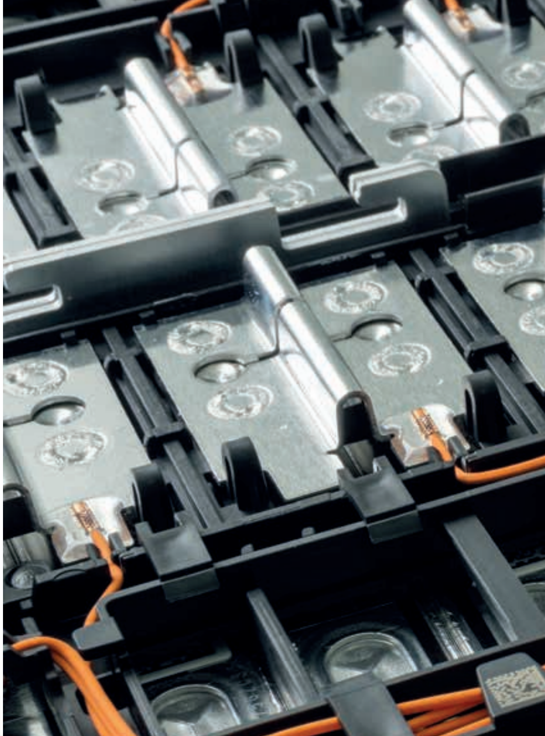
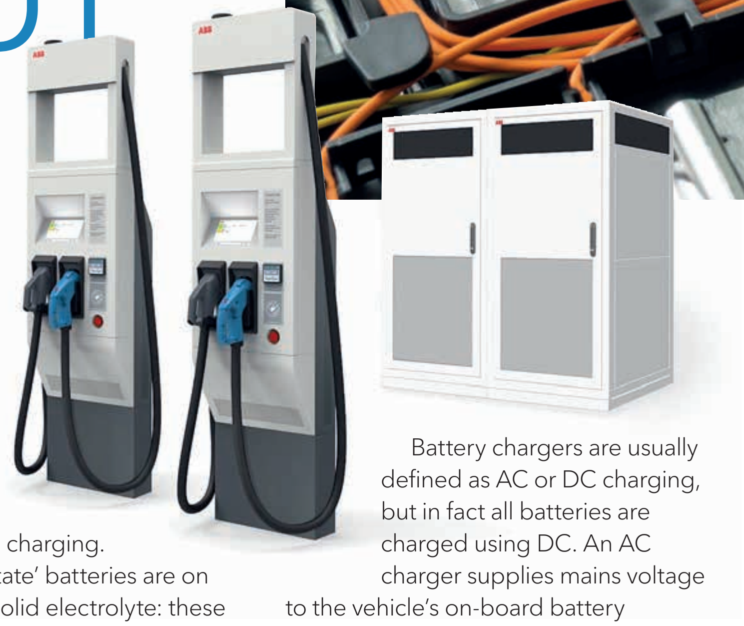


Battery charging used to be a minor concern – and usually only an issue for seasonal vehicles that lay dormant for months at a time. But as they come to take a greater responsibility in propulsion, their importance continues to grow. Toby Clark gets to grips with charge and charging

ALL ABOUT CHARGE



A battery is actually an assembly of cells (pictured above): each stores electrical energy at a particular voltage, and the battery has enough cells connected in series to give the desired voltage. Cell voltage depends on its chemistry: a lead-acid cell has a nominal voltage of 2.1V, so six cells are needed for a '12V' car battery. Nickel metal hydride (NiMH) runs at 1.2V, while a typical lithium-ion cell has a voltage of 3.2V. An electric vehicle's traction battery might run at 300V, so 94 cells would be needed – although for packaging purposes 96 cells is more likely.

Lithium-ion (Li-ion) cells are the most usual type of rechargeable cell found in battery-electric vehicles (BEVs), and these consist of a cathode usually of lithium iron phosphate ($LiFePO_4$, or LFP) and an anode largely made of graphite. These are separated by a liquid electrolyte.

Temperature affects the electrolyte, but lithium-ion batteries can operate over a wide temperature range (generally from -20°C to +60°C). However, they should be charged over a much narrower range: from 0°C to around +45°C. Below freezing, 'plating' can occur, in which metallic lithium is deposited on the anode, degrading the cell and potentially leading to a fire hazard. Some chargers can operate at low temperatures, but this requires very low current (slow) charging.

So-called 'solid state' batteries are on the way, using a solid electrolyte: these should allow ultra-fast charging and less temperature sensitivity.

ELECTRICAL UNITS AND BASIC CONCEPTS

Power – the amount of electrical or mechanical energy produced or consumed per unit of time – is measured in Watts (W) or (more usually) kiloWatts (kW). 1kW = 1,000W. Electrical energy can be measured in Joules (J): 1 Joule = 1 Watt x 1 second, or a Watt-second. But it is usually measured in kiloWatt-hours (kWh). 1kWh = 3,600,000J. In a DC (direct current) circuit, power is given by voltage (V, measured in Volts) multiplied by current (I, in Amps): 1W=1V x 1A. So a 300V battery passing 100A of current is putting out 30kW. So a 600V motor to produce 240kW (or 322hp) it needs to pass 400 Amps of current.

Battery chargers are usually defined as AC or DC charging, but in fact all batteries are charged using DC. An AC charger supplies mains voltage to the vehicle's on-board battery management system (BMS), which converts it to DC at the appropriate voltage, whereas a DC charger provides power at the appropriate voltage and current according to the needs of the batteries.

AC chargers are typically rated at 22kW output – but this depends on being wired to a 400V, 32A three-phase supply; with a household-type 230V single-phase supply, the charging output is limited to 7.2kW. A high-capacity DC charger requires a substantial power supply: a 300kW charging station such as ProjectEV's EV-300D, for instance, needs a three-phase supply at 435 Amps.

HOW CHARGING WORKS

AC chargers use the seven-pole 'Type 2' connector, while DC chargers use a two-pole CCS pattern, usually in conjunction

©Nischaporn - stock.adobe.com

with the communication ports of the Type 2 connector (both pictured above). This charger-to-vehicle communication link is important in determining the state of charge of the battery. If it is sufficiently discharged, the charger typically starts to supply a constant current (known as the CC phase), and the state of charge increases at a linear rate. As the state of charge approaches the maximum, cell voltage increases and the charger switches to constant voltage (CV) operation, allowing the current to drop gradually – so the state of charge increases at a slower rate. This is known as CCCV charging.

However, if you dramatically increase the current in the CC phase, you will reach the voltage limit at a lower state of charge – and must switch to slower CV charging. Therefore, doubling the initial current may not halve the charging time. Some have likened fast charging to pouring a bottle of beer too quickly: a 'head' of foam is produced, limiting the capacity of the glass. So charging rate must be controlled, especially when the battery is almost at full capacity (that is, approaching 100% state of charge).

As a battery consists of many cells, and in practice these are not identical, the BMS may limit the charge rate based on the least effective cell, reducing the overall charging rate. An idle period after a 'full' charge, when the battery is not being charged and is under light load, can help to 'balance' the cells and determine charge state more accurately.

The lifetime of a battery is dependent on many factors, including the charge-discharge cycle. In some cases a battery charged to 100% state of charge and then discharged to 50% may degrade more quickly than one that is charged to 50% then fully discharged. It important that the vehicle supplier knows the likely use case for the batteries, so they can specify them properly.

One term that crops up frequently is 'state of health': this describes how the batteries have deteriorated with age and use. One common definition is as a percentage of the initial capacity. However, it is not defined consistently, so it should be specified precisely by the supplier.

STATE OF CHARGE AND USABLE CAPACITY

While you can run a petrol or diesel vehicle's fuel tank from full-to-the-brim to almost empty without any hit on performance, the same does not hold for battery-electric vehicles: they cannot operate effectively either completely 'full' or practically 'empty'. These conditions are better expressed in terms of state of charge: completely 'full' is 100% state of charge while 'empty' is 0% state of charge.

The battery management system (BMS) measures factors such as voltage, current and temperature to determine the state of charge. But state of charge gets even more difficult to measure if the battery is being used; and in practice, running at a true 100% state of charge is difficult, so a more sophisticated BMS might indicate 100% when the actual state of charge is nearer 90%.

Some batteries show a dramatic change of voltage depending on the state of charge – a conventional lead-acid car battery is a good example – while LFP cells give a very stable voltage over a wide range of state of charge, from around 20% to 90%. This is useful for many purposes, but makes determining the state of charge more difficult.

As Jean-Philippe Kretz, electromobility solutions sales director at Renault Trucks, puts it: "We operate the battery from 10% to 90% – above 10% to preserve driveability, and below 90% to preserve battery life." So the usable capacity of the battery is around 80% of its (theoretical) 'true' capacity. For example, Renault's trucks typically use four battery packs of 66kWh (each made up of 30 modules of 12 cells) for a nominal capacity of 264kWh – but the usable energy is 211kWh:

Usable energy = (90% - 10%) x 264kWh =
80% x 264 = 211kWh

Say a battery pack is being charged by a DC charging station at 50kW, from 10% to 90% state of charge:

Time to charge = 211kWh/50kW =
4.22 hours = 4 hours 13 minutes

With a more powerful fast charging station, such as the 175kW chargers found at some fuel stations, the time would be much shorter:

211kWh/175kW = 1.21 hours =
1 hour 12 minutes

In fact the time to charge might not be quite so short, depending on battery temperature, age and operating profile.

Large electric vehicle technicians can now prove their competence by earning an irtec licence for work on high voltage systems.