive gear
- braking system
- steering system
- suspension system
- running gear
- electrical systems

A mechanic servicing such vehicles must have appropriate qualifications because, unlike the conventional design of a car with an internal combustion engine, electric and hybrid cars are equipped with high-voltage systems in which the voltage value can reach up to 1000 V. The new environment of high-voltage modules requires workshops (Janowski, 2018):

- ensuring maximum safety for employees
- protecting vehicle components against damage
- protection against warranty liability and liability for incorrect maintenance activities
- having instruments enabling measurements to be carried out in high voltage environments in electric and hybrid vehicles

Janowski M. (2018), Serwisowanie napędów elektrycznych i hybrydowych, WERTHER International Polska Sp. z o.o., https://www.werther.pl/download/obsluga_samochodow_hybrydowych.pdf [dostęp: 28.11.2018]

When servicing electric vehicles, the workshop station plays a huge role. In addition to the basic equipment, it should be adapted to operate electric and hybrid cars and have workplace instructions, also in the field of high voltage (HV). Safe work requires specialized insulated tools (VDE), appropriate measuring equipment and additional occupational health and safety equipment. All tools should be insulated (VDE). In addition, you should use insulating tapes and mats, as well as DC meters. You also need to ensure access to the sorbent in case of battery leakage. This is important because Lithium-Ion

(Li-Ion) batteries contain an organic electrolyte which, if leaked, can be removed by workers with specialized equipment.

(*https://goodonepr.prowly.com/102736-wyzwania-w-serwisowaniu-samochodow-elektrycznych*).

The equipment of a workshop servicing batteries and electric cars can be divided into:

- traditional ones used in the repair of traditional vehicles (they can be used if the vehicle has lost the status of a dangerous vehicle),
- specialized ones used during work without disconnecting the dangerous voltage (repair or service work without disconnecting the high voltage, battery repair after opening the casing).

Personal protection.

The equipment necessary in car workshops serving drivers of hybrid and electric cars includes certified insulating gloves, footwear, an apron, a face shield and respiratory protection. There should be an eyewash station nearby. The personal protective equipment in question must meet the requirements for compliance assessment, which are specified in separate regulations. Personal protective equipment is primarily intended to protect the employee and minimize the risk of bodily injury.

An example set of personal protective equipment:

https://i.st-firmy.net/9qpzgdm/zestaw-ochronny-do-obslugi-samochodow-elektrycznych-real-bhp-artykuly-bhp-i-sprzet-elektroizolacyjny.jpg

A personal protection kit consisting of 6 elements for working on electric and hybrid vehicles, equipped with:

- arc protection suit, antistatic IEC61482-1-2 8.6cal/cm2

- rubber electrical insulating gloves class 0 to 1000V 5kV test standard PN-EN 60903:2006

- protective leather gloves worn over electrical insulating gloves

- electrical insulating mat 750x750 mm. voltage class 2 17000V

- electrical insulating helmet with visor for arc SECRA-1 EN 397, EN 50365 1000V, EN 166, EN 61482-1-2-Box Test

- electrically insulating footwear up to 1000V for professional use PN-EN ISO 20347:2012 OB HRO SRC and PN-EN 50321-1:2018-5 voltage class 0 AC

- electrically insulating footwear, gloves and mat have current voltage test.

- The helmet has a shelf life of 5 years from the date of production

https://real-bhp.firmy.net/zestaw-ochronny-do-obslugi-pojazdow-elektrycznych-1000v,MMDS.html

Eye wash kit with acid and alkali neutralizer.

https://real-bhp.firmy.net/zestaw-do-plukania-oczu-z-neutralizatorem-kwasow-i-zasad,MMSQ.html

Elements of the protection zone and work station.


Plastic fence with rubber bases

https://real-bhp.firmy.net/ogrodzenie-plastikowe-z-podstawami-gumowymi-1106,MMYR.html

 A set of sorbents for chemicals and oils

- a set of sorbent mats intended for use in car zones or vehicles protects against leaks of chemical and oil substances

- The set includes 20 sorption mats, 1 universal sleeve, protective gloves and a waste bag, all packed in a portable bag

- The set is intended for leaks of up to 18 liters of various chemical and oil substances

- ideal for drivers of trucks, delivery vans, forklifts and as a rescue kit for machines and mechanical devices as well as car workshops servicing electric and mechanical vehicles

https://real-bhp.firmy.net/zestaw-sorbentow-na-chemikalia-oraz-oleje-u17,G6CW.html

Specialized tools for 1,000V AC and 1,500V DC

Tools used when servicing electric and hybrid vehicles should have appropriate declarations and certificates. Their condition and cleanliness should be impeccable. Any damage or expiry of the date of approval for use disqualify them from further use.

Sample toolkit:

Set with product number 117.1890 – KS Tools.

Tools should meet the requirements of VDE 0105-100.

https://warsztat.pl/artykuly/bezpieczne-narzedzia-auta-elektryczne-i-hybrydy-w-,71872

Universal measuring and insulation control meters.

The basic meter used during service and repair are voltage controllers. They should meet the requirements in accordance with the standards NR EN 61010-600V cat. 3 and IEC 61243-3 (VAT/DDT)


Two-pole voltage indicator for 1000V LCD Voltage Tester

https://real-bhp.firmy.net/dwubiegunowy-wskaznik-napiecia-do-1000v,MMSP.html

Universal multimeters are also often used. They should have appropriate declarations and certificates. The measurement range, parameters and accuracy of these meters vary, which determines their use in specific situations.

Multifunction LCD digital multimeter

https://real-bhp.firmy.net/wielofunkcyjny-multimetr-cyfrowy-lcd,MMSD.html

Insulation resistance measurement.

A very important parameter for checking the condition of high-voltage electrical installation elements is the measurement of insulation resistance. The condition of insulation has a significant impact on the safety and proper operation of devices. There are many devices on the market intended for this type of measurement. However, not all of them are adapted to vehicle inspections. The control voltage during insulation measurement is determined based on the rated HV voltage of the vehicle.

The minimum requirements are defined according to UNECE Regulation No. 100 and must be between the high voltage busbar and the ground of 500 Ω/V of the rated voltage. It follows that the amount of voltage generated in the measuring device depends on the rated voltage of the high-voltage installation.

Testers and devices needed to service and repair traction batteries.

A separate group of supported systems in electric and hybrid cars are traction batteries. Diagnosis and repairs require the use of specialized instrumentation and reliable measurements. To meet the needs of specialized workshops, companies offer special devices.

Functions of measurement modules:

- potential equalization control,
- measurement of DC voltages at any points, including vehicle mas,
- active measurement of insulation resistance up to 1000 V,
- measurement of insulation resistance in accordance with the SAE J1766 standard,
- quality control of electrical contacts,
- measurement of electrical capacity,
- diode test,
- immediate interruption of the measurement if a fault is detected or the probes are accidentally touched,
- measurement of any voltages (not only relative to body mass),
- software supporting both before and during measurement.
- instrument self-test before each measurement.

Device for measuring the resistance of traction battery modules with functions:

- a DC discharge pulse was applied (current sink),
- measurement of voltage drops,
- the internal resistance of the module/contact between modules is calculated

Device for charging and discharging traction battery modules with functions:

- freely adjustable target voltage,
- individual cell monitoring and conditioning,
- support for modules with analog or digital interface,
- charging up to 80A,
- voltage, class B1, 75V,

A device for checking the tightness of the traction battery housing with functions:

- checking the tightness of the traction battery housing +/- 140 mbar,
- checking cooling circuits for leaks up to 3 bar
- measurements based on pressure drop,
- automated measurement process with integrated pump,

Battery lifts.

Intended for disassembly and installation of batteries in electric and hybrid cars, as well as engines, gearboxes, suspension components and fuel tanks. Their feature is the appropriate shape and dimensions of the transport platform, lifting height and load capacity. The lifts should have a running gear enabling the transport of batteries to other positions.

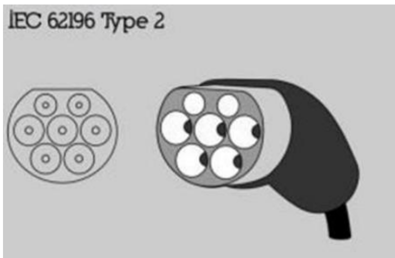
Devices used for computer diagnostics.

The need to read information from controllers, erase errors, program basic settings, perform operation tests, view current parameters, read the so-called frozen frames, switching on appropriate operating modes, the possibility of their configuration, coding and many others require the use of devices compatible with a given vehicle system. Not all electric vehicles have a standard OBD-2 connector. Companies producing electric vehicles limit access to many functions of the vehicle's control system.
The existence of one tester who could perform all possible functions is still a dream.
Car services have full access to the functions of a specific vehicle.
Car testers existing on the market, depending on the type of device, have a larger or smaller range of functions that can be implemented. This often allows for service repairs to be performed in unauthorized workshops. Some testers enable online connection to service servers and perform diagnostic or repair work on a periodic subscription basis or for a unit connection fee.
The choice of tester depends mainly on the type and scope of repairs of electric vehicles and the brand of the vehicle.
Types of connectors and parameters of the electric vehicle charging device.

TYPE 1/ CCS Combo 1

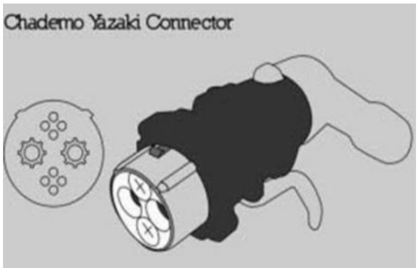
• current: 200 A.
• voltage: 200-600V (direct current).
• power: up to 125 kW.
• most vehicles that are sold on American market, e.g. Nissan Leaf (USA), Chevrolet Volt.

TYPE 2/CSS Combo 2



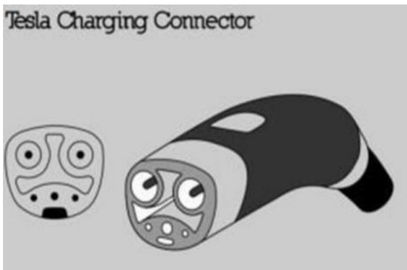
CCS Combo 2 has two additional pins compared to the Type 2 plug.
It is used in very fast chargers, e.g. in Porsche with a power of up to 350 kW.
• current: 63A.
• voltage: 250-400V (direct current).
• power: 22 kW, CCS Combo 2 up to 350 kW.

CHAdeMO/TYPE 4



The CHAdeMO/TYPE 4 connector comes from Asia.
charges with direct current.
• current: 120 A.
• voltage: 500V (direct current).
• Power: up to 60 kW.
Occurs in cars: Nissan Leaf, Kia Soul EV, Mitsubishi i-MiEV, Peugeot Ion, Nissan e-NV200, Mazda Demio EV.

Tesla TYPE



• TESLA connector.
•Current: 12A/80A/100A.
•Voltage: 250V (AC)/ 110V (AC) /480V (DC).
•Power: 1,32 kW/19.26 kW/48 kW.
Telsa S, Tesla X, Tesla Model 3, (american version).

2. LECTURE NOTES

2.1 POTENTIAL RISKS AND CHALLENGES DURING EV REPAIR, HANDLING OR MAINTENANCE.

Transport of electric vehicles

Towing electric cars is very similar to conventional cars with automatic transmission. Manufacturers prohibit towing them, even over a short distance. Electric cars should be transported on a trailer. During transport, carriers should follow the following rules: the vehicle's wheels cannot rotate freely, the car must be pulled in at a speed of less than 5 km/h. When pulling in an electric car, turn on the transport mode and turn off the self-leveling suspension (if the car is equipped with this option).

Safely lifting electric vehicles

When lifting eletric cars, pay attention to the appropriate positioning of the lift legs so that access to the high-voltage battery is possible; you can use jacks that lift the vehicle by the wheels. A battery lift should be used when disassembling and installing a high-voltage battery. Attention should be paid to the large weight of the battery, which may pose not only an electrical but also a mechanical hazard.

Hazards occurring during operation, maintenance and repair of electric vehicles

Electric and hybrid vehicles are equipped with high-voltage electrical installations. As defined in UNECE Regulation No. 100, the term high voltage in vehicles refers to the classification of electrical components or circuits which operate at an operating voltage exceeding 60V and not more than 1500V direct current (DC) or exceeding 30V and not more than 1000V rms current. alternating current (AC). When servicing, maintaining and repairing electric cars, mechanics work with a heavy assembly such as the battery. An electric car battery can weigh up to 700 kg. Which constitutes direct threats related to pressing body parts of people operating electric vehicles. An electric battery can reach high temperatures (the permissible operating temperature for most batteries is 50^0C). When the temperature of the lithium-ion battery reaches 70^0C, a reaction occurs between the electrolyte and the anode in the cell, at a temperature of approximately 1300C the separator begins to melt, which causes an internal short circuit. However, at a temperature of approximately 1500C, the safety valve in the battery opens and flammable gases escape. Black smoke and flames are released.

Security protocol

In the case of electric cars, we have a different service procedure compared to combustion models. Before operating a vehicle equipped with a high-voltage network, an employee authorized to operate high-voltage vehicles must follow the procedure of performing the following steps:

Disconnection of the high voltage system: Turn off the ignition and wait 1 minute.Disconnect the negative pole of the 12V battery.Disconnect the high voltage service switch connector.Wait 10 minutes (or more according to the vehicle's owner's manual).

Protection against accidental switching on of high voltage: Removing the key from the ignition (if present), securing the key.Protection of the service switch against unauthorized access.

Confirmation of the absence of high voltage in the system: Wait the time specified by the manufacturer (time needed to discharge the capacitors).Check the correct operation of voltage measurement devices.The correct operation of the device should be checked in accordance with the recommendations of the measuring device manufacturer. The operation of the device can be checked by testing the voltage of the 12 V battery.Check the lack of voltage at the measuring points (according to the vehicle manual).

No voltage at all points - you can start servicing the vehicle.

Marking the electric vehicle and its surroundings

When servicing electric cars, mark the car and its surroundings appropriately. The environment in which the operated electric vehicle is located should be separated in a visible manner in order to inform third parties that they are prohibited from entering the designated area. The car should be marked with a sign informing about high voltage.

Maintenance of tools and equipment needed to operate, maintain and repair electric vehicles

ELSEC electrically insulating gloves - are five-finger gloves with an anatomical shape, made of high-quality natural latex. Each ELSEC electrical insulating glove has its own individual number and is electrically tested on a computer-controlled measuring station. A report on the tests carried out is attached to each ELSEC electrical insulating glove. The ergonomic shape and flexibility of the ELSEC electrical insulating glove allows you to work freely with anti-sweat inserts and protective leather gloves. ELSEC electrical insulating gloves are intended for use exclusively for electrical purposes as basic personal protective equipment for work at voltages up to 1 kV or as additional protective equipment at voltages higher than 1 kV.

The protective helmet is designed to protect the head against injuries caused by falling objects, and also provides protection against electric shock by preventing the flow of shock current through the head, protection against electric arc and molten metal spatters.

The electrical insulating mat is a means of collective protection. Protects against electric shock when working under voltage. Electrical insulating mats meet the requirements of the IEC 61111:2009 standard. The mats should be used at temperatures of -40°C to +55°C. Avoid contact with concentrated acids and greases. Place the mats on a clean and smooth surface free of sand, gravel, metal particles, etc. When working, place your feet in the center of the mat.

Electrical insulating shoes provide electrical insulating properties that reduce the risk of electric shock, the footwear is made in accordance with the requirements of the PN-EN 50321-1:2018 standard. Each new shoe is subjected to an inspection by the manufacturer - an electrical voltage test using a test voltage of 20 kV.

The evacuation hook is designed to pull a person or their limbs away from a energized device, which makes it possible to initiate an immediate rescue action without having to wait for the device to be disconnected from the voltage.

The evacuation hook is used to pull away limbs (arms or legs) and can be used with devices with a rated voltage of up to 1 kV.

2.2 ELECTRICAL INSTALLATION AND FUNCTIONAL SYSTEM SAFETY.

Electrical short circuit (danger and risk)

When repairing high-voltage systems in electric cars, the greatest threat is not only the risk of electric shock, which results in current flowing through the human body. Although such a situation is very dangerous, it rarely happens because the mechanic would have to make two mistakes at the same time: i.e. touch the positive and negative poles of the battery at the same time. Fortunately, this is difficult to achieve. However, it should be borne in mind that the energy stored in traction batteries poses a very serious risk of electric shock. In addition, traction batteries and the high-voltage installation pose a daily challenge due to the potential occurrence of flash arcs. These are uncontrolled electrical discharges that can lead to dangerous situations and damage. Mechanics must be aware of the potential hazards of arc flash when repairing high-voltage electrical systems. An electric arc most often occurs between two conductive elements with different potentials as a result of short circuits in the electrical installation. The causes of these short circuits may be damage to the wire insulation or human error. An electrical discharge may occur where two electrical wires with a voltage difference exceeding 100 V DC are exposed. The result of the discharge is an arc flash, which is a dangerous phenomenon. It involves the movement of electric current through air between two exposed conductors.

Personal protection

Only a small part of personal protective clothing provides adequate protection against the thermal impact of an electric arc. When performing work related to high-voltage systems in electric vehicles, it is extremely important that employees are provided with specialized clothing and protective equipment that meet stringent safety standards. This is important due to the potential dangers associated with an electric arc explosion. The effects of this phenomenon, such as extreme temperatures, flash and energy emission in the form of heat, light, sound and pressure, may be dangerous to the health and life of employees performing repairs or maintenance of high-voltage systems. This type of protective clothing should meet stringent European standards such as IEC 61482-1-1:2009 or IEC 61482-1-2:2007, which specify requirements for protection against the thermal effects of an electric arc. Such specialized clothing can be easily recognized thanks to the appropriate pictogram placed on the label, next to the assigned value of the clothing's safety level coefficient in relation to the arc, expressed in inches/cm^2. Protective clothing minimizes the risk of burns and other injuries when working with electrical hazards. In addition, mechanics working on high-voltage vehicle systems should be equipped with the following personal protective equipment: protective helmet with a visor - protects against thermal hazards caused by an electric arc and against impacts of molten metal particles, insulating gloves - specialized electrically insulating gloves protect hands and hands against contact with elements under voltage and against the thermal impact of an electric arc, electrically insulating shoes - shoes with appropriate electrical resistance on the soles minimize the risk of shock current flowing through the human body and feet.

Extinguishing electric batteries

The battery ignition process in an electric car is the same. First of all, we need to realize when to put out a fire and when not to. Here, the battery itself can warn about it - just before the explosion, clouds of smoke and a hissing sound begin to emerge, but from the very beginning, the battery catching fire is characterized by gray smoke emerging near the chassis and the previously mentioned hissing sound. A reaction then occurs which will soon cause a fire to break out.

Rules for extinguishing electric cars (batteries)

The following extinguishing agents can be used to extinguish a battery fire: water and extinguishing powders. Small fires can be extinguished with water or using ABC or AB fire extinguishers - maintaining the distance indicated on the extinguisher label as when extinguishing electrical devices. A developed car fire should be extinguished with water, a visible fire in the vehicle battery should be extinguished with water and the manufacturer's instructions should be followed in the rescue card. The effects of extinguishing and cooling the battery should be monitored using a thermal imaging camera or pyrometer. Apply cooling until the surface temperature drops below 50°C and there is no tendency for it to increase further. Monitor the temperature for 30 minutes and repeat cooling if it increases. The use of a container to sink an electric car may only be used in justified cases (when the techniques described above prove ineffective). Do not fill the container with water higher than necessary, i.e. up to the upper edge of the battery. Preventive flooding of the vehicle is not recommended.

Vehicle rescue card

The rescue card presents important information for emergency services. It marks key areas of the vehicle, such as the reinforced bodywork, the location of the high-voltage cable, the location and number of safety airbags and seat belt tensioners (which may explode during a collision).

Identification and familiarization with the operating systems of an electric vehicle

Series-produced vehicles should be built to ensure the electrical safety of high-voltage systems. To this end, they should protect against electric shock during normal use and ensure the safe use of the vehicle. During maintenance (e.g. when washing the vehicle) and operation, the high voltage system cannot pose a risk to the driver and operating staff, provided that everything works properly. This also applies to situations in which the high-voltage plug connectors are disconnected (unintentionally by an unauthorized person). In order to meet electrical safety requirements during normal use of high-voltage vehicles, manufacturers make the plug connectors and insulation of this system in such a way that contact does not pose an electrical hazard. The systems are equipped with an insulation resistance monitoring system and a circuit continuity monitoring system. The systems recognize damaged insulation and loose plug connections and automatically deactivate the high-voltage system if necessary. Electrical safety must also be maintained in the event of a road accident. If the collision sensor detects an impact (airbags are activated), the high-voltage system will turn off. In the event of an accident caused by the high-voltage system, there should be no threat to passengers and rescuers. When the ignition is turned on or the 12V battery is disconnected, the high voltage system turns off. In addition, high voltage systems have a so-called service switch, which must be disconnected before starting all maintenance activities.

High-voltage installation of an electric car

The high-voltage system controller is powered by the on-board network voltage and is turned on and off by the electric ignition switch. The high-voltage controller is networked to the vehicle's traditional systems and critical high-voltage components. Part of the data exchange takes place via a data bus. Thanks to the received signals, the high-voltage system controller implements an appropriate operating strategy, e.g. determines when the electric machine operates as an electric motor and when as a generator. For this purpose, the controller primarily uses information received from the high-voltage battery controller, engine controller and braking system. The battery charge level and the current driving condition are the basis for determining the intensity of electricity produced by the electric machine when operating as a generator and the power to drive the vehicle in the electric motor mode.

Construction of high voltage networks

A traditional 12 V network uses ground as a second wire. The car body cannot constitute a negative polarity due to high voltages and the associated risk of electric shock and the use of the body as a ground for a 12 V installation (technically it is not possible to use the same cable for a network with two different voltages).

Therefore, a two-wire IT type installation is used. All cables have double insulation and are protected against voltage polarization change. They are orange in color. The cables are terminated with special connectors that eliminate the possibility of accidental connection. The advantage of this solution is high resistance to failure. This means that if an error (insulation damage) occurs in one polarization or phase (in one place) in the network, the system can continue to operate. There is no danger of a network short circuit provided that all other insulation is functional.

Onboard resistance monitoring

The on-board resistance monitoring system is called IMD and detects insulation faults by measuring residual currents. For this purpose, it measures the insulation resistance between high-voltage components and the vehicle body at regular intervals. The IMD module detects the resistance between the various high voltage phases and the body by applying a measurement voltage. This allows you to determine whether the insulation is still safe enough. According to UNECE Regulation No. 100, which specifies technical requirements for the propulsion of road vehicles, if the high-voltage AC buses and the high-voltage DC buses are insulated from each other, the insulation resistance between the high-voltage bus and the electrical mass must be at least 100 Ω/V voltage operating voltage for DC buses and at least 500 Ω/V for AC pad buses. If the AC high-voltage buses and the DC high-voltage buses are galvanically connected, the electrical resistance must be 100 Ω/V operating voltage.

Connector disconnection signaling monitors proper connection of high-voltage cables to eliminate electrical hazards due to accidental disconnection of high-voltage contacts of active high-voltage systems. For this purpose, the system is equipped with a safety pilot cable. It is powered by a 12V mains cable running in series from one connector to the other. If the wire circuit is disconnected in one of the pilot contact plug connectors, the high voltage system controller will recognize this. Then the high voltage controller will open the high voltage relay and turn off the high voltage. Pilot contacts are present in all important plug connectors, including the main switch.

A potential equalization system in the on-board high-voltage network is necessary

for reliable powering of mass-produced high-voltage vehicles. In electrical installations, protection against electric shock in the event of a failure and failure to trip the emergency stop of the high voltage system by the insulation monitoring system is of fundamental importance.

Regenerative braking system

In electric cars, supported by a vacuum actuator, the vacuum must be generated by an electric pump. The vacuum pump is powered by 12 V

from the on-board network. In order for the pump to produce the appropriate vacuum, the braking system is equipped with an appropriate sensor that measures the pressure in the brake master cylinder. Depending on the pressure level, the pump is switched on or pumped out. Instead of a vacuum brake pump, manufacturers are increasingly using an electromechanical brake pump with electrical assistance. They contain a dual-circuit tandem brake pump, a brake pedal sensor, an electronic controller and an electric motor with a gear that generates and transmits braking assistance. The electric motor then supports the driver's foot pressure on the brake pedal, replacing the classic vacuum device.

Cooling and heating system

Lithium-ion and nickel-hydroxide batteries should be operated at a specific temperature to maintain optimal power and durability. The core temperature of a lithium-ion battery cell should not exceed 400C. If this limit is exceeded for a long time, the battery will age quickly. This applies to nickel-hydroxide batteries, which are slightly less sensitive to heat and can reach temperatures of 50^0C. Both types of batteries have the feature that at negative temperatures their ability to discharge and charge decreases. Manufacturers state that the readiness for operation is at a temperature of -15^0C or even -20^0C. Battery cells warm up automatically while drawing and storing electricity. Moreover, if necessary, in countries with a cold climate, manufacturers use battery heating during longer stops, e.g. using an electric heater in the battery cooling circuit. Unlike heating the battery, it is necessary to cool it. It's not only about its operation at high external temperatures, but also about the battery's automatic heating during operation and charging. Especially short-term high current loads causing cells to heat up. Various cooling methods are used to avoid battery overheating. In the first, theoretically simplest system, air is sucked in from the air-conditioned interior of the vehicle and used to cool the battery. The cool air sucked in from inside the vehicle has a temperature below 40°C. This air flows around the freely accessible surfaces of the battery. In the second option, a special evaporator plate located in the battery cell is connected to the vehicle's air conditioning system. The so-called splitting method is used on the high- and low-pressure side through flexible conduits and an expansion valve. In this way, both the vehicle interior evaporator and the battery plate evaporator, which functions like a regular evaporator, are incorporated into one and the same circuit. The different tasks of the two evaporators result in correspondingly different refrigerant flow requirements. In the third case, used in larger capacity batteries, the correct temperature is of fundamental importance. Therefore, at very low temperatures, additional heating of the battery is required to maintain the temperature in the optimal range. This is the only way to achieve a satisfactory range in electric driving mode. To provide additional heating, the battery is integrated into the secondary circuit. This circuit ensures a constant, ideal operating temperature ranging from 15°C to 30°C.

2.3 BATTERY SYSTEM SAFETY.

Types of battery protection.

To protect the batteries against conditions that could cause them to be damaged, the vehicle is equipped with a number of solutions that protect it against failure. A battery cooling system is used to prevent excessive temperature increases. Air cooling systems (simpler and cheaper) or liquid cooling systems (more efficient, more difficult to use) are used. An important element of the security system is a strong casing that protects against mechanical damage and ensures appropriate structural stiffness. A mechanically created firewall separates modules and other vehicle components from each other and limits potential losses. Cutting off the high voltage outside the vehicle reduces the risk of losses in other vehicle components. A similar role is played by the high voltage disconnection system when the vehicle is parked.

External factors affecting the risk of battery damage

There are external factors that damage batteries. Their existence does not depend on the technical condition of the vehicle or its structure. When exposed to high temperatures, your vehicle's battery may lose its ability to cool properly. An excessive increase in temperature may trigger a number of reactions that initiate a fire. Another danger with unpredictable consequences is mechanical damage. Their impact on battery components is not predictable and depends, among others, on: on the magnitude, direction, time and direction of mechanical factors. Mechanical damage may include coolant leaks. Electrolytes leaking from damaged high-voltage energy storage systems are typically irritating, flammable and potentially corrosive. Excessive current loads that may arise when charging the battery should not occur if the BMS module is functioning properly. A damaged or missing BMS can cause excessive currents to flow, causing a dangerous temperature increase. A battery fire begins with thermal runaway, a process in which the temperature of lithium-ion cells increases uncontrollably above a certain threshold. This results in a sudden release of flammable gases and excessive heat. A failure involving an uncontrolled increase in temperature is usually accompanied by sparks and the production of large amounts of dark smoke. This process takes place in individual cells, so its potential risk increases when heat spreads, also in the form of fire and uncontrolled temperature increase throughout the battery.

Safety of the battery removed from the vehicle

Batteries removed from the vehicle, after initial assessment while still in the vehicle, are transported to a specially equipped station where they are disassembled. Service workers must pay special attention to safety. Batteries are often not discharged. There is a real risk of electric shock. When repairing batteries, for safety reasons, the work is performed by two employees at the same time. It is recommended to use a large metal container for transporting the high-voltage energy storage system or parts thereof when disconnected from the vehicle. Pay attention to the condition of the high-voltage energy storage system (e.g. presence of smoke, noise, sparking, heating) and prepare for the possibility of flooding the metal container. The rules for handling batteries are specified in the directives of the European Parliament.

Markings for servicing and repairing electric vehicles

Graphic information and warning signs are used during service, repair and operation. They constitute an important element of the security system. Persons involved in work with electric vehicles and batteries must be familiar with these markings.

Safe disconnection and connection of batteries.

To safely disconnect or connect high-voltage components, you must know and follow procedures in accordance with the guidelines and recommendations provided by the manufacturer. Not all vehicles have identical technical solutions. Using procedures designed for a specific vehicle allows for professional and trouble-free operation of the electric vehicle. Existing HV emergency disconnection procedures described in rescue cards do not guarantee that some vehicle components will not be damaged. Using these procedures will allow you to cut off the high voltage, but it will not allow you to perform service work or service the vehicle and batteries in a professional manner. An employee who knows the features of the system and its control can professionally disconnect the HV and 12V batteries without a service manual, but must perform a number of measurements. This requires professional knowledge and experience.

2.4 TOOLS AND EQUIPMENT FOR ELECTRIC VEHICLE TECHNICIANS.

Car repair and servicing is the domain of automotive services and the car repair shops that provide them. Cars, regardless of their drive type, require servicing, as repair and maintenance are essential elements of the operation of any technical facility. Servicing an electric or hybrid car requires performing activities similar to those for a conventional vehicle. (does not apply to servicing the combustion engine in electric vehicles).

Systems requiring servicing in electric cars: cooling system of the power conversion system, cabin air conditioning system, drive transmission, braking system, steering system, suspension system, running gear, electrical systems.

Tools used when servicing hybrid and electric vehicles

When servicing electric vehicles, the workshop station plays a huge role. In addition to the basic equipment, it should be adapted to operate electric and hybrid cars and have workplace instructions, also in the field of high voltage (HV). Safe work requires specialized insulated tools (VDE), appropriate measuring equipment and additional occupational health and safety equipment. All tools should be insulated (VDE). In addition, you should use insulating tapes and mats, as well as DC meters. You also need to ensure access to the sorbent in case of battery leakage. This is important because Lithium-Ion (Li-Ion) batteries contain an organic electrolyte which, if leaked, can be removed by workers with specialized equipment.

The environment of high-voltage modules requires workshops to: ensure maximum safety for employees, protect vehicle components against damage, protect against warranty liability and liability for incorrect maintenance activities, and have instruments allowing for measurements in the high-voltage environment in electric and hybrid vehicles.

The equipment of a workshop servicing batteries and electric cars can be divided into: traditional ones used in the repair of traditional vehicles (they can be used if the vehicle has lost the status of a dangerous vehicle), specialized ones used during work without disconnecting the dangerous voltage (repair or service work without disconnecting the high voltage, battery repair after opening the casing).

Personal protective equipment for an employee at a service station for hybrid and electric vehicles.

The equipment necessary in car workshops serving drivers of hybrid and electric cars includes certified insulating gloves, footwear, an apron, a face shield and respiratory protection. There should be an eyewash station nearby. The personal protective equipment in question must meet the requirements for compliance assessment, which are specified in separate regulations. Personal protective equipment is primarily intended to protect the employee and minimize the risk of bodily injury.

Equipment for servicing and repairing electric vehicles

An electric vehicle service station should be able to set up a barrier separating this station from the rest. It may be, for example, a plastic fence with rubber bases. A set of sorbents for chemicals and oils should also be available. Tools used when servicing electric and hybrid vehicles should have appropriate declarations and certificates. Their condition and cleanliness should be impeccable. Any damage or expiry of the date of approval for use disqualify them from further use.

Universal measuring and insulation control meters.

The basic meter used during service and repair are voltage controllers. They should meet the requirements in accordance with the standards NR EN 61010-600V cat. 3 and IEC 61243-3 (VAT/DDT).

Universal multimeters are also often used. They should have appropriate declarations and certificates. The measurement range, parameters and accuracy of these meters vary, which determines their use in specific situations.

A very important parameter for checking the condition of high-voltage electrical installation elements is the measurement of insulation resistance. The condition of insulation has a significant impact on the safety and proper operation of devices. There are many devices on the market intended for this type of measurement. However, not all of them are adapted to vehicle inspections. The control voltage during insulation measurement is determined based on the rated HV voltage of the vehicle. The minimum requirements are defined according to UNECE Regulation No. 100 and must be between the high voltage busbar and the ground of 500 Ω/V of the rated voltage. It follows that the amount of voltage generated in the measuring device depends on the rated voltage of the high-voltage installation

Specialized devices for servicing batteries

A separate group of supported systems in electric and hybrid cars are traction batteries. Diagnosis and repairs require the use of specialized instrumentation and reliable measurements. To meet the needs of specialized workshops, companies offer special devices.

Measuring modules with functions such as: potential equalization control, measurement of DC voltages at any points, including vehicle mass, active measurement of insulation resistance up to 1000 V, measurement of insulation resistance in accordance with the SAE J1766 standard, quality control of electrical contacts, measurement of electrical capacitance, diode test , immediate interruption of the measurement in the event of detecting a fault or accidentally touching the probes, measurement of any voltages (not only in relation to the body mass), supporting software before and during the measurement, self-test of the device before each measurement.

A device for measuring the resistance of traction battery modules with the following functions: a DC discharge impulse is used (current sink), measurement of voltage drops, internal resistance of the module/contact between modules is calculated.

Device for charging and discharging traction battery modules with functions: freely adjustable target voltage, individual cell monitoring and conditioning, support for modules with analog or digital interface, charging up to 80A, voltage, class B1, 75V.

Device for checking the tightness of the traction battery housing with functions: checking the tightness of the traction battery housing +/- 140 mbar, checking cooling circuits for leaks up to 3 bar, measurements based on pressure drop, automated measurement process with an integrated pump.

Devices used for computer diagnostics.

The need to read information from controllers, erase errors, program basic settings, perform operation tests, view current parameters, read the so-called frozen frames, switching on appropriate operating modes, the possibility of their configuration, coding and many others require the use of devices compatible with a given vehicle system. Not all electric vehicles have a standard OBD-2 connector. Companies producing electric vehicles limit access to many functions of the vehicle's control system.

The existence of one tester who could perform all possible functions is still a dream.

Car services have full access to the functions of a specific vehicle.

Car testers existing on the market, depending on the type of device, have a larger or smaller range of functions that can be implemented. This often allows for service repairs to be performed in unauthorized workshops. Some testers enable online connection to service servers and perform diagnostic or repair work on a periodic subscription basis or for a unit connection fee. The selection of a tester depends mainly on the type and scope of repairs of electric vehicles and the brand of the vehicle.

Types of connectors and parameters of the electric vehicle charging device.

There are several types of connections for charging electric vehicles. The standard in Europe is the Type 2 socket.

3. QUESTIONS AND ANSWERS

1. Why should a vehicle carrier be able to distinguish an electric vehicle from a car powered by a traditional combustion engine?

Electric cars have different transport and lifting requirements. Standard guidelines must be followed and additional rules related to the presence of a high voltage system and the design of the drive system (the electric motor is constantly mechanically connected to the vehicle's wheels) must be met. The high voltage of electricity in a high voltage circuit can be turned off by following the appropriate procedure. This activity should be performed by a person with appropriate qualifications. Please remember that the traction battery, after applying the high voltage deactivation procedure, is still an electrical source with high voltage DC.

Electric cars have a large electric battery that is usually part of the chassis, so please follow these steps when lifting electric vehicles

with the vehicle's technical manual so as not to damage the battery housing.

2. List the identifying features that can be used to determine that the car has an electric drive.

An electric car has the following features:

- ✓ characteristic markings on external body elements or "green license plates" (in Poland);
- ✓ markings on the plastic engine cover (under the hood);
- ✓ charging socket or sockets, which may be located in different places depending on the manufacturer and model;
- ✓ orange covers of components, especially high voltage cables;
- ✓ no exhaust pipe – in fully electric vehicles;
- ✓ markings on the dashboard indicating the activity of the electrical power system;
- ✓ no fuel level indicator – in fully electric vehicles;
- ✓ QR code, VIN number or other types of markings used by car manufacturers.

3. When do we consider an electrical circuit to be high voltage? How high voltage affects the human body?

As defined in UNECE Regulation No. 100, the term high voltage in vehicles refers to the classification of electrical components or circuits which operate at an operating voltage exceeding 60V and not more than 1500V direct current (DC) or exceeding 30V and not more than 1000V rms current. alternating current (AC). The occurrence of high voltages and the flow of current when contact occurs may cause: values of 5mA - cause tingling, 10mA - cause spasms, difficulties in putting down tools, 50mA - cause ventricular fibrillation, apnea and 80mA - cause fatal threats. The flow of current may be accompanied by: the occurrence of an electric arc (burns, eyesight), the occurrence of poisonous vapours (risk to the respiratory tract), secondary threats such as cuts, limb injuries, etc.

4. Explain why, the person switching off the high voltage circuit should do so in accordance with the vehicle manufacturer's procedure?

Deactivation of the high voltage circuit is an activity that must be performed in a manner strictly specified by the manufacturer. This affects the safety of the person performing this activity and the people operating the vehicle. The correct procedure ensures the safety of people operating the electric vehicle and ensures that parts of the vehicle system are not damaged.

General developed procedures for all vehicles are intended for emergency services. They are intended to protect people and the surroundings against high voltage electric shock. These procedures do not protect system components from damage.

5. Explain how the suitability of protective gloves is checked and what the purpose of such testing is?

Protective gloves have an expiration date. They can be used within a specified period of time, but before each use they must be checked for damage. The check involves inflating the gloves with air, e.g. with your mouth, and checking whether the air does not escape. This way we check whether the gloves are tight, any mechanical damage is a place where an electric arc can flow. The expiration date of the gloves is marked on the outer upper part.

6. Is an electric car safe because it has high voltage?

For safety reasons, a car powered by an electric engine is designed to ensure the safety of users and persons servicing the vehicle. The high voltage system is active if the conditions are met:

4. a 12V battery is connected to the car's installation,
5. the ignition is on,
6. the service switch or service plug of the high voltage system is turned on,
7. insulation of high-voltage system components and cables is efficient,
8. all plug connections are functional,
9. the collision sensor cannot signal a collision (no airbag can be activated).

7. What is a vehicle rescue card and what information does it contain?

The vehicle rescue card presents important information for emergency services. It indicates key areas of the vehicle, such as reinforcement points in the body, where the high-voltage cable is located, the location and number of safety airbags and seat belt tensioners (which may explode during a collision).

8. Discuss the protection of high-voltage cables.

The high voltage circuit is a two-wire IT network. All wires have double insulation and are protected against changing voltage polarity. They are orange. The cables are terminated with special connectors that eliminate the possibility of accidental connection. The high-voltage system is equipped with an on-board resistance monitoring system called IMD, which detects insulation damage by measuring residual currents. The system is equipped with a pilot safety cable. It is powered by a 12V mains cable running in series from one connector to the other. If the wire circuit is disconnected in one of the pilot pin connectors, the high voltage system controller recognizes this and deactivates the high voltage.

The high-voltage installation has a potential equalization system. In the event of damage to the insulation of wires of live high-voltage network elements, the risk of electrocution to vehicle passengers or employees is minimal thanks to potential equalization using a protective equipotential bonding, which enables equalization of different voltage levels between high-voltage elements and the body.

9. Explain the differences between the design of the braking system of an electric car and a car powered by an internal combustion engine.

Electric cars do not have an air intake system, so they cannot use the negative pressure that powers the servo. Therefore, these vehicles are equipped with vacuum pumps powered by electricity, or an electric system is used to support the brake pump.

The braking system of electric cars enables energy recuperation during braking. When the braking deceleration is below 3.5 m/s2, the electric motor works as a generator, receiving the vehicle's kinematic energy and charging the high-voltage battery.

10. Why should a traction battery be cooled?

High voltage battery should not exceed the specified temperature. The ideal battery temperature is between 15°C and 30°C. Reaching a temperature above 50°C causes its degradation. The battery becomes warm during operation and charging. Fast charging (with high DC current) has a negative impact on the battery. Exceeding a sufficiently high temperature causes irreversible changes in battery cells and may lead to fire. When the temperature of the lithium-ion battery reaches 70^0C, a reaction occurs between the electrolyte and the anode in the cell, at a temperature of approximately 130^0C the separator begins to melt, which causes an internal short circuit. However, at a temperature of approximately 150^0C, the safety valve in the battery opens and flammable gases escape.

11. Discuss the mechanism of threat formation during the so-called “electrical abuse”

Lithium-ion batteries are designed to receive and store a specific amount of energy over a specific period of time. Exceeding these limits due to charging or overcharging too quickly may degrade performance or result in premature failure. Internal chemical reactions caused by overcharging can theoretically result in a short circuit and, consequently, a fire. Importantly, in the case of many electric vehicles, "electrical abuse" is not possible at all, as long as their BMS is properly designed and works properly.

12. Why is it recommended that at least two people be involved when disassembling (repairing) a high-voltage battery?

When repairing batteries, for safety reasons, the work is performed by two employees at the same time. These employees must have the knowledge and authorization to open batteries. For safety reasons, everyone says out loud what they are doing at any given moment so that a colleague can react quickly in the event of an emergency. They are dressed in special protective clothing without metal elements, thick gloves and masks.

13. Why is it important to equalize the cell charge level during battery repair?

The cells in a battery are connected in series and parallel. It is very important that all cells connected in series have the same degree of charge. A cell less charged than the others in the series will run out of charge earlier during operation (discharge too much) and limit the flow of current. A cell charged more than the others will reach its state of charge earlier during charging and will also limit the current flow. Both situations are detrimental to the overall battery capacity. This step is important when replacing modules. The controller may not allow the battery to start if the charge difference is too large.

14. How is it recommended to transport damaged or used batteries?

It is recommended to use a large metal container for transporting the high-voltage energy storage system or parts thereof when disconnected from the vehicle. Pay attention to the condition of the high-voltage energy storage system (e.g. presence of smoke, noise, sparking, heating) and prepare for the possibility of flooding the metal container. When transporting a lithium-ion battery, additional regulations regarding the transport of hazardous materials apply. Their transport takes place on the basis of a transport document and the driver must have safety instructions. Return transport of damaged high-voltage batteries should be in the original packaging.

15. What requirements should tools and measuring devices for live repairs meet?

Tools and measuring devices used for repairs under voltage should be approved for this type of activities and have appropriate certificates and approvals. Their expiration date should not be exceeded. It is important that their technical condition does not raise any doubts. It should be clean and without mechanical damage. The housing and covers should be complete and functional. Cables and connection terminals cannot be repaired. Measuring and control devices should have a measuring range appropriate to the values of the parameters being tested. Device documentation should be available.

4. CASE STUDIES

4.1 CASE STUDY 1

Loading and transport protocol for electric cars involved in collisions and road accidents.

Background

A roadside assistance company is preparing to transport electric cars involved in road collisions and accidents. The aim is to develop a protocol of conduct when providing towing services for electric vehicles.

Scenario:

The Service Provider recognizes the rules developed by rescue services (fire brigade) regarding procedures during rescue operations involving electric cars. Intends to develop protocols (rules) to be followed by employees called to remove a car involved in a collision or road accident.

Analysis:

Highlight the need to develop rules of conduct when loading and transporting electric cars involved in road accidents. Emphasize the need for specialized employee training to safely operate electric cars. Disconnecting the high-voltage system and procedures for determining whether the high-voltage battery has not been damaged and rules of conduct when symptoms of battery damage occur (increase in battery temperature).

Discuss the rules for transporting and loading a disabled car onto a tow truck that has not been involved in a collision or accident.

Discuss the rules for recognizing an electric car if the service provider does not obtain information about the car involved in the incident.

Discuss the principles of disconnecting the high-voltage system and checking whether the high-voltage system has disconnected automatically via the collision sensor.

Discuss the rules for dealing with a vehicle handed over to rescue services with a deactivated high voltage system.

Discuss the rules for dealing with a vehicle with symptoms of high-voltage battery damage.

Discuss the rules for storing (parking) vehicles with a damaged high-voltage battery.

Recommendations:

The transport service provider establishes a safety protocol for loading and transporting disabled electric cars and cars involved in a road accident. Highlights safety rules for high voltage systems and high voltage batteries. It includes specialist training for employees in the field of high voltage and electric cars to ensure their safety and the safety of the entire environment.

4.2 CASE STUDY 2

Protocol for the use and maintenance of the personal protective equipment system in a car service.

Background

A company dealing in the repair and maintenance of passenger cars is expanding its services to include electric cars. The aim is to develop a protocol for the use of personal protective equipment against high voltage shock.

Scenario:

The Service Provider recognizes the rules developed by electric vehicle manufacturers specifying how to deactivate the high voltage system. The aim of the activities is to develop a uniform protocol regarding the use and storage of personal protective equipment. Intends to develop and implement uniform instructions for the use, maintenance and storage of protective equipment used when operating, maintaining and repairing electric cars.

Analysis:

Emphasize the need to develop rules for the use, maintenance and storage of personal protective equipment. Emphasize the need to use protective equipment in accordance with its instructions. Emphasize the need to select appropriate protective equipment to protect the health and life of mechanics.

Discuss the principles of selecting protective equipment for the scope of work performed related to the operation, maintenance and repair of electric cars.

Discuss the rules for checking protective equipment before using it.

Discuss the rules for storing protective equipment.

Discuss the principles of maintenance and inspection of protective equipment.

Discuss the principles of marking faulty control measures and their disposal.

Recommendations:

The car service develops protocols regarding the rules of use and the selection of protective equipment

from electric shock. Specifies the work in which personal protective equipment protecting against electric shock must be used. Provides people operating electric cars with specialized training in the field of electrical qualifications and operation of electric cars, in order to perform repairs in a safe manner and in accordance with the requirements of the vehicle manufacturer.

5. MULTIPLE CHOICE QUESTIONS (FOR THE ENTIRE MODULE)

TEST 1

Multiple choice test. Only one answer is correct.

11. Towing an electric car is:

A) allowed,

B) allowed for short distance,

C) prohibited.

12. hat features should a workshop lift have for lifting electric cars?

A) allow the car to be lifted by the wheels,

B) have a lifting capacity of up to 1,000 kg, because electric cars are lighter than cars with an internal combustion engine,

C) should be made of plastic to isolate the vehicle from the ground

13. The car battery lift should provide lifting capacity:

A) at least 50 kg,

B) at least 100 kg,

C) at least 500kg.

14. We can recognize an electric car by:

A) external dimensions, these are always small class A and B vehicles

B) lack of exhaust silencer,

C) having a camera observing the surroundings, it is an autonomous vehicle

15. High voltage cables are in:

A) green color

B) orange color

C) black color

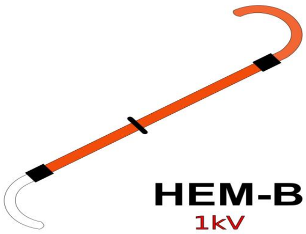
16. Procedure for connecting high voltage in electric cars:

A) is the same in all cars,

B) depends on the solution of the vehicle model,

C) disconnect the battery from the drive system by disconnecting the high-voltage cable connecting the batteries with the electric motor.

17. The figure shows:



A) rescue hook

B) electrical insulating mat

C) assembly pole

8. High voltage installation is an installation with a voltage of:

A) above 24V DC

B) above 24V AC

C) above 60V DC

9. In most vehicles, the high voltage installation is deactivated by:

A) disconnecting the 12 V battery,

B) starting to charge the vehicle's battery,

C) stopping the vehicle and applying the parking brake.

10. The permissible operating temperature of most electric car batteries is:
A) 70^0C

B) 50^0C

C) 130^0C

Answers

1	2	3	4	5	6	7	8	9	10
C	A	C	B	B	B	A	C	A	B

MODULE 5

EV WORKPLACE SAFETY

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1 LECTURE NOTES

1.1 POTENTIAL RISKS AND CHALLENGES DURING EV REPAIR, HANDLING OR MAINTENANCE.

Transport of electric vehicles

Towing electric cars is very similar to conventional cars with automatic transmission. Manufacturers prohibit towing them, even over a short distance. Electric cars should be transported on a trailer. During transport, carriers should follow the following rules: the vehicle's wheels cannot rotate freely, the car must be pulled in at a speed of less than 5 km/h. When pulling in an electric car, turn on the transport mode and turn off the self-leveling suspension (if the car is equipped with this option).

Safely lifting electric vehicles

When lifting electric cars, pay attention to the appropriate positioning of the lift legs so that access to the high-voltage battery is possible; you can use jacks that lift the vehicle by the wheels. A battery lift should be used when disassembling and installing a high-voltage battery. Attention should be paid to the large weight of the battery, which may pose not only an electrical but also a mechanical hazard.

Hazards occurring during operation, maintenance, and repair of electric vehicles

Electric and hybrid vehicles are equipped with high-voltage electrical installations. As defined in UNECE Regulation No. 100, the term high voltage in vehicles refers to the classification of electrical components or circuits which operate at an operating voltage exceeding 60V and not more than 1500V direct current (DC) or exceeding 30V and not more than 1000V rms alternating current (AC). When servicing, maintaining, and repairing electric cars, mechanics work with a heavy assembly such as the battery. An electric car battery can weigh up to 700 kg which constitutes direct threats related to pressing body parts of people operating electric vehicles. An electric battery can reach high temperatures (the permissible operating temperature for most batteries is 50^0C). When the temperature of the lithium-ion battery reaches 70^0C, a reaction occurs between the electrolyte and the anode in the cell, at a temperature of approximately 1300C the separator begins to melt, which causes an internal short circuit. However, at a temperature of approximately 1500C, the safety valve in the battery opens and flammable gases escape. Black smoke and flames are released.

Security protocol

In the case of electric cars, we have a different service procedure compared to combustion models. Before operating a vehicle equipped with a high-voltage network, an employee authorised to operate high-voltage vehicles must follow the procedure of performing the following steps:

Disconnection of the high voltage system: Turn off the ignition and wait 1 minute. Disconnect the negative pole of the 12V battery. Disconnect the high voltage service switch connector. Wait 10 minutes (or more according to the vehicle's owner's manual).

Protection against accidental switching on of high voltage: Removing the key from the ignition (if present), securing the key. Protection of the service switch against unauthorised access.

Confirmation of the absence of high voltage in the system: Wait for the time specified by the manufacturer (time needed to discharge the capacitors). Check the correct operation of voltage measurement devices. The correct operation of the device should be checked in accordance with the recommendations of the measuring device manufacturer. The operation of the device can be checked by testing the voltage of the 12 V battery. Check the lack of voltage at the measuring points (according to the vehicle manual).

No voltage at all points - you can start servicing the vehicle.

Marking the electric vehicle and its surroundings

When servicing electric cars, mark the car and its surroundings appropriately. The environment in which the operated electric vehicle is located should be separated in a visible manner in order to inform third parties that they are prohibited from entering the designated area. The car should be marked with a sign informing about high voltage.

Maintenance of tools and equipment needed to operate, maintain, and repair electric vehicles.

ELSEC electrically insulating gloves are five-finger gloves with an anatomical shape, made of high-quality natural latex. Each ELSEC electrical insulating glove has its own individual number and is electrically tested on a computer-controlled measuring station. A report on the tests carried out is attached to each ELSEC electrical insulating glove. The ergonomic shape and flexibility of the ELSEC electrical insulating glove allows you to work freely with anti-sweat inserts and protective leather gloves. ELSEC electrical insulating gloves are intended for use exclusively for electrical purposes as basic personal protective equipment for work at voltages up to 1 kV or as additional protective equipment at voltages higher than 1 kV.

The protective helmet is designed to protect the head against injuries caused by falling objects, and also provides protection against electric shock by preventing the flow of shock current through the head, protection against electric arc and molten metal spatters.

The electrical insulating mat is a means of collective protection. It protects against electric shock when working under voltage. Electrical insulating mats meet the requirements of the IEC 61111:2009 standard. The mats should be used at temperatures of -40°C to +55°C. Avoid contact with concentrated acids and greases. Place the mats on a clean and smooth surface free of sand, gravel, metal particles, etc. When working, place your feet in the center of the mat.

Electrical insulating shoes provide electrical insulating properties that reduce the risk of electric shock. The footwear is made in accordance with the requirements of the PN-EN 50321-1:2018 standard. Each new shoe is subjected to an inspection by the manufacturer - an electrical voltage test using a test voltage of 20 kV.

The evacuation hook is designed to pull a person or their limbs away from an energised device, which makes it possible to initiate an immediate rescue action without having to wait for the device to be disconnected from the voltage.

The evacuation hook is used to pull away limbs (arms or legs) and can be used with devices with a rated voltage of up to 1 kV.

1.2 ELECTRICAL INSTALLATION AND FUNCTIONAL SYSTEM SAFETY

Electrical short circuit (danger and risk)

When repairing high-voltage systems in electric cars, the greatest threat is not only the risk of electric shock, which results in current flowing through the human body. Although such a situation is very dangerous, it rarely happens because the mechanic would have to make two mistakes at the same time: i.e. touch the positive and negative poles of the battery at the same time. Fortunately, this is difficult to achieve. However, it should be borne in mind that the energy stored in traction batteries poses a very serious risk of electric shock. In addition, traction batteries and the high-voltage installation pose a daily challenge due to the potential occurrence of flash arcs. These are uncontrolled electrical discharges that can lead to dangerous situations and damage. Mechanics must be aware of the potential hazards of arc flash when repairing high-voltage electrical systems. An electric arc most often occurs between two conductive elements with different potentials as a result of short circuits in the electrical installation. The causes of these short circuits may be damage to the wire insulation or human error. An electrical discharge may occur where two electrical wires with a voltage difference exceeding 100 V DC are exposed. The result of the discharge is an arc flash, which is a dangerous phenomenon. It involves the movement of electric current through air between two exposed conductors.

Personal protection

Only a small part of personal protective clothing provides adequate protection against the thermal impact of an electric arc. When performing work related to high-voltage systems in electric vehicles, it is extremely important that employees are provided with specialised clothing and protective equipment that meet stringent safety standards. This is important due to the potential dangers associated with an electric arc explosion. The effects of this phenomenon, such as extreme temperatures, flash, and energy emission in the form of heat, light, sound and pressure, may be dangerous to the health and life of employees performing repairs or maintenance of high-voltage systems. This type of protective clothing should meet stringent European standards such as IEC 61482-1-1:2009 or IEC 61482-1-2:2007, which specify requirements for protection against the thermal effects of an electric arc. Such specialised clothing can be easily recognised thanks to the appropriate pictogram placed on the label, next to the assigned value of the clothing's safety level coefficient in relation to the arc, expressed in inches/cm^2. Protective clothing minimises the risk of burns and other injuries when working with electrical hazards. In addition, mechanics working on high-voltage vehicle systems should be equipped with the following personal protective equipment: protective helmet with a visor - protects against thermal hazards caused by an electric arc and against impacts of molten metal particles, insulating gloves - specialised electrically insulating gloves protect hands and hands against contact with elements under voltage and against the thermal impact of an electric arc, electrically insulating shoes - shoes with appropriate electrical resistance on the soles minimise the risk of shock current flowing through the human body and feet.

Extinguishing electric batteries

The battery ignition process in an electric car is the same. First of all, we need to realise when to put out a fire and when not to. Here, the battery itself can warn about it - just before the explosion, clouds of smoke and a hissing sound begin to emerge, but from the very beginning, the battery catching fire is characterised by gray smoke emerging near the chassis and the previously mentioned hissing sound. A reaction then occurs which will soon cause a fire to break out.

Rules for extinguishing electric cars (batteries)

The following extinguishing agents can be used to extinguish a battery fire: water and extinguishing powders. Small fires can be extinguished with water or using ABC or AB fire extinguishers - maintaining the distance indicated on the extinguisher label as when extinguishing electrical devices. A developed car fire should be extinguished with water, a visible fire in the vehicle battery should be extinguished with water and the manufacturer's instructions in the rescue card should be followed. The effects of extinguishing and cooling the battery should be monitored using a thermal imaging camera or pyrometer. Apply cooling until the surface temperature drops below 50°C and there is no tendency for it to increase further. Monitor the temperature for 30 minutes and repeat cooling if it increases. The use of a container to sink an electric car may only be used in justified cases (when the techniques described above prove ineffective). Do not fill the container with water higher than necessary, i.e. up to the upper edge of the battery. Preventive flooding of the vehicle is not recommended.

Vehicle rescue card

The rescue card presents important information for emergency services. It marks key areas of the vehicle, such as the reinforced bodywork, the location of the high-voltage cable, the location and number of safety airbags and seat belt tensioners (which may explode during a collision).

Identification and familiarisation with the operating systems of an electric vehicle

Series-produced vehicles should be built to ensure the electrical safety of high-voltage systems. To this end, they should protect against electric shock during normal use and ensure the safe use of the vehicle. During maintenance (e.g. when washing the vehicle) and operation, the high voltage system cannot pose a risk to the driver and operating staff, provided that everything works properly. This also applies to situations in which the high voltage plug connectors are disconnected (unintentionally by an unauthorised person). In order to meet electrical safety requirements during normal use of high-voltage vehicles, manufacturers make the plug connectors and insulation of this system in such a way that contact does not pose an electrical hazard. The systems are equipped with an insulation resistance monitoring system and a circuit continuity monitoring system. The systems recognise damaged insulation and loose plug connections and automatically deactivate the high-voltage system if necessary. Electrical safety must also be maintained in the event of a road accident. If the collision sensor detects an impact (airbags are activated), the high-voltage system will turn off. In the event of an accident caused by the high voltage system, there should be no threat to passengers and rescuers. When the ignition is turned on or the 12V battery is disconnected, the high voltage system turns off. In addition, high voltage systems have a so-called service switch, which must be disconnected before starting all maintenance activities.

High voltage installation of an electric car

The high voltage system controller is powered by the on-board network voltage and is turned on and off by the electric ignition switch. The high voltage controller is networked to the vehicle's traditional systems and critical high voltage components. Part of the data exchange takes place via a data bus. Thanks to the received signals, the high voltage system controller implements an appropriate operating strategy, e.g. determines when the electric machine operates as an electric motor and when as a generator. For this purpose, the controller primarily uses information received from the high-voltage battery controller, engine controller and braking system. The battery charge level and the current driving condition are the basis for determining the intensity of electricity produced by the electric machine when operating as a generator and the power to drive the vehicle in the electric motor mode.

Construction of high voltage networks

A traditional 12 V network uses ground as a second wire. The car body cannot constitute a negative polarity due to high voltages and the associated risk of electric shock and the use of the body as a ground for a 12 V installation (technically it is not possible to use the same cable for a network with two different voltages).

Therefore, a two-wire IT type installation is used. All cables have double insulation and are protected against voltage polarisation change. They are orange in color. The cables are terminated with special connectors that eliminate the possibility of accidental connection. The advantage of this solution is high resistance to failure. This means that if an error (insulation damage) occurs in one polarisation or phase (in one place) in the network, the system can continue to operate. There is no danger of a network short circuit provided that all other insulation is functional.

Onboard resistance monitoring

The on-board resistance monitoring system is called IMD and detects insulation faults by measuring residual currents. For this purpose, it measures the insulation resistance between high voltage components and the vehicle body at regular intervals. The IMD module detects the resistance between the various high voltage phases and the body by applying a measurement voltage. This allows you to determine whether the insulation is still safe enough. According to UNECE Regulation No. 100, which specifies technical requirements for the propulsion of road vehicles, if the high-voltage AC buses and the high voltage DC buses are insulated from each other, the insulation resistance between the high voltage bus and the electrical mass must be at least 100 Ω/V voltage operating voltage for DC buses and at least 500 Ω/V for AC pad buses. If the AC high voltage buses and the DC high voltage buses are galvanically connected, the electrical resistance must be 100 Ω/V operating voltage.

Connector disconnection signaling monitors proper connection of high voltage cables to eliminate electrical hazards due to accidental disconnection of high voltage contacts of active high voltage systems. For this purpose, the system is equipped with a safety pilot cable. It is powered by a 12V mains cable running in series from one connector to the other. If the wire circuit is disconnected in one of the pilot contact plug connectors, the high voltage system controller will recognise this. Then the high voltage controller will open the high voltage relay and turn off the high voltage. Pilot contacts are present in all important plug connectors, including the main switch.

A potential equalisation system in the on-board high voltage network is necessary for reliable powering of mass-produced high-voltage vehicles. In electrical installations, protection against electric shock in the event of a failure and failure to trip the emergency stop of the high voltage system by the insulation monitoring system is of fundamental importance.

Regenerative braking system

In electric cars, supported by a vacuum actuator, the vacuum must be generated by an electric pump. The vacuum pump is powered by 12 V from the on-board network. In order for the pump to produce the appropriate vacuum, the braking system is equipped with an appropriate sensor that measures the pressure in the brake master cylinder. Depending on the pressure level, the pump is switched on or pumped out. Instead of a vacuum brake pump, manufacturers are increasingly using an electromechanical brake pump with electrical assistance. They contain a dual-circuit tandem brake pump, a brake pedal sensor, an electronic controller, and an electric motor with a gear that generates and transmits braking assistance. The electric motor then supports the driver's foot pressure on the brake pedal, replacing the classic vacuum device.

Cooling and heating system

Lithium-ion and nickel-hydroxide batteries should be operated at a specific temperature to maintain optimal power and durability. The core temperature of a lithium-ion battery cell should not exceed 400C. If this limit is exceeded for a long time, the battery will age quickly. This applies to nickel-hydroxide batteries, which are slightly less sensitive to heat and can reach temperatures of 50^0C. Both types of batteries have the feature that at negative temperatures their ability to discharge and charge decreases. Manufacturers state that the readiness for operation is at a temperature of -15^0C or even -20^0C. Battery cells warm up automatically while drawing and storing electricity. Moreover, if necessary, in countries with a cold climate, manufacturers use battery heating during longer stops, e.g. using an electric heater in the battery cooling circuit. Unlike heating the battery, it is necessary to cool it. It's not only about its operation at high external temperatures, but also about the battery's automatic heating during operation and charging. Especially short-term high current loads causing cells to heat up. Various cooling methods are used to avoid battery overheating. In the first, theoretically simplest system, air is sucked in from the air-conditioned interior of the vehicle and used to cool the battery. The cool air sucked in from inside the vehicle has a temperature below 40°C. This air flows around the freely accessible surfaces of the battery. In the second option, a special evaporator plate located in the battery cell is connected to the vehicle's air conditioning system. The so-called splitting method is used on the high- and low-pressure side through flexible conduits and an expansion valve. In this way, both the vehicle interior evaporator and the battery plate evaporator, which functions like a regular evaporator, are incorporated into one and the same circuit. The different tasks of the two evaporators result in correspondingly different refrigerant flow requirements. In the third case, used in larger capacity batteries, the correct temperature is of fundamental importance. Therefore, at very low temperatures, additional heating of the battery is required to maintain the temperature in the optimal range. This is the only way to achieve a satisfactory range in electric driving mode. To provide additional heating, the battery is integrated into the secondary circuit. This circuit ensures a constant, ideal operating temperature ranging from 15°C to 30°C.

1.3 BATTERY SYSTEM SAFETY

Types of battery protection

To protect the batteries against conditions that could cause them to be damaged, the vehicle is equipped with a number of solutions that protect it against failure. A battery cooling system is used to prevent excessive temperature increases. Air cooling systems (simpler and cheaper) or liquid cooling systems (more efficient, more difficult to use) are used. An important element of the security system is a strong casing that protects against mechanical damage and ensures appropriate structural stiffness. A mechanically created firewall separates modules and other vehicle components from each other and limits potential losses. Cutting off the high voltage outside the vehicle reduces the risk of losses in other vehicle components. A similar role is played by the high voltage disconnection system when the vehicle is parked.

External factors affecting the risk of battery damage

There are external factors that damage batteries. Their existence does not depend on the technical condition of the vehicle or its structure. When exposed to high temperatures, your vehicle's battery may lose its ability to cool properly. An excessive increase in temperature may trigger a number of reactions that initiate a fire. Another danger with unpredictable consequences is mechanical damage. Their impact on battery components is not predictable and depends, among others, on the magnitude, direction, time, and direction of mechanical factors. Mechanical damage may include coolant leaks. Electrolytes leaking from damaged high voltage energy storage systems are typically irritating, flammable and potentially corrosive. Excessive current loads that may arise when charging the battery should not occur if the BMS module is functioning properly. A damaged or missing BMS can cause excessive currents to flow, causing a dangerous temperature increase. A battery fire begins with thermal runaway, a process in which the temperature of lithium-ion cells increases uncontrollably above a certain threshold. This results in a sudden release of flammable gases and excessive heat. A failure involving an uncontrolled increase in temperature is usually accompanied by sparks and the production of large amounts of dark smoke. This process takes place in individual cells, so its potential risk increases when heat spreads, also in the form of fire and uncontrolled temperature increase throughout the battery.

Safety of the battery removed from the vehicle

Batteries removed from the vehicle, after initial assessment while still in the vehicle, are transported to a specially equipped station where they are disassembled. Service workers must pay special attention to safety. Batteries are often not discharged. There is a real risk of electric shock. When repairing batteries, for safety reasons, the work is performed by two employees at the same time. It is recommended to use a large metal container for transporting the high-voltage energy storage system or parts thereof when disconnected from the vehicle. Pay attention to the condition of the high-voltage energy storage system (e.g. presence of smoke, noise, sparking, heating) and prepare for the possibility of flooding the metal container. The rules for handling batteries are specified in the directives of the European Parliament.

Markings for servicing and repairing electric vehicles

Graphic information and warning signs are used during service, repair, and operation. They constitute an important element of the security system. Persons involved in work with electric vehicles and batteries must be familiar with these markings.

Safe disconnection and connection of batteries.

To safely disconnect or connect high voltage components, you must know and follow procedures in accordance with the guidelines and recommendations provided by the manufacturer. Not all vehicles have identical technical solutions. Using procedures designed for a specific vehicle allows for professional and trouble-free operation of the electric vehicle. Existing HV emergency disconnection procedures described in rescue cards do not guarantee that some vehicle components will not be damaged. Using these procedures will allow you to cut off the high voltage, but it will not allow you to perform service work or service the vehicle and batteries in a professional manner. An employee who knows the features of the system and its control can professionally disconnect the HV and 12V batteries without a service manual but must perform a number of measurements. This requires professional knowledge and experience.

1.4 TOOLS AND EQUIPMENT FOR ELECTRIC VEHICLE TECHNICIANS.

Car repair and servicing is the domain of automotive services, and the car repair shops that provide them. Cars, regardless of their drive type, require servicing, as repair and maintenance are essential elements of the operation of any technical facility. Servicing an electric or hybrid car requires performing activities similar to those for a conventional vehicle (does not apply to servicing the combustion engine in electric vehicles).

Systems requiring servicing in electric cars: cooling system of the power conversion system, cabin air conditioning system, drive transmission, braking system, steering system, suspension system, running gear, electrical systems.

Tools used when servicing hybrid and electric vehicles

When servicing electric vehicles, the workshop station plays a huge role. In addition to the basic equipment, it should be adapted to operate electric and hybrid cars and have workplace instructions, also in the field of high voltage (HV). Safe work requires specialised insulated tools (VDE), appropriate measuring equipment and additional occupational health and safety equipment. All tools should be insulated (VDE). In addition, you should use insulating tapes and mats, as well as DC meters. You also need to ensure access to the sorbent in case of battery leakage. This is important because Lithium-Ion (Li-Ion) batteries contain an organic electrolyte which, if leaked, can be removed by workers with specialized equipment.

The environment of high-voltage modules requires workshops to ensure maximum safety for employees, protect vehicle components against damage, protect against warranty liability and liability for incorrect maintenance activities, and have instruments allowing for measurements in the high-voltage environment in electric and hybrid vehicles.

The equipment of a workshop servicing batteries and electric cars can be divided into the following:

- traditional ones used in the repair of traditional vehicles (they can be used if the vehicle has lost the status of a dangerous vehicle),
- specialised ones used during work without disconnecting the dangerous voltage (repair or service work without disconnecting the high voltage, battery repair after opening the casing).

Personal protective equipment for an employee at a service station for hybrid and electric vehicles

The equipment necessary in car workshops serving drivers of hybrid and electric cars includes certified insulating gloves, footwear, an apron, a face shield, and respiratory protection. There should be an eyewash station nearby. The personal protective equipment in question must meet the requirements for compliance assessment, which are specified in separate regulations. Personal protective equipment is primarily intended to protect the employee and minimise the risk of bodily injury.

Equipment for servicing and repairing electric vehicles

An electric vehicle service station should be able to set up a barrier separating this station from the rest. It may be, for example, a plastic fence with rubber bases. A set of sorbents for chemicals and oils should also be available. Tools used when servicing electric and hybrid vehicles should have appropriate declarations and certificates. Their condition and cleanliness should be impeccable. Any damage or expiry of the date of approval for use disqualify them from further use.

Universal measuring and insulation control meters.

The basic meter used during service and repair are voltage controllers. They should meet the requirements in accordance with the standards NR EN 61010-600V cat. 3 and IEC 61243-3 (VAT/DDT).

Universal multimeters are also often used. They should have appropriate declarations and certificates. The measurement range, parameters and accuracy of these meters vary which determines their use in specific situations.

A very important parameter for checking the condition of high-voltage electrical installation elements is the measurement of insulation resistance. The condition of insulation has a significant impact on the safety and proper operation of devices. There are many devices on the market intended for this type of measurement. However, not all of them are adapted to vehicle inspections. The control voltage during insulation measurement is determined based on the rated HV voltage of the vehicle. The minimum requirements are defined according to UNECE Regulation No. 100 and must be between the high voltage busbar and the ground of 500 Ω/V of the rated voltage. It follows that the amount of voltage generated in the measuring device depends on the rated voltage of the high voltage installation.

Specialised devices for servicing batteries

A separate group of supported systems in electric and hybrid cars are traction batteries. Diagnosis and repairs require the use of specialised instrumentation and reliable measurements. To meet the needs of specialised workshops, companies offer special devices.

Measuring modules with functions such as: potential equalisation control, measurement of DC voltages at any points, including vehicle mass, active measurement of insulation resistance up to 1000 V, measurement of insulation resistance in accordance with the SAE J1766 standard, quality control of electrical contacts, measurement of electrical capacitance, diode test , immediate interruption of the measurement in the event of detecting a fault or accidentally touching the probes, measurement of any voltages (not only in relation to the body mass), supporting software before and during the measurement, self-test of the device before each measurement.

A device for measuring the resistance of traction battery modules with the following functions: a DC discharge impulse is used (current sink), measurement of voltage drops, internal resistance of the module/contact between modules is calculated.

Device for charging and discharging traction battery modules with functions: freely adjustable target voltage, individual cell monitoring and conditioning, support for modules with analogue or digital interface, charging up to 80A, voltage, class B1, 75V.

Device for checking the tightness of the traction battery housing with functions: checking the tightness of the traction battery housing +/- 140 mbar, checking cooling circuits for leaks up to 3 bar, measurements based on pressure drop, automated measurement process with an integrated pump.

Devices used for computer diagnostics

The need to read information from controllers, erase errors, program basic settings, perform operation tests, view current parameters, read the so-called frozen frames, switching on appropriate operating modes, the possibility of their configuration, coding and many others require the use of devices compatible with a given vehicle system. Not all electric vehicles have a standard OBD-2 connector. Companies producing electric vehicles limit access to many functions of the vehicle's control system.

The existence of one tester who could perform all possible functions is still a dream.

Car services have full access to the functions of a specific vehicle. Car testers existing on the market, depending on the type of device, have a larger or smaller range of functions that can be implemented. This often allows for service repairs to be performed in unauthorised workshops. Some testers enable online connection to service servers and perform diagnostic or repair work on a periodic subscription basis or for a unit connection fee. The selection of a tester depends mainly on the type and scope of repairs of electric vehicles and the brand of the vehicle.

Types of connectors and parameters of the electric vehicle charging device.

There are several types of connections for charging electric vehicles. The standard in Europe is the Type 2 socket.

M5
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Presentation Flow

LEARNING UNITS

- 5.1 Potential risks and challenges during EV repair, handling or maintenance
- 5.2 Electrical installation and functional system safety
- 5.3 Battery system safety
- 5.4 Tools and Equipment for Electric Vehicle Technicians

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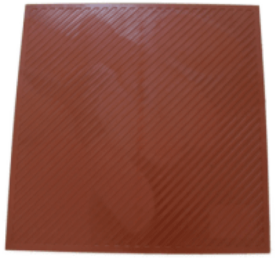
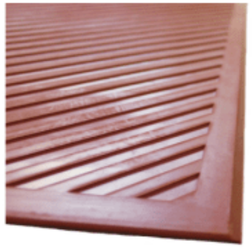
The aim of this module is to equip the student with the necessary knowledge, skills and competences in the safe operation, maintenance and repair of electric cars. The student will be able to safely mark the car and workplace. In addition to the risks associated with maintaining and repairing electric and hybrid vehicles. The learner will be able to select appropriate personal protective equipment and tools needed to maintain and repair the vehicle. The student will learn the impact of electric current on the human body.





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Learning Unit 1: Potential risks and challenges during EV repair, handling or maintenance

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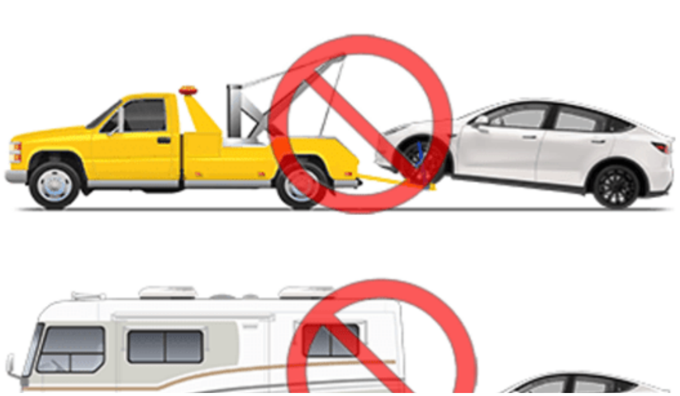
Transportation of electric vehicles

Towing electric cars is very similar to conventional cars with automatic transmission. Manufacturers prohibit towing them, even over a short distance.



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Safely lifting electric vehicles

Electric cars are usually much heavier than typical cars with combustion engines. They also have a completely (or almost completely) flat floor. There are lithium-ion batteries under the passenger compartment of the car, with a cooling and heating system (using a glycol-based fluid).

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Features of the lift for electric cars

- Should allow the lift arms to lift the car by the wheels, this is to ensure adequate access to the batteries, which are placed flat in the floor of the car.
- Should allow cars to be lifted by the chassis to enable repairs to the suspension, steering or braking system.
- Should offer appropriate stabilisation of the vehicle on the lift, with level differences greater than 10 - 15 mm.
- Some lifts use asymmetric arms with columns designed in such a way that they allow easy entry and exit from the car.
- The standard lifting capacity for passenger cars is usually from 3.2 to 3.5 tons.

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EVTECH

Battery lift

When working on the disassembly and assembly of electric car batteries, a battery lift is needed. This is due to the weight of the battery. The weight of electric car batteries is several hundred kilograms. The flat working surface of the lift is designed to support the battery so that the battery is not damaged.

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The principles of lifting electric cars are presented in the video

https://www.youtube.com/watch?v=K9BR0fYt7LI&t=127s

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EVTECH

Using the technical manual for electric vehicles

The vehicle's technical manual contains information that defines the rules for the transport and parking of vehicles involved in collisions and road accidents.

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EVTECH

Main identifying features

Characteristic markings on external body elements or "green license plates" (in Poland)

Markings on the plastic engine cover (under the hood).

Charging socket or sockets, which may be located in different places depending on the manufacturer

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EVTECH

Main identifying features

Orange covers for components, especially high voltage cables

No exhaust pipe – in fully electric vehicles

Dashboard markings indicating electrical power system activity.

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EVTECH

Main identifying features

No fuel level indicator – in fully electric vehicles

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EVTECH

Main identifying features

QR code, VIN number or other types of markings used by car manufacturers

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EVTECH

Potential risks and challenges during EV repair, handling or maintenance

High electrical voltage

An operating voltage exceeding 60 V and not more than 1500 V direct current (DC) or exceeding 30 V and not more than 1000 V effective alternating current (AC).

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EVTECH

Potential risks and challenges during EV repair, handling or maintenance

Mechanical hazards

An electric car battery can weigh up to 700 kg. It constitutes direct threats related to pressing body parts of people operating electric vehicles.

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Potential risks and challenges during EV repair, handling or maintenance

Thermal hazards

The electric battery can reach high temperatures (the allowable operating temperature for most batteries is 500). When the temperature of the lithium-ion battery reaches 700C, a reaction occurs between the electrolyte and the anode in the cell, at a temperature of approximately 1300C the separator begins to melt, which causes an internal short circuit. However, at a temperature of approximately 1500C, the safety valve in the battery opens and flammable gases escape.

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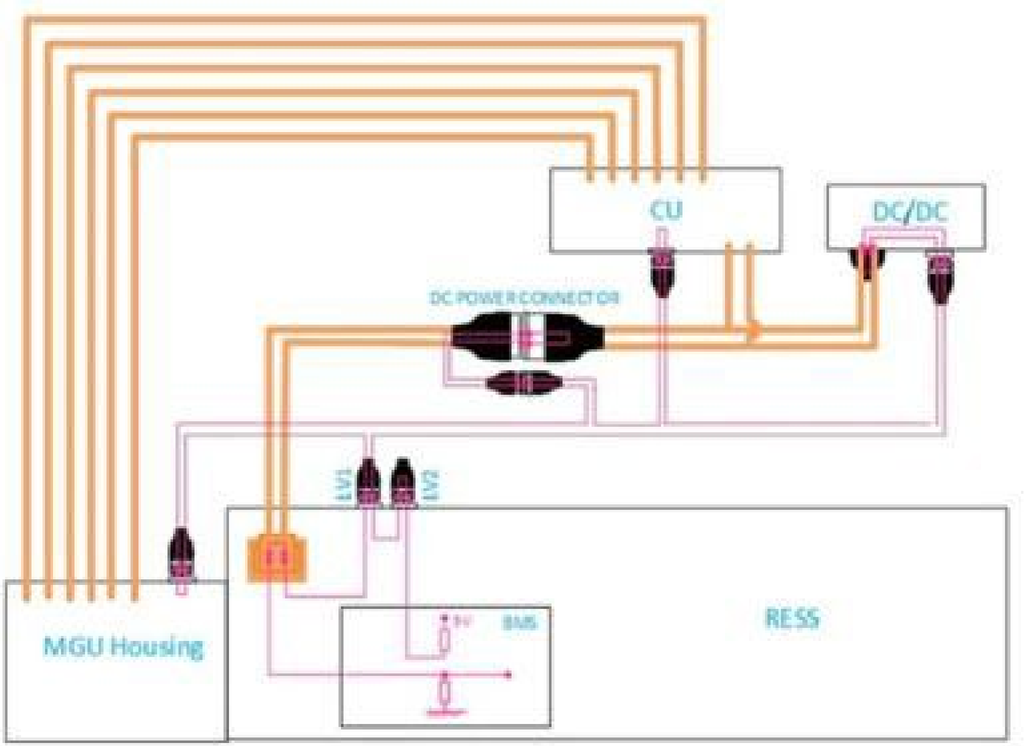
General procedure for turning off high voltage in an electric vehicle

Disconnection of the high voltage system

- Turn off the ignition and wait 1 minute
- Disconnect the negative terminal of the 12V battery
- Disconnect the high voltage service switch connector
- Wait 10 minutes (or more according to your vehicle's owner's manual)



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EVTECH

General procedure for turning off high voltage in an electric vehicle

Protection against accidental switching on of high voltage :

- Removing the key from the ignition (if present) securing the key
- Protection of the service switch against access by unauthorized people

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General procedure for turning off high voltage in an electric vehicle

Confirmation of the absence of high voltage in the system.

- Wait the time specified by the manufacturer (time needed to discharge the capacitors)
- Check the correct operation of voltage measuring devices.

The correct operation of the device should be checked in accordance with the recommendations of the measuring device manufacturer. The operation of the device can be checked by testing the voltage of the 12 V battery.

- Check the lack of voltage at the measurement points (according to the vehicle manual)

No voltage at all points - you can start servicing the vehicle.

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EVTECH

Marking the electric vehicle and its surroundings

- ✓Marking of the space in which a car equipped with a high-voltage circuit is operated (no unauthorized persons are allowed)
- ✓ The car should be marked with a high voltage sign in a visible place

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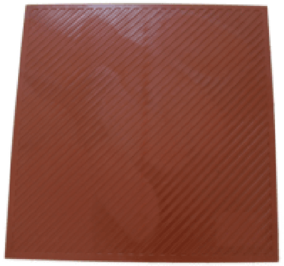
EVTECH

Tools and equipment needed to support the maintenance and repair of electric vehicles

- electrical insulating gloves

- safety helmet

- insulating mats



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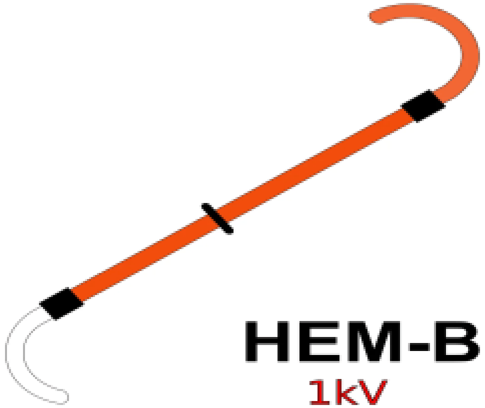
EVTECH

Tools and equipment needed to support the maintenance and repair of electric vehicles

- electrically insulating shoes

- escape hook



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EVTECH

Learning Unit 2: Electrical installation and functional system safety

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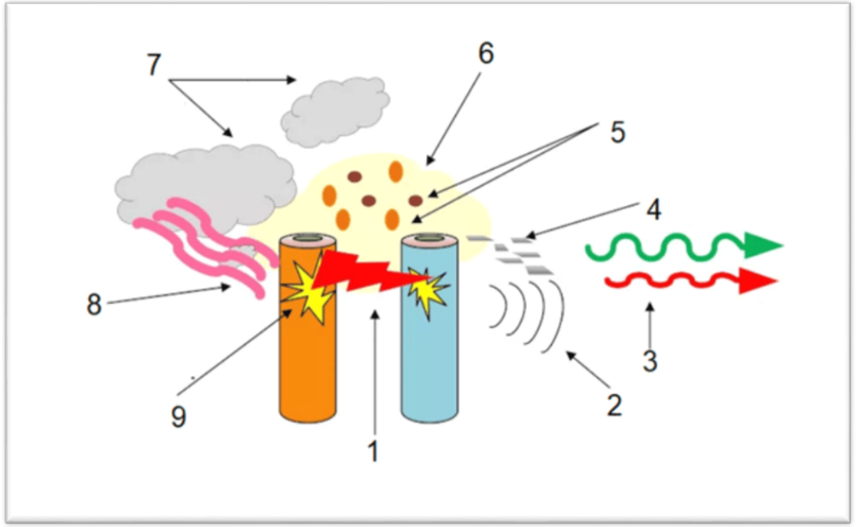
Electrical short circuit

An electric arc most often occurs between two conductive elements with different potentials as a result of short circuits in the electrical installation. The causes of these short circuits may be damage to the wire insulation or human error.



1-electric arc, 2-shock wave, sound wave, 3- UV, IR radiation, 4-accelerating charges, 5-particles of molten metal and plastic, 6- plasma at a temperature of 10,000 -20,000 0C, 7-aggressive chemical fumes, 8- thermal radiation, 9- damaged insulation

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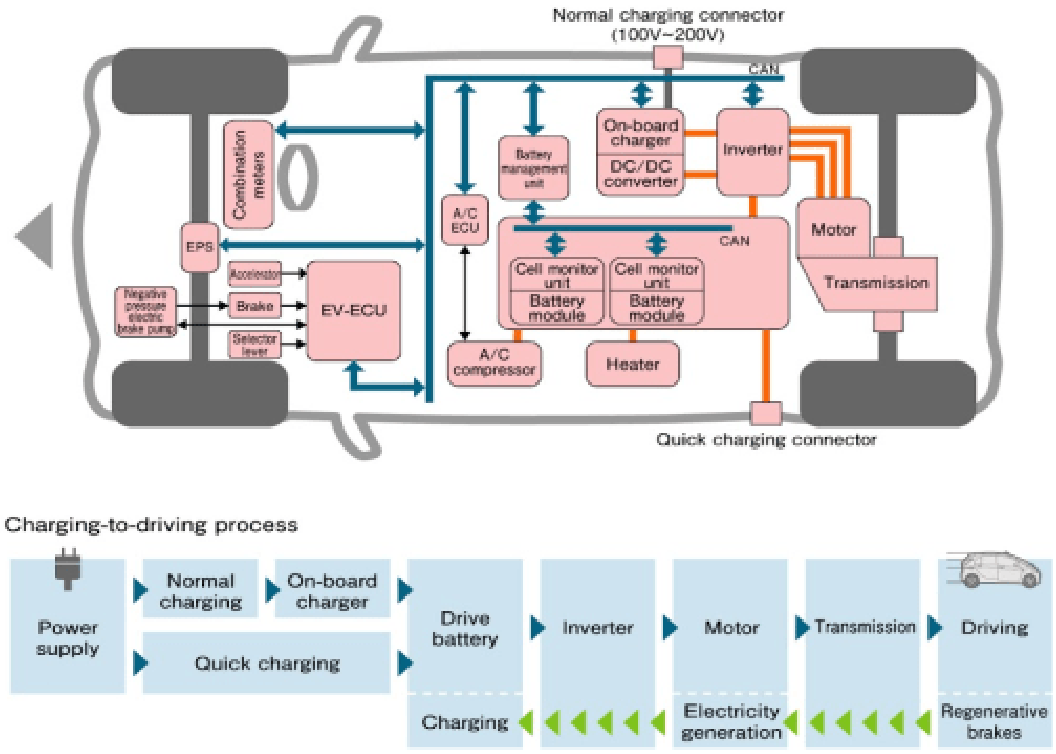
EVTECH

Diagram of the high voltage system of an electric car (Mitsubishi)



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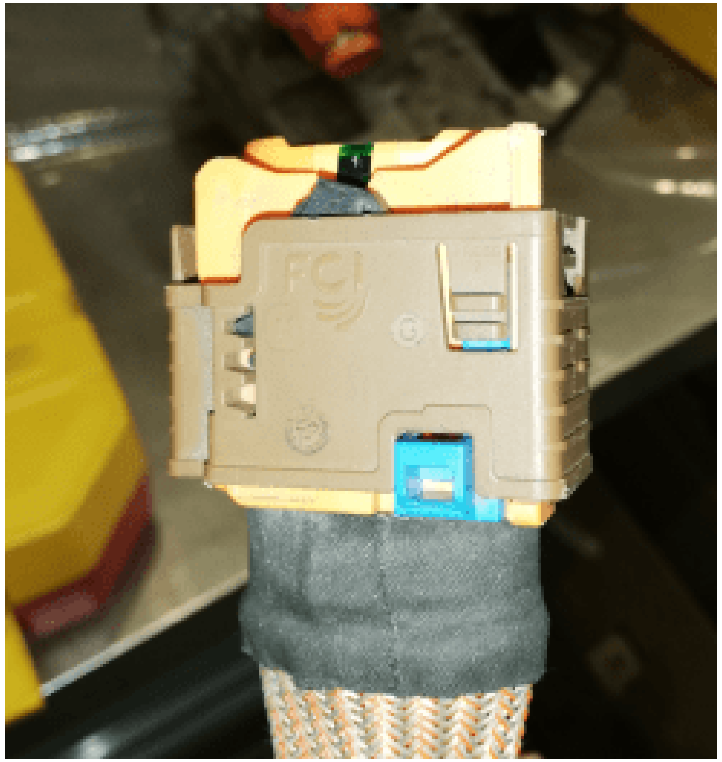
EVTECH

High voltage installation cables



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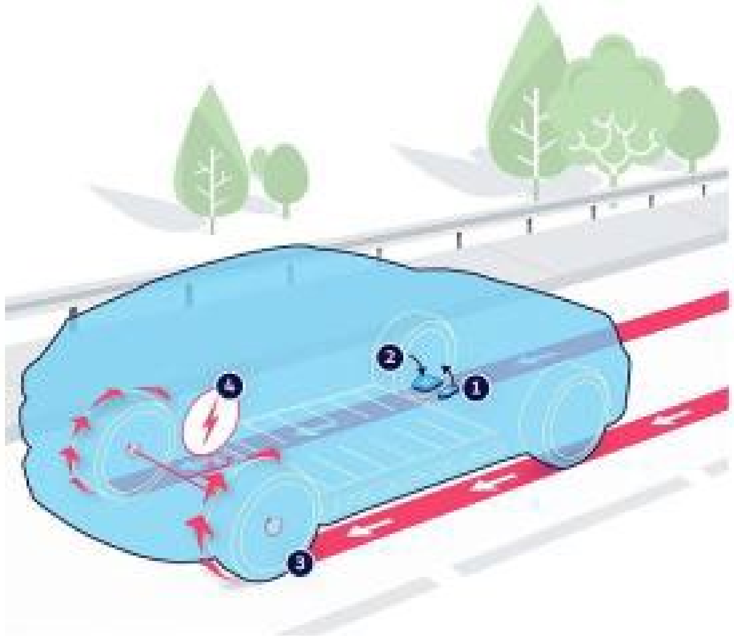
EVTECH

Regenerative braking system

- regenerative braking, braking delay up to 3.5 m/s2

- friction braking, braking deceleration above 3.5 m/s2



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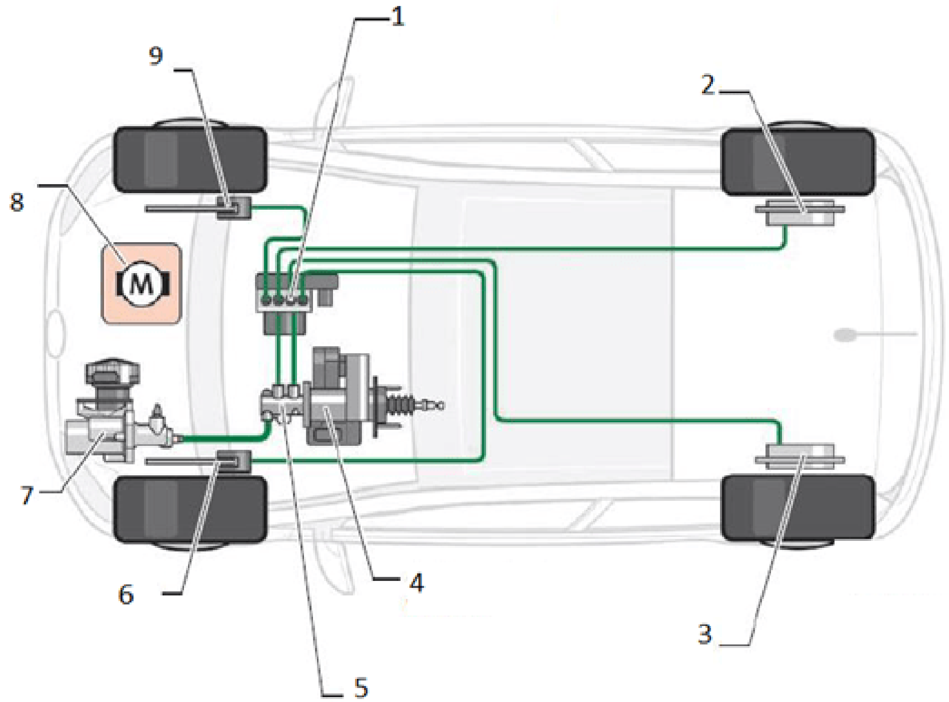
EVTECH

Construction of the electronic braking system – VW e-Up/ e-Golf



1 ESC/ABS system

2 rear wheel brake

3 rear wheel brake

4 electromechanical braking force amplifier

5 two-section brake pump

6 front wheel brake

7 pressure reservoir

8 three-phase drive unit and electronic power and control module of the electric drive

9 front wheel brake

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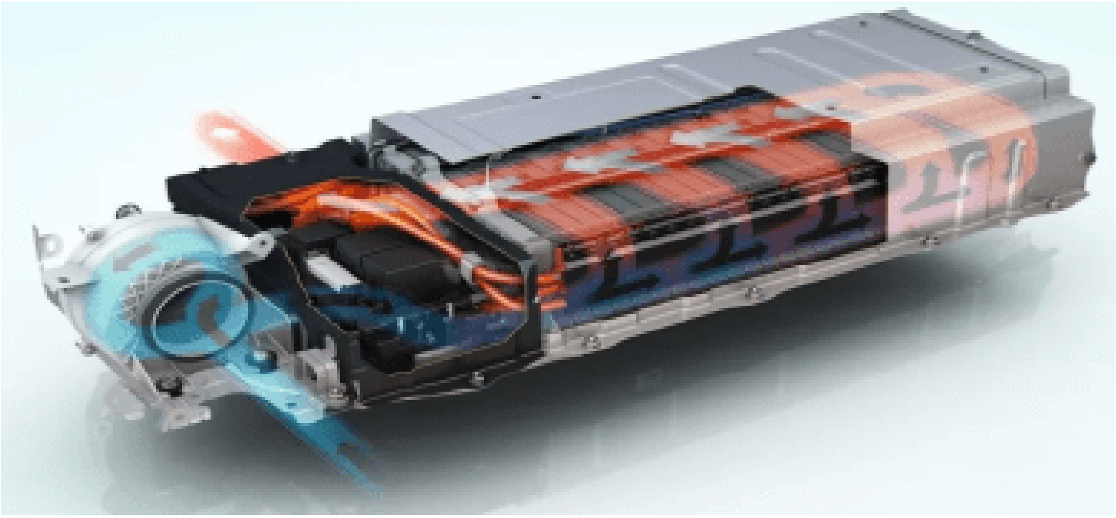
EVTECH

Cooling and heating system

Lithium-ion and nickel-hydroxide batteries should be operated at a specific temperature to maintain optimal power and durability. The core temperature of a lithium-ion battery cell should not exceed 400C. If this limit is exceeded for a long time, the battery will age quickly. This applies to both nickel-hydroxide batteries, which are slightly less sensitive to heat and can reach temperatures of 500C.



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EVTECH

Tools for servicing electric vehicles

A station for servicing electric and hybrid cars must also have job instructions in the field of high voltage (HV). Safe work requires specialised insulated tools (VDE), appropriate measuring equipment and additional occupational health and safety equipment.

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EVTECH

Learning Unit 3: Battery system safety

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EVTECH

Types of battery protection in a vehicle

- Cooling system that protects the battery from overheating.
- Reinforced protective casing to prevent mechanical damage.
- The firewall separates the battery modules, limits potential damage and protects other vehicle components from ignition.
- The high voltage emergency shutdown system reduces the risk of ignition.
- A circuit that separates the high voltage (HV) battery voltage from the rest of the vehicle's electrical system when parked significantly increases safety when the vehicle is not in use.

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EVTECH

External factors affecting the risk of battery damage

- Thermal factors.
- Mechanical factors.
  - Road accidents.
  - Coolant leaks from the cooling system.
  - Electrolyte leaks from cells.
- Electrical abuse.
- Thermal runaway.

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EVTECH

Battery safety outside the vehicle

- Rules for transporting batteries

  Batteries transported alone without a car are treated as transport of hazardous materials

- Battery disassembly

  When working after opening the battery, it is recommended that at least two people work together at the same time

- Technical condition assessment

  Assessment for leaks, module condition, and identification of damaged components. Qualification of further proceedings

- Installation and checking the tightness of the casing

  Replacement of modules and tight installation of the housing. Checking the tightness with a pressure of +/- 150mbar

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EVTECH

Signs used in the operation of electric and hybrid vehicles


Flammable


Poisonous


Danger of explosion


Corrosive, skin irritating


Dangerous to health


Dangerous to the environment

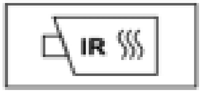

Electric vehicle


Rinse with plenty of water

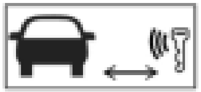

Attention high voltage


Attention danger (description next to symbol)


Dangerous voltage



Use a thermal imaging camera


Remove the key from the car

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EVTECH

Learning Unit 4: Tools and Equipment for Electric Vehicle Technicians

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EVTECH

Equipment for servicing and repairing electric vehicles

Voltage controller

The basic meter used during service and repair are voltage controllers. They should meet the requirements in accordance with the standards NR EN 61010-600V cat. 3 and IEC 61243-3 (VAT/DDT) or (according to DIN VDE 0682-401).

Employee safety depends on reliability and correct operation.

Before measurement, always check the operation of the controller by e.g. test measurement of a 12v battery.

Multimeters commonly used on the market cannot be used, even if they have a measurement range of up to 1000V.

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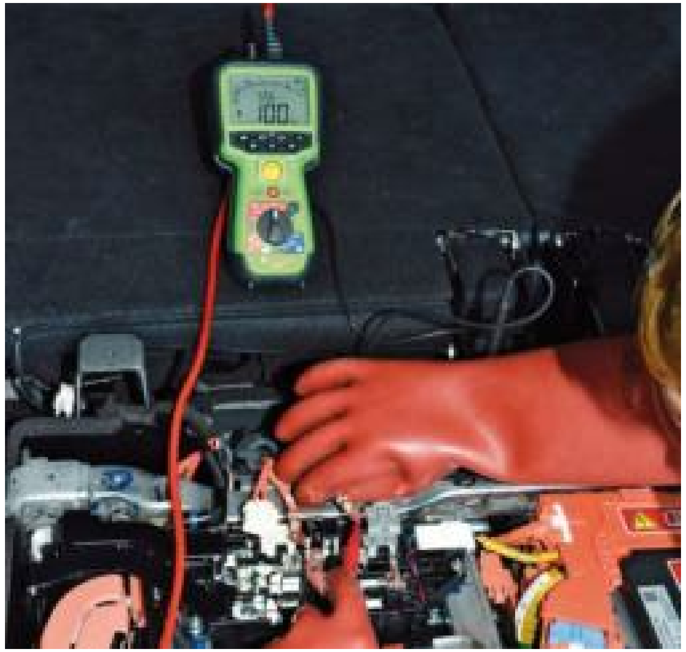
EVTECH

Equipment for servicing and repairing electric vehicles

Insulation resistance measurement

An important parameter for checking the condition of high voltage electrical installation elements is the measurement of insulation resistance. There are many devices on the market intended for this type of measurement. However, not all of them are adapted to vehicle inspections. We determine the test voltage during insulation measurement based on the rated HV voltage of the vehicle.



The minimum requirements are defined in accordance with UNECE Regulation No. 100 and must be between the high voltage busbar and ground 500 Ω/V rated voltage.

When measuring the insulation resistance of HV cables, it is necessary to disconnect them from the devices.

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EVTECH

Equipment for servicing and repairing electric vehicles

- Service diagnostic testers or those using service data.

  A full range of car diagnostics and servicing. Access to the latest data for the latest models. Access to electrical diagrams. Access to spare parts catalogues. Access to service information. Intended for a specific brand. Full compatibility. Available in the service network of a given brand.

- Universal diagnostic testers.

  Incomplete scope of diagnostics. No or little access to service information. Designed to support multiple brands. Frequent lack of support for vehicle anti-theft protection. Potential risk of damage to vehicle electronic components. An alternative for independent workshops without cooperation with an authorised service.

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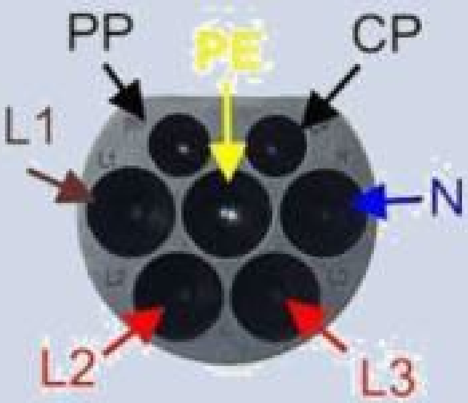
EVTECH

Types of charging connectors.

	AC	DC
Ameryka Combined Charging System Typ 1 (CCS1)		
Azja AC Typ 1/DC CHAdeMO		
Europa AC Typ 2/DC Combined Charging System Typ 2 (CCS2)		

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MODULE 5

EV WORKPLACE SAFETY

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1 QUESTIONS AND ANSWERS

1.1 Why should a vehicle carrier be able to distinguish an electric vehicle from a car powered by a traditional combustion engine?

Electric cars have different transport and lifting requirements. Standard guidelines must be followed, and additional rules related to the presence of a high voltage system and the design of the drive system (the electric motor is constantly mechanically connected to the vehicle's wheels) must be met. The high voltage of electricity in a high voltage circuit can be turned off by following the appropriate procedure. This activity should be performed by a person with appropriate qualifications. Please remember that the traction battery, after applying the high voltage deactivation procedure, is still an electrical source with high voltage DC.

Electric cars have a large electric battery that is usually part of the chassis, so please follow these steps when lifting electric vehicles with the vehicle's technical manual so as not to damage the battery housing.

1.2 List the identifying features that can be used to determine that the car has an electric drive.

An electric car has the following features:

- ✓ characteristic markings on external body elements or "green license plates" (in Poland);
- ✓ markings on the plastic engine cover (under the hood);
- ✓ charging socket or sockets, which may be located in different places depending on the manufacturer and model;
- ✓ orange covers of components, especially high voltage cables;
- ✓ no exhaust pipe – in fully electric vehicles;
- ✓ markings on the dashboard indicating the activity of the electrical power system;
- ✓ no fuel level indicator – in fully electric vehicles;
- ✓ QR code, VIN number or other types of markings used by car manufacturers.

1.3 When do we consider an electrical circuit to be high voltage? How high voltage affects the human body?

As defined in UNECE Regulation No. 100, the term high voltage in vehicles refers to the classification of electrical components or circuits which operate at an operating voltage exceeding 60V and not more than 1500V direct current (DC) or exceeding 30V and not more than

1000V rms current. alternating current (AC). The occurrence of high voltages and the flow of current when contact occurs may cause the following: values of 5mA - cause tingling, 10mA - cause spasms, difficulties in putting down tools, 50mA - cause ventricular fibrillation, apnea and 80mA - cause fatal threats. The flow of current may be accompanied by the following: the occurrence of an electric arc (burns, eyesight), the occurrence of poisonous vapours (risk to the respiratory tract), secondary threats such as cuts, limb injuries, etc.

1.4 Explain why the person switching off the high voltage circuit should do so in accordance with the vehicle manufacturer's procedure?

Deactivation of the high voltage circuit is an activity that must be performed in a manner strictly specified by the manufacturer. This affects the safety of the person performing this activity and the people operating the vehicle. The correct procedure ensures the safety of people operating the electric vehicle and ensures that parts of the vehicle system are not damaged.

Generally developed procedures for all vehicles are intended for emergency services. They are intended to protect people and the surroundings against high voltage electric shock. These procedures do not protect system components from damage.

1.5 Explain how the suitability of protective gloves is checked and what the purpose of such testing is.

Protective gloves have an expiration date. They can be used within a specified period of time, but before each use they must be checked for damage. The check involves inflating the gloves with air, e.g. with your mouth, and checking whether the air escapes. This way we check whether the gloves are tight, any mechanical damage is a place where an electric arc can flow. The expiration date of the gloves is marked on the outer upper part.

1.6 Is an electric car safe because it has high voltage?

For safety reasons, a car powered by an electric engine is designed to ensure the safety of users and persons servicing the vehicle. The high voltage system is active if the conditions are met:

1. a 12V battery is connected to the car's installation,

2. the ignition is on,
3. the service switch or service plug of the high voltage system is turned on,
4. insulation of high-voltage system components and cables is efficient,
5. all plug connections are functional,
6. the collision sensor cannot signal a collision (no airbag can be activated).

1.7 What is a vehicle rescue card and what information does it contain?

The vehicle rescue card presents important information for emergency services. It indicates key areas of the vehicle, such as reinforcement points in the body, where the high-voltage cable is located, the location and number of safety airbags and seat belt tensioners (which may explode during a collision).

1.8 Discuss the protection of high-voltage cables.

The high voltage circuit is a two-wire IT network. All wires have double insulation and are protected against changing voltage polarity. They are orange. The cables are terminated with special connectors that eliminate the possibility of accidental connection. The high-voltage system is equipped with an on-board resistance monitoring system called IMD, which detects insulation damage by measuring residual currents. The system is equipped with a pilot safety cable. It is powered by a 12V mains cable running in series from one connector to the other. If the wire circuit is disconnected in one of the pilot pin connectors, the high voltage system controller recognises this and deactivates the high voltage.

The high-voltage installation has a potential equalisation system. In the event of damage to the insulation of wires of live high-voltage network elements, the risk of electrocution to vehicle passengers or employees is minimal thanks to potential equalisation using a protective equipotential bonding, which enables equalisation of different voltage levels between high-voltage elements and the body.

1.9 Explain the differences between the design of the braking system of an electric car and a car powered by an internal combustion engine.

Electric cars do not have an air intake system, so they cannot use the negative pressure that powers the servo. Therefore, these vehicles are equipped with vacuum pumps powered by electricity, or an electric system is used to support the brake pump.

The braking system of electric cars enables energy recuperation during braking. When the braking deceleration is below 3.5 m/s2, the electric motor works as a generator, receiving the vehicle's kinematic energy and charging the high voltage battery.

1.10 Why should a traction battery be cooled?

High voltage battery should not exceed the specified temperature. The ideal battery temperature is between 15°C and 30°C. Reaching a temperature above 50°C causes its degradation. The battery warms up during operation and charging. Fast charging (with high DC current) has a negative impact on the battery. Exceeding a sufficiently high temperature causes irreversible changes in battery cells and may lead to fire. When the temperature of the lithium-ion battery reaches 70^0C, a reaction occurs between the electrolyte and the anode in the cell, at a temperature of approximately 130^0C the separator begins to melt, which causes an internal short circuit. However, at a temperature of approximately 150^0C, the safety valve in the battery opens and flammable gases escape.

1.11 Discuss the mechanism of threat formation during the so-called "electrical abuse."

Lithium-ion batteries are designed to receive and store a specific amount of energy over a specific period of time. Exceeding these limits due to charging or overcharging too quickly may degrade performance or result in premature failure. Internal chemical reactions caused by overcharging can theoretically result in a short circuit and, consequently, a fire. Importantly, in the case of many electric vehicles, "electrical abuse" is not possible at all, as long as their BMS is properly designed and works properly.

1.12 Why is it recommended that at least two people be involved when disassembling (repairing) a high-voltage battery?

When repairing batteries, for safety reasons, the work is performed by two employees at the same time. These employees must have the knowledge and authorisation to open batteries. For safety reasons, everyone says out loud what they are doing at any given moment so that a colleague can react quickly in the event of an emergency. They are dressed in special protective clothing without metal elements, thick gloves and masks.

1.13 Why is it important to equalise the cell charge level during battery repair?

The cells in a battery are connected in series and parallel. It is very important that all cells connected in series have the same degree of charge. A cell less charged than the others in the series will run out of charge earlier during operation (discharge too much) and limit the flow of current. A cell charged more than the others will reach its state of charge earlier during charging and will also limit the current flow. Both situations are detrimental to the overall battery capacity. This step is important when replacing modules. The controller may not allow the battery to start if the charge difference is too large.

1.14 How is it recommended to transport damaged or used batteries?

It is recommended to use a large metal container for transporting the high voltage energy storage system or parts thereof when disconnected from the vehicle. Pay attention to the condition of the high-voltage energy storage system (e.g. presence of smoke, noise, sparks, heating) and prepare for the possibility of flooding the metal container. When transporting a lithium-ion battery, additional regulations regarding the transport of hazardous materials apply. Their transport takes place on the basis of a transport document and the driver must have safety instructions. Return transport of damaged high-voltage batteries should be in the original packaging.

1.15 What requirements should tools and measuring devices for live repairs meet?

Tools and measuring devices used for repairs under voltage should be approved for this type of activities and have appropriate certificates and approvals. Their expiration date should not be exceeded. It is important that their technical condition does not raise any doubts. It should be clean and without mechanical damage. The housing and covers should be complete and functional. Cables and connection terminals cannot be repaired. Measuring and control devices should have a measuring range appropriate to the values of the parameters being tested. Device documentation should be available.

2 CASE STUDIES

2.1 CASE STUDY 1

Loading and transport protocol for electric cars involved in collisions and road accidents.

Background

A roadside assistance company is preparing to transport electric cars involved in road collisions and accidents. The aim is to develop a protocol of conduct when providing towing services for electric vehicles.

Scenario:

The Service Provider recognises the rules developed by rescue services (fire brigade) regarding procedures during rescue operations involving electric cars. Intends to develop protocols (rules) to be followed by employees called to remove a car involved in a collision or road accident.

Analysis:

Highlight the need to develop rules of conduct when loading and transporting electric cars involved in road accidents. Emphasise the need for specialised employee training to safely operate electric cars. Disconnecting the high-voltage system and procedures for determining whether the high-voltage battery has not been damaged and rules of conduct when symptoms of battery damage occur (increase in battery temperature).

Discuss the rules for transporting and loading a disabled car onto a tow truck that has not been involved in a collision or accident.

Discuss the rules for recognising an electric car if the service provider does not obtain information about the car involved in the incident.

Discuss the principles of disconnecting the high-voltage system and checking whether the high-voltage system has disconnected automatically via the collision sensor.

Discuss the rules for dealing with a vehicle handed over to rescue services with a deactivated high voltage system.

Discuss the rules for dealing with a vehicle with symptoms of high-voltage battery damage.

Discuss the rules for storing (parking) vehicles with a damaged high-voltage battery.

Recommendations:

The transport service provider establishes a safety protocol for loading and transporting disabled electric cars and cars involved in a road accident. Highlights safety rules for high voltage systems and high voltage batteries. It includes specialist training for employees in the field of high voltage and electric cars to ensure their safety and the safety of the entire environment.

2.2 CASE STUDY 2

Protocol for the use and maintenance of the personal protective equipment system in a car service.

Background

A company dealing in the repair and maintenance of passenger cars is expanding its services to include electric cars. The aim is to develop a protocol for the use of personal protective equipment against high voltage shock.

Scenario:

The Service Provider recognises the rules developed by electric vehicle manufacturers specifying how to deactivate the high voltage system. The aim of the activities is to develop a uniform protocol regarding the use and storage of personal protective equipment. Intention to develop and implement uniform instructions for the use, maintenance and storage of protective equipment used when operating, maintaining and repairing electric cars.

Analysis:

Emphasise the need to develop rules for the use, maintenance and storage of personal protective equipment. Emphasise the need to use protective equipment in accordance with its instructions. Emphasise the need to select appropriate protective equipment to protect the health and life of mechanics.

Discuss the principles of selecting protective equipment for the scope of work performed related to the operation, maintenance and repair of electric cars.

Discuss the rules for checking protective equipment before using it.

Discuss the rules for storing protective equipment.

Discuss the principles of maintenance and inspection of protective equipment.

Discuss the principles of marking faulty control measures and their disposal.

Recommendations:

The car service develops protocols regarding the rules of use and the selection of protective equipment from electric shock; specifies the work in which personal protective equipment protecting against electric shock must be used; provides people operating electric cars with specialised training in the field of electrical qualifications and operation of electric cars, in order to perform repairs in a safe manner and in accordance with the requirements of the vehicle manufacturer.

3 MULTIPLE CHOICE QUESTIONS (FOR THE ENTIRE MODULE)

Multiple choice test. Only one answer is correct.

3.1 Towing an electric car is:

A) allowed,

B) allowed for short distance,

C) prohibited.

3.2 What features should a workshop lift have for lifting electric cars?

A) allow the car to be lifted by the wheels,

B) have a lifting capacity of up to 1,000 kg, because electric cars are lighter than cars with an internal combustion engine,

C) should be made of plastic to isolate the vehicle from the ground

3.3 The car battery lift should provide lifting capacity of:

A) at least 50 kg,

B) at least 100 kg,

C) at least 500kg.

3.4 We can recognise an electric car by:

A) external dimensions, these are always small class A and B vehicles

B) lack of exhaust silencer,

C) having a camera observing the surroundings, it is an autonomous vehicle

3.5 High voltage cables are in:

A) green color

B) orange color

C) black color

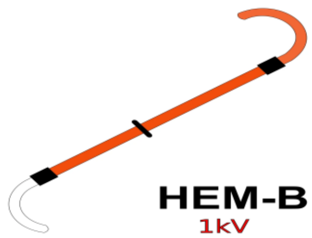
3.6 Procedure for connecting high voltage in electric cars:

A) is the same in all cars,

B) depends on the solution of the vehicle model,

C) disconnects the battery from the drive system by disconnecting the high-voltage cable connecting the batteries with the electric motor.

3.7 The figure shows:



A) a rescue hook

B) an electrical insulating mat

C) an assembly pole

3.8 High voltage installation is an installation with a voltage of:

A) above 24V DC

B) above 24V AC

C) above 60V DC

3.9 9. In most vehicles, the high voltage installation is deactivated by:

A) disconnecting the 12 V battery

B) starting to charge the vehicle's battery

C) stopping the vehicle and applying the parking brake

3.10 The permissible operating temperature of most electric car batteries is:

A) 70⁰C

B) 50⁰C

C) 130⁰C

Answers

1	2	3	4	5	6	7	8	9	10
C	A	C	B	B	B	A	C	A	B