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ELECTRIC VEHICLES
WHAT'S UNDER THE BONNET?
INFORMATION SHEET

So, imagine the scenario, your neighbour has a new electric car and as they are proudly showing it to you, they open the bonnet. "What do you think?" they ask. You peer in, you weren't expecting to see a petrol engine of course, but what on earth is all this stuff, nothing looks familiar. You nod sagely. "Very technical!" you mutter.

In this information sheet we describe the key components of an electric vehicle. To keep it simple this document assumes we are talking about a plug-in electric vehicle (PEV) and not a hybrid vehicle.

At the time of writing different manufacturers are using different technologies and have come up with different solutions to the technical problems, so what is true for one type of electric vehicle may not necessarily be true for another. The technology is still in its relative infancy and progress is happening fast.

We are going to be saying 'high voltage' a lot in this document. In the context of electric vehicles this means DC voltages between 60 and 1500 Volts, and also the drive circuits to the AC motor. Accidents at these voltages can be fatal, so work on these systems should only be performed by experienced professionals.

The high voltage cables

On an electric vehicle all high voltage cables and connectors are coloured orange. They are made of heavy gauge copper cable to enable high currents to flow, even at these high voltages the current required to move the vehicle is still considerable. The wire is covered in thick insulation for safety.

On a typical vehicle there will be:

- A pair of single core cables from the battery to the inverter, one positive & one negative (these connectors are usually bolted in to place)
- 3 single core cables from the inverter to the motor (these connectors are usually bolted in to place)
- A 2 core cable with connector plug supplying power to the cabin heater
- A 2 core cable with connector plug supplying power to the DC to DC buck converter
- A 2 core cable with connector plug supplying power to the air conditioning compressor
- A multi core cable from the charging receptacle to the high voltage battery charger
- A cable connecting the high voltage battery charger to the high voltage battery

The high voltage cables usually have a screen or metallic shielding around them to prevent electromagnetic interference to other circuits. The screen is connected to the vehicle body (12 volt system earth).

To give some idea of size these high voltage conductors generally have a cross sectional area (CSA) of at least 50mm^2.

There are other high voltage cables but the ones above will be found on most vehicles. There will also be a lot of other cables that are not orange; these are 'low voltage' cables used for control systems, powering the lights, windscreen wipers, horn, etc.

Note: AC is alternating current, like mains electricity. DC is direct current such as that supplied by a battery.

The high voltage battery pack

The battery pack is usually found under the rear seat or boot floor. Its large sealed enclosure houses much more than just a battery though.

The high voltage battery pack typically contains:

- A large number of cells connected together to give the required output voltage
- A control module to monitor the condition of the battery, cell voltage and temperature
- 2 high current relays (also called contactors)
- A 'Manual service disconnect' (MSD) to disconnect the power to enable maintenance work on the car to be safety carried out.
- A battery heater. The chemistry inside the cells is not efficient at very low temperatures.
- A battery cooling system. This is normally some sort of water cooling, as the battery heats up in use and must be prevented from getting too hot. Older vehicles sometimes used air cooling but it is much harder to accurately regulate the temperature of an air-cooled battery.

The high voltage relays (also called contactors)

A relay can be thought of as an electrically controlled switch.

These are inside the high voltage battery pack. Their function is to disconnect the high voltage from the rest of the vehicle when the vehicle is not being used. They also have a very important safety function.

The relays will cut off the power for safety if:

- The 12 volt battery is disconnected
- The pilot line goes open circuit
- The 'service plug' has been removed (this is usually under the bonnet and interrupts the pilot line)
- The SRS module detects the vehicle has crashed e.g. the air bags have deployed
- A 'loss of isolation' fault is detected

When the relay contacts open when a large current is flowing, this causes an arc to form and a lot of heat to be liberated. To control the arc the relays are sealed and filled with gas.

In ceramic hermetically sealed high voltage DC relays this gas is hydrogen. This is fine as although hydrogen is very flammable, in the absence of oxygen the hydrogen cannot burn.

Epoxy hermetically sealed high voltage DC relays use nitrogen instead, as the hydrogen molecules are so small, they can leak out through the epoxy. Sometimes the gas is a mixture of nitrogen and sulphur hexafluoride.

The 'Manual service disconnect' (MSD)

This is a large connector, unsurprisingly coloured orange, that is normally part of, or very close to, the high voltage battery. Its function is to disconnect the power to enable maintenance work on the car to be safety carried out.

The MSD is actually one of the links between the battery cells, usually the middle one, so that the battery is separated into two parts and thus the maximum voltage present inside the battery pack is halved and because the circuit is broken there is no path for electricity to flow outside the battery pack.

The '12 Volt' battery

This is surprisingly important on an electric vehicle as it performs 2 functions:

- To provide power to the control systems to activate the high voltage system
- To provide power to low voltage items such as the lights, horn, windscreen wipers, dashboard, etc.

It is important to have the 12 volt battery tested regularly as if the control system detects an issue, it will not enable the high voltage system to start up and the vehicle will not be going anywhere!

The 12 volt battery is normally of AGM (absorbed glass mat / absorbent glass mat) construction and requires fine control of the charging voltage and current. Some batteries have an internal temperature sensor and an external connector that is used to monitor the charging process. These batteries should not be charged using a normal battery charger.

The inverter

The inverter controls the speed of the drive motor.
An inverter converts DC to a pulse modulated signal approximating an AC wave form.

An inverter can be single phase, 3 phase or multiphase. 3 phase or multiphase are normally used to power the drive motor

The drive/traction motor

Most electric vehicles use a 3 phase or multi-phase electric motor.
Multi-phase converters are more efficient but are more complex and thus more expensive to produce.
There are many configurations for using the motor such as:

- A separate motor for each wheel – but this leads to a poor ride quality due to the increased unsprung mass
- A motor, reduction gears, and differential driving either the front or rear axle
- An all-wheel drive set up having a motor, reduction gears and differential driving the front axle and another set driving the rear axle

The motor usually performs the function of a generator during regenerative braking to slow the vehicle and recover some electrical energy.

The reduction gears and differential

As the electric motor provides torque pretty much uniformly across its entire speed range, there is no requirement to use a gearbox with different ratios to match the road speed to the motor. To say an electric vehicle is 'automatic' is not strictly true. Sure, the driver does not change gear, but then the car doesn't either, it simply is not required (except in a hybrid).

The electric motor will have a set of fixed ratio reduction gears and these will drive the differential which in turn will drive the wheels. These gearboxes are low maintenance but the oil level and condition must be checked from time to time.

A small number of vehicles have a separate motor for each wheel. In this case the differential is not required as the required difference in wheel speed when cornering is taken care of electronically.

The DC to DC converters

A DC to DC converter is used to change the voltage. Electric vehicles have at least two:

- To convert high voltage DC from the high voltage battery to low voltage DC to charge the 12 volt battery and power the auxiliary systems such as the lights and windscreen wipers.
- To convert power generated by regenerative braking to a suitable voltage to charge the high voltage battery

A DC to DC converter that raises the voltage is called a **boost** converter
A DC to DC converter that lowers the voltage is called a **buck** converter

The cabin heater

Different manufacturers use different systems. There are 3 common types used.

- A heat pump – think of it as a bidirectional air conditioning system that can pump heat in or out.
- A high voltage positive temperature coefficient (PTC) heating element heating the air.
- A high voltage electric heater heating a fluid, I would say coolant but it's for heating. This system also has an electric circulating pump and a radiator inside the car using a very traditional setup.

The air conditioning compressor

The air conditioning compressor is powered by an electric motor, this motor can be:

- 48 volts DC
- High voltage DC
- High voltage AC supplied by a built-in inverter
- High voltage AC supplied by an external inverter

For safety it is vital that only the appropriate air conditioning compressor oil is used as water absorbing conductive oils found in a conventional air conditioning system may be dangerous.

As the air conditioning uses electricity it is usually possible to program the car to achieve the desired temperature whilst it is connected to the charger, thus no battery capacity is wasted getting the car to a comfortable temperature before you drive off.

The pilot line (also called the safety interlock circuit)

This is a low voltage circuit that uses either micro switches or magnets and reed switches to detect if a cover for a high voltage component has been removed or has vibrated loose. It also detects if a high voltage cable has become disconnected.

The pilot line forms one continuous loop around all the high voltage components and if that loop is broken at any point the high voltage relays in the high voltage battery will open and disconnect the power to prevent danger.

Some vehicles have a 'service plug' under the bonnet, this interrupts the pilot line to prevent accidental energising of the high voltage system. However, the 'service plug' is an addition to and not a substitute for mechanically disconnecting the high voltage system using the MSD when work on the high voltage system is to be undertaken.

The High voltage distribution module

The high voltage distribution module provides the connections for ancillary equipment, such as the high voltage battery heater. The outputs are often protected by ceramic fuses. The high voltage distribution module may also contain control circuitry for these components.

The charging receptacle

This receptacle is where you connect the charging cable. At the base of the receptacle is a drain. It is important that this drain is kept clear as you do not want water to accumulate near the connector.

Whilst charging, the vehicle will lock the plug in for safety. It is only possible to remove the plug once both the car and the charging station have 'agreed' the power is off and it is safe to do so.

The charging receptacle also has connections for the Proximity Pilot (PP) and Control Pilot (CP).

- The Proximity Pilot detects when you have a connection to the charging station.
- The Control Pilot is used to communicate between the vehicle and the charging station.

There may also be connections for DC fast charging.

The most common connector type in the UK is the IEC 62196 Type 2 connector (also called the Mennekes plug as they designed it)

Other types of connectors include:

AC

- Type 1 (SAE J1772)
- Type 2 (Mennekes, IEC 62196)

DC

- CHAdeMO (Japanese JEVS)
- CCS (Combined Charging System or 'Combo')
- Tesla's proprietary supercharger connectors

For cars with IEC 62196 Type 1 connector adapters are available.
You can find the location of public charging points from websites such as https://www.zap-map.com

The high voltage battery charger (also called the 'on board charger module')

Apart from DC fast charging where the charging station controls the charging process and supplies the correct voltage accordingly, all types of AC charging use the high voltage battery charger.

The AC charging can be either single or 3 phase, each phase is handled separately, by an identical circuit.

The charge must be converted to DC using a rectifier. Rectifiers use diodes to convert AC to DC.

The DC voltage must be matched to that required to charge the battery. That is to say just above normal battery voltage. This is done with a DC to DC boost converter.

During the charging process the high voltage battery charger uses data from the high voltage battery control module to monitor the high voltage battery to ensure the correct charge is delivered.

The thermal management system

Many of the high voltage components produce heat when in use and need cooling to maintain them at a safe and efficient temperature.

Items that require temperature management are:

- The inverter
- The high voltage battery
- The DC to DC converters
- The high voltage battery charger

The thermal management system can utilise a liquid thermal management fluid. This would be called ‘coolant’ if it were only used for cooling.
On some vehicles the air condition system is utilised to improve heat dissipation.
