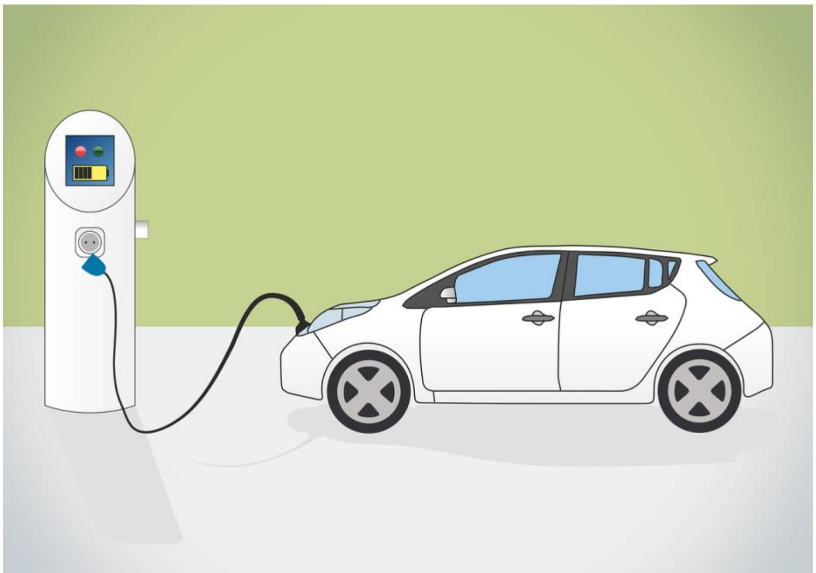
Sustainable Energy Solutions for Islands

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION



E-Mobility

SIDS DOCK in cooperation with PCREEE, CCREEE and ECREEE.
Developed with key technical support of UNIDO and CIEMAT.
With the financial support of AECID and ADA.

Contenido

Module Objectives

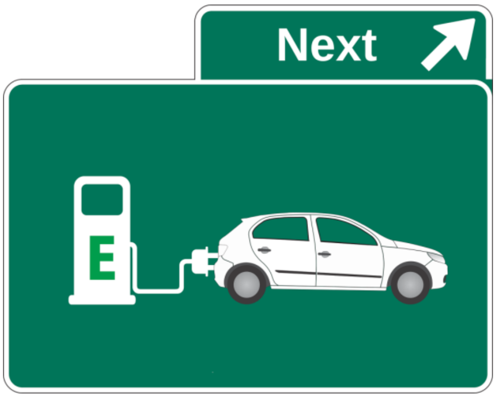


Figure 1. E-Mobility

General objective

The main objective of this course is giving a knowledge in the electric mobility solutions and technologies focused in the region.

Specific objectives

- Knowledge of basics and working principles of the constitutive parts of electric vehicles.
  - Energy storage, Batteries, Electric motors, Control electronics, Chargers, Mechatronics.
- Knowledge of the different vehicle alternatives and characteristics.
  - Bicycles, motorcycles, light cars, cars, buses.
- Comprehension of charging of electric vehicles
  - Charging process, modes, plugs and connectors
- Understanding of the existing electric network, related to electric vehicles.
  - Knowledge of the existing electric network.
    - Generation, transportation, distribution and consumption.

- Comprehension of the integration of e-mobility in the existing electric networks.
- Knowledge of the future of Smart Networks.
  - Distributed generation
  - Management and integration of Smart electric vehicles.

E-Mobility Why?

Global Climate Change

The Earth climate has changed over great periods of time, glacial periods and warmings have happen over millions of years, but in recent decades the earth climate has changed due to human activities. The term used in recent times to refer to the anthropogenic forced change may be "global warming" or "climate change".

The causes are diverse, from natural events to anthropogenic ones. However, the anthropogenic (e.g. increased emissions of greenhouse gases and dust), are the ones that humans can change and decrease.

The effects of global warming are over the weather, the sea levels, the global average temperature increases and the melting of the continental and sea ice.

In figure 2, the temperature increase over the years. Some of the meteorological agencies show that the global temperature has increased over one Celsius degree in the last years.

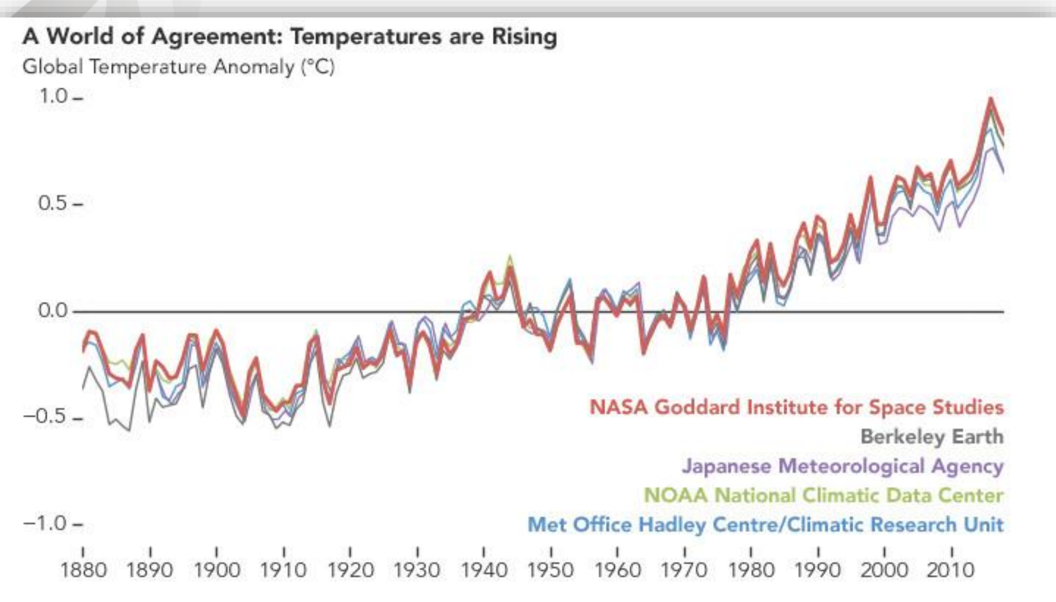


Figure 2. Temperature change over recent years. NASA

The effect for the islands is the sea level rising, shown in figure 3, which for some islands may mean flooding and sinking. For low-lying countries, it is a very high risk. Some island have disappeared for example, five Solomon Islands.

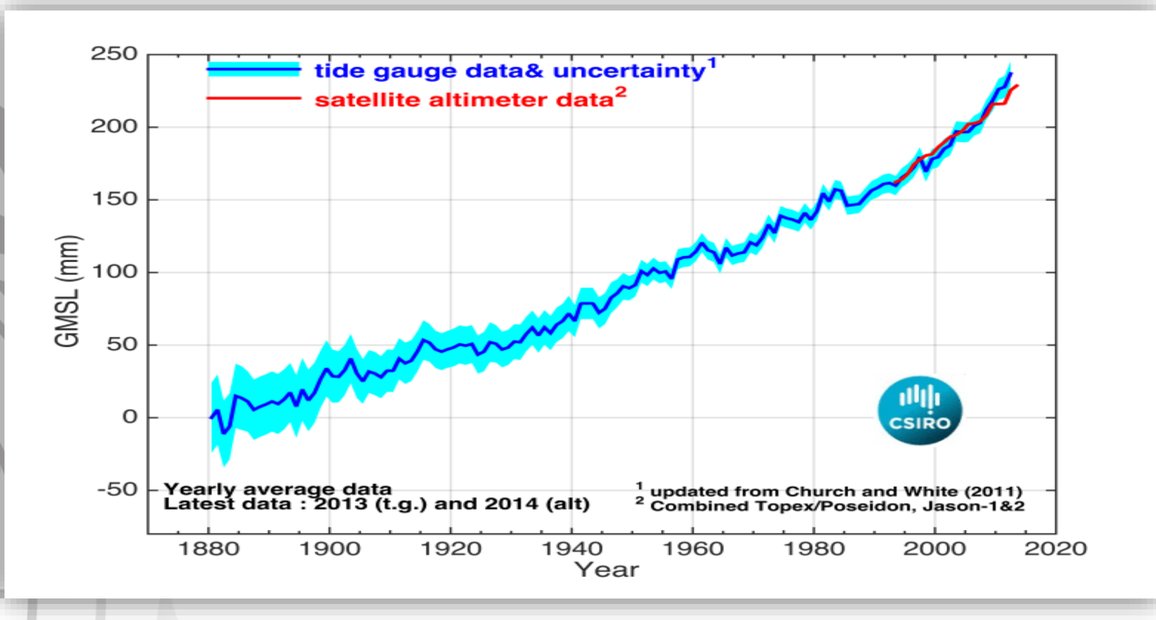
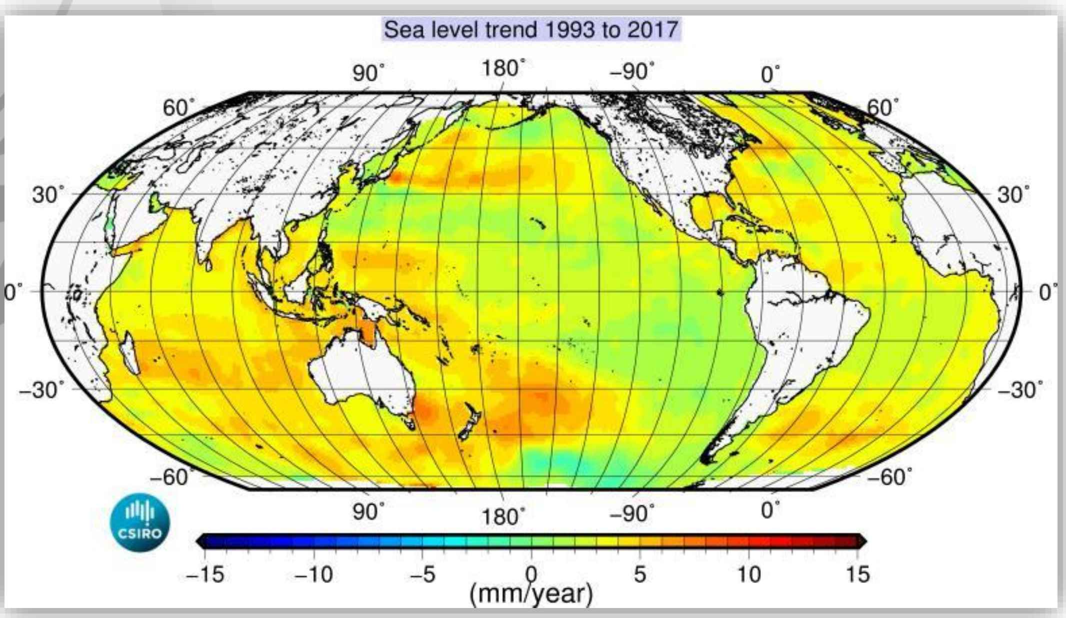


Figure 3. GMSL. Global Mean Sea Level increase in mm. (CSIRO)



This is a consequence of the greenhouse effect produced by CO_2 emissions.
There are more reasons for using less carbon mobility solutions:

- Improve Human Health and Air Pollution
- Less Particles and less NOX, CO2

- Decrease Global Warming
- Less water sea levels rising
- Improve Local economics
- Lower Cost with renewable energies
- Local industries improvement and employment
- Less dependence of fuel imports from outside

Therefore, E-mobility combined with electric renewable sources are one of the best solutions to solve, or decrease the consequences of this situation.

1. Electric Vehicles constitutive parts

Firstly, when we talk about electric vehicles (EV), we are talking about vehicles that use electricity to produce movement.

In electric vehicles, there is an energy storage element on board and electronics is used to control the movement of the whole system. This chapter explains the constituent parts of an EV and the relationship between them, focusing on the elements that differentiate this class of vehicle from the others.

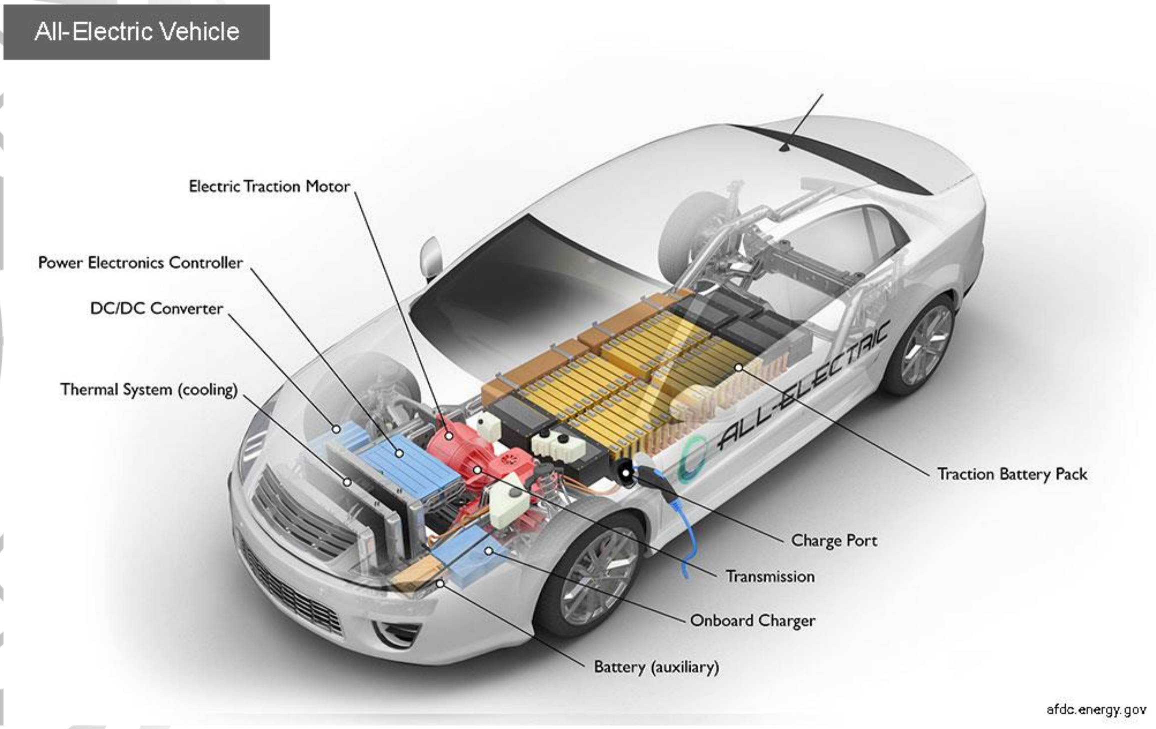


Figure 4. EV vehicle parts in place (Wiki).

In Figure 4, you see an X-ray view of the constitutive parts of an electric car showing the placement of the different parts of it. The bigger part of an EV is the energy storage element, which in that Figure is the battery. The motor is an electric one and its size is smaller than the equivalent of combustion. The cooling system is smaller, than the equivalent of combustion, due to the higher performance of whole system including batteries, power electronics and electric motor.

In Figure 5, you see the schematic description of the EV parts:

- Energy storage (battery is the most used nowadays)
- Power electronics control
- Electrical Motor, EM
- DC/DC converters
- Battery Charger

- Mechatronics.

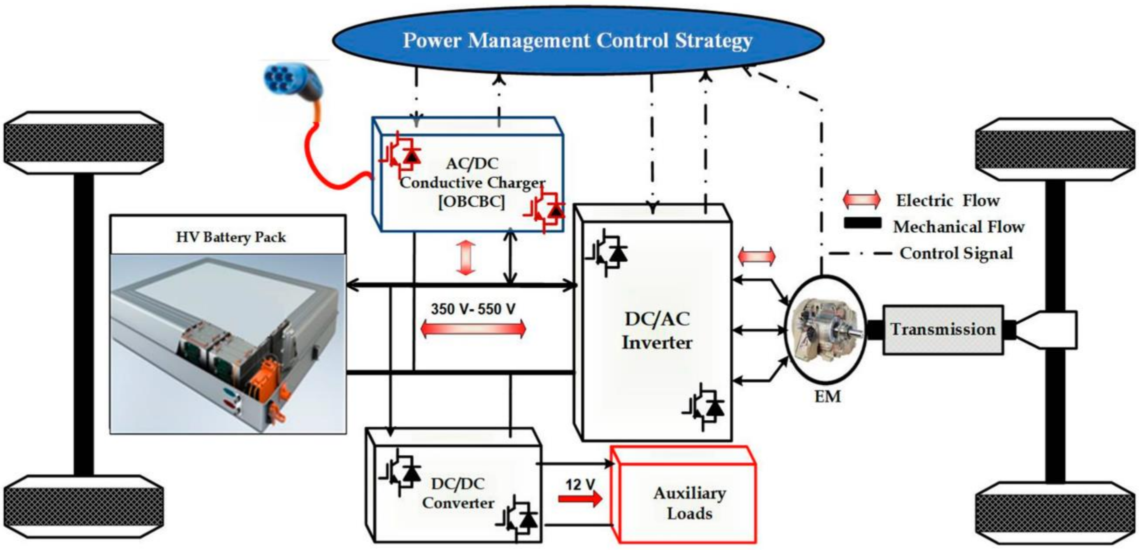


Figure 5. EV Parts schematic

Therefore, you are going to discover the different parts of an electric vehicle.

1.1 Energy Storage

An electric car moves using the energy storage in some kind of reservoir. The combustion cars use fuel storage in a fuel tank. In an electric car, there are other devices that storage electrical energy that will be used later by the electrical motor to obtain the desired movement, speed and acceleration. Now we will see different alternatives to storage energy in an electric car

1.1.1 Batteries

Electrochemistry

The most used electrical energy storage devices are batteries, and nowadays there are a dominant technology related with Lithium (this is the lighter metal in nature) because of the high reactivity of lithium (is an alkaline metal), and its low weight. But these are low voltage devices, in the volts range (3-5V).

Batteries use a reversible redox chemical process, are electrochemical devices, and because of its chemical nature, have a great dependence of the temperature.

The chemical process uses one cathode (negative terminal), one anode (positive terminal) and the electrolyte (normally in liquid or gel state).

Cathode is normally made of graphite, anode is made in with a compound of lithium, and the electrolyte normally consists of lithium salts in an organic solvent.

Different compounds of lithium make different families of lithium batteries.

Ions (cations) flow through the electrolyte and the electrons flows through the electrical circuit closing it, and making the energy flows.

In charge mode the chemical process behaves in the opposite way than in the discharge process. Charge mode storages energy in the chemical process, the electrical current, flowing from the charger to the battery, makes that the chemical process storages this energy.
When the circuit behaves as source, the energy stored in the chemical process dissipates in the electrical load, ions moves in the opposite way and the electrical current flows through the circuit as shown in Figure 6.

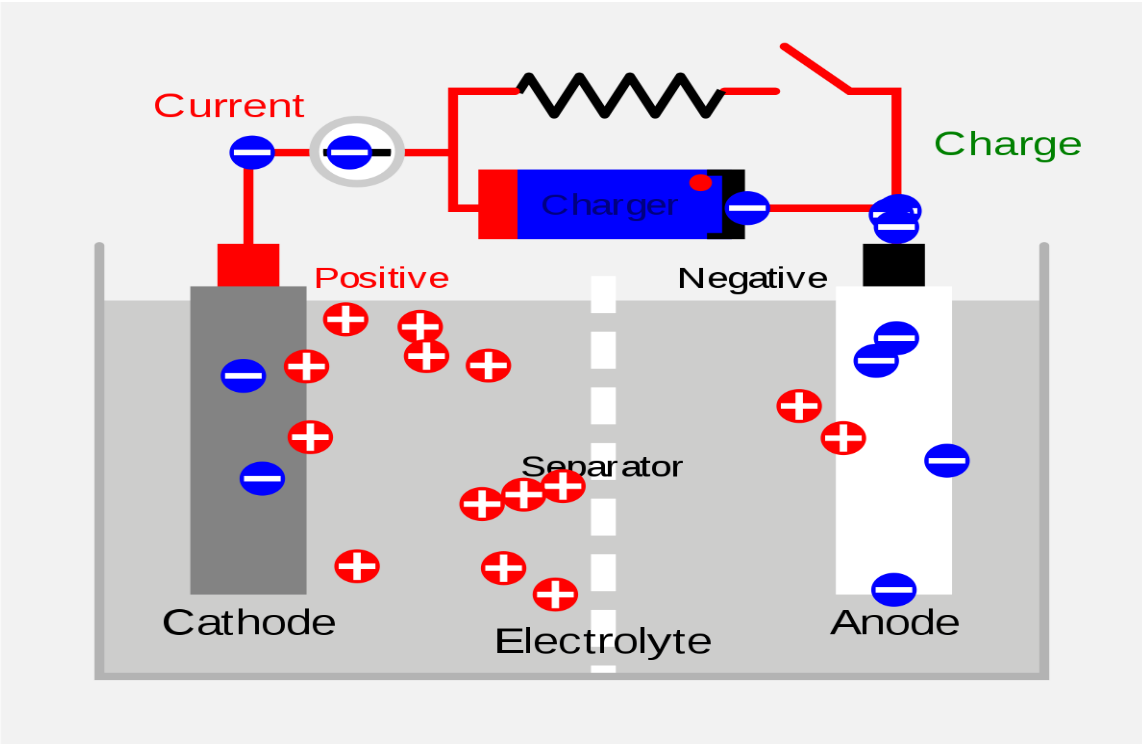


Figure 6. Batteries, working principles

Battery modules

As single module storages low voltage, low current and low power, they must be arranged in series/parallel combination modules. You can obtain hundreds of volts and amperes-hour, providing Kilowatts of energy storage (Figure 7).

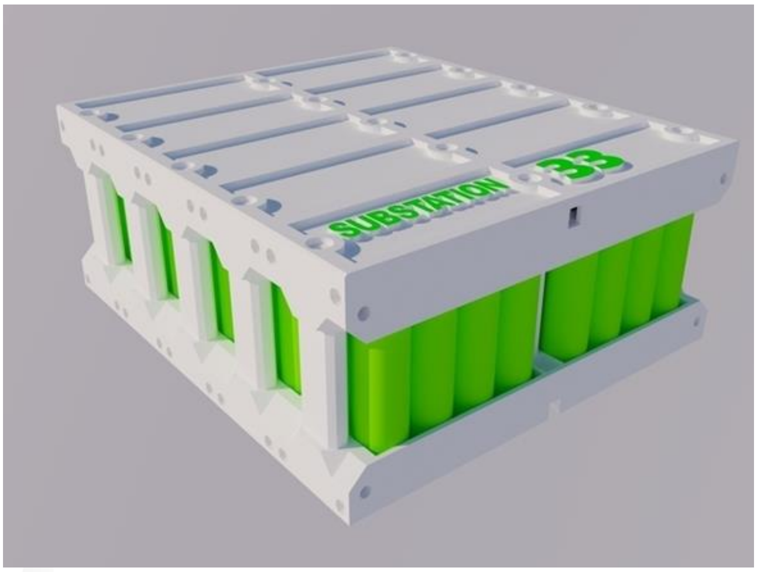


Figure 7. Battery Module

Packs of modules, in series/parallel configuration, provides higher voltages (48V, 96V, 252V), higher Charges 100Ah, 200Ah, and consequently higher powers 22Kw, 44Kw.

Battery technologies

There are a high number of battery types and chemistries, but here we will see only the most used ones:

- Lead–acid battery
  - Used in the past for traction applications.
  - Nowadays used as auxiliary batteries.
  - Low weight/capacity ratio (33-42 Wh/kg)
- Lithium batteries,
  - LiPo (100-265 Wh/kg), but safety concerns.
  - LiFePo4 (90-110 Wh/kg)
  - High Weight/capacity, security, low price, State of the art batteries.

Lithium batteries properties:

- There are the actual dominant technology
- Lithium as Low Weight, High electronegativity, alkaline metal.
- Lithium metal or compound as anode
- Security issues, liquid electrolyte.
- High performance power capacity/weight ratio
- Price is an issue.
- Different chemistries and characteristics.

The next table summarizes the different battery chemistry technologies, indicating year and characteristics for each Lithium battery type.

Table 1. Lithium battery types and acronyms

Acronym	Technology	Year	Characteristics
NMC	Lithium Nickel Manganese Cobalt Oxide	2008	Good specific energy and specific power density
LMO	Lithium Manganese Oxide	1996	
LFP	Lithium Iron Phosphate	1996	Moderate density (2 A·h outputs 70 amperes) High safety compared to Cobalt / Manganese systems.
LiCo	Lithium Cobalt Oxide	1991	High specific energy
NCA	Lithium Nickel Cobalt Aluminum Oxide	1999	High specific energy, good life span

Other aspects and characteristics of battery modules are nominal voltage and current and nominal storage power. In charging and use conditions, SOC (State of Charge) indicates, in working conditions, the remaining available storage power in the battery and SOH (State of health) shows the longevity status of the battery, the health of the battery, showing the actual charging capacity versus the nominal value. As a battery ages, by cycle charges, temperature and other stress factors, the longevity of the battery and the actual capacity are reduced.

1.1.2. Fuel-Cells

Fuel cells are chemical power storage that combines fuel and oxidant without burning it. In fact, the energy storage is done in the fuel and oxidant. The electrical energy production process is done in a Cell. The Cell combines the fuel and the oxidant by producing electricity and the combined chemical product. Using Hydrogen (H_2) and Oxygen (O_2) the result product will be water (H_2O).
They combine the elements through a proton exchange membrane, and the process produces electricity continuously. As Hydrogen does not exist free in nature, it must be generated first by electrolysis. The Cell has an anode, positive terminal, a cathode, the negative terminal, and one proton exchange membrane; normally the anode and cathode are made of Platinum, a very expensive metal. The fuel tank, that storages the hydrogen (oxygen is taken from air), can be of various types, pressurized gas (about 200-300 kg/cm²), cryogenic liquid form, or chemical storage (dissolving H_2 in salts). The performance of a fuel cell is lower than lithium batteries, and is more expensive. However, it has more energy capacity storage for the same weight and volume.
The whole storage process from electricity production, hydrogen generation with an electrolyser has a 60% of efficiency and electricity generation from hydrogen in the fuel cell, has an average

performance of 60%, so the overall process has a performance of about 40%. Batteries have overall performance of 80%.
Therefore, the future of this technology is not clear, and there are criticism related with the difficulty of production, storage of hydrogen, efficiency and high costs of fuel cells, compared with other electricity storage technologies, like batteries.

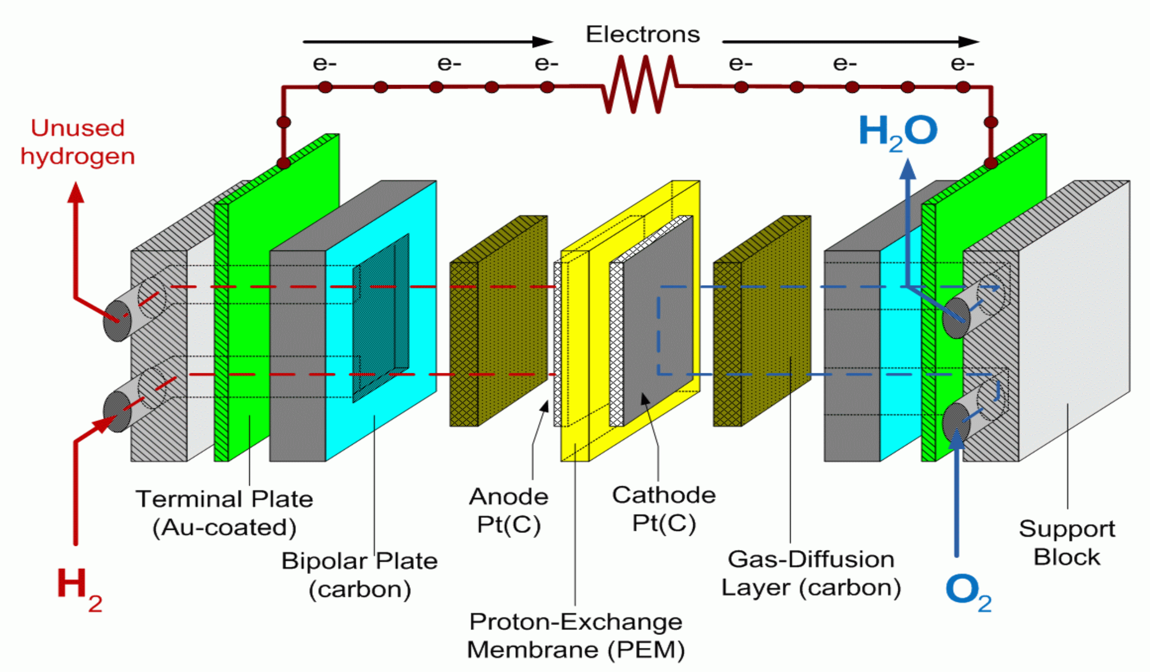


Figure 8. Fuel Cell, working principle.

1.1.3 Super Capacitors

Just as the present belongs to Lithium batteries, the future is for super capacitors (SC). A basic super capacitor usually consists of two metal plates, separated by an insulator. During charging, electrons accumulate on one conductor and depart from the other. One side gains a negative charge while the other side builds a positive one. So there is not chemical reaction, electron accumulates in one of the terminals.
Electrochemical supercapacitors contain two metal plates, only coated with a porous material, activated carbon. They are immersed in an electrolyte made of positive and negative ions dissolved in a solvent. One plate is positive and the other is negative. The Figure shows the working schematics of a supercapacitor, in charging mode. Changing power source by a load reverse the current discharging the supercapacitor.
Voltage drops as the supercapacitor discharges and increase as the supercapacitor charges. The storage energy follow the following formula, where E is the electricity stored, energy in watts, C is the capacity in Farads, and ΔV^2 is the Voltage drop in volts.

$$E = \frac{1}{2} * C * \Delta V^2$$

The capacity of one supercapacitor is in the order of hundreds or thousands of farads. This is a very huge capacity compared with *normal* capacitors with a micro farads range.

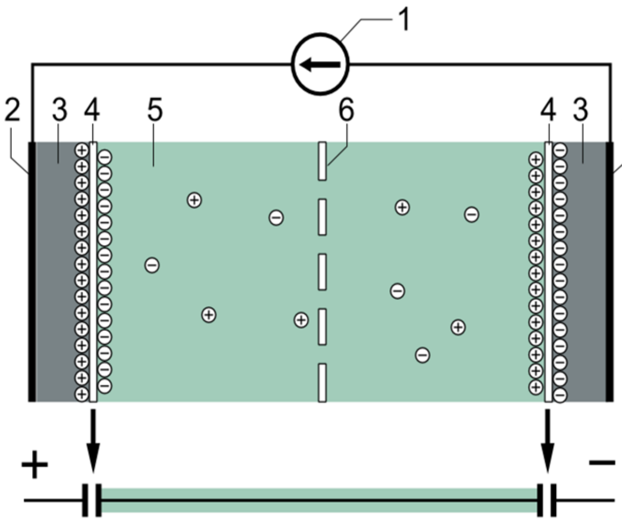


Figure 9. Super capacitor working principle.

Legend: 1.Power source, 2.Collector, 3.Polarized electrode, 4.Helmholtz double layer, 5.Electrolyte having positive and negative ions, 6. Separator

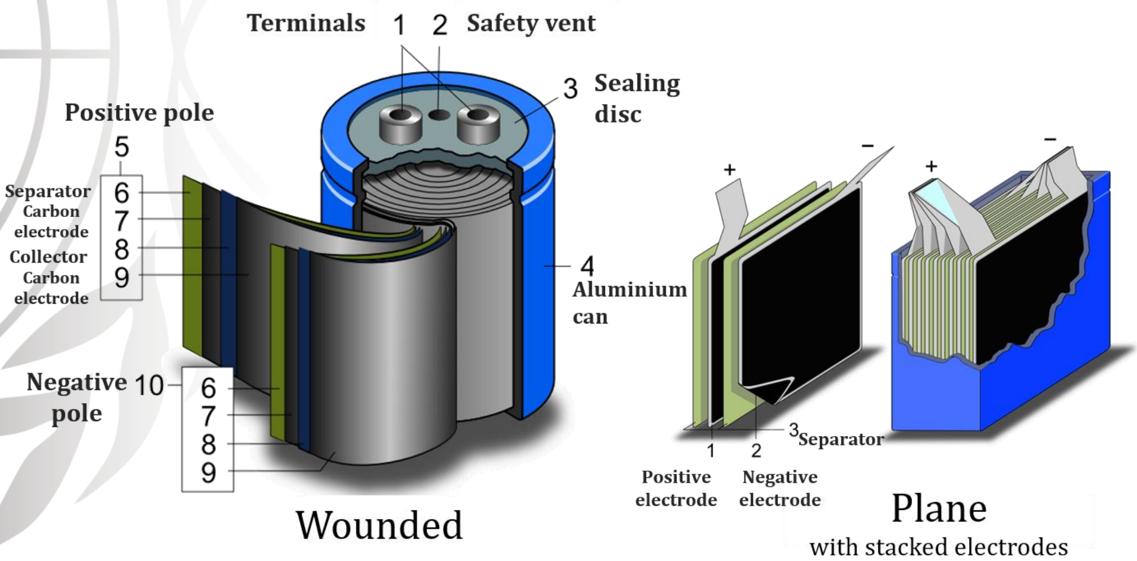


Figure 10. Construction details of a wound (left) and stacked (right) supercapacitor.

Legend: 1. Terminals, 2. Safety vent, 3. Sealing disc, 4. Aluminium can, 5. Positive pole, 6. Separator, 7. Carbon electrode, 8. Collector, 9. Carbon electrode, 10. Negative pole

Energy density is higher in supercapacitors; they can storage about 1500W/kg and batteries can storage about 150 W/kg and the efficiency of a SC is higher.
However the price of a SC is high and since is it not possible to make supercapacitors modules capable of energy storage in the tens of kilowatts range, therefore it is not possible to actually make an energy storage pack for an electric car.

Supercapacitors are widely used in electric mobility, not only for main energy storage, but also for auxiliary process; giving instantaneous power, and energy storage as a buffer, for its speed, giving high currents when demanded.

1.2 Electric Motors

Electric motors are the element of an electric vehicle that transforms electrical energy in mechanical energy providing rotary movement and when coupled to the wheels, the wheels provide the movement. The motor provide torque and rotational speed that must be mechanically converted into force (acceleration) and speed. Electrical currents flowing through the motor provide a rotational torque and speed. The efficiency of an electric motor is very high; the actual technology allows having motors with an efficiency near a 95%. That means that the mechanical energy that provides the motor is a 95% of the electrical energy, taken from the battery. A good combustion motor does not have an efficiency more than a 30%. In addition, an electrical motor provides less heat, so engine cooling devices are small.

1.2.1 Working principles

An electric motor uses electricity and converts electrical energy into mechanical energy. In the interaction between magnetic field and electrical current, Lorentz Force is the basic working principle. So the force **F**, in Newtons, acting on a particle of electric charge **q**, in coulombs, with velocity **v**, in meters per second, $\vec{B}$ is the external magnetic field in Teslas, and electric external field E, in Volts per meter, all of them are given in SI units:

$$\vec{F} = q * (\vec{E} + \vec{v} \times \vec{B})$$

Where $\times$ is the vector cross product. Normally in a motor the electrical external field is not used, motors that use it are electrostatic motors, and must be operated at high voltages and are not very practical. Current motor technology uses magnetic Field and current (moving charge), so the former equation transforms into:

$$\vec{F} = q * (\vec{v} \times \vec{B})$$

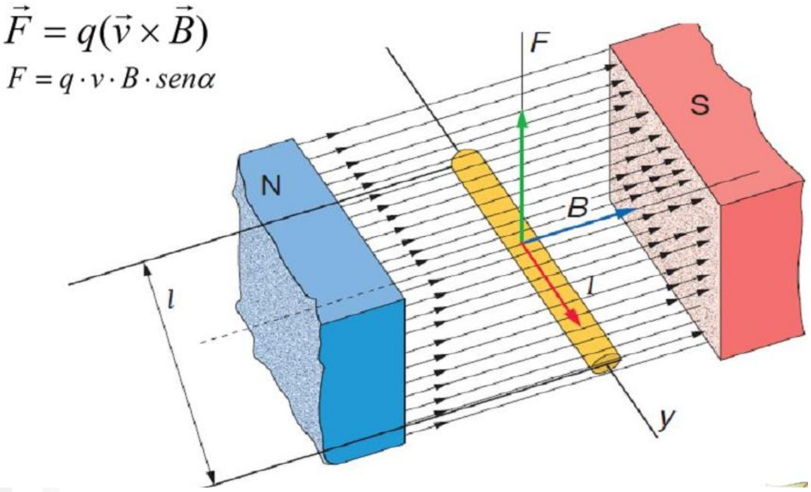


Figure 11. Lorentz Law.

And the modulus of the force vector is given by the following equation, the angle between the moving particle and the magnetic field is proportional to the sine of the angle, so an angle of 90º sexagesimal degrees, provides the maximum force.

$$F = q * v * B * \sin\,\alpha$$

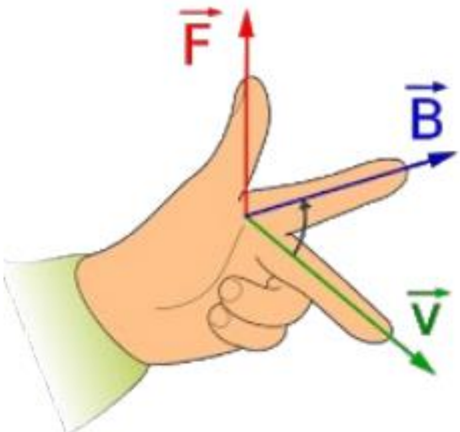


Figure 12. Left hand Rule, for magnetic motor force.

Left hand rule shows the direction of the force, providing the charge speed (current) and the magnetic field.

When using a current, current is a charge in movement, in a rotary arrangement, as shown in figure 13.
The figure shows the process: there is a magnetic field from right to left, (blue vector), the horizontal left wire (yellow) has a force F acting in the red sense and in the right wire the force is in the opposite sense, downside makes the loop to turn, by the torque provide from the forces of each wire. The other wire (yellow) makes the loop do not contribute to the movement.

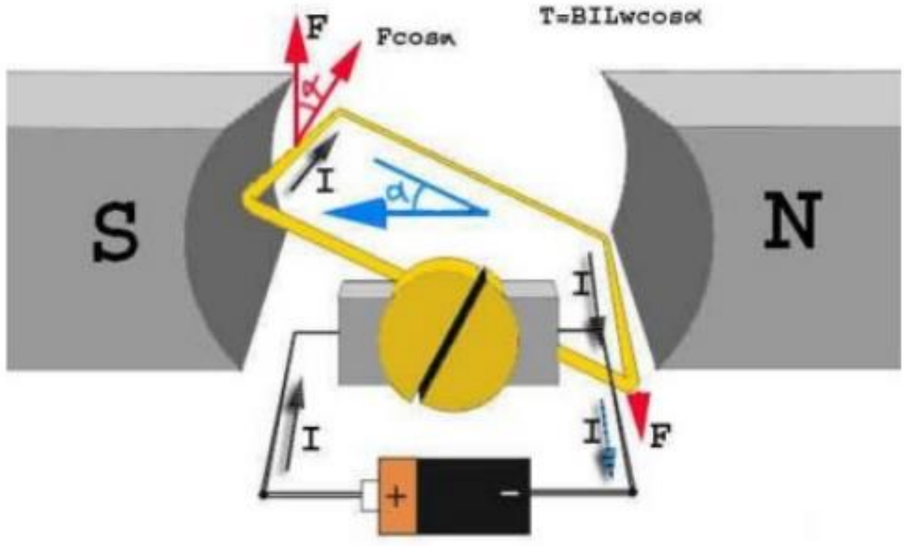


Figure 13. Basic rotary magnetic motor working principle.

1.2.2 Electric motor characteristics.

In an electric motor, there are some characteristics that must be given to select and compare with others:

- Electrical and mechanical characteristics:
  - Motor type (AC, DC, induction, synchronous, asynchronous, PM, BLDC...)
  - Nominal electrical power, electrical power needed for nominal working motor
  - Nominal Current, nominal current at nominal Torque
  - Nominal Voltage, nominal voltage at nominal speed
  - Rotational speed at nominal voltage, rpm
  - Maximum values of current, speed, and power.
  - Torque versus speed curve, speed in X axe torque in Y axe.
  - Safe operating area (SOA)
  - Efficiency

1.2.3 Motor types

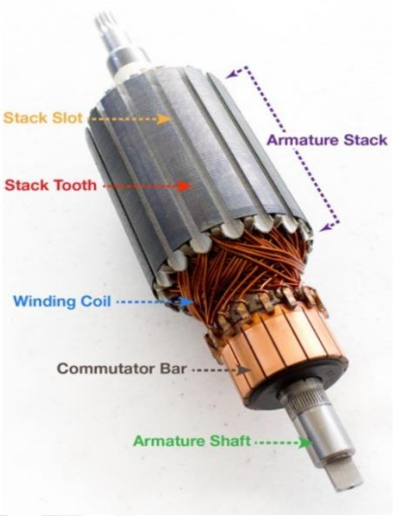
There are a great diversity of electric motor types, but we will show the most used in electric vehicles. One classification comes from the electricity type used for driving the motor, so DC (direct current motors) and AC (Alternate current motors). Others classifications take into account other characteristics, the commutation type, self-commutated, brush versus brushless and synchronous machines versus asynchronous machines and with permanent magnets or without them.

The most used motors in traction (electric vehicles) could be:

Motor Type	Control and use	Pros	Cons
Universal Motor	AC/DC for low power applications,	High Torque, no magnets,	Low efficiency, difficult to change direction, Heating, use brush contacts, high maintenance
Brush DC Motor	DC from low to medium power applications	Easy control, Cheap control and use. generator	Use rare earth magnets, use brush contacts, high maintenance
Synchronous AC	AC, vector control, High Power applications	High power, high control at low speed, AC Generation	Expensive. Use rare earth magnets, difficult to make
Squirrel cage AC	Ac, vector control, low to High power applications	No magnets, easy construction, Very cheap, low maintenance high mileage	Needs an advance electronics controller. Difficult to control at low speeds.

Universal motor
Used in low power traction electric vehicles as golf cars or electric domestic appliances like electric screwdriver, mixers, it is a universal motor and can use AC or DC electric current. It has a high torque because the windings of the stator and the rotor are connected in series. To change rotation it must change the serial connection between rotor and stator, and the control is not easy. For electric vehicles is not used, except in rare electrical vehicles. It also has brushes, so for heavy use it is not recommended. But it is very cheap and easy to make, and does not have magnets.

Brush DC Motor
This motor type is used for small powers, it is very simple to build and control, the rotational speed is proportional to the mean applied voltage. The torque is proportional to the flowing current. Commutation is mechanical through brushes, with a collector. The rotational speed must be maintained low and brushes has a low life, and must be changed in intensive applications. There are widely used for auxiliary operations as little actuation motors.



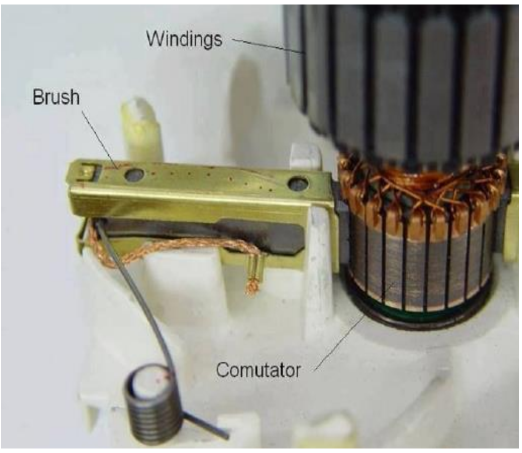
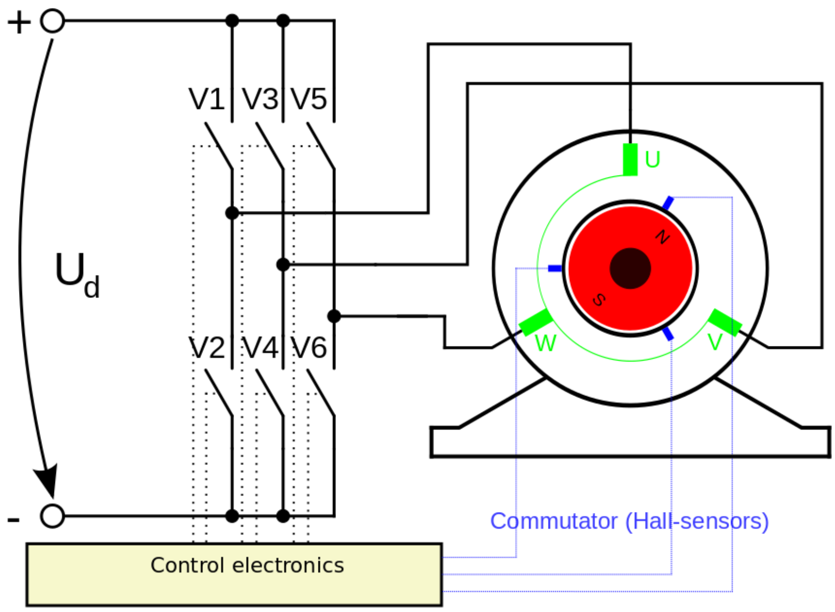
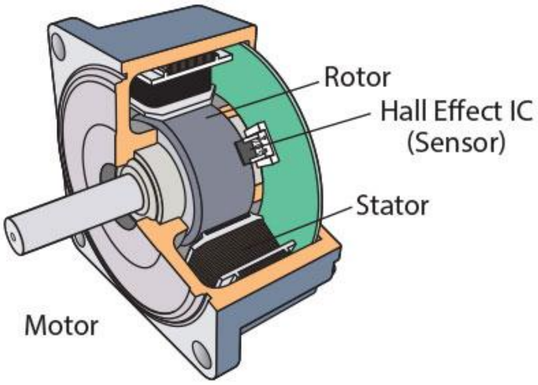


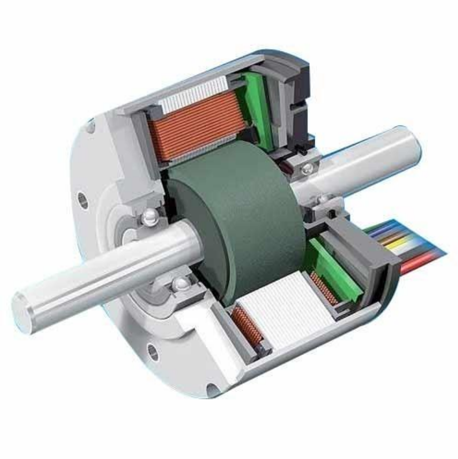
Figure 14.Constitutive parts of a DC motor

BLDC motor

This motor is a permanent magnet, high density power, expensive because of the use of strong magnets made of neodymium, easy to control, without brushes (Brushless Direct Current motor). More expensive that other alternatives but widely used for scooters, electric bikes, and also in electric cars and motorcycles. The control electronics are very easy to build. They allow high speeds, high torque at low speeds, and a big operating area. The main problem is related with high magnetic field magnets made of rare earth neodymium, very expensive. In the figure rotor is made of permanent magnet bars, and stator is made of coil windings, so heat can be dissipated in the exterior part of the motor. Three hall sensors detect the position of the rotor, to actuate accordingly trough the electronic commutator.



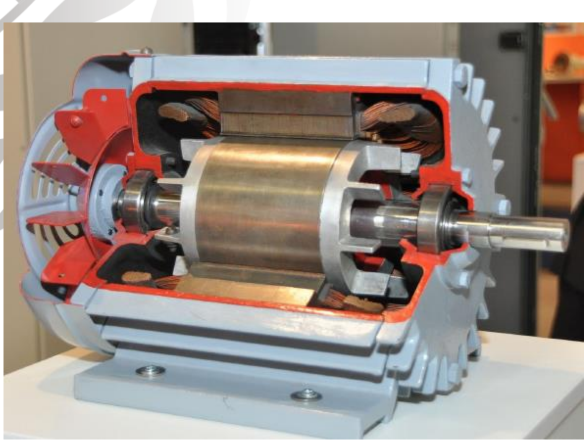




AC asynchronous induction motor, squirrel cage motor

Other motor widely used is the AC asynchronous motor, it is called squirrel cage motor, it was invented by Nikola Tesla, and does not use brushes nor magnets, so it is very easy to build and cheap, and it has a very long live working. It consists of a stator made of copper windings that creates the magnetic field and a rotor made of short circuit rings, as it were in a squirrel cage. The AC asynchronous motors do not have magnets and BLDC has them. AC motors need to be fed with an AC signal, in high power motors, normally a three-phase AC signal, and with a complex controlling schema. Power electronics and integrated microprocessors make AC motor controller more used using VFD (variable frequency drive).

Heat is dissipated in the outside, and density power is less that BLDC motors, but this AC motors are cheaper and easy to make. Some electric cars have AC asynchronous motors and other have BLDC motors. In the figures, you will see the windings outside in the stator and the short-circuited ring and bars in cage of the rotor.



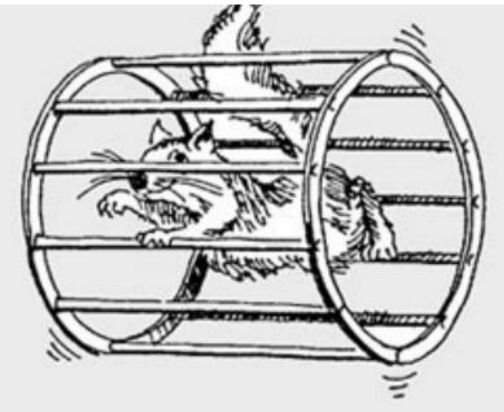
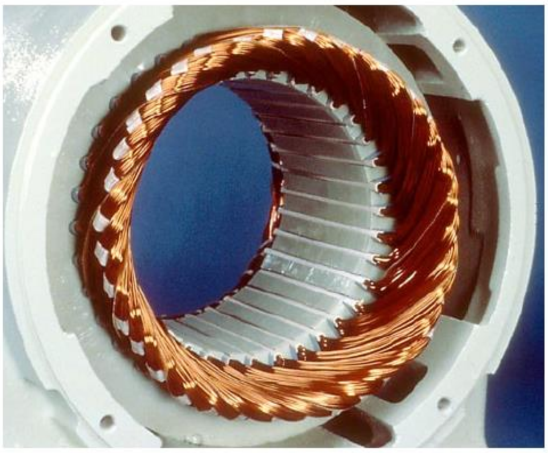
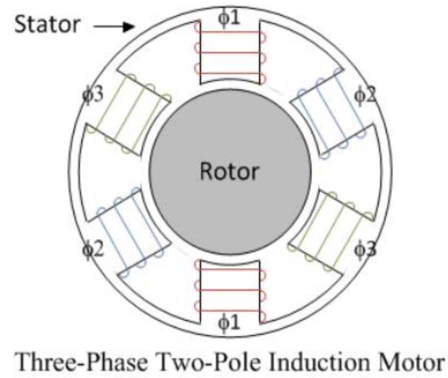


Figure 15. Constitutive pars of AC motor.





1.3 Control Electronics

Control electronics are the elements that make the electric vehicles controllable and efficient. The new power electronics semiconductors, like power MOSFET and IGBT (Insulated gate bipolar transistors), allow a high efficiency for the control with low commutation losses.

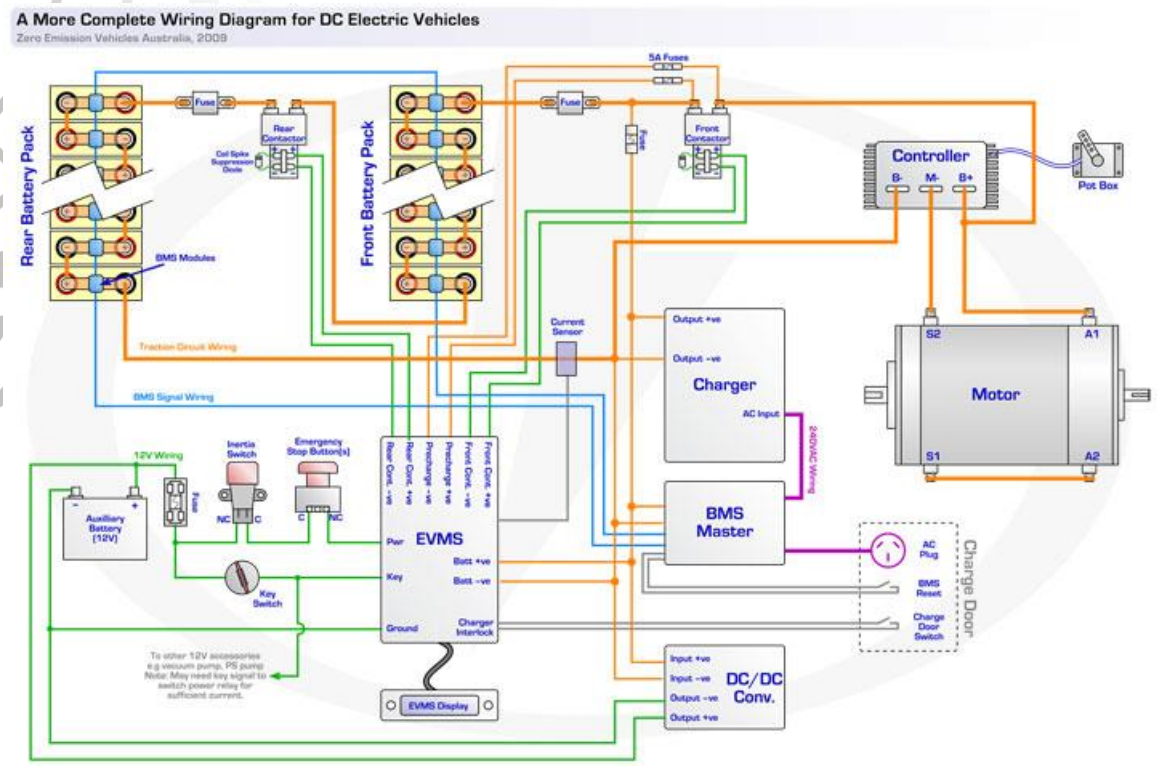


Figure 16. Electric car wiring schematics.

Figure 16 shows electric car wiring schematics with power electronic modules and auxiliary electronics, with security devices. This is a schema of the connections and principal elements of

an electric generic car, orange wires show the high voltage, high power connections (physical wires carrying high voltage and currents must have this orange colour).
So energy is storage in batteries and when charging, the charger takes energy from the electric network system and injects it into the batteries at the proper current and voltage rate over time. BMS supervises the charging process, providing equalization, maintaining each battery module under limits. BMS also supervises the discharging process and the regeneration charge.
The energy storage in the batteries goes through the converter to the electric motor; the converter takes control signals from the driver, like throttle and brake among others, and modulates the electric motor behaviour, which provides speed and torque to the wheels.
A DC/DC converter, provides auxiliary energy for other circuits like lights, displays, ABS, ESP, electrical assisted steering and brake, also it charges the auxiliary battery normally a standard 12V system.
There are also security devices like fuses, contactors, and inertial switch, avoiding great overcurrents or fire in case of short circuit in car crash accident.

1.3.1 Power electronics elements

There are some elements that contribute to the rise of the use of electric vehicles, and some of them belong to power electronics. The use of MOSFET and IGBT of high currents and High voltages, at a low price, allow the construction of power controllers capable of managing from Kilowatts for small e mobility devices as scooters to hundreds of kilowatts to control electric cars.
Also powerful IC with high computing power and low consumption allows the use of complex control algorithms needed to run the complex AC motors.
In addition, power electronics provides charge to the batteries and battery management systems (BMS) in order to maintain the battery healthy and in proper SOC (state of charge).
Therefore, the elements used always in an electric vehicle are the inverter, the charger, the BMS, the control electronics, and auxiliary circuits. We will see in detail some of these modules. There are also some auxiliary modules for other functions as ABS, ESP and other systems, but these auxiliary electronics exist in all type of cars.

1.3.2 Inverters

Inverters are other of the elements than, combined with the electric motor, form the traction module. Normally these power electronics are placed near the electric motor, and they are connected to the motor with big wires, because of the high currents flowing from the inverter to the electric motor. The inverter takes energy from the battery in DC form and transforms this energy from the battery to the voltage and in the way needed by the electric motor. If the motor is three phase AC induction motor the inverter converts the DC voltage from the battery into three phase Ac power signals that drives the motor with the frequency, voltage and current needed. The efficiency of this electronics is very high near 95% in advanced drives. Also the signals coming from the driver modulates the power signals giving the desired power, torque and speed to the motor. Also other control signals coming from the motor, voltage and currents, speed and position of the rotor, give the feedback signals needed for a right motor control. In some cases, when the motor brakes, it takes this energy recharging the battery, so inverter also makes regenerative braking, taking this kinetic energy transformed in electrical energy and injecting into the battery.

The power electronic components used in inverters are MOSFETs for medium voltage (under 200V) motors and batteries and IGBTs for higher voltages (over 200V). These power devices have low losses giving a high efficiency to the inverter, between 90-95%.
Scooters and other personal electric transportation vehicles are cooled by air flow, but in electric cars is water cooling combined with the electric motor cooling. The cooling system is considerably smaller than the equivalent combustion type.

1.3.3 Chargers

Charger is electronic device that takes energy from the electrical network, and injects it into the vehicle batteries. It can communicate with the electric network, and always communicates with the BMS, for injecting the energy at the proper current and voltage range. The efficiency of this module must be very high near 90-95%, and must modulate the charge taking into account time, battery characteristics. In some advanced smart charging modes, it can communicate with the electric network and charge the battery taking into account different strategies like charging when cheaper energy is available, or at a high rate for quick charge.
If it is connected to AC networks, first it rectifies the signal transforming it in DC, then stabilizes it and after, transform it with a DC/DC converter into the appropriate voltage and current charging levels, and stop charging when batteries are charged at the specified SOC level. Also, in smart modes, it can start/stop charging at specified times, and taking the proper energy from the electric network.

1.3.4 BMS

Battery management systems (BMS) are connected to the batteries modules and to the charge/discharge systems, in order to maintain the health of the modules, avoiding overcharge and undercharge each module. BMS measures voltage, current and temperature of each module or group of them, and activates or deactivates the charging/discharging process of each module maintaining the health. BMS gives the SOH (State Of Health) of each module group, extends the operating number of charges and lowers the aging of the battery. Also controls the refrigeration/heating of the battery module to the appropriate levels.

1.4 Mechatronics

There are other mechanic elements inside an electric car, normally combined with an electronic controller. For example, electrical steering assistance, ABS brake or ESP. Therefore, there are a large amount of mechanic elements coupled with electronics, not only for vehicle movement but also for driver and occupants comfort. Electric assistance brakes combines electronics with mechanical actuators, and in the future the activation of steering, brakes and other parts will be by wire. So control by wire, also in security parts of the vehicle will be the standard.
It will allow more efficiency, for example, electric motor will brake the car in many occasions but if an emergency brake is needed, the friction brake will be activated. If the car becomes smart and if the car detects some obstacle, it could brake automatically, without human command.
In addition, electric vehicles combined with mechatronics allow the use of autonomous cars; it is very easy to automate an electric vehicle with mechatronics parts.
Therefore, there are many mechatronics parts in an electric vehicle more than the combustion equivalent vehicle. In personal transportation devices, scooters or other small devices there are less mechatronics parts, but in electrical vehicles like cars, trucks, or vans the number of mechatronic devices increases. In fact, in a near future, all of the mechanical parts will be

mechatronic parts including the main steer, brake, and suspension functions. Wheels also could be monitored, for pressure, aging. In trucks, for example, there are systems that inflate tyres and wheels depending of different factors, like weight, temperature, tyre status and aging.

Therefore, the near future in electric vehicles integrates all mechanical parts with electronics, so when using them they will be mechatronic parts.

Resume of Chapter 1

An electric car is made of different parts and subsystems:

- Energy storage (battery is the most used nowadays).
- Power electronics control.
- Electrical Motor, EM.
- DC/DC converters.
- Battery Charger.
- Mechatronics.

The energy storage is one of the most expensive parts of the car, and efficiency is one of the primary goal to achieve for all of the electric car elements. You can consider an electric vehicle is a battery with an attached motor and electronics. In fact, there are many elements that contribute to safety, and other important vehicle functions.
Therefore, modelling energy storage, for Island electrical network integration could simplify the car for dimensioning the energy storage and charge elements. This will increase the efficiency in using and transform the energy taken from electrical island network.

Talking about energy storage, Lithium batteries of different types are the actual dominant technology. In near future supercapacitors will probably appear as auxiliary power technology or substitute to batteries. Batteries must be used with care and BMS (battery management systems) must take care of the batteries charge and discharge process to maximize efficiency and longevity for the battery. Quick charges and discharges, deep discharges (bellow 20%) and overcharges over (80%), reduce the battery life, so battery charge must be made in several hours to avoid premature aging of the battery. Quick charge must be made rarely, in order to have a long life battery. When the battery capacity falls below 80% of nominal charge capacity, it must be changed. These batteries can be used in stationary applications as storage for electrical island network surplus, giving them a second life.

Electrical motors and power electronics constitute the traction part of the car. Neither clutch nor variable transmission gear ratio is needed in an electric car. These parts lower the efficiency of the traction part. So in electric cars electric motor is coupled to the wheels with a fixed gear ratio, with the minimum coupling elements. The total efficiency between battery electric power and the mechanical energy transferred to the road by the wheels could be near the 75%-80%; this is much higher than the combustion engine counterpart.

2. Electric Vehicles, alternatives

Electric vehicles have many implementations. There are personal transportation devices like scooters and Segway, electrical bikes, electrical motorcycles, cars, vans, buses and trucks. In this classification, we will not include trains, tramways or other big collective transportation systems that do not carry energy storage (batteries).

Therefore, we will see different classifications, naming and acronyms related with electrical vehicles used in islands environments. In addition, we will include a short history about electric vehicles. We will put the focus in electric vehicles powered by batteries, used in islands.

2.1 Classification of electric vehicles.

One classification based on **use and size** of the electric vehicles give the following classification.

- Electric Personal transportation
    - little scooters
    - Skateboards
    - Electric bikes
    - Unicycles
    - Hoverboards.
    - Segway and self-balancing personal transportation type.
- Motorcycles
    - Lightweight motorcycles, scooters
    - motorcycles
- Light vehicles, without driving license.
- Cars
- Buses
- Trucks

The next figure shows photos of different electrical vehicle types

2.2 Past, present and future of EV's.

We can think that electric vehicles are new and have appeared recently, but it is not true. In the beginning of the cars, the electric vehicles and electric cars were a very good alternative until the internal combustion car improvement and fuel development. In the beginning of car history, in 1900, fuel was rare and very difficult to obtain, but there was electricity in more places that fuel, so electric cars were an option. However, Fuel improvement, petroleum finding and a poor battery technology (only lead batteries), made that in the following years, internal combustion cars dominated. The improvement in battery technology has made that electric cars could be a real thing.

Nowadays, a great range of different electric transportation solutions exists, including high end electric cars. Electric cars are no more small or low end cars. So in the near future there will be a substitution of internal combustion engine cars by the electrical alternative, also it will appear different electrical mobility solutions, lighter and cheap, more suitable for islands mobility solutions.

2.3 Types of electric vehicles.

This table shows the acronyms and type of electric vehicles. The suffix EV is combined with different prefix indicating some characteristics of these electrical vehicles types

ACRO	TYPE
EV	Electric Vehicle
AEV	All Electric Vehicle
BEV	Battery Electric vehicle
CEV	City Electric Vehicle
NEV	Neighbourhood EV
NZEV	Neighbourhood Zero Emission EV
LEV	Light EV (quadracycle)
HEV	Hybrid EV
PHEV	Plug-in Hybrid vehicle
H2EV	Hydrogen EV (Fuell cell powered)
FCEV	Fuel Cell EV

3. Charging of Electric Vehicles

One of the most important systems and processes in an electric vehicle is the charging process, mainly in battery-type electric vehicles. This process normally takes energy from the electrical network in the form of AC, and transforms it into an electrical energy suitable for charging the batteries, DC, with controlled voltage and current. In addition, there could be communication between the car and the electrical network, giving some intelligence to the charging process.
The charging point could have standard connections or dedicated charging points. In the case of a car, there are usually dedicated connection points, which can have different power and affect the charging time.
The international standards that regulate charge of electric vehicles are:

Conductive charge:

- Security; IEC-61851 "*Electrical vehicles conductive charge system"*
- Connectors: IEC 62196. "*Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicles"*
- Communications ISO 15118*. "Road vehicles-communication protocol between electrical vehicles and grids"*
- Electromagnetic Compatibility IEC 61000. *Electromagnetic compatibility (EMC)*

Wireless charge:

- IEC 61980 Wireless charging is under development, and IEC have published the IEC 61980 *"electric vehicle wireless power transfer (WPT) systems".*

In this section, we will focus in conductive technology, the actual dominant and more efficient charging technology.

3.1 Charging modes. IEC 61851-1

The International Electrotechnical Commission classifies charging modes (IEC 61851-1).

- Mode 1 – slow charging (AC) from a regular electrical socket (single-or three-phase) with a limit of 16A of charging current and 250V in single phase and 480V in three phase.
- Mode 2 – slow charging (AC) from a regular electrical socket (not specific for EV), with a limit of 32A of charging current and 250V in single phase and 480V in three phase (from 3,7 kW to 26kW of available charging power). It needs a special cable and control box, with pilot control and protections.
- Mode 3 – slow or fast charging (mono or three phase connection) using a specific EV multi-pin socket with control and protection functions (IEC 62196-2).
- Mode 4 – fast charging using some special charger technology such as CHAdeMO or Tesla supercharger, the charger is off-board, and charging is in DC 500V/125A, with full communications between VE and charge station, with control and advanced protection systems.

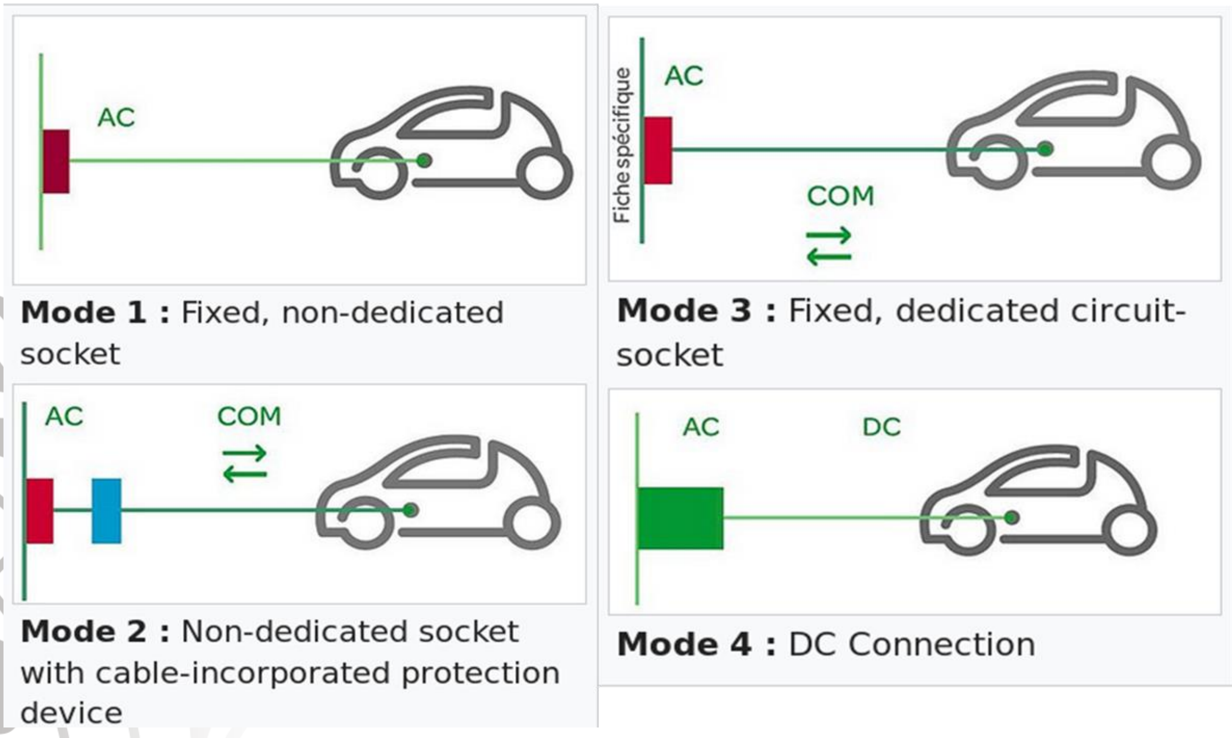


Figure 17. Charging modes. IEC-61851

3.2 Charging connectors and plugs.

3.2.1 Connector types IEC 62196-2

Type I: SAE-J1772 (Max 250V 32A mono phase) – widely use in Japan and USA. It is commonly named as 5 pins *Yazaki* connector.

Figure 18. Type I connectors

Type II: mono phase (max 70 A-250V) or three-phase (Max 63A-500V) 7 pins (5 pins power and 2 pins control). It is widely used in Europe, and it is required in all of European public charging stations. It supports charging in mode 3. It is commonly named as *Mennekes* connector.

Figure 19. Type II connector

Type III. Three phase (Max 32A, 21kW), and 4,5 or 7 pins. It is commonly named as SCAME connector. It has an oval connector with three different designs:

- single-phase charging at up to 16 A, without control pilot contact,
- single-phase charging at up to 32 A.
- three-phase charging at up to 63 A.

Figure 20. Type III connectors

3.2.2 Connector types IEC 62196-3 (DC quick charge)

AA: DC charge (Max 600V, 200A), isolated. It is commonly named as CHADEMO. Communications use CAN protocol. Maximum available power is 120 kW.

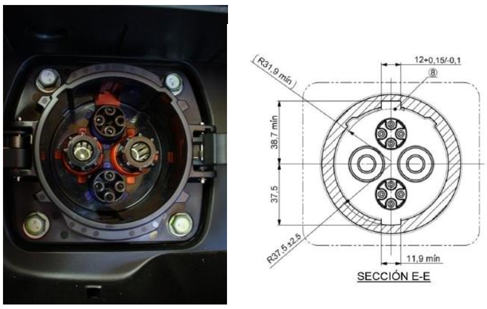


Figure 21. Type AA connector (CHAdeMO)

BB: DC charge (Max 750V, 250A), isolated or not isolated. It is mostly used in China and implements system B, also known as GT/T DC. Communications use CAN protocol. Maximum available power is 187,5 kW.

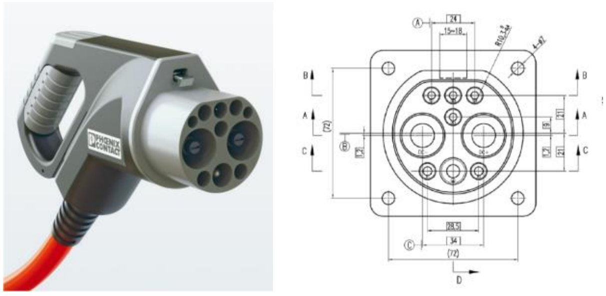


Figure 22. Type BB connector. China GB/T DC

EE: DC charge (Max 600V, 200A), isolated or not isolated. Configuration EE is commonly named as the "CCS1 connector" or "Combo1 connector". It extends type 1 connector, with a Combined Charging system. It is mostly used in US and Asia. This type implements System C (IEC-61851-23) and communications by PLC.

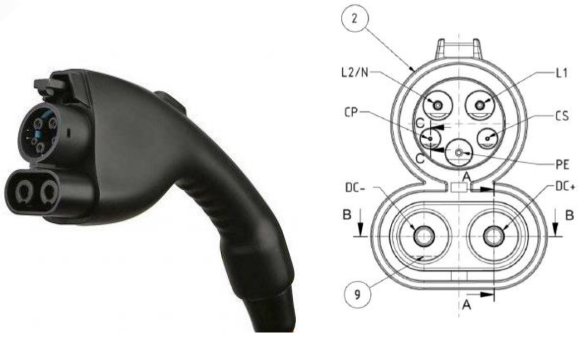


Figure 23. Type EE connector. CCS1 connector

FF: DC charge (Max 1000V, 200A), isolated or not isolated. It extents type II connector to allow DC charge. This is the global standard and in Europe all of DC public charging stations must have this type of connector. It is commonly named as "CCS2 connector" or "Combo 2 connector". It implements System C (IEC-61851-23) and communications are PLC.

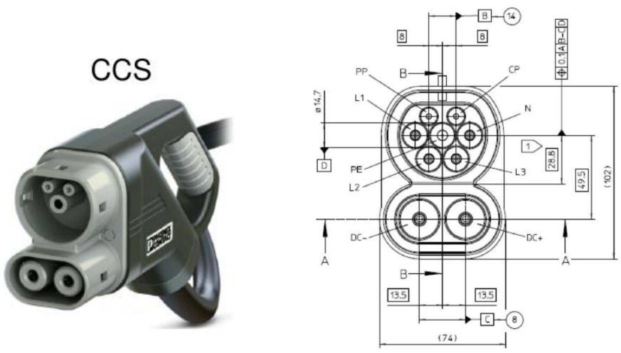


Figure 24. Type FF connector. CCS2 connector

3.3 Chargers and infrastructure.

Charging stations can be connected to the electrical grid and can be isolated from the grid taking energy from sun or wind. They also can be public or private, and can be inside or outside of a building.
In order to extend and make wide use of electric vehicles, there must be a great number of interoperable public charging stations. In islands, the isolated charging station solutions, using wind or photovoltaic power sources, can be a very easy way of installing public charging stations.
Some data needed to understand charge times are that a 100km charge for a BEV, can take between 6-8 hours with a type 1 charging mode, or 3-4 hours for type 2 charge, and 30-40 minutes in a DC high power quick charger. Other personal electric vehicles need a standard plug with a slow charging schema, so the dimensioning must be made for large vehicles. Personal transportation devices work as an electric appliance, so they does not need special precautions.

3.3.1 Charging station types

Residential

In Residential charging stations, the user or proprietary of an electric vehicle can charge his vehicle at home, usually during night when there are lower electricity prices. The charger could use a normal electricity plug if the connected vehicle allows them, in other occasions a dedicated connection from the electricity meter to the WallBox, allows charging with more power, protections and electricity network communication.
In other occasions, there are new electricity meter connected to the wall box but this is a rare situation, when the electricity power must be available at the same time for charging and using electric power at home. The normal situation is to charge at night where electricity power it is not been used at home, so this power is available for charging; in islands, it could be the normal situation.
In neighbourhood parking the WallBox could be the same and the connection must be made from the electricity counter of a particular person to the community parking.

Figure 25. Residential chargers WallBox

Public charger stations

Public charging stations need a public charger infrastructure using a mixture of slow charging and fast charging stations. Normally, in developed countries the electricity network has enough power to charge a great number of electric vehicles, using the valleys at electricity power consumption, normally at night. In islands, it could be necessary to use dedicated and isolated charging stations, powered by renewable energies, as in remote locations not connected to electric grid. For highways and long distance roads it is necessary to install high power quick chargers, but this is not the case for the majority of islands.

In the Figure 26 you can see different charging stations wind powered, solar photovoltaic, dedicated parking chargers, and road combined slow and quick charge station (from left to right and top to bottom).

Figure 26. Public charging stations

In order to find public charging stations there are specialized road signals shown below.

Figure 27. Public sign charging station signals.

Battery swap stations

Other solution for quick charge a battery is using dedicated quick swap stations. An automatized station that swaps an exhausted battery for a fresh charged, in ten minutes. The Figure 28 shows a battery swap station. The system is like an express car wash tunnel, but instead of washing the car, the system takes out the exhausted battery with a robotic system a replaces it with a charged one. The storage batteries are charged at night when electricity prices are lower, and there is more available energy.

Figure 28. Battery swap station

4. Electric Grid for EV's.

4.1 Description of the electric grid.

We will describe electric grid in an island. Figure 29 shows a complete electric grid in an island, If the island is small, some systems and connections may not be present.

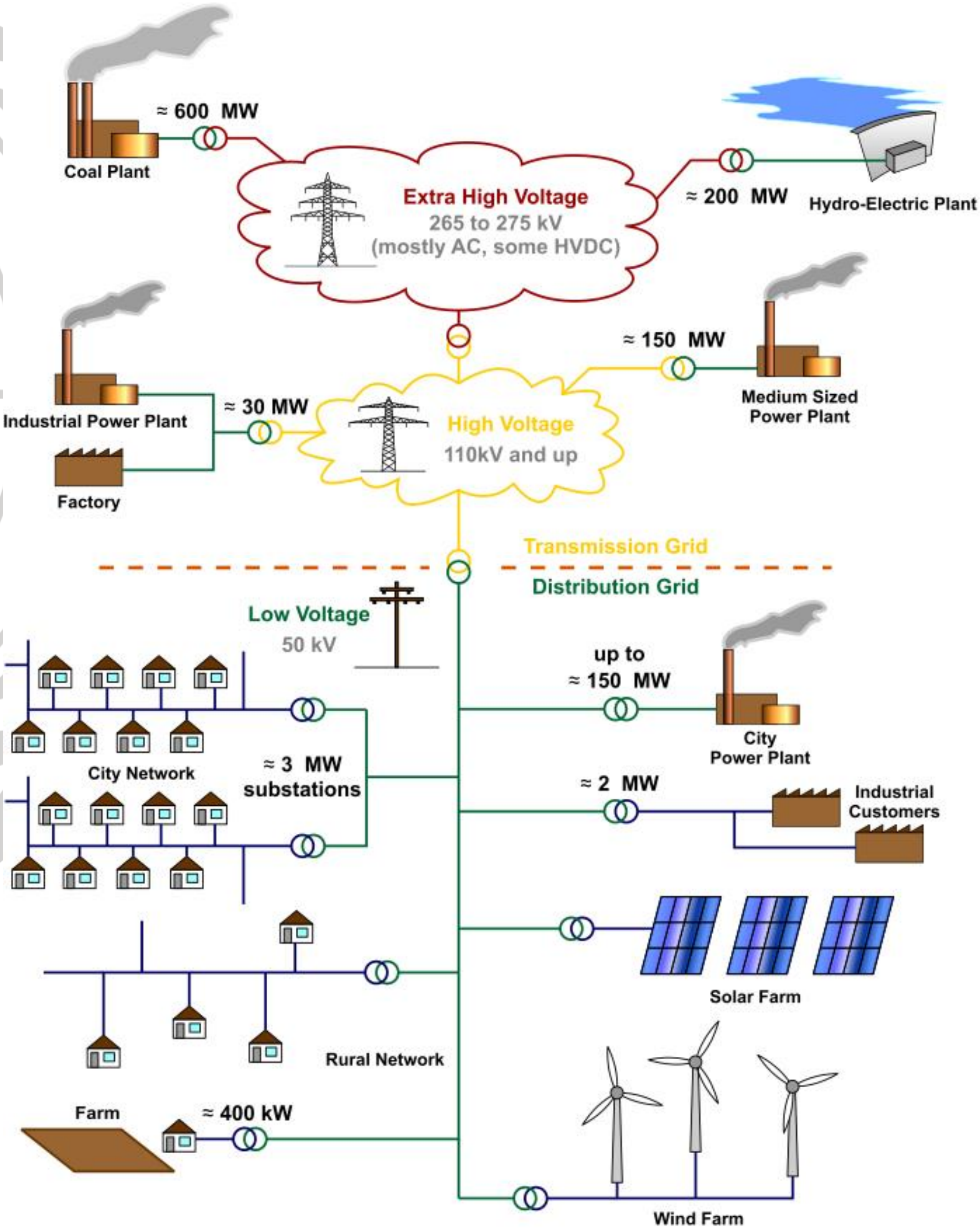


Figure 29. Electric grid schema

An electric grid has different elements from production to consumption. The main objective of the whole system is to maximize the efficiency, lowering the losses, between energy productions to energy consumption. AC transmission is the most used, because the easy voltage level interchange. In order to transmit electricity power and energy over long distance, it is needed higher voltage, because losses are related with higher currents, so as power is the product of voltage and current, an increase in the voltage level, decrease the current accordingly for the same power transmission. Voltage levels are limited by safety and to avoid air discharges. Therefore, 440KV are the maximum voltage used for transmission power, but in islands with lower distances, the voltage is about 250kV as its maximum value.

So electric grid has the following parts:

- Generation, All of the systems that generates electric power using any type of energy fuels, gas, hydroelectric, wind, solar panels, normally is connected to the transportation grid except for low power production systems that can be connected directly to the distribution grid.
- Transport, the part of the network that transports energy, minimizing losses using high voltage (up to 250kV in Islands).
- Distribution, part of the network that connects transmission grid to distribution grid to consumers, it uses a reduced voltage, and finally transforms into the voltage use at home and industries, 125v/230V.
- Consumption, all of the consumers that connect to distribution grid. One exception is high demand energy consumers (50MW) that connects directly to the transport grid.

4.2 Generation.

Islands can have a great distributed generation schema, using renewable energy sources (like photovoltaic panels and small wind turbines), or a concentrated generation model or a mixture between them.
Electrical grid begins with electricity generation plants that transforms his voltage to the transmission voltage in order to minimize losses using transformers; they are located at substations near the production plants. For example, a wind turbine generator produces a power of 1.8MW at 690V, this is transformed into 34.5kV, near the turbine field, and then it is again transformed to transmission voltage of 230kV AC. In some special cases, for example inter-island power transmission instead of using Ac transmission it can be used DC to minimize power transmission losses. These transmission in DC, is more expensive and complicated and seldom used, only in these special cases, where surrounding water or other conditions suggest the use of DC power transmission. This is used for wind turbines generation off-shore to minimize losses in the transmission path.

4.3 Renewable energy sources and EV's.

In islands the better generation schema come from renewable energy sources as wind, hydroelectric, photovoltaic or sea waves generators. Depending of the size of the generators field, they will connect to transportation grid (for high power installations hundreds of MW), to

the distribution network at medium voltages, directly to customers (as photovoltaic panels over roof homes), or can be isolated installations for isolated islands locations.
One example of island connection can be the wind turbines in the 'El Hierro' island that has 11.5MW of wind turbines generation connected to a hydroelectric plant that produces and energy and also it is used as an energy storage when there are more generated energy than consumption. In near future electric vehicles can replace or complement this energy storage using car batteries as storage for this surplus power during some periods.
Other solutions come from photovoltaic plants and roof photovoltaic at home.
The Maama Mai farm is located next to Tonga archipelago, South East of Nuku'alofa, Tongatapu island. It has 1MW of production installed power, and there are also more installed photovoltaic plants along the island.
Photovoltaic plants combines well with wind turbines, because maximum production of photovoltaic plants normally happens in central hours when sun is up, this complements wind power that can work at night, so photovoltaic can produces energy when peak consume occurs.

4.4 Electricity Timeline generation and consumption

Figure 33, shows the electricity timeline generation, in a medium size island (El Hierro) showing the generation from renewable sources. Normally the timeline generation curve has a valley around 3-4 am, and two peaks at noon and at 8-9pm. This hours can change, depending of the country and other parameters, but the shape of the curve is similar.

The timeline generation curve shows that the installed capability power must be sized to high peaks, and there is some available power in power valleys generation time. In order to calculate the available power that can be storage, we will need the available power timeline.

The electricity grid must be adapted to the estimated power consumption; red line in the figure represents the estimated, demanded power using historical data series. Production accommodates and adapt in advance for this estimated power demand. If there is a smart grid this is estimated but can be controlled, adapting also consumption and generation. Actual electric grids only adapt production and some high demand interruptible consumers, but Smart grids could adapt the vast majority of consumers.

Timeline power generation curve shows that the ideal situation could be the less power generation schema, adapted to the power generation capability, maximizing efficiency and energy availability, when energy is present.

The real production schema, can switch off production available sources because of the low power demand causing the misuse of the available energy, coming from example from wind turbines. Real actual electric grids have a low and some cases a null storage capacity, so having real electric storage systems; can increase the efficiency and costs of the whole grid.

For example if you have a great wind production at night, but there are low consumption, you lose all of this energy, in 'El Hierro', an attached hydroelectric system storage energy in water level form, pumping water from low altitude to high altitude water storage. When demanding power is needed at different time, water flows and generates power. If a great group of electric vehicles where available to the network they can storage the energy for transportation or if V2G technology is available could provide electric energy to the electric grid. The electric vehicle energy storage is two times more efficient than the hydroelectric storage, (65% versus 30%), taking into account all of the losses.

The timeline of daily generation allows operating the electric grid in real time, and anticipates with historical data the behavior of the generation and consumption.

Normal electric grids only can actuate over the production system and only interruptible loads.

In a Smart Grid all of the agents presents in the system can interact to maximize the efficiency of the whole grid modulating generation, loads and storage systems.

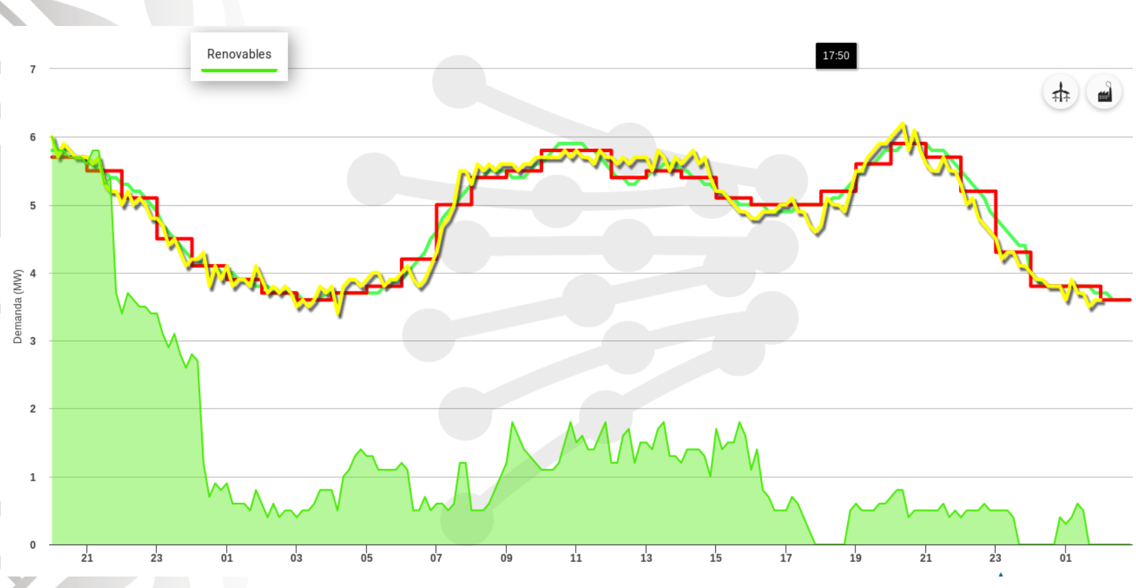


Figure 30. Electricity timeline generation in islands.

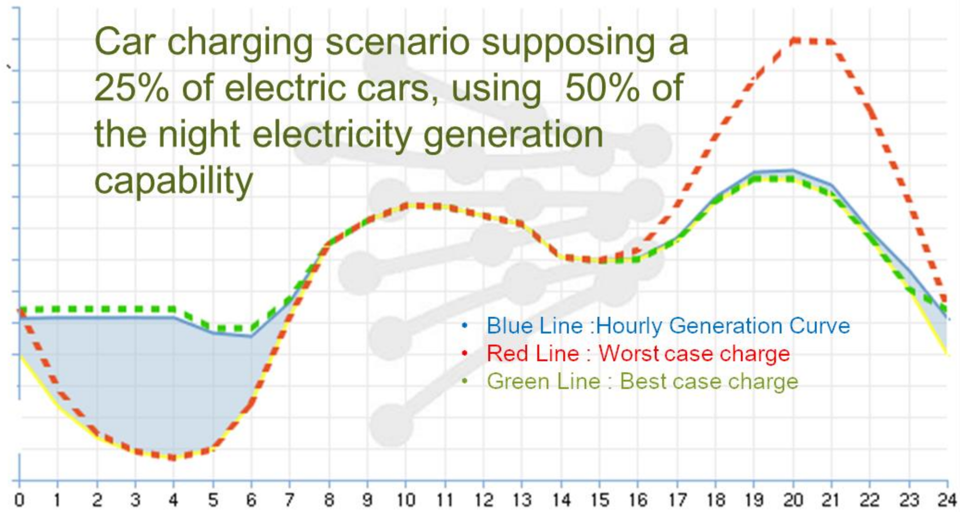
4.5 Electric vehicle integration on the existing networks

There are different scenarios in the interaction between electric vehicles and electric grids, here well see the interaction between normal existent electrical grids, smart grids and Vehicle to grid technologies will be covered in the next chapter.

Electric vehicles needs the electrical grid in order to obtain charge for their batteries, so electrical power present in the network, will be taken to charge the batteries.

The common situation is charging a car by night where energy is available and cheaper. The actual normal situation, without intelligence of the system is charging the cars by users where necessary, and to avoid charge at peak, low available and expensive energy is using a time-price policy. Grid operators and consumer energy sellers, gives a policy of prices by time slots, knowing the prices with moths in advance, where electricity price depends of statistic time available energy. For example at night, the price could be around 25% of the price at pike prices. With these policies, around 80% of electrical vehicles users tend to charge vehicles at night, at lower prices. And only a 20% of the users charge its vehicles at higher prices, only when it is necessary, assuming higher costs. This is a self regulation energy management ruled by price.

Other approach is giving a flexible price by hour, making prices to be known one day in advance, so users can program their vehicles in this mode to take advantage of this flexibility, this approach is more efficient than the previous one. This is a market price matching schema. This is self regulated, acting on the electricity price per hour, but one day in advance. It is more flexible. We will see that using smart grid the feedback time is reduced, and efficiency is increased.
The most used actually is the price driven by time periods with months, semesters or years in advance, because of the price simplicity, but it is less efficient.
Integrating electric vehicles in the electrical grid, for charging a great amount of vehicles requires test and design the existing electric system.
First we need to know the available, the amount of available energy, to charge the cars are the difference from the Power Generation scenarios and the consumption. With this energy, you must first calculate the available power to charge the cars in the different scenarios.



We need to calculate the power needed to charge an average car, and the preformance of the charging process.

$$Electrical\ energy\ needed\ for\ charge\ an\ average\ car = \frac{Car\ Energy\ Storaged}{Performance\ ratio}$$

So in order to charge the vehicle you need more power than the storaged in the batteries, because of losses in the charging system.

The Best charge option is the one that charge the most number of cars, it is very easy to demostrate that this case is the one that combines (maximum power generation, maximum available energy). The worst charge option is the one that combines the least available energy charge in the charge period .

In the Best solution it is possible to use all of the available energy, so to calculate the amount of maximum possible number of full charges, it enough to divide the available energy by the energy use for a medium full charge.

$$Number\ of\ cars\ fully\ charged = \frac{Sum\ of\ available\ Energy}{Energy\ for\ one\ car\ for\ full\ charge}$$

This number of cars is the *maximum number of cars that can be fully charged* considering that all the cars can be available to be charged, when necessary.

In the worst case, the available power can only be used in the charging period in the worst available generation energy in this period of time. Therefore, there is a huge difference between the Best scenario and the worst.

The total number of charged cars are different from the numbers calculated above, because not all the cars charge completely every day. So If using the simultaneous charging ratio, the average travel distance per day and the average ratio of distance per charge, the total number of charging cars are bigger than the number of cars calculated before.

$$Number\ of\ cars\ partially\ charged\ = \frac{Sum\ of\ available\ Energy}{Energy\ for\ one\ car\ for\ full\ charge} * simultaneous\ charging\ ratio$$

$$simultaneous\ charging\ ration = \frac{distance\ traveled\ with\ a\ full\ charge}{average\ travel\ by\ day}$$

The simultaneous charging ratio could be in the range of 10-20 depending of the car and island considered. So the cars connected for recharging every day is bigger that the cars than can be fully charged.

Using the full charge average can be used as a merit factor to compare different scenarios. However, the real numbers are more related with the use of the average distance ratio per charge and the average distance per car.

5. Smart Networks and EV's

5.1 Description and elements

Smart grids are electrical grids with intelligence distributed around the grid. Producers, consumers and grid are connected not only for power and electricity but also with data intelligence.

All of the systems connected to a complete smart grid have intelligence, to connect at different times, optimizing price and network performance. Electric smart vehicles can take or provide electricity power depending of the demand and necessity of the network. The electric vehicles can storage electricity at high power available energy and give in return to the grid if necessary.

So electric vehicles can be a storage electricity system in smart networks. This is possible of course if the user does not need all of the storage power, these technologies are V2G(vehicle to grid) and G2V Grid to vehicle.

Figure 31, shows the smart grid subsystems and interconnections, showing producers, consumers, electric vehicles, smart houses, renewable energy sources, standard power plants in an island environment. Smart grid allow distributed generation of power, and increase efficiency through intelligence. The electricity timeline generation is accommodated so it can be storage in electric vehicles and use in intelligent homes and industries that use that power when most efficiency is needed (only if possible). But there are uses that can be accommodated in time when energy is available. Correct use of the energy contributes to the coupling between energy dimensioning producer systems, energy storage and energy consumption, maximizing efficiency and money.

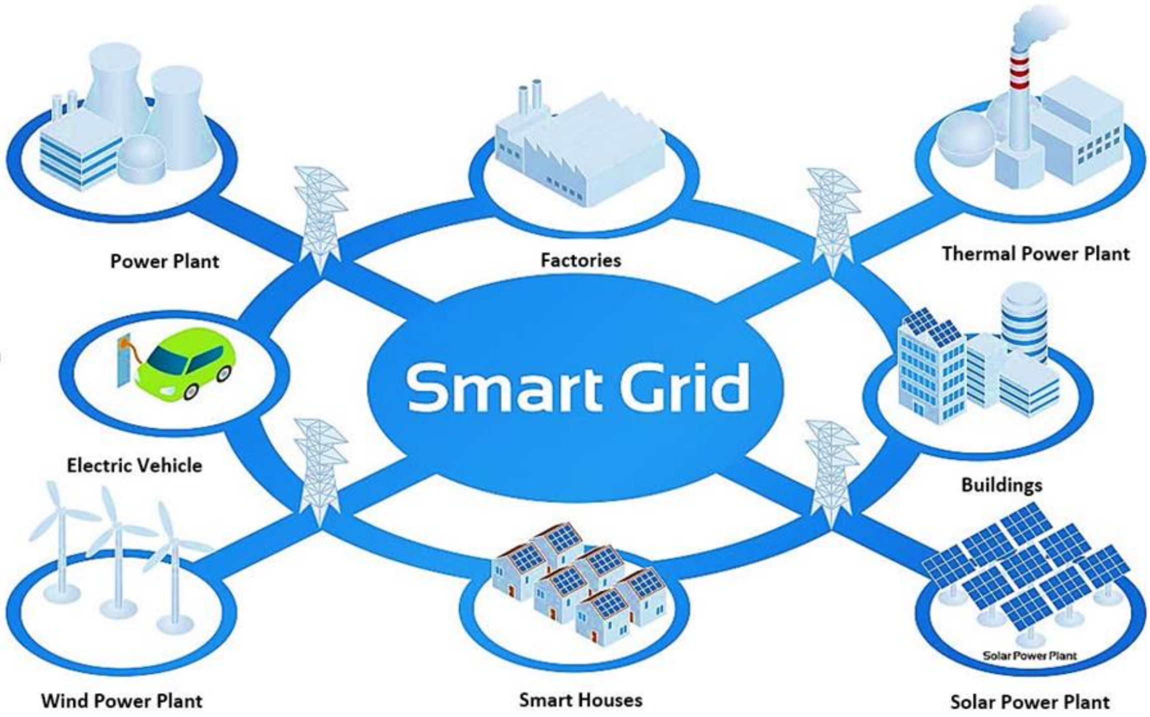


Figure 31. Smart grid schema.

5.2 V2G and G2V.

Technologies that makes electric vehicles suitable for this kind of smart grids are V2G (vehicle to grid) and G2V (Grid to vehicle). In Vehicle to grid, where the vehicle is parked and connected, and have enough energy, it can give part of this energy to the grid, obtaining some profit. You must take into account that most of the time in most of the vehicles, are parking time. Therefore, if you use this time with the power storage in the car, it can give this power making the seizing of the network better. The actual V2G is a bidirectional approach using the car as a controlled load in charge mode, modulating the charge of the vehicle, depending of the available power, with some intelligence based in prices or incentives.

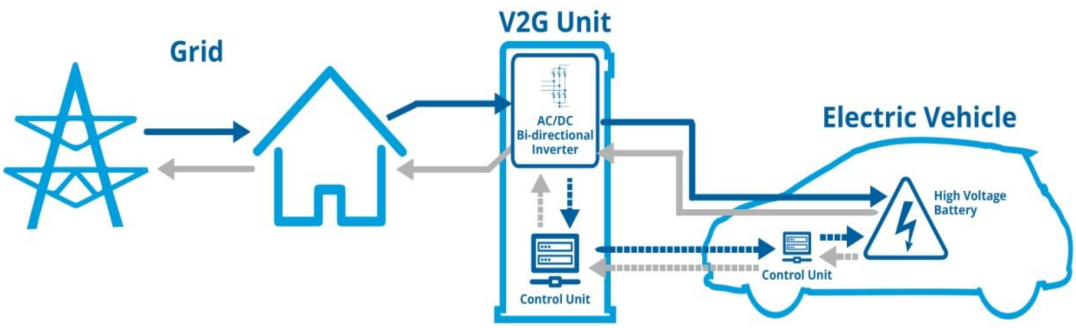


Figure 32. V2G connection schema.

There are variable prices depending of different policies for charging cars. If there are enough power the grid communicates with the vehicle and agrees (with directives given by the user), when and at which rate it can charge/discharge the vehicle.

You must take into account that a car of 21kWh of battery can supply 3kWh per day during a week at a normal home. If the car as an extended range of 60kWh it can provide three weeks of power to a normal home. So most of the time users have cars that storage more energy than needed for a normal day, waiting for using during specials long range drives. In an island, the medium normal drive could be around 20km/day, taking only 3KWh (15kWh/100km) of the battery, so the rest of the battery remains available for other uses. Using it as a grid stabilization/storage system allows the grid to have less power installed sources.

A bidirectional approach is used nowadays in a smart grid, so V2G technology is used as the whole name, so V2G has the vehicle to grid and grid to vehicle capabilities.

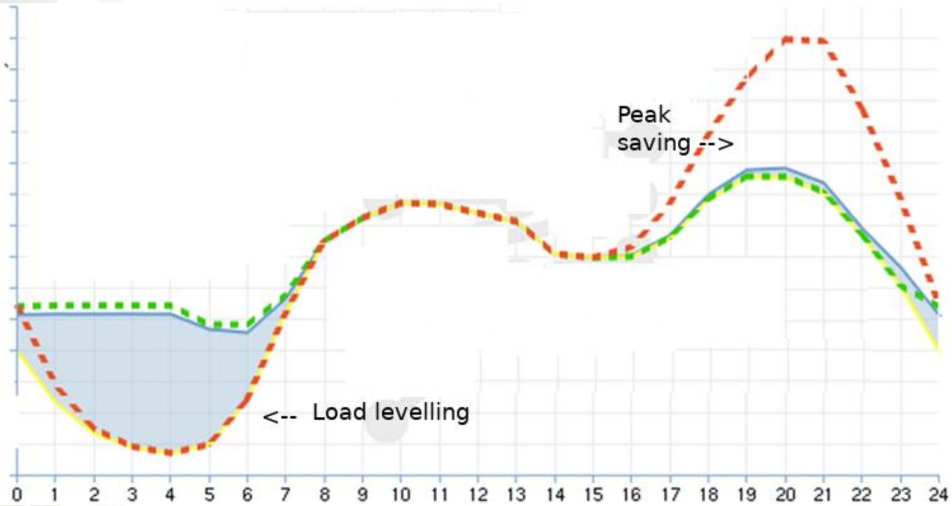


Figure 33. Timeline generation curve in Islands

For example in the production timeline generation curve in an island (Figure 33), you can use the available power during night to charge the smart electric vehicles, modulating the charge adapting to the available power curve; when peak power is needed and if the car is parked with enough energy, the grid can take this energy form parked cars, allowing more efficiency of the grid. The grid helped with electric cars will need less installed power waiting for peak demands. These lower the cost of the whole system, and allows to the proprietary of electric cars to make profit of the 'expensive' electric cars, while giving energy back to the network.

It is a win-win schema, for islands takes fuel generators less necessary for peak electricity demands. Wind generator and other renewable sources, will use cars are storage systems, so when this renewable sources, that depends heavily in weather conditions can use electric vehicles as a storage of energy for peak demands.

Generally, V2H (Vehicle to Home), V2V (Vehicle to vehicle) and V2G (Vehicle to Grid) involve elements such as power sources, power loads, power grid aggregator, power transmission system, communication system, electric vehicles, and vehicle to grid chargers.

In vehicle to home, the grid could be only one home, very interesting in isolated homes that using renewable energy sources use the electric vehicle as storage; in that case, the electrical grid is a micro grid of one home.

Vehicle to vehicle allows energy sharing using one car as energy donor to other car, allowing the charging from one car to another, in emergency cases or for long trips.

V2G and the integration with electric vehicles increases the efficiency of the grid, allows a better integration of renewable energies, makes a perfect match between electric cars and renewable sources, and balances the electrical grid. It is a technology of the near future, but today only works partially. The accomplishment of the V2G technology needs the active participation and collaboration of government, power utilities, V2G aggregators and EV owners. Appropriate V2G management system with incentive-based policy will be the important catalyst towards the successful V2G technology implementation.

Glossary

ABS	Antilock Braking System
AC	Air Conditioning
AEV	All Electric Vehicle
BEV	Battery electric Vehicle
BLDC	Brushless Direct Current (motor)
BMS	Battery Management System (rechargeable battery technology)
CAN	Controller Area Network
CCS	Combined Charging System connector
CEV	City Electric Vehicle
CHADEMO	"CHArge de MOve" charging connector
CO2	Carbon dioxide gas
CSIRO	Commonwealth Scientific & Industrial Research Organisation (Australia)
DC	Direct Current (electricity)
EMC	Electromagnetic Compatibility
EM	Electric Motor
ESP	Electronic Stability Program
EV	Electric Vehicle
FCEV	Fuel Cell EV
GB/T	Guobiao Standard, CNS standards of Taiwan,China
GMSL	Global Mean Sea Level
H2EV	Hydrogen EV (Fuel cell powered)
HEV	Hybrid EV
IC	Integrated Circuit
IEC	International Electrotechnical Commission

IGBT	Insulated Gate Bipolar Transistor
ISO	International Organization for Standardization
LEV	Light EV (Quadra cycle)
LFP	Lithium Iron Phosphate
LMO	Lithium Manganese Oxide
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
NASA	National Aeronautics and Space Administration (USA)
NCA	Lithium Nickel Cobalt Aluminium Oxide
NEV	Neighbourhood EV
NMC	Lithium Nickel Manganese Cobalt Oxide
NOX	A generic term for the nitrogen oxides most relevant for air pollution, mostly nitric oxide (NO) and nitrogen dioxide (NO2)
NZEV	Neighbourhood Zero Emission EV
PHEV	Plug-in Hybrid vehicle
PLC	Power Line Carrier (using power lines to carry data/voice signals)
PM	Permanent Magnet Motor
SAE	Society of Automotive Engineers
SC	Super Capacitor
SI	System International
SOA	Safe Operating Area
SOC	State of Charge
SOH	State of Health
VFD	Variable Frequency Drive
WPT	Wireless Power Transfer (electrical energy)

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Index of graphics, figures, and tables