Learner's E-book

September 2024

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INTRODUCTION

The EVTECH project aspires to increase the supply, quality and relevance of Vocational Education and Training (VET) provision in the automotive industry, aiming to address the emerging occupational needs and skills mismatches, resulting from the increasing adoption rates of Electric Vehicles (EVs). The project has developed a learning curriculum with work-based learning opportunities on Electric Vehicles servicing, maintenance and repair work. Focus is placed, apart from typical EV specific maintenance/repair procedures, on aspects that are currently missing from existing courses (i.e. IT systems, data visualization and safety protocols).

This e-book is an entry point to the EVTECH course, and it is based on the structure of the project's curriculum. Its goal is to provide a brief, comprehensive view of the course developed by the EVTECH consortium and specifically partners involved directly in the field of automotive industry, namely FREMM (Spain), CKZ (Poland), and CELF (Denmark). The course is aimed at car technicians and Initial Vocational Education and Training (I-VET) students in Automotive Technician Programmes, who wish to extend their technical knowledge and digital skills as well as to keep up with sectoral trends for coping with emerging workplace requirements.

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MODULE 1: EV ESSENTIALS

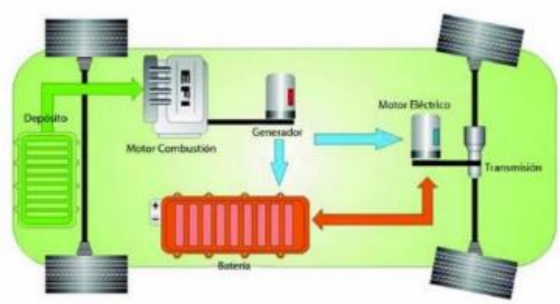
1.1 OVERVIEW OF EV TECHNOLOGY

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 one 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.

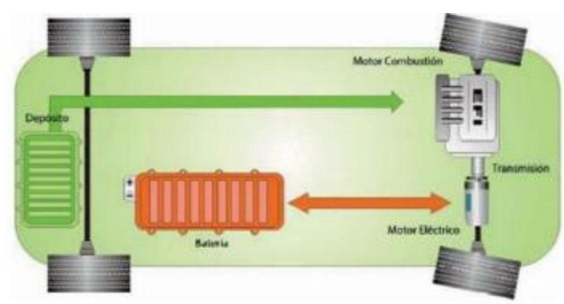
Series Hybrid Vehicles

This 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).



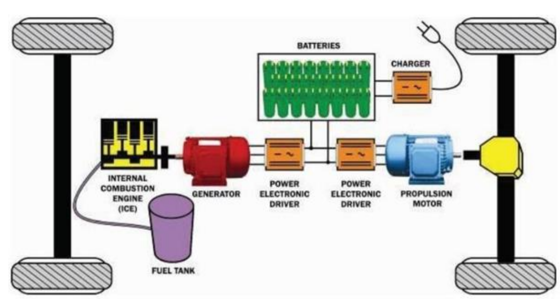
Parallel Hybrid Vehicles

In parallel architecture hybrid vehicles, both the combustion engine (ICE) and the Traction Electric Motor (TEM) work simultaneously to set the vehicle's wheels in motion.



Plug-in Hybrid Electric Vehicles (PHEV)

The type of Plug-in Hybrid Electric Vehicles (PHEV), 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, but also by connecting it to the external electrical grid (in a building, at a charging station etc.).



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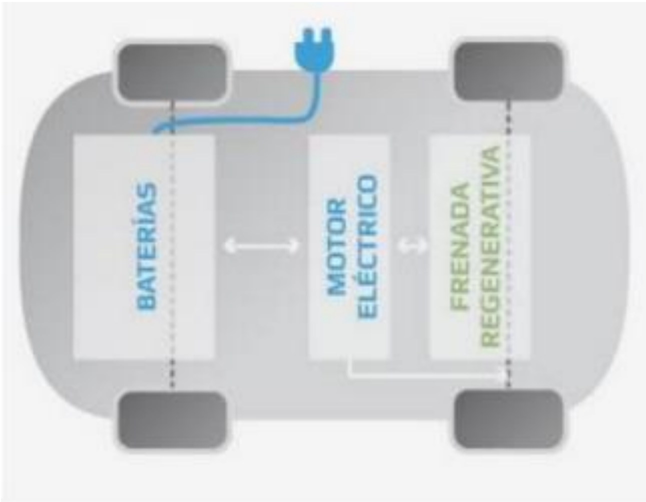
Non-Plug-in Hybrid Vehicles

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.

Pure Electric Vehicles (EV)

Regarding these vehicles, 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).



1.2 CURRENTLY AVAILABLE IMPLEMENTATIONS

Central Electric Motor

Currently, in the market, two fundamental types are available:

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

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

Frame Types in Electric Vehicles

- Body-on-frame
- Unibody (Monocoque) chassis
- Electric vehicle platform (skateboard chassis)

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1.3 EV ARCHITECTURE (MAIN COMPONENTS)

Motor Control and Regulation

Understanding how motors operate is essential in the world of electric vehicles. Synchronous motors, commonly used, 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.

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.

On-board Charger and DC/DC Converter

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.

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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 battery pack is 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.

High-voltage Electrical System Control Units

A cluster of control units ensures seamless management of the powertrain circuits. Every control unit, including the MCU (Motor Control Unit) that manages motor operations, the EVMS that supervises charging, and the numerous other control units included into inverters, on-board chargers, and DC/DC converters, are essential to the overall functionality and safety of the EV.

Motor Controllers (Inverters)

The motor controllers, functioning as inverters, receive high-voltage inputs and distribute three-phase alternating current essential for powering electric motors.

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.

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Inertia Switch and Key Switch (Ignition Key)

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

1.4 ENERGY STORAGE SYSTEMS

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.

Assembly Of a Battery Pack

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.

Types of battery pack cooling

- **Air-Cooled:** Utilises fresh air flow to cool the battery pack. It is simple and cost-effective, but temperature regulation depends on external conditions.

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- **Liquid Cooling:** Circulating a cooling fluid through the battery pack is commonly used. This method provides efficient and controlled cooling, but it is 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.

1.5 BATTERY RECHARGE

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.

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Regenerative Braking Strategies

Two primary strategies in implementing regenerative braking systems (series control and parallel control) are highlighted, focusing on their unique approaches and impact on vehicle range. The role of Brake-By-Wire systems in facilitating series control regenerative braking strategies is also examined.

1.6 OPERATION OF ELECTRIC MOTORS

The main technologies used in electric motors for traction systems include 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 beneficial 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**

These are an improvement over permanent magnet motors, with a simpler design that uses a rotor without magnetic materials. They leverage magnetic resistance in the rotor against the electromagnetic field to generate motion, controlled through power electronics.

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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.

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2.1 LDC VEHICLE ELECTRIC CIRCUITS - PRINCIPLES AND PROPERTIES OF MAGNETISM APPLIED TO VEHICLE CIRCUIT DEVICES

Electricity and Magnetism are the fundamentals of DC Vehicle Electric Circuits. Electricity describes 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 reverse.

Magnetism examines 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), describes the alignment of magnetic dipoles under an external magnetic field.

Electric current creates magnetic field around conductors it flows through. This knowledge is essential in comprehending natural phenomena and designing technological devices like generators and motors.

2.2 INTERPRETATION OF WIRING DIAGRAMS

Understanding Electrical Systems in Automobiles

Electricity is the key for modern vehicles, powering essential functions from engine ignition to interior electronics. To deal with the complexity of automotive electrical systems, one should comprehend the fundamental units, basic circuit elements, circuit types, main components, electrical symbols, and the interpretation of wiring diagrams.

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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.

Electric current, quantified in Amperes (A), represents the flow of electrons within a circuit.

Electrical resistance, measured in Ohms (Ω), characterizes the opposition encountered by a conductor to the flow of current.

Electrical power consumption is defined in Watts (W), highlighting the power consumed by a device drawing one ampere under a one-volt potential difference.

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 colour codes.

Recipients and consumers in vehicle electrical systems use this energy. Switches play a crucial role in controlling circuit connectivity and activating or deactivating various vehicle components.

2.3 CIRCUIT PROTECTION DEVICES

Fuses play a crucial role in securing automotive and electric vehicle (EV) electrical systems, protecting electronic components, and preventing damage due to overcurrent.

Classification of Fuses is 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 overcurrent, while others offer slower response times. The choice depends on the application and sensitivity of the vehicle electronics.

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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 secure the lighting system, while another might protect the engine control system.

In the event of an overload or short circuit, the fuse is destroyed, interrupting the current flow, thus preventing damage to expensive and sensitive electrical and electronic components.

2.4 EARTHING PRINCIPLES AND METHODS

The grounding of electric and hybrid vehicles is essential for their safe operation and for mitigating 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.

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 carefully 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.

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 megohmmeters 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.

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2.5 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, assist in error code reading, system monitoring, and reprogramming of modules, ensuring accurate diagnostics.

Component and Wiring Tests

Multimeters 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.

Repair and Maintenance Procedures

Replacing defective components follows a specific protocol, addressing root causes for optimal repair. Adjustments, preventive maintenance, software updates, and functional tests complete the repair and maintenance procedures, ensuring efficient, reliable, and safe service for electric vehicles.

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MODULE 3: PRACTICAL APPLICATION OF EV TECHNOLOGIES AND MEASURING ON HV SYSTEMS

3.1 BASIC HIGH VOLTAGE SYSTEM EXPLAINED – FULL HYBRID

A full hybrid vehicle has no charging socket, which means it only recharges its batteries using regenerative charging. So, when braking or when the combustion engine is running, one of the 2 motor generators produce electricity which is then stored on the High Voltage battery.

When dealing with vehicles that have High Voltage batteries the voltage is around 140 Volts. That does not mean there are no other levels of voltage in the vehicle, it is only the High Voltage component that is around this value. Most of the electronic components in the vehicle are still using 12 Volts.

Along with battery pack there is the service plug, that can be pulled down and out, so one can disconnect it. Furthermore, there are 3 temperature sensors located over the battery pack, that allow control of any cooling needed.

The battery pack is often a Nickel metal hydride battery, which is very stable and durable, and its lifespan is between 10 and 20 years long. Of course, the capacity of the battery is variable over time. This is known as State of Health (SoH).

There is also a measuring component including a sensor unit that measures how many Amps are added or removed from the battery. This is known as State of Charge (SoC).

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.

The battery pack consists of 20 battery modules that, combined, reach 140 Volts. There is a simple division informing you what each module contains.

A High Voltage control unit also exists. This unit contains both an inverter and a converter. A converter is the little block at the end of mobile phone chargers. It converts the alternating current into direct current (AC to DC). It is often from 220 to 3.7 Volts. As this unit is also an inverter, it can convert DC into AC too.

It is necessary to charge the High Voltage battery occasionally as without a charged battery the vehicle won't start. When the vehicle brakes, electricity from the engine comes through 3 cables, the so called 3 phased AC electricity.

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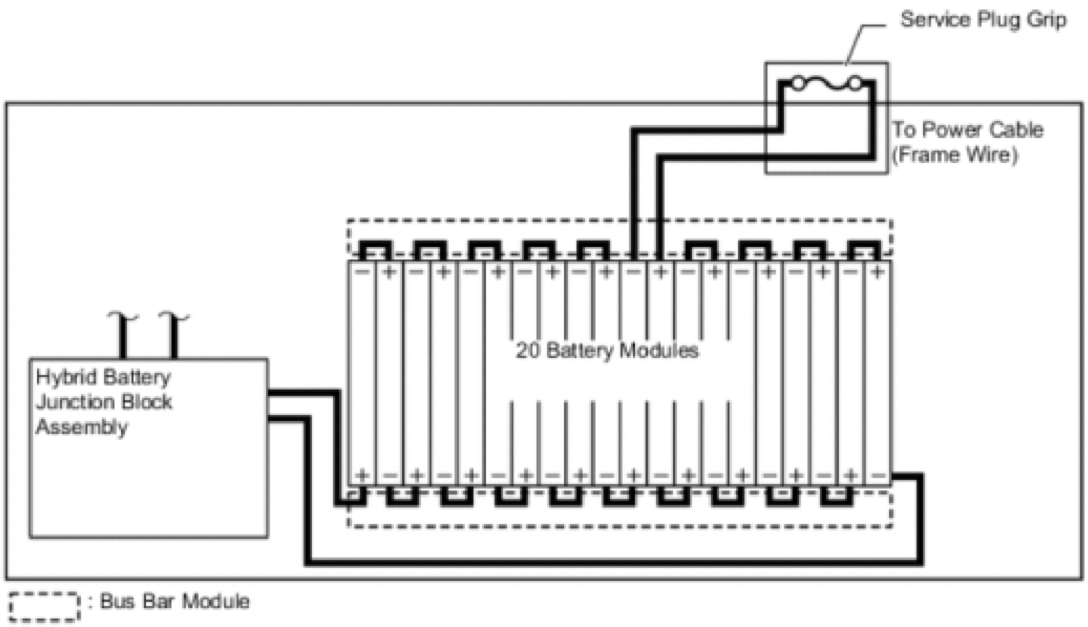

3.2 BASIC HIGH VOLTAGE SYSTEM EXPLAINED – PLUG IN HYBRID

These vehicles have a charging socket, which means their batteries can be recharged. Their charging socket connects to a standard 220 Volt wall socket or a charging station. When braking the vehicle, the electric motor/generator produces alternating current, which then is rectified and stored on the High Voltage battery. If the combustion engine is running, the starter/generator can charge the high voltage battery.

When dealing with vehicles that have High Voltage batteries it is around 400 Volts. That does not mean there are no other levels of voltage in the vehicle, it is only the High Voltage component that is around this value. Most of the electronic components in the vehicle are still using 12 Volts.

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. The starter/generator is attached with coolant hoses for temperature regulation. This is necessary as it can produce high amounts of electricity.

3.3 HIGH VOLTAGE SYSTEM BASIC EXPLANATION – FULL ELECTRIC VEHICLE

In a full Electric Vehicle, there is a charging socket and some wires behind it. Two of them are going directly to the battery and they contain only direct current for fast charging of the battery.

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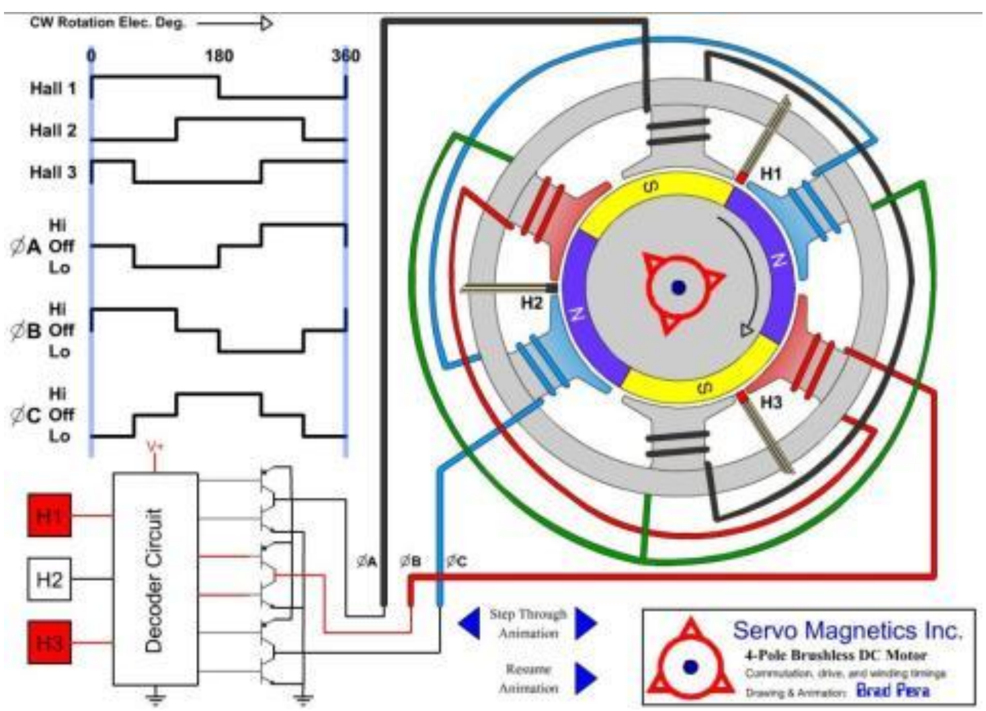
The rest of the high voltage wires from the charging socket are going along the right-hand side of the battery to the inverter/converter. Those wires contain alternating current which is then rectified by the inverter/converter into direct current.

So, this vehicle has no onboard charger, but the inverter/converter rectifies the alternating current, so it can be stored on the battery for later use.

An EV has a large battery pack because it's the only power source for the electric motor to go as far as possible for the consumer.

Another fundamental device of the EVs is the rotor, made of very powerful permanent magnets. These permanent magnets are quite sensitive to heat and if they get too hot, they lose their efficiency. The Magnetic Fields in the coils of the stator, and the Magnetic Fields from the permanent magnets determine how much torque the engine is going to produce. Therefore, these two Magnetic Fields are very important, and need to be as strong as possible, otherwise the vehicle loses torque.

The rotor is the part that is connected to the gears and propels the vehicle through the differential.



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4.1 INTRODUCTION TO BATTERY TECHNOLOGY – ELECTRICITY

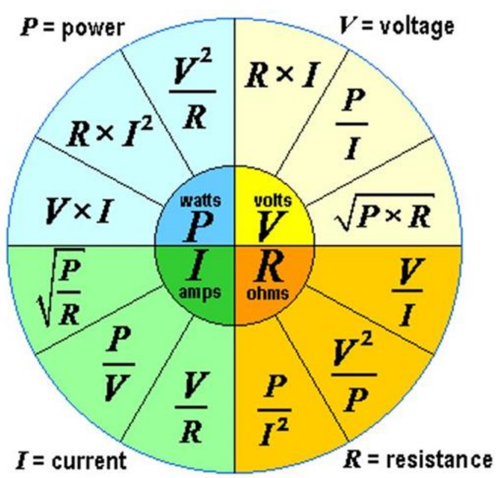
Electricity is a form of energy, resulting from the move of charged particles, primarily electrons. It is a versatile energy source that powers various devices, from light bulbs and appliances in homes to the intricate circuits in electronic devices.

Atoms are 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. An atom is electrically neutral when the number of electrons equals the number of protons.

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.

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 expresses how many electrons pass through a point in a circuit per second.

3. **Resistance (R)**: Resistance describes the struggle of the electric current to flow in a material. It's measured in Ohms (Ω) and depends on the material's properties and shape.

The formula P=I×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

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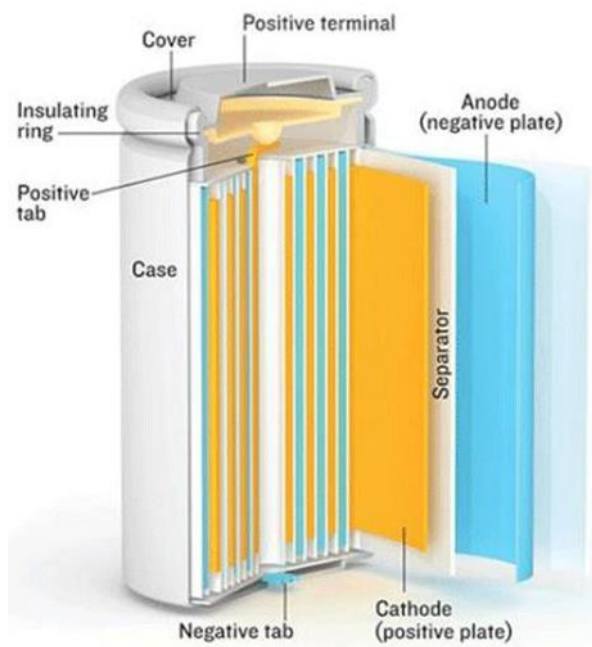
formula is fundamental in electrical engineering and is used to calculate the power consumption or generation in any electrical device or system.

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.

In conclusion, electricity is the flow of electrons through conductors, and it can be used 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.

4.2 THE APPLICATION OF HIGH VOLTAGE BATTERIES



Lithium-ion (Li-ion) batteries are rechargeable and are used extensively in modern electric vehicles due to their high energy density, low self-discharge, and long lifespan. 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 $LiCoO_2$, $LiMn_2O_4$, $LiFePO_4$, 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.

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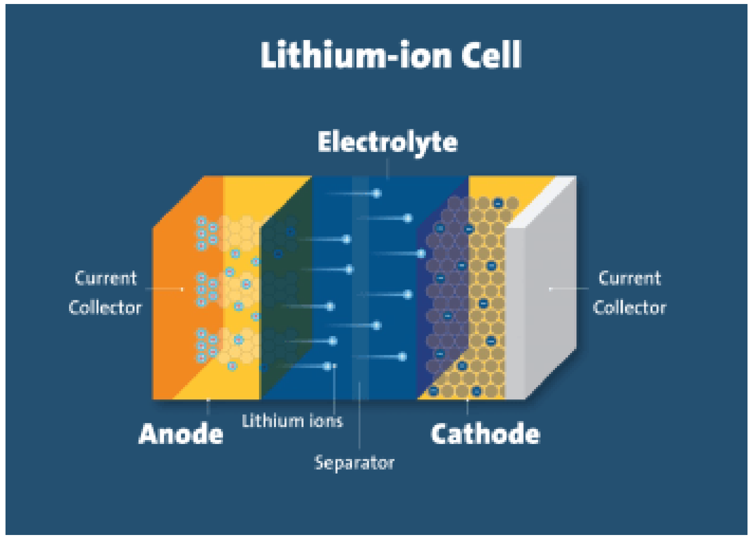
Chemistry and Operation



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.

4.3 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

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5.1 POTENTIAL RISKS AND CHALLENGES DURING EV REPAIR, HANDLING OR MAINTENANCE

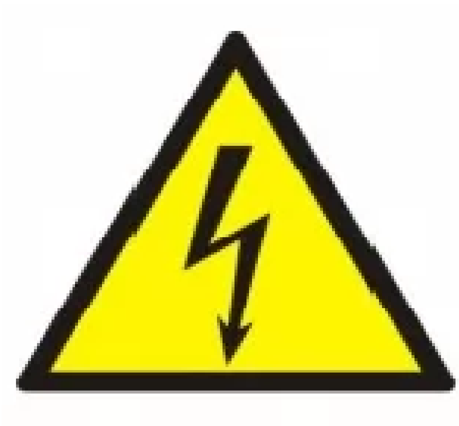
Transport of electric vehicles

Towing electric cars is very similar to transporting a conventional car with automatic transmission. In particular, manufacturers prohibit towing them, even over a short distance. Electric cars should be transported on a trailer.

Safely lifting electric vehicles

When lifting electric cars, attention should be paid to the appropriate positioning of the lift legs so that access to the high-voltage battery is possible; jacks that lift the vehicle by the wheels could be used. When disassembling and installing a high-voltage battery a battery lift is recommended. The large weight of the battery is an issue that needs to be considered, as it may cause 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 run at an operating voltage between 60V and 1500V direct current (DC) or between 30V and 1000V rms alternating current (AC). An electric car battery might weigh up to 700 kg constituting direct risk for electric vehicles' technicians. An electric battery might reach high temperatures (the permissible operating temperature for most batteries is 50^{0}C). Once the temperature of the lithium-ion battery reaches 70^{0}C, a reaction between the electrolyte and the anode in the cell takes place. At a temperature of approximately 1300^{0}C the separator starts melting, causing an internal short circuit. However, at a temperature of approximately 1500^{0}C, the safety valve in the battery opens and flammable gases escape. Black smoke and flames are released.

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5.2 ELECTRICAL INSTALLATION AND FUNCTIONAL SYSTEM SAFETY

Electrical short circuit (danger and risk)

When repairing high-voltage systems in electric cars, the greatest danger is the risk of electric shock, which results in current flowing through the human body. Although such a situation is very dangerous, it doesn't happen often because the mechanic would have to touch the positive and the negative pole of the battery at the same time. However, it should be kept in mind that the energy stored in traction batteries pose a very serious risk of electric shock.

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 strict 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. Protective clothing minimises the risk of burns and other injuries when working with such systems.

Regenerative braking system

In electric cars, supported by a vacuum actuator, the vacuum is generated by an electric pump. The vacuum pump is powered by 12 V from the on-board network. 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. 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 400^{0}C. If this limit is exceeded for a long time, the battery will age quickly. This applies

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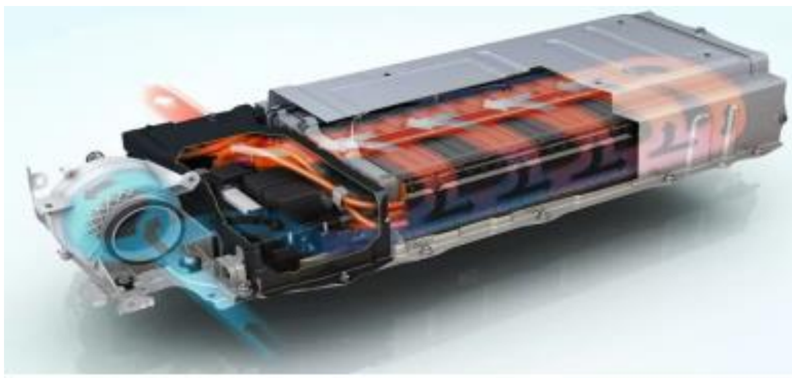
to nickel-hydroxide batteries, which are slightly less sensitive to heat and can reach temperatures of 50^{0}C.

Various cooling methods are used to avoid battery overheating. The simplest system is air sucked in from the air-conditioned interior of the vehicle and used to cool the battery. The second option is a special evaporator plate located in the battery cell and connected to the vehicle's air conditioning system. The third choice is the so-called splitting method, used on the high and low-pressure side through flexible conduits and an expansion valve. It is used in larger capacity batteries, where 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.



5.3 BATTERY SYSTEM SAFETY

Types of battery protection

To protect batteries against conditions that could cause damage, a vehicle is equipped with several mechanisms that protect it against failure. A battery cooling system is used to prevent excessive temperature increase. An important part 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 loss. The high voltage disconnection system acts similarly when the vehicle is parked.

External factors affecting the risk of battery damage

There are external factors that could also harm batteries. Their existence does not depend on the technical condition of the vehicle or its structure. When exposed to high temperatures, a vehicle's battery may lose its ability to cool properly. An excessive increase in temperature may

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trigger several reactions that might initiate a fire. Another danger with unpredictable consequences is mechanical damage, with impact on battery components not being predictable and depends, among others, on the magnitude, time, and direction of mechanical factors.

A damaged or missing BMS can cause excessive currents to flow, causing dangerous temperature increase. A failure involving 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.

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. 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 when disconnected from the vehicle. 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 and they constitute an important element of the security system.

Safe disconnection and connection of batteries

To safely disconnect or connect high voltage components, one should know and follow procedures in accordance with the guidelines and recommendations provided by the manufacturer. Following procedures designed for a specific vehicle allows for professional and trouble-free operation of an electric vehicle. A technician knowing the features of the system and how to control them can professionally disconnect the HV and 12V batteries without a service manual but must first perform several measurements. This requires professional knowledge and experience.

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5.4 TOOLS AND EQUIPMENT FOR ELECTRIC VEHICLE TECHNICIANS

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 like 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

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 also be an eyewash station nearby. Personal protective equipment is primarily intended to protect an employee and minimise the risk of body injury.

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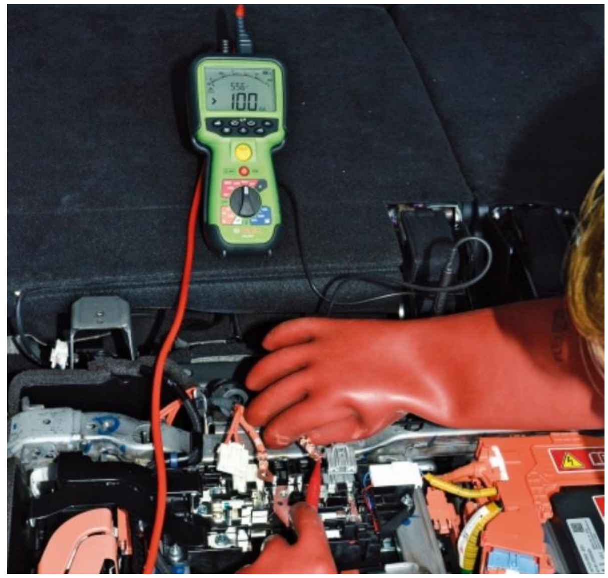
Equipment for servicing and repairing electric vehicles



An electric vehicle service station should set up a barrier separating this area from the rest. It may be, for example, a plastic fence with rubber bases. 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, yet they should have appropriate declarations and certificates.

A very important parameter for checking the condition of high-voltage electrical installation elements is the measurement of insulation resistance. The control voltage during insulation measurements 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.

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 for:

- Measuring the resistance of traction battery modules
- Charging and discharging traction battery modules
- Checking the tightness of the traction battery housing

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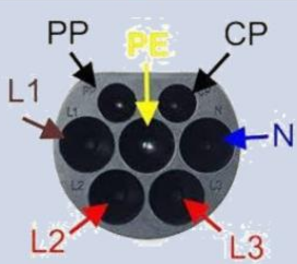
Devices used for computer diagnostics

The need to read information from controllers, erase errors, program basic settings, perform operation tests, view current parameters, read the so-called frozen frames, switch on appropriate operating modes, the possibility of their configuration, coding and many others require the use of devices compatible with a given vehicle system. However, companies producing electric vehicles limit access to many functions of the vehicle's control system.

Car testers that exist 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 an electric vehicle's repair and its brand.

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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EVTECH

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