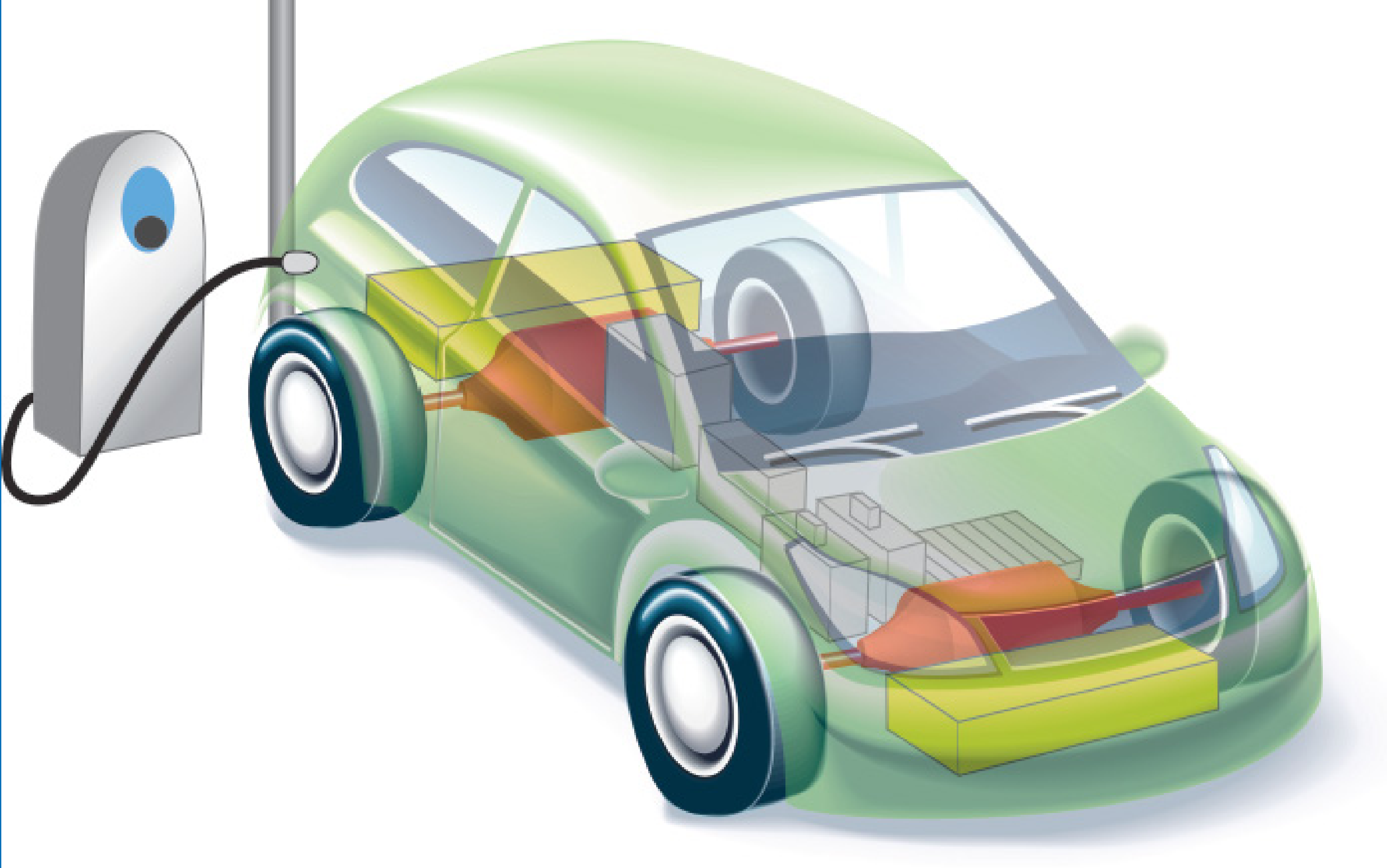
Power quality in the electric vehicle market

Solving the challenges of EV adoption by rethinking component design

Despite the burgeoning growth of the electric vehicle market, there are still some important questions that need to be answered surrounding component design, battery technology and charging infrastructure before the market is well positioned to offer a truly viable alternative to the age-old model of internal combustion vehicles. Solving these challenges requires a fundamental change in the way we look at the role of power quality in electric vehicles.



For years, the adoption of electric vehicles (EVs) has been marred by a slow diffusion of innovation among consumers. Probably the most obvious problem is that buyers have been apprehensive of the high initial cost of buying EVs, as well as the total cost of owning an electric vehicle over the course of its lifetime compared to traditional petrol and diesel-powered vehicles.

However, in its annual Electric Vehicle Outlook 2017 report, Bloomberg New Energy Finance (BNEF) brought to light recent data showing that this is changing faster than ever before. According to the report, in the third quarter of 2016, global sales of electric vehicles rose 63 per cent compared to the same period last year, and it projects that total annual sales will exceed one million units for the first time.

This success, in part, can be attributed to a more aggressive push by automakers and governments to bring about change. Swedish manufacturer Volvo became the first major car manufacturer to announce a move to go all-electric by 2019 and Tesla introduced its first budget-friendly, mass market car in the form of the Model 3.

Elsewhere, Volkswagen AG has teamed up with its Chinese partners to invest more than $12bn into the development of "new-energy vehicles" (NEVs) in China by 2025.

The market shows no signs of stalling any time soon either. According to the BNEF report, by 2040, 54 per cent of new car sales and 33 per cent of the global car fleet will be electric, driven predominantly by regulatory changes, falling prices of lithium-ion batteries, increased EV commitments from automakers, more competitively priced EVs across all classes of vehicle, and the increased role of "intelligent mobility," a term it uses to describe the trend for car sharing, ride hailing services and autonomous self-driving technology.

Government policy

Following years of sluggish policy development for the EV market, governments are beginning to respond. The UK Government in particular has recently responded with its industrial strategy, a series of new commitments designed to address the UK's low productivity and skills shortage.

The industrial strategy aims to promote the uptake of zero emissions vehicles. The strategy announced a further £100m for the plug-in car grant to incentivise the purchase of battery electric vehicles, as well as a new £400m Charging Infrastructure Investment Fund.

Government policy aside, one of the truest indications that we are experiencing a paradigm shift towards clean transport is the response from big oil. Traditional bastions of fossil fuel such as BP, Shell and ExxonMobil are making moves to alter the fundamental makeup of their oil-heavy portfolios. Whether it's investment in straightforward alternative energies such as wind and solar, or research into microalgae-based biofuels, it's clear that EVs are inspiring far-reaching changes.

Our approach is to undertake a comprehensive package of measures to promote the uptake of zero emission vehicles. We have announced a further £100m for the plug-in car grant to incentivise the purchase of battery electric vehicles, and we are committing to 25 per cent of the cars in central government department fleets being electric by 2022. We are announcing an additional £200m of public investment, to be matched by private investment to create a new £400m Charging Infrastructure Investment Fund, and we will regulate to support further expansion of the charging infrastructure network.

UK Industrial Strategy - November 2017

Batteries

However, despite this progress, there are still concerns in three core areas: batteries, charging infrastructure and component design. With the shift away from lithium-ion batteries using liquid electrolytes to solid state ones that pack a higher energy density into a smaller package, the issue of safety and range will become negligible.

The bigger issue with batteries is the cost. Bloomberg Technology calculates that, to truly compete with petrol and diesel vehicles, the cost of EV batteries needs to fall to around $100/kWh, something that is not expected to happen until 2026.

Charging infrastructure

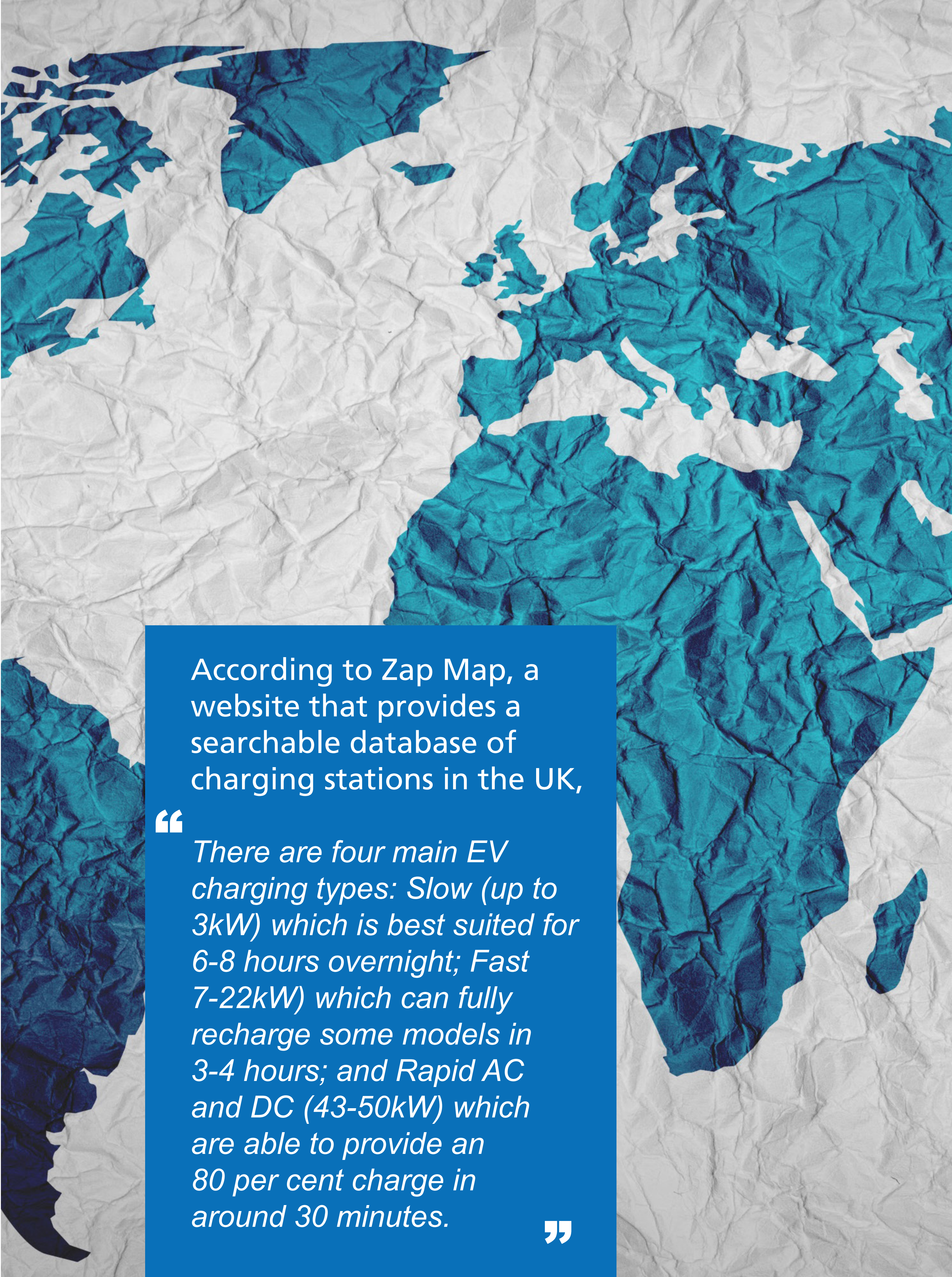
The next barrier to the adoption of EVs is the charging infrastructure. There simply isn't a sufficient one in place. The adoption problem will only truly be solved when buyers can overcome their range anxiety, and that will only be possible when charging points are widely available.

Where a typical car can achieve anywhere up to 800km on a full tank of fuel, a decade ago the average range for an EV was 120km and the norm today is around 190km. There are exceptions with some newer models, such as the new Nissan LEAF and Tesla Model 3 capable of up to 400 and 500km respectively.

The Economist argues that, "the amount of daily driving that people actually do, combined with an ability to charge at home, mean public charging facilities are rarely needed. Four out of five Europeans drive less than 100km a day. The average daily distance a car covers in Britain, for example, is less than 40km. Americans cover around 70km a day."

Although 90 per cent of EVs are currently charged at home, we will need more public charging stations to cater for those people without garages and external connection points or for those that drive longer distances. The US now has over 16,000 public charging stations, Germany has around 10,000 and the UK has over 14,000.

In its Global EV Outlook 2017 report, the International Energy Agency (IEA) estimated that, in 2016, electric car stock totalled two million units globally. This was supported by 212,000 publicly available slow charging outlets and 110,000 fast ones, which means that charging stations are outnumbered six to one by the number of electric vehicles.



According to Zap Map, a website that provides a searchable database of charging stations in the UK,

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There are four main EV charging types: Slow (up to 3kW) which is best suited for 6-8 hours overnight; Fast 7-22kW) which can fully recharge some models in 3-4 hours; and Rapid AC and DC (43-50kW) which are able to provide an 80 per cent charge in around 30 minutes.

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In November 2017, Daimler, BMW, Volkswagen and Ford announced a joint venture, called IONITY, to build a pan-European network of 400 fast charging stations by 2020, with a capacity of 350kW — capable of charging a small car to three-quarters full in only four minutes.

However, for all the benefits this will provide to the consumer — not least the ability to cut down refuelling time to a matter of minutes — there is a knock-on effect on the electrical grid that manufacturers need to consider.

Although most EVs use an onboard charger, which consists of a rectifier circuit designed to convert AC to DC to charge the car's battery, it's only suited to slower charging modes. Fitting an onboard system capable of handling fast charging would not only be extremely costly, it would also pose thermal problems. If the car is to work with fast chargers that are rated beyond 240V AC and 75A, it is better if the charging station can directly deliver DC power.

According to the IEA report, "the additional generation required to meet the EV and PHEV demand amounts to 1.5 per cent of the total electricity demand by 2030, which would represent only 6 per cent of the increase in demand due to new loads".

The problem is that electric car usage patterns — such as just before or after peak rush-hour in the morning and evenings — could negatively affect how and when power is drawn from the grid.

For example, if generation demand was to outstrip capacity, we could see an increase in wholesale electricity prices. Furthermore, to avoid the extraneous stress placed on the transmission network at peak times, utility companies would need to fit better frequency control systems and better manage the reserve capacity.

Any resulting overloading on the distribution lines and transformers would lead to voltage drops and excessive wear on the infrastructure, which would necessitate upgrades to fortify electrical substations in the grid.

As well as a more robust charging infrastructure, solving this problem requires us to think more carefully about which parts of the grid will be most affected. For example, the demand on the low-voltage domestic grid can be alleviated by providing targeted access to charging systems on medium and high voltage grids, at places like commercial business parks, and incentivising the use of small-scale renewable solar and off-peak battery energy storage systems for residential use.

Component design

The third major barrier to the adoption of electric vehicles, and arguably the most important one, is the design of components. The modern motor vehicle is a far cry from the crude, greasy and heavy electromechanical systems of old.

Yet, despite the advancement in nearly every other area of engineering, sitting in a car today, you would be unlikely to tell that the vehicle is being propelled by largely the same internal combustion technology that was invented 159 years ago.

Electric systems are now so capable of running efficiently that, if the car was invented today, it would seem ludicrous to use inefficient petrol and diesel engines. However, for all their inefficiency, the components used in internal combustion vehicles are certainly robust, capable of handling a myriad of forces and ingress exerted over the course of hundreds of thousands of miles.

According to Toyota, the average vehicle is made up of 30,000 parts right down to each individual screw. All of these parts must be able to withstand repeated bouts of acceleration and braking, as well as low and high-speed driving over smooth and rough terrain. The same parts must also perform in a variety of weather conditions, from hot and humid environments to cold and wet ones.

This is what makes it challenging for engineers to design the next generation of electric vehicle. Whereas internal combustion technology has undergone over a century and a half of design refinement, electric vehicles — despite being invented around the same time as the first production automobile — have only become commercially viable in the last decade.

As a manufacturer of wound components, German power quality specialist REO knows the challenges of EV component design better than most. Established in 1925, the company has extensive experience in designing and manufacturing components as diverse as electronic filters, resistors, transformers and other types of power electronics for sectors including renewable energy, rail and automotive.

The demand for electric vehicles has spurred the company to adapt its offering to include specialist components for EVs.

Managing director of REO UK, Steve Hughes, believes that the challenge of EV component design stems from three issues: space, cooling and power quality.

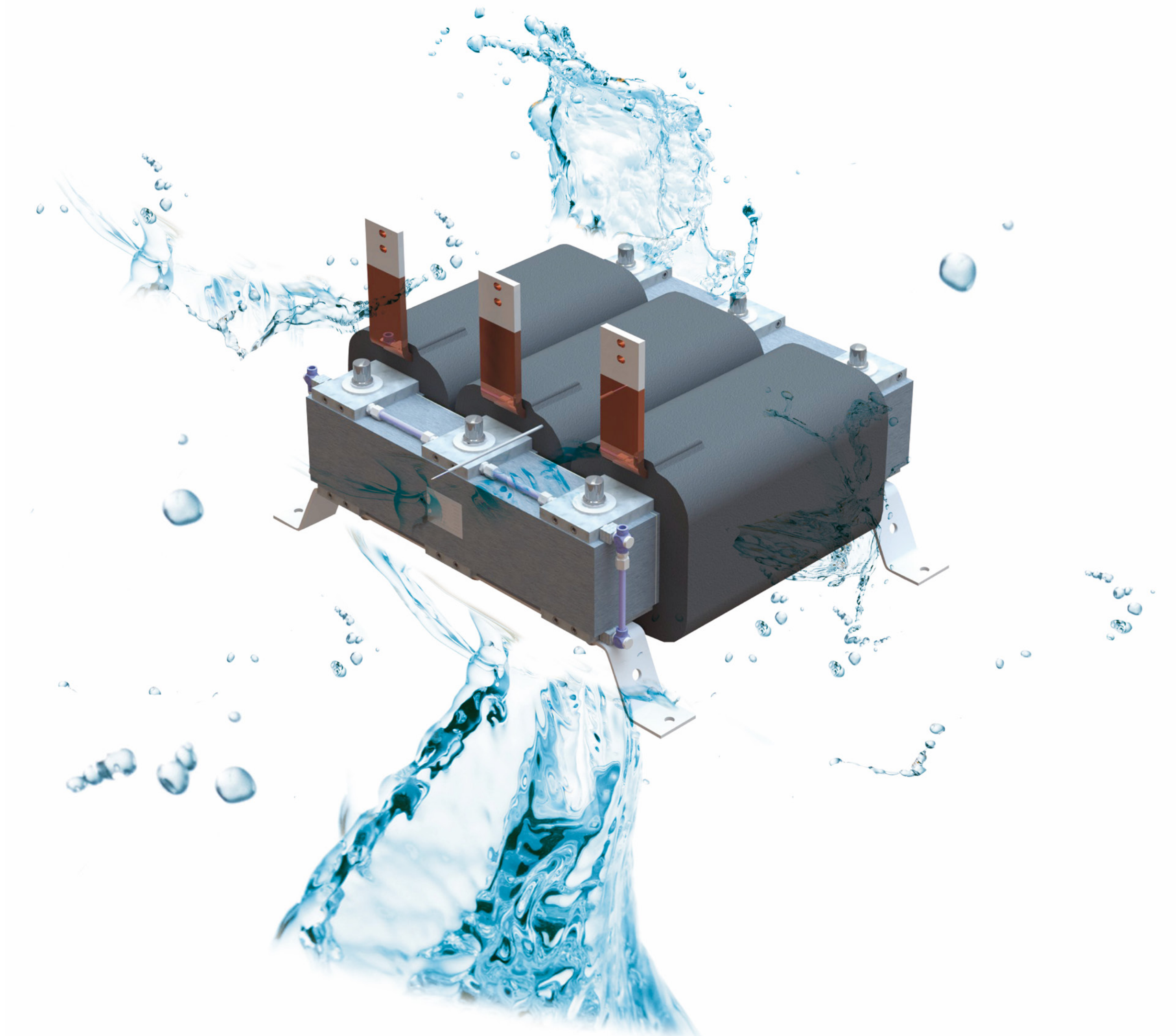
"Over the last few years, we've delivered design and development projects for a few of the well known German vehicle manufacturers. One of the key constraints has been the small space-envelope available to design engineers to fit electrical components into a vehicle that already has a high component density.

"What's more, this means that we can no longer use air-cooling to dissipate the heat generated from the components during normal operation, so we have developed specialised liquid-cooling systems to manage the thermal properties of the electrical components while allowing them to meet the space constraints of the vehicle."

However, with so many electrical and electronic components working in such close proximity to each other, EVs pose a bigger problem in the form of power quality issues. Although EV components provide a much more efficient transfer of energy, the process of power conversion — especially for high frequency inverters — used by these electronics results in electromagnetic interference (EMI), more commonly known as electrical noise.

This is compounded by the fact that the same lines used to deliver power to the electric vehicle are also used for data signalling to provide the battery management control system with information on variables like charge status, temperature and voltage. A failure to address EMI can result in overheating, efficiency losses and potential radio frequency issues that interfere with the vehicle's data communication systems.

To meet this challenge, REO has built on its extensive experience in railway electrification and developed a variety of inductive and resistive components for electric vehicles and their charging systems. EVs have some equivalent subsystems to those found in their internal combustion counterparts. The powertrain consists of batteries combined with an electric motor to generate propulsion and the drivetrain uses electric motors to drive the wheels.



Transformers for charging stations

For the EV charging systems, this takes the form of a single-phase transformer and electromagnetic compatibility (EMC) filter. As transformers get bigger for higher frequency applications, the proportion of losses and eddy currents rises. To keep these at bay, it's preferable to keep the size of the transformer small. REO achieves this by using better core materials such as amorphous cores, nanocrystalline cores and ferrite cores.

The cooling capacity of the high frequency transformers can also be increased by using aluminium housing, which can be attached to a cold plate for optimum heat dissipation.

If ingress protection is a priority, the transformer can also be completely encapsulated within plastic housing, which also improves the insulation class.

A note on EMC filtering

EMC filters are used to suppress conducted electromagnetic interference by maximising the impedance mismatch between line and load. The filtering effect works in both directions, from the charger to the car and from the car to the charger.

At the heart of the EV

In addition to the batteries and electric motors, the electric vehicle also consists of an inverter and a DC-DC converter to efficiently manage the power conversion using high frequency switching. Here, high frequency components such as transformers, chokes, braking resistors, filters, choppers and storage reactors help to protect the sensitive semiconductor power-electronics.

Chokes work alongside transformers to fulfil two functions; either attenuate undesired frequencies or for energy saving and energy storage. REO's common mode chokes suppress this electrical noise in the inverter, and the company's storage chokes are designed to effectively store and discharge magnetic energy from the core, regardless of whether it's made from a ferrite, amorphous or nanocrystalline material.

The next two components are designed to cope with day-to-day driving. Where a normal petrol or diesel vehicle uses friction to convert mechanical braking energy into heat and wear on the brake pads, the electric motor used to drive the wheels in an electric vehicle requires a braking chopper. The chopper is directly responsible for converting the energy that is created as a result of high speed changes.

This heat energy is then made useful by the water-cooled braking resistor, which acts as a high voltage recuperation heater, using the waste energy to heat the cabin and provide effective pre-heating to the car's batteries in cold weather.

The same braking resistor also works with the DC-link to dissipate unwanted power from the system safely. This is especially vital in the event the drive system fails, the energy can be safely discharged.

The new norm

Electric vehicles are no longer a new concept. Now that the first few generations of vehicle have been introduced and the market is growing, adoption will follow. To keep pace with consumer demand, it's important that original equipment manufacturers, design engineers and automotive companies continue to solve the challenges posed by electric vehicle design and development to offer a product that is not only as robust as petrol and diesel vehicles, but also better for the environment.

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