e-mobility
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Interview: The use of simulation in BMS and ADAS

Dr Christophe Bianchi, CTO

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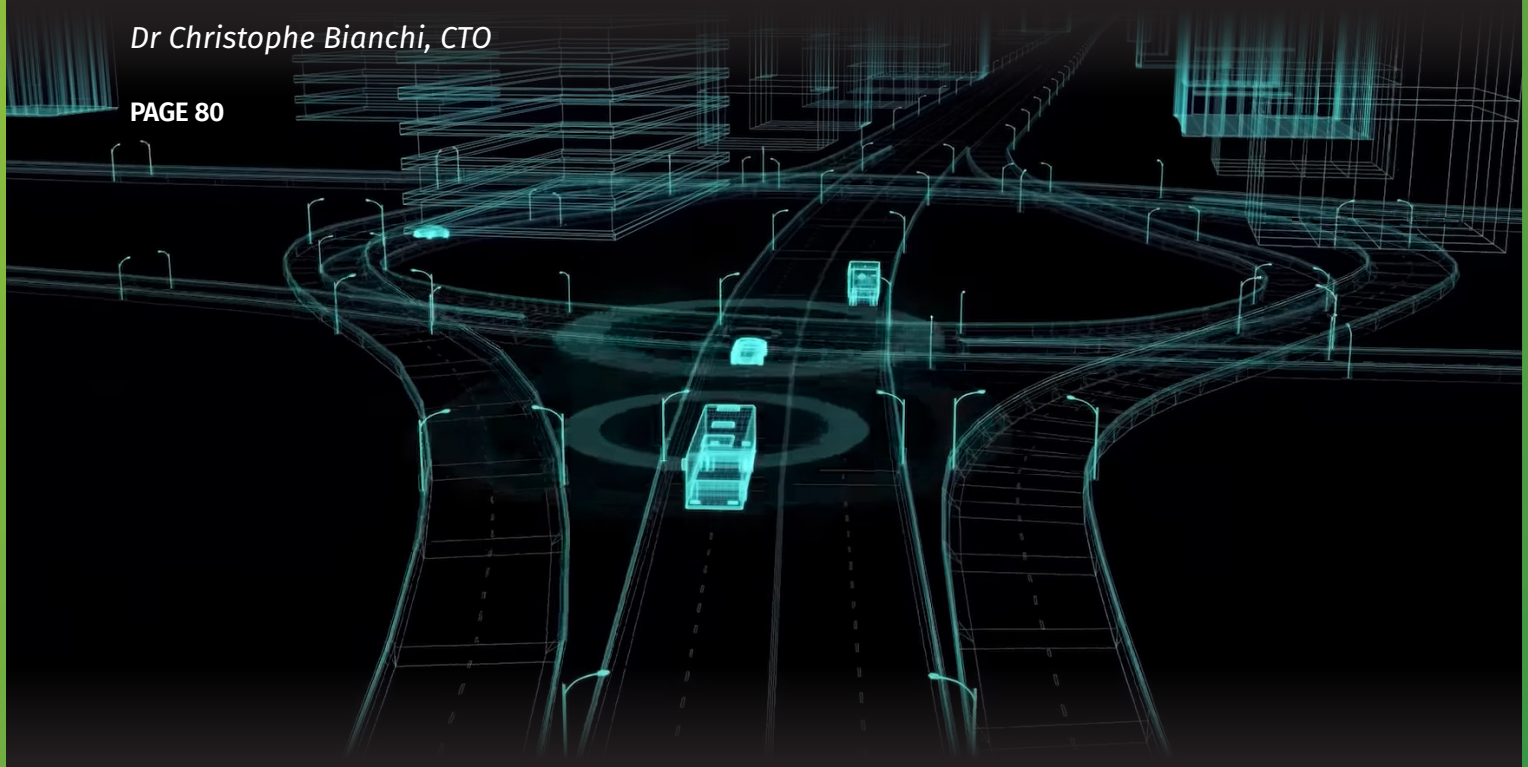

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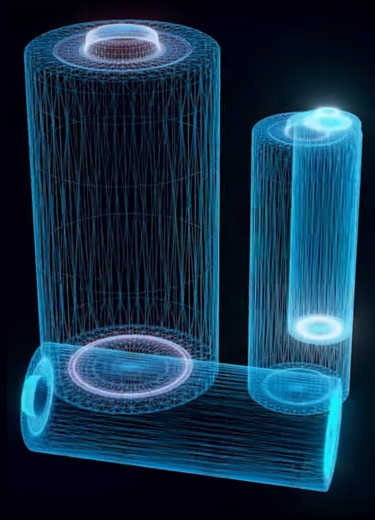
MARK PHILIPS
EDITOR A NOTE -

Electric vehicles have been available for decades. Now they've finally become mainstream.



Car manufacturers are already committed to deadlines, most have changed their production lines and business models and have plans to stop manufacturing ICE vehicles. Technology companies in the sector are demonstrating their commitment and investment and the majority of car manufacturers are equally taking the role to net zero seriously.– the consumer shift is happening.

Electrification in the US is at an earlier stage than other regions globally but has made huge progress over the last few years, with electric cars making up nearly 9% of new registrations in the first half of 2023.

China leads the way with BYD selling 1.857 million EVs in 2022. That represented a 213% leap from its 2021 figures of roughly 593K units.

This surge not only demonstrates the market's increasing appetite for EVs. But it also underscores the OEM's role in driving this transformation.

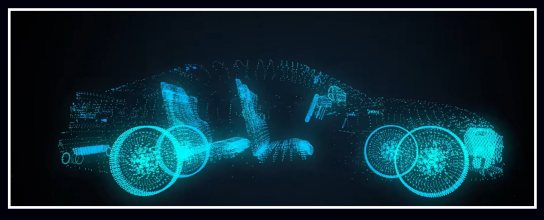
Batteries are expensive and account for around 40% of an EV's price tag, a cost that has so far made them unaffordable for many consumers.

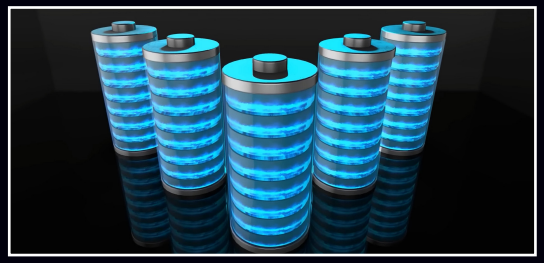
But those prices are steadily coming down as carmakers invest in new battery chemistries, materials and software to make more efficient EVs.

One advance to keep an eye on the coming years is in so-called solid-state batteries. Lithium-ion batteries and related chemistries use a liquid electrolyte that shuttles charge around; solid-state batteries replace this liquid with ceramics or other solid materials making them safer with shorter charging times. Many OEM's have announced new advances in this technology for as early as 2024.

The news for electric vehicles is good overall, despite some lingering "range anxiety, there's more preference for EVs than ever before.

There are still big challenges ahead. Most of the vehicles must become cheaper. Charging options need to be more convenient. Clean electricity generation will have to increase dramatically to accommodate the surge in vehicle charging. And it will be a massive undertaking to make enough batteries.





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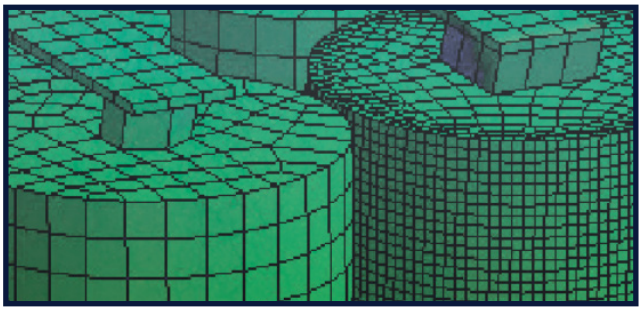

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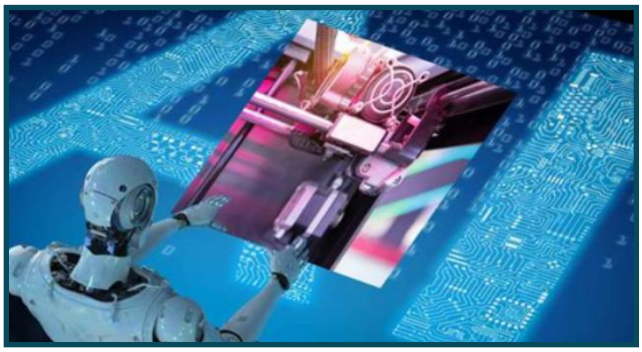

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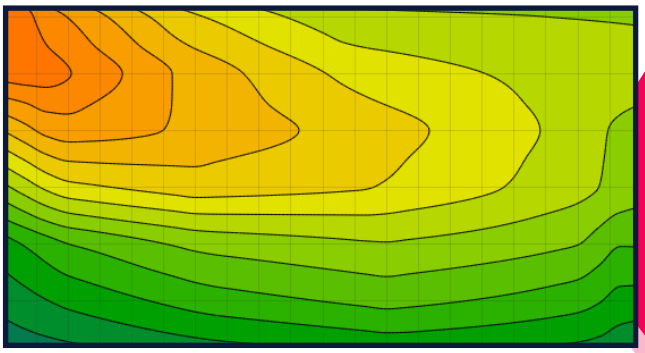

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Charging batteries in record time

A Swiss SME makes it possible to load an e-truck with freight and "refuel" its batteries in the same step.

Patrick Kern

As a start-up spun off from "Brugg Cables" three years ago, "BRUGG eConnect AG" now presents products that are making headlines in the sector. The SME's strategy for success includes cable solutions for industry, wind energy and e-mobility. "With our charging systems, BRUGG eConnect AG, on the one hand, wants to make e-mobility accessible to everyone and, on the other hand, drive forward the energy transition," says Patrick Kern, CEO of BRUGG eConnect AG.

Milestone reached

Technological developments are progressing rapidly in terms of the speed of a charge. Today, depending on the car model and charging capacity, it takes between 15 and 30 minutes to charge a battery at a high-power charging station. This performance is achieved, for example, with a maintenance friendly uncooled PURWIL HPC 500 Cable. ***"New charging stations with cooled charging systems will allow this under 10 minutes, which will make the charging process comparable to refueling vehicles with combustion engines,"*** Patrick continued.

In October 2022, the company unveiled its latest coup: the so-called Megawatt Charging System (MCS), designed for use with all types of heavy-duty vehicles used in a variety of industries - specifically including battery-electric trucks.

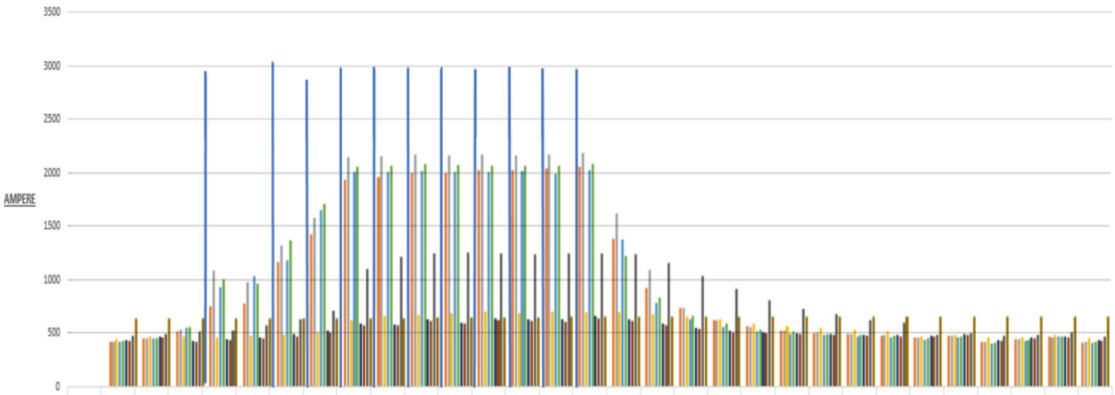
There are now many charging stations for electric passenger cars - but only a few exist for trucks. A gap in the market - because every minute counts in the highly competitive logistics market, powerful fast-charging stations are in demand. For example, the batteries of trucks can now be charged while they are being loaded with goods.

Based on the new connector specification (MCS), together with the Swiss engineering group Cavotec we have developed a cooled MCS charging system that enables charging currents for the first time of up to 3,000 kilowatts (kW) - a world first.

During the first round of testing in August 2022, the development team still struggled with some challenges, such as the cooling hoses, which could not withstand the temperatures at the high loads. Further, the system pressure was also immense, which led to a heavy load on the insulation of the power conductors. However, this problem was solved with the help of a redesign of the connection technology. In October 2022, the MCS Level 3 system was successfully tested.

Under a load of 3000A, stable temperature values could be maintained over a long period of time (see Figure 1: Charging cable 3000 Ampere). After the termination of the current load of 3000A and 1500 V, the temperature values recovered quickly, so that the system would be ready for use again after a short period.

Charging cable 3000 Ampere



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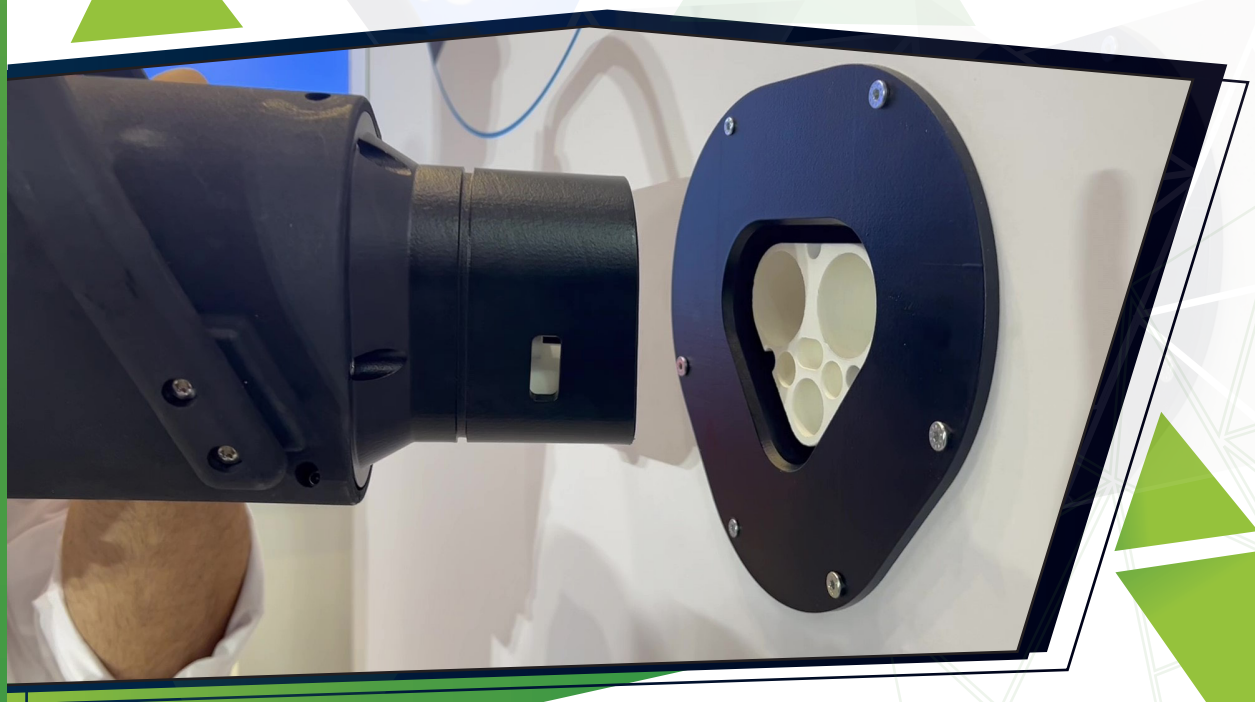
current trafo	0	0	0	0	2946	858	3023	2864	2974	2984	2975	2984	2958	2983	2978	2967	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TC DC+ contact	0	15.6	16.6	18.9	27.6	28.4	42.5	52	70.3	71.2	72.7	72.9	73.7	73.7	74.2	74.8	50.5	33.8	26.9	22.8	20.7	19.4	18.5	18	17.6	17	17.6	15.6	16.3	17.2	15.3
TC DC- contact	0	15.6	16.6	19.7	39.5	35.9	48.1	57.5	78.1	78.5	79	78.6	78.9	78.8	79	79.6	59	39.8	26.9	22.9	20.6	19.4	18.8	18.2	17.8	17.1	17.5	15.5	16.3	17.1	15.4
TC cable	0	16.4	17.2	17.2	17.1	17.5	17.8	18.6	22.9	24.2	24.5	25.2	25.7	25.1	25.8	25.5	25.5	24.9	24	23	21.8	20.8	20.1	19.5	19	17.4	17.9	16.9	17.1	17.7	16.6
TC DC+ out	0	15.5	16.7	20.3	34.1	37.8	43.2	60.2	73.1	73.1	73.5	73	73.2	73.3	72.6	73.7	50.1	28.8	23	20.4	18.9	18.1	17.8	17.2	17	16.2	17	15	15.9	17.2	15.1
TC DC- out	0	15.8	16.8	20.4	36.6	35.2	49.8	62.3	74.7	75.1	75.6	75.4	75.2	75	75.1	75.6	44.6	30.4	24.2	21.6	19.7	19	18.2	17.9	17.5	16.6	17.2	15.3	16.1	17.3	15.4
inlet Busbar +	0	16.2	17.3	15.8	16.4	16.9	18	19.3	21.7	21.5	23	22.1	23.4	23.2	23	24.3	23.2	21.7	20.3	19.4	18.6	18.3	18.1	17.8	17.7	17.6	18.1	16.1	16.9	17.4	16.1
inlet Busbar -	0	15.9	16.9	15.4	16.1	16.7	17.4	18.8	21.1	21	22.4	21.7	22.7	22.5	22.3	23.5	22.5	21.2	20	18.8	18.3	18	17.7	17.5	17.3	17.2	17.9	15.9	16.7	17	15.7
Cable surface	0	17.6	18.1	19.1	19.3	21.1	23.2	26.2	40.1	44.3	45.5	45.7	45.6	45.2	45.4	45.6	45.2	42.1	37.9	33.3	29.7	26.8	24.9	22.8	21.9	17.8	18.4	17.6	17.9	18.7	17.4
Ambient		23.4	23.3	23.3	23.3	23.4	23.4	23.4	23.4	23.4	23.6	23.7	23.8	23.8	23.9	23.9	24	24	24	24	24	24	24	24	24	24	24	24.1	24.1	24.1	24.1

Figure 1



Joaquin Raposo

Innovative, high-quality and sustainable products as focus

BRUGG eConnect AG, a young company with old roots, has been focusing on innovation and excellent Swiss quality since 1896. The company is continuously investing in new production facilities in Switzerland, Poland and the USA to meet increasing demand. The planned expansion is expected to double production capacity by 2025.

To improve and ensure the quality of our products, we expanded the Quality Department in January 2023 to work more effectively. This is headed by Joaquin Raposo, the Chief Quality Officer (CQO). ***"I am committed to flawless processes and quality, as they are a key factor in our success, along with our innovations,"*** says Joaquin Raposo.

In the meantime, several pilot systems have already been delivered to customers, some of which are already being used for field tests.

In the future, the fast-charging system can be used for electrically powered commercial vehicles, ships and aircraft. Our existing CCS 2 charging systems can conduct 850 kW and are also market leaders in this area, Patrick said. The CCS2 system will continue to be used for passenger vehicles, he said.

The Megawatt Charging System (MCS) will help make electric commercial vehicles economically attractive. This will make it possible for new brownfields to operate in a CO2-neutral manner. In construction, for example, this leads to a win-win situation for the environment, local residents and employees. Electronic commercial vehicles are much quieter and do not emit heat like vehicles with combustion engines.

Innovation is firmly embedded in the company's mission. We hold regular strategy seminars with the company's key people, discussing the latest market trends and challenges faced by customers and end users. This constantly generates new starting points for innovations, which are then evaluated and further developed according to the design thinking approach.

We also attach great importance to sustainability and plan to score points with our sustainable products in the future. The new production facilities will help to improve process optimizations, automation and the company's own CO2 footprint. By 2030, the entire Group has set itself the goal of being CO2 neutral, and to achieve Net Zero by 2050.

"We understand sustainability as a corporate management strategy that is focused on long-term success and aims to use all resources carefully to meet the needs of current and future generations," says Dr. Stephan Wartmann, CEO of BRUGG Group. ***"Therefore, BRUGG pursues a holistic sustainability strategy that considers all three components - environmental, social and governance (ESG)."***

The group has developed three programs to implement the ESG areas. In 2022, the company laid the groundwork for implementing sustainability and conducted initial pilot projects. The lessons learned will be incorporated into the sustainability strategy, the Group-wide implementation of which will start in 2023. For fiscal 2023, BRUGG will publish a comprehensive sustainability report based on globally recognized reporting standards (in particular GRI) and the United Nations' 2030 Sustainable Development Goals (SDGs).

"We are aware of our responsibility and live sustainability as a practiced corporate culture at all levels," says Raposo. ***"More and more is also being done to promote diversity in the social sphere; this year, for example, BRUGG Group held its first women's networking event and is also committed to age diversity.***

In the future, BRUGG eConnect AG wants to score points not only with new innovations and their quality, but also with sustainably produced products.

Patrick Kern, *CEO of* **BRUGG eConnect AG**

Unleashing the Potential of Electric Vehicles

Exploring Battery Cloud Monitoring's Role

Anna Heising

The global transition to e-mobility is gaining momentum, revolutionizing the transportation industry and paving the way for a cleaner, more sustainable future. Batteries are at the center of this revolution.

Batteries generate high volumes of data, and this information can be tremendously valuable when software is applied. In recent years cloud-based battery analytics has emerged as a game-changer. Recognizing that improving battery efficiency is a key driver in the widespread adoption of electric vehicles, this article explores the value of battery cloud monitoring solutions for electric vehicles (EVs) and their role in battery safety, efficiency, and cost savings.

Battery Management Systems' Role in Battery Operation

The Battery Management System (BMS) functions as the core processor of a battery, responsible for ensuring that the battery operates within its designated parameters while providing abstract data such as State of Charge (SOC) to the higher-level energy management system. It continually monitors the voltage, current, and temperature of all battery modules to carry out its tasks. However, if a sensor malfunctions or if the BMS logic becomes corrupted, it can result in potentially hazardous situations, such as:

- Unintended shutdown because of an incorrect assessment that the battery has exceeded its operational limits.
- Inaccurate SOC calculations leading to an underutilization of the battery and system imbalance.
- Deep discharging, which can cause the anode tab's copper to dissolve and create an internal short-circuit risk.
- Overcharging, potentially leading towards a dangerous thermal runaway event.

Three Challenges Facing Electric Fleet Operators

Fleet operators must ensure that their electric vehicles operate efficiently, reliably, and safely. These are our customers' top three challenges and where battery analytics can help.

1

Ensuring Battery Safety and Reliability

Battery failures can have severe consequences, ranging from financial losses to safety-critical events. Battery cloud monitoring acts as an early warning system, providing insights into potential safety issues like cell imbalance, overcharging or discharging, excessive plating, insufficient cell quality, manufacturing defects, assembly faults, and abnormal temperature behavior. By promptly detecting these anomalies, users can take a proactive maintenance approach helping to prevent catastrophic battery failures.

2

Identifying Performance and Efficiency Issues

For fleet operators, unexpected failures and downtime result in higher maintenance expenses and often a loss in revenue. For example, an incorrect SOC estimation can lead to a lower range than indicated to the driver. This misinformation often results in a vehicle breakdown.

By using cloud computing to monitor parameters such as voltage, current, and temperature, it becomes possible to identify inefficient charging or discharging patterns. Users can fine-tune charging strategies, optimize energy usage, and extend battery life. This not only improves the overall efficiency of battery-powered systems but also reduces operational costs and environmental impact.

3

Optimizing Replacement and Maintenance

Unexpected downtime and operational disruption can also be caused by sudden replacement and maintenance needs. To minimize those disruptions, battery cloud monitoring supports optimizing battery replacement cycles by enabling proactive planning and budgeting for battery maintenance. It facilitates effective maintenance strategies by providing actionable data on battery health.

By monitoring individual cell performance within a battery pack, it's possible to identify weak or deteriorating cells that may compromise overall system performance. An accurate assessment of battery degradation helps determine the remaining useful life of batteries. This information enables targeted maintenance, such as cell replacement or balancing, rather than replacing entire battery packs unnecessarily.

Unexpected battery failures can lead to vehicle breakdowns, service calls, and time-consuming root cause analysis. While it might only be one vehicle within the fleet having a problem, this negatively impacts the entire fleet's operation.

But, what causes a battery to fail?

Case Study: EV Battery Breakdown

It's a scenario that is all too common for fleet operators—a vehicle stranded on the side of the road. In this case, the vehicle appeared to have a remaining SOC of 20% when it failed. The fleet operator reached out to ACCURE for a root cause analysis.

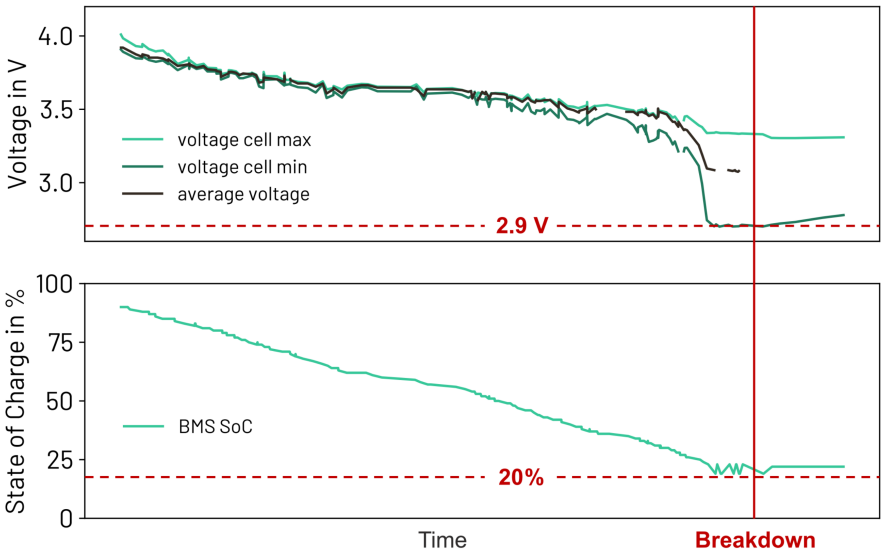


Figure 1: Minimum, Maximum and Average Cell Voltages of the Vehicle; Battery Management System SOC

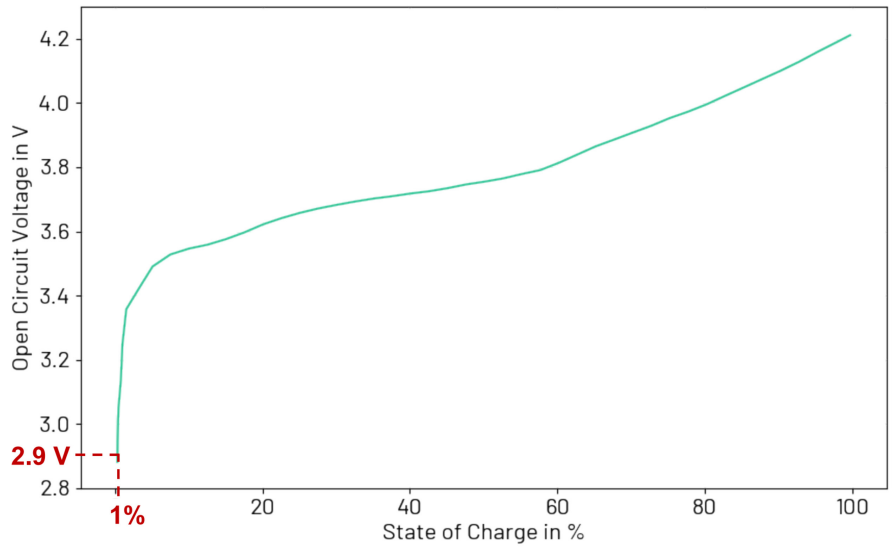
After analyzing the data, we found that the voltage curve of the vehicle contains several deep discharges. Figure 1 displays the latest discharge before the breakdown, showing a huge spread of the minimum, average, and maximum cell voltage. In a normal scenario, this should not occur. While this is not a safety-critical issue, it can affect performance.

The BMS determines the SOC based on the battery's nominal capacity — the amount of energy delivered by a fully charged battery. The result is not an accurate representation of the remaining vehicle range. Instead, the determination of the actual usable SOC must consider the minimum cell voltage.

! It's important to understand the relationship between voltage and SOC. The battery's voltage fluctuates, either decreasing or increasing, based on their level of charge. When the battery is fully charged, the voltage reaches its peak, while it drops to its lowest point when the battery is empty. The specific correlation between voltage and SOC is directly influenced by the type of battery technology employed.

To assess the practical SOC for batteries during operation, diagnosis techniques such as the Open Circuit Voltage (OCV) curve can be employed. Each battery cell possesses a distinctive OCV curve (Figure 2), serving as a unique fingerprint for individual cell types. The OCV curve is the voltage curve of a battery as a function of the charge when no external current is flowing (and all chemical reactions inside of the battery are relaxed). If there is an OCV value given, it's easy to determine the respective usable SOC – and the other way around.

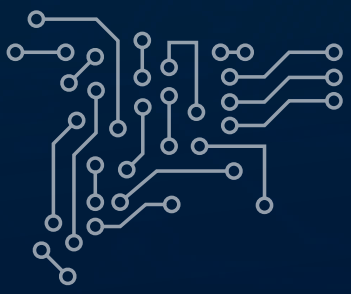
Figure 2: Open Circuit Voltage Curve of Battery Cell Type



Considering the minimum cell voltage of the time series in Figure 1, the OCV curve shows an actual usable SOC of around 1% in Figure 2, even if the vehicle appeared to have 20% left.

The problem was clear. The failure was due to a systematic error in the SOC calculation by the BMS.

Monitoring the vehicle's battery data from its first day of operation can prevent and reduce downtime. In this example, cloud monitoring would have detected the battery behavior in advance, allowing the operator to proactively address the problem.



Detecting Malfunctions with Battery Cloud Monitoring

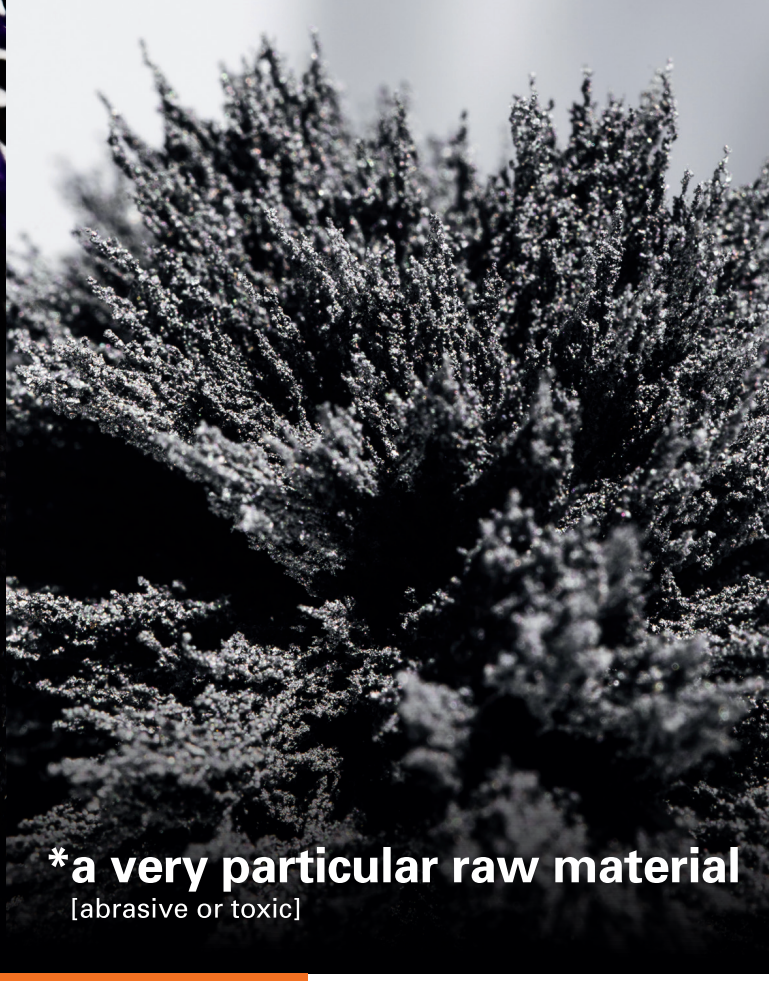
The EV breakdown described above is just one example of how battery cloud monitoring can detect problems in advance. By using larger data sets and cloud computing power, many other battery problems can be identified, including:

- Rapid capacity changes (cell connection issues or knee-points of individual cells)
- Excessive battery self-discharge behavior (internal micro-short circuits)
- Anomalies in battery impedance (weak cells or manufacturing imperfections)
- Anomalies in electrode potential (loss of lithium or loss of active material)
- Hot and cool spots (cooling system outages, contaminations within a cell, bad welding connections or uneven distribution of the material at the thermal interface)
- Drifting temperature behavior (overcurrent, uneven load distribution)
- Balancing anomalies (sudden degradation or poorly calibrated BMS)

It's clear that battery cloud monitoring is essential for electric vehicles. ACCURE is at the forefront of this transformation and is committed to developing pioneering AI and machine-driven software that ensures safe and reliable battery operations.

Anna Heising,
Customer Success Manager
ACCURE Battery Intelligence

Meanie*



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Function Test Bench

Fostering innovations in e-mobility with state-of-the-art test stands

Philip Claussen

The rapid expansion of e-mobility is transforming the automotive industry. Factors such as technological advancements, the global push for CO2 reduction, and supportive government policies around the globe are driving the adoption of electric vehicles (EVs) while an advanced charging infrastructure is being developed as a basis for this expansion. However, the widespread use of electric vehicles also brings unique challenges for OEMs and suppliers.

Pressure Cycle Test Bench

Effective thermal management systems are an important factor for addressing these challenges and to ensure optimal performance and safety of the vehicle. Additionally, these systems also maximize the driving range of an electric vehicle by minimizing its energy consumption: Efficient temperature control ensures that the battery, power electronics, and electric motor operate within their optimal performance range, reducing energy loss and increasing overall efficiency. In addition, electric vehicles require efficient heating, ventilation, and air conditioning systems to ensure passenger comfort. Since EVs do not generate excess heat from an internal combustion engine, alternative methods are needed to heat the cabin without significantly affecting the performance of the vehicle and thereby its driving range.

Testing technology for thermal management components and cooling circuits in electric vehicles is vital to validate the performance, reliability, and safety of thermal management systems. With the growing adoption of EVs, effective testing methods have become essential to ensure the success of new electric vehicle designs and their thermal management systems. “Comprehensive testing methodologies are necessary to ensure the efficiency, reliability, and safety of electric vehicle components”, says Johannes Montag, Managing Director of Germany-based company Poppe + Potthoff Maschinenbau GmbH. “When integrating state-of-the-art testing technology into R&D processes, our test stands can foster innovation and drive the automotive industry forward by providing customers with data on function, strength and much more”.

To prove the quality and longevity of media-carrying components, drive units (e-motors), valves, cooling and heating circuits, hose lines, pipes, pressure vessels and other components are pressurized in specific test stands. The focus here is on efficient energy management and performance under changing temperature conditions. The performance and power consumption of components and systems must be studied in realistic service life conditions. While testing for durability and fatigue strength, the tests allow for identifying the electronic components limit the vehicles range.

Pressure changes at varying temperatures

In a typical test, the component is inserted into the test chamber of the pressure cycling test bench. This can be a cooling unit for an ECU of an electric car or valves, hoses and other hollow bodies that need to withstand more than 100,000 load changes over the lifetime of the vehicle (up to 15 years). The test medium is a water-glycol mixture or pure glycol (for example Glysantin G40, G44, G48). The cooling circuit is tested at -40°C to +20°C (-40°F to +68°F) while a heating circuit is tested in temperatures from +20°C to +140°C (68°F to 284°F). A specially developed closed test media circuit uses pressure to prevent the formation of alcoholic vapours (which create a risk of explosion). A system can also be analyzed in a climate chamber. Test standards evolve and over- and under pressure testing can be added if required.

The flow rate of the test medium can vary from 1-50 l/min at a pressure of 0.2-12 bar or higher. The load changes are freely programmable with sinusoidal or trapezoidal rise at a test frequency of 0.2-2 Hz or faster. The test stand can be used for complete systems, assemblies and components made of various plastics, metals and sealants. Weak points in the material combination, as around a weld seam, can be sounded out and optimized early in the development process as well as during production.

Time lapse for long-term tests

A long-term test usually takes 20-30 days, depending on the frequency of the load changes. The temperature and volume flow of the test medium as well as the ambient temperature (if the test takes place in the climatic chamber) vary according to the test specification. The temperature at the inlet and outlet of the test object is measured continuously, as well as the flow rate, pressure and pressure drop, and current and voltage (both in the high and low range). The focus is on the thermal and electrical performance of the heating and cooling unit under varying environmental conditions. Thermal sensors can be mounted on the DUT (device under test) to indicate during the test when energy is lost (thermal bridges) or when the component becomes very hot (and thus presents a fire hazard).

Testing energy efficiency in battery operation

Power consumption and performance are typically tested at alternating temperatures – optionally with a low- or high-voltage power supply to simulate operation via onboard battery and generator or the traction accumulator.

In many EVs, the heating and cooling systems drain the battery and negatively affect the vehicle's range. Comparison of test results before and after a load test on the pressure cycling test bench can show how power consumption and performance change over the vehicle's service life. The test object is connected to the power supply (low voltage 0-20VDC/5A) or high voltage (0-600VDC/150A) and the test media circuit. The test medium is circulated at a temperature of between -40°C to +100°C (-31°F to +212°F) and a flow rate of 1-50 l/min. The test can also be carried out in a climatic chamber at -40°C to +140°C (-40°F to +284°F) simulating changing ambient temperatures.

Poppe + Potthoff Maschinenbau test systems are easy to operate and extremely safe. The test chamber consists of welded stainless steel and a high-strength polycarbonate safety window. Any test sequences created on the PC can simply be called up manually via coded recipe management or by a handheld scanner. The integrated LabView software from National Instruments enables efficient data acquisition and visualization. Test procedures and data are automatically stored on the system and can be exported to the network for evaluation. The open software structure makes it possible to integrate additional sensors and data during testing.

Philip Claussen, *Director*
Poppe + Potthoff Maschinenbau GmbH

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How Hard Can It Be?

Why you don't have a self-driving car (yet)

Dr Nick Reed

The act of driving appears deceptively easy. With only four main actions – steer left, steer right, speed up, slow down – it seems that it should be almost trivial to develop electronic systems capable of managing these four operations. Google first revealed their work on self-driving cars over a decade ago and billions have subsequently been invested by vehicle manufacturers, technology companies, investors and governments in their development. So why are we still waiting for self-driving cars to make a global impact on the mobility of people, goods and services? Of course, whilst the actions might be simple, the real challenge lies in deciding which action to take and when.

Why does this feel easy to us?

Driving is not a task for which evolution directly has shaped our human abilities. However, our transport infrastructure, the vehicles that use it and the rules that govern the system have been shaped by those abilities. For example, steering, accelerator and brake controls became standardised to suit how we could mechanically manipulate vehicle behaviour. Once vehicles capable of sustaining high speeds were available, motorways were created to facilitate rapid journeys – these needed to have lane widths, road curvature and gradients that made it possible for humans to operate cars, trucks, buses or motorcycles at appropriate speeds; road signs needed to have text and pictograms that could be read from sufficient distance and so on. Faster vehicles necessitated more efficient braking systems to slow our vehicles sufficiently rapidly in response to emerging hazards. Motorway service areas are suitably spaced to enable us to meet our physiological needs to rest, refuel and refresh when completing longer journeys. With due consideration for safety and efficiency, the road system also accommodates individuals with a wide range of needs and capabilities and vehicles of different sizes, configurations and characteristics.

How should we consider introducing a self-driving vehicle to this environment that has been adapted to our human capabilities?

At first glance, it seems very similar. A self-driving vehicle has sensors to collect information about the environment surrounding it. Computing power substitutes for our brain, processing this information and deciding what to do next in the context of stored knowledge of the road system and the rules of the road. It then sends a message to actuators that cause the vehicle to follow the required instructions for steering, acceleration and / or braking. However, there are some crucial differences.

Firstly, the process by which electronic systems gather information about the driving scene is very different. Although other senses are relevant (particularly hearing and proprioception), driving is primarily a visual task.

The central region of human vision has a resolution that measures in the hundreds of megapixels and connects to neural processing systems that are finely tuned to detect and resolve movements in 3D. It can do this readily, compensating for movement of the observer and any bumps or vibrations they experience (within limits!) and has a wide dynamic range, capable of dealing with highly contrasting and rapidly changing lighting conditions. This system is far from foolproof, as any book of visual illusions will demonstrate, and can be affected by fatigue, intoxication or any number of diseases or degenerative conditions. It only covers a forward horizontal field of view of around 200 degrees (with a much lower spatial resolution in the peripheral regions) and a driver must process reversed images presented in the mirrors to build a more complete picture of the surrounding environment. However, it is a system that has evolved over hundreds of millions of years to help us avoid predators or catch prey and the task of driving has developed accounting for its extraordinary capabilities.

By contrast, a self-driving vehicle may use cameras, lasers, radar or ultrasound systems for gathering information about its local environment. Each generates data about the scene with varying degrees of resolution and resilience to environmental and dynamic conditions it experiences. Sensors can be placed at locations all around the vehicle such that the system has a continuous 360 degree perspective on the outside world. This data then must be processed for the vehicle to build its own representation of its surroundings. Whilst self-driving vehicles with limited capability have been around for decades, recent developments in computer processing and machine learning techniques have dramatically increased the capabilities of electronic systems in synthesising and analysing multiple sources of data to extract key information and determine what to do next. As well as exceeding human capabilities in terms of visual field, different sensors can provide more precise information about the movement of other objects – radar gives very accurate information about relative speeds and locations of other objects, which can only be estimated by a human observer.

Secondly, memory plays distinct roles for humans and self-driving vehicles. A human driver driving on a familiar road can use their memory to help position the vehicle appropriately for upcoming manoeuvres or to manage their speed more effectively based on their stored knowledge of upcoming road configurations or hazards. They also must use their memory of the rules of the road and the expected behaviours to navigate safely and in a predictable manner. When driving in a new environment, a human driver has the flexibility to use their skills, senses, memory and judgement to manage the situation, driving in a more cautious manner to compensate for their unfamiliarity with the road and its features. Specific memories can fade but the skill of driving is very durable. Once learnt it is not easily forgotten.

Memory has different characteristics in the context of computers. Large quantities of stored data can usually be accessed very accurately and rapidly. Some developers use stored high-definition maps to enable the vehicle to understand where it is, to plan its route from its origin to its destination and to detect any differences when the map is cross-referenced against the information received by its sensors. In effect, the vehicle has a perfect memory of the configuration of the world around it and can use that to help with positioning and navigation. However, this means that the vehicle is limited to regions that have been mapped to the required quality. Other developers are taking a different approach and use systems that are effectively capable of applying the principles of driving in a wide variety of situations. This means they are not limited to specific environments but may necessarily have to drive more cautiously to make up for their more limited foreknowledge of the road configuration.

Another notable difference is our appreciation that contravening the rules can result in punishment and that poor driving behaviours may result in harm to ourselves, our passengers or to others. Computers can be made to operate in full compliance with the rules of the road and this should lead to reduced risk. However, they cannot be punished in the same way as a human driver and do not have an innate sense of self-preservation or desire to avoid harming others. We trust human drivers will do all that they can to prevent collisions that could result in casualties (and this might very occasionally mean breaking the rules of the road). Whilst we can trust the developers of self-driving vehicles to have done the same, programming errors or some unusual combination of stimuli might result in a self-driving vehicle causing harm in what would be considered a very safe situation for human drivers.

However, the final piece of the puzzle is perhaps the one that is the greatest challenge for the developers of this technology.

Humans are social creatures with an innate ability developed over millions of years to observe, understand and predict the behaviour of others and to take reasonable actions in response - even in situations that are incredibly rare or bizarre. Tiny details, such as a pedestrian taking a quick glance over their shoulder, that would be barely perceptible to a self-driving vehicle's sensors would be immediately recognised by a human observer and used to guide future actions – in this example, appreciating that the pedestrian may want to cross the road and so preparing to take avoiding action if needed. With improving sensors and exposure to more and more human interactions, computers are beginning to develop these skills but they are far behind in the sensitivity and subtlety of situations that we humans find trivially easy to comprehend.

Recent events in San Francisco highlight such challenges for this technology. Self-driving vehicles deployed in the city have been observed stopping in intersections, driving into roadworks, obstructing emergency vehicles and ignoring guidance from police officers. The resulting publicity surrounding such incidents has provoked activists into placing traffic cones on the bonnet of self-driving vehicles.

This disables the vehicles and, in their eyes, highlights them as the hazard they perceive self-driving vehicles to be. The city transport authority has also urged greater caution and more transparency from self-driving vehicle operators to build confidence in the safety of their services.

Make no mistake, it is incredibly impressive to see self-driving vehicles operating in public on busy city streets. This is a phenomenal software and hardware engineering accomplishment. However, the difficulties observed with these early deployments highlight how far we still need to go for self-driving vehicles to reach the capabilities we human drivers display – and it is our innate human ability to understand the world around us that is the most challenging for them to match.

Dr Nick Reed, *Founder*
Reed Mobility

Noise-Damping Shims for Electric Vehicles

Martin Søgaard

Electric vehicles (EVs) typically use regenerative braking, where the electric motor generates electricity that is stored in the battery. However, there are several brake conditions under which regenerative braking may not be an option (i.e., at low speeds, at speeds where deceleration is above a certain threshold value, and during emergency braking). Consequently, EVs are also equipped with traditional means of braking, typically disc brakes or drum brakes. As EVs carry a heavy battery, disc brakes are often chosen due to superior braking performance over drum brakes.

Efforts to limit brake noise

During braking with a disc brake, a large amount of energy is released, most of it as heat, however, a small part of it is generated as vibrations in the disc and pad. These vibrations are within the audible range and may reach levels as high as 100-120 dB in the form of brake squeals. A such level of noise can be disturbing for the driver and for the environment surrounding the car. Brake noise can also lead to high warranty costs and poor customer reviews. For these reasons, large efforts are put into the noise-damping of disc brake systems. This includes modifications to the brake caliper, discs and pads, but also a stronger focus on the application of anti-noise shims to the backplate of the brake pad.

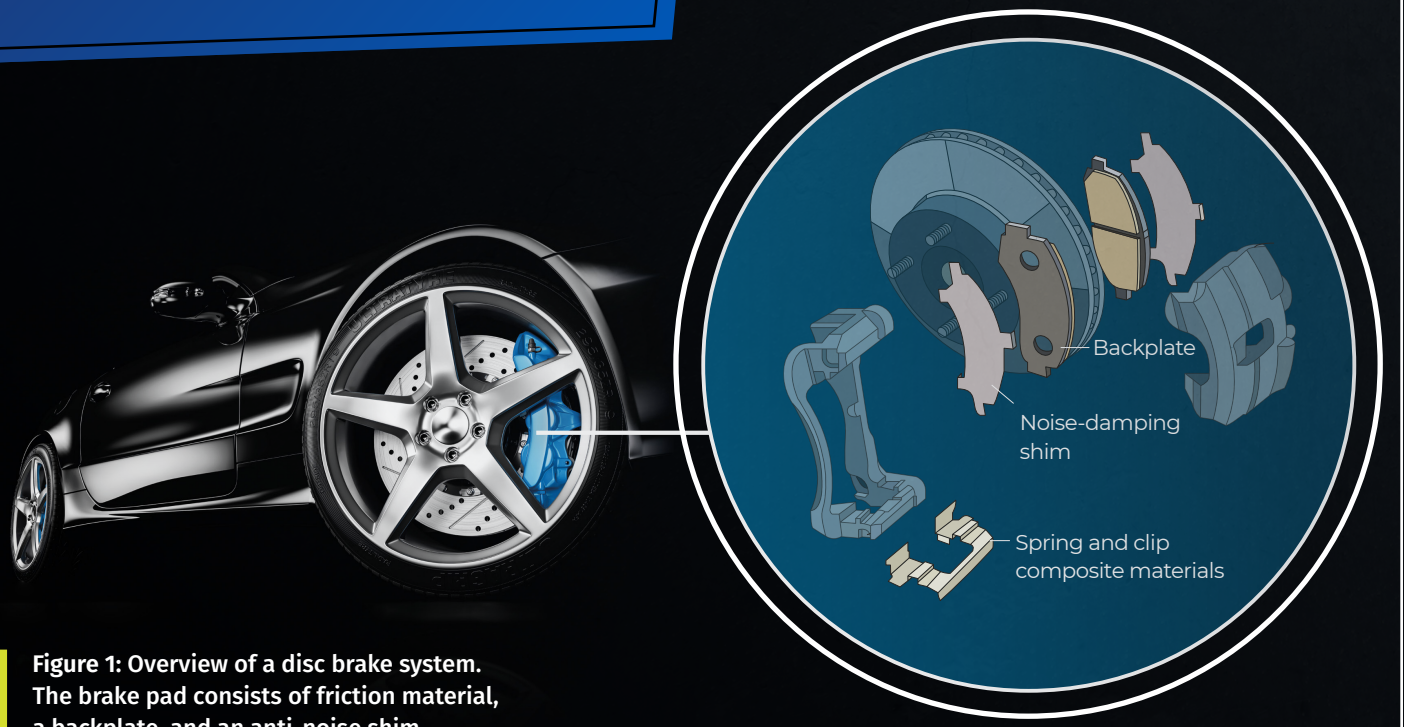


Figure 1: Overview of a disc brake system. The brake pad consists of friction material, a backplate, and an anti-noise shim.

Steel, rubber, adhesive: Constrained Layer Damping

Anti-noise shims are typically made of a steel layer onto which rubber is attached using advanced thin film coating techniques. The rubber-coated steel plate is then attached to the brake system of the car using specially developed adhesives with noise-damping properties. The overall concept is called Constrained Layer Damping (CLD).

Cancelling cold noise: how to tackle low noise acceptance in EVs?

During braking operation, an EV has lower temperatures on the pad and disc compared to vehicles with an internal combustion engine (ICE) due to the usage of regenerative braking in EVs. Figure 2 shows a typical temperature profile of a brake disc in an EV and in a vehicle with an ICE.

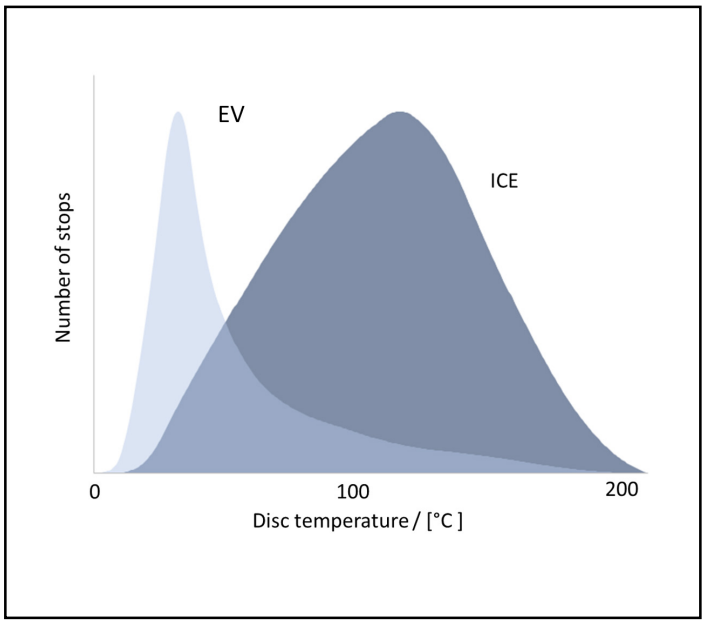


Figure 2: Disc temperature for a typical EV and for an ICE vehicle. The disc temperature of the EV is much lower than that of the vehicle with an ICE. Ambient conditions will also have a significant impact on the disc temperature of an EV.

Typical disc temperatures for EVs are below 150°C, meaning that the typical maximum backplate and shim temperatures are in the temperature range of 50 – 70°C.

The ambient conditions play a key role in the temperature levels of the disc, backplate, and shim. Lower temperatures are in general beneficial for the durability of the brake pad and shim. However, at lower temperatures, there is an increased risk for water and ice to remain longer on the disc, resulting in an increased risk of noise issues. Additionally, brake pads last longer on EVs due to lesser usage. This allows for a decrease in the thickness of the friction material of the brake pad, which will significantly add to the risk of increased noise levels.

As the noise acceptance level is generally lower in EVs, due to the overall lower noise levels, it is critical to find an anti-noise shim solution that is suitable for the vehicle and brake system in question.

The need for innovative solutions

Anti-noise shim materials of today already cover a broad temperature range and have a main damping centered around +20°C. As the noise acceptance level is even more critical for EVs, it requires development of additional solutions to dampen noise from -20°C to +80°C. In some cases, standard solutions can be used, and in other cases, innovative solutions are needed.

The importance of adhesives in anti-noise brake technology

There are three main types of adhesives used in anti-noise brake shim technology: silicone, phenolic, and acrylic adhesives.

1

Silicone adhesives: excellent compressibility – higher cost

Silicone adhesives have the advantage of high-temperature stability up to 250-300°C for prolonged periods of time. They have a low compressibility which is beneficial for the overall brake performance. One disadvantage is that the cost of silicone adhesives is higher than acrylic adhesives.

2

Phenolic adhesives: broad damping – energy & time consuming

When combined with rubber, phenolic adhesives provide good damping in a broad temperature range. However, phenolic adhesive requires a bonding process to the backplate that involves heat (>200°C) and pressure for longer periods of time (up to 3 min). Although an extremely good bonding between the backplate and the shim is achieved, which is very suitable for high-performance cars, the complex bonding procedure is energy-intensive and time-consuming. Phenolic adhesive is therefore gradually being phased out of the market.

3

Acrylic adhesives: price competitive – lower performance at high temperatures

Acrylic adhesives are price competitive, their damping properties can easily be modified, and the adhesive can be tailored to be hard or soft. One disadvantage of using acrylic adhesive is that the adhesive will get oxidized at high temperatures of 250-300°C, whereby the material becomes brittle and the damping performance in the adhesive is lost. The standard acrylic adhesives have been on the market for many years and are typically used for aftermarket shims.

Figure 3a. shows a damping plot of a standard acrylic adhesive sandwiched between two steel layers. The main damping is located around +20°C in a broad frequency range (1 kHz – 12 kHz).

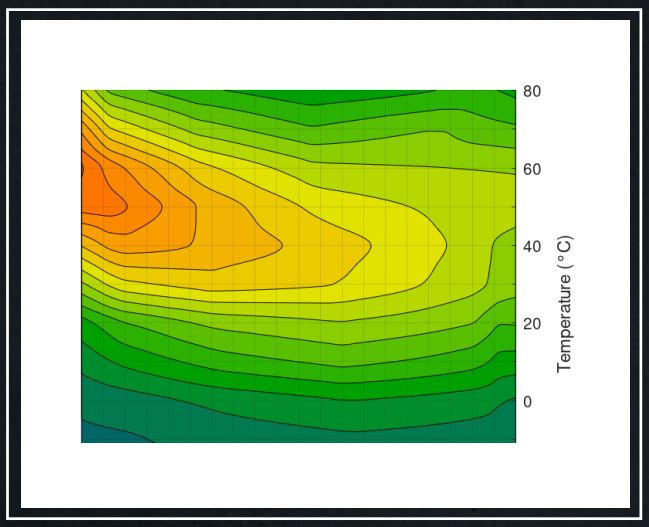


Figure 3a: Typical damping plot of a standard acryl adhesive.

Figure 3b. shows an adhesive with a cold noise-damping profile that offers excellent performance criteria such as compressibility. This type of adhesive is new to the market. The cold noise-damping adhesive has a main damping of around 0°C in a broad frequency range. This means that the adhesive will damp particularly well for brake systems where noise issues occur in this temperature range.

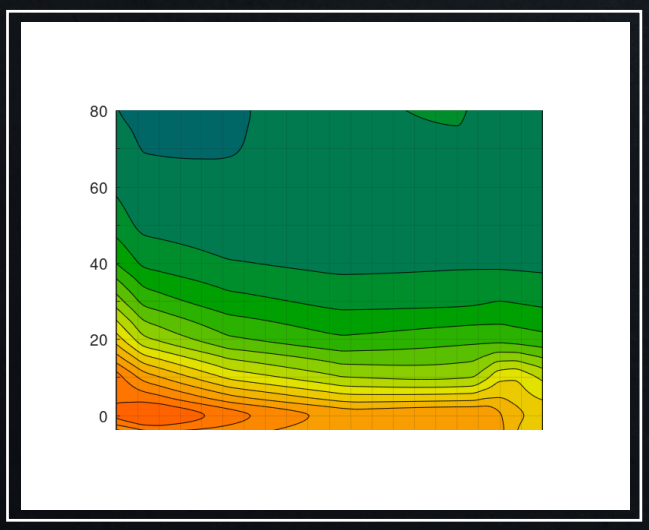


Figure 3b: Damping plot of a cold noise adhesive. Main damping is now at 0°C in a broad frequency range.

Figure 3c. Damping plot of a warm noise acrylic adhesive. The main damping is at 40-65°C in the frequency range <7 kHz.

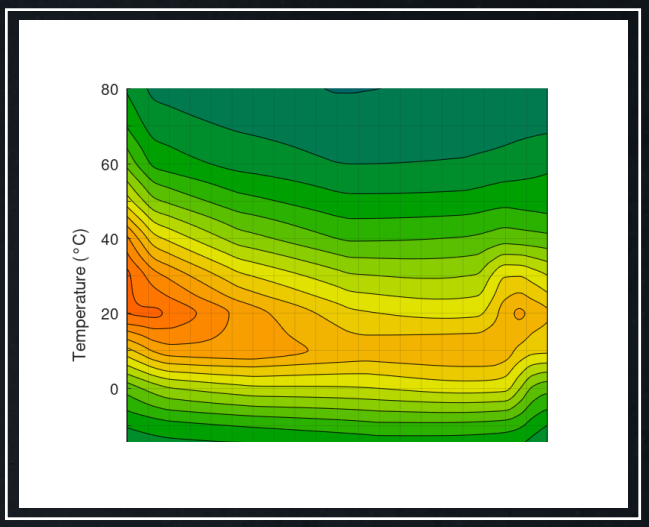
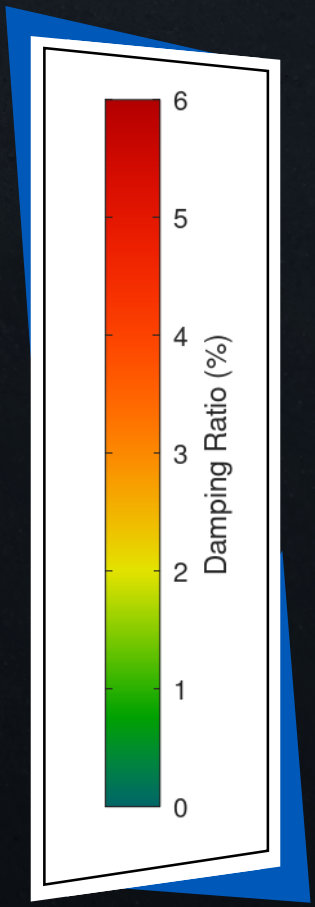


Figure 3c: shows a new type of acrylic adhesive that recently entered the anti-noise shim market. The adhesive has a main damping in the region +40-65°C, which makes anti-noise shims using this type of adhesive particularly attractive for EVs operating in areas with a warmer climate.



Noise incidents significantly reduced with anti-noise shim technology

Figure 4a shows noise results from a noise dynamometer test (dyno test) of a brake system from a large EV platform. The purpose of a dyno test is to measure the noise level of a given brake system when exposed to different conditions. The result shown in Figure 4a is from a dyno test run at low temperatures, with a backplate and shim temperature range from approximately -15°C to +15°C (see left axis). The right axis shows the sound volume measured in dB. The blue lines (braking under forward driving) and red lines (braking when driving reverse) mark noise events above 70 dB. Approximately 60% of the stops have significant noise above 70 dB and going up to 110 dB.

Decrease in noise acceptance levels calls for novel noise-damping solutions

In conclusion, although regenerative braking will be the most frequently used braking technique in EVs, there will still be a need for standard disc brakes. Considering EVs' noise acceptance level being strongly decreased, there is an increased need to find novel solutions. It will require innovative solutions from the producers of brake systems, brake pads, and from anti-noise shim suppliers. The way forward for anti-noise shim suppliers will typically translate to broadening their product portfolio to be able to fulfill the OEMs' requirements for low-noise vehicles.

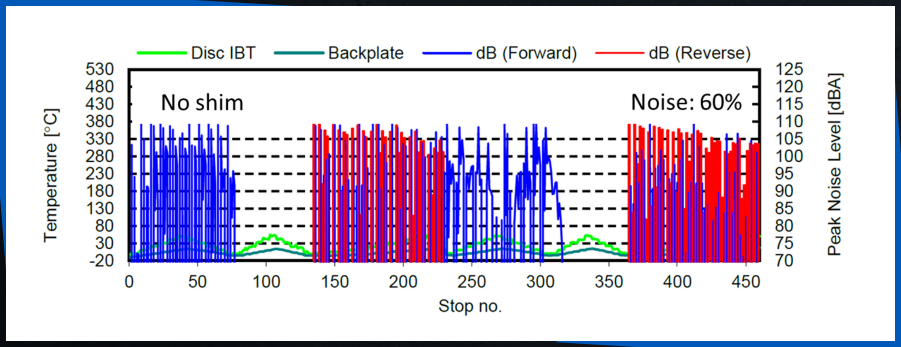
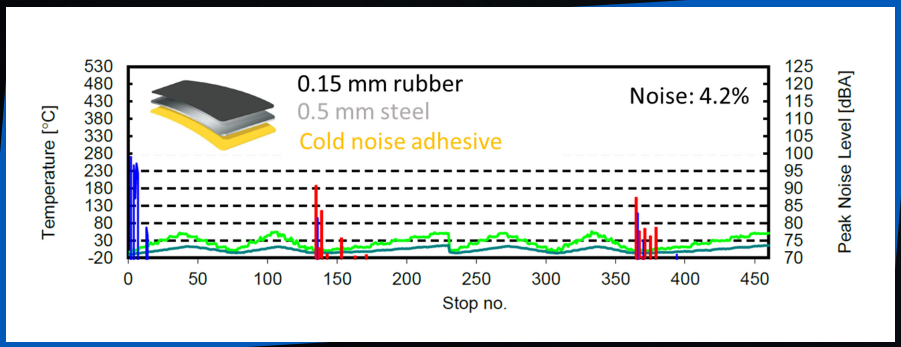


Figure 4a: Noise dyno test of a brake system from EV platform. The test is run from -15°C to 15°C and noise incidents are shown as blue (forward) and red (reverse) lines. For this test, there was no use of an anti-noise shim on the brake pad.

Figure 4b. shows the noise results from the exact same test hardware, but this time, the brake pad was equipped with an anti-noise shim with cold noise adhesive. By applying cold noise adhesive, the number of noise brake stops was successfully reduced from 60% down to 4.2%.



Martin Søgaard, *Group R&D Manager* **Meneta**

Figure 4b: Same dyno test as in Figure 4a, this time with an anti-noise shim with cold noise adhesive applied on the brake pad. Noise incidents are significantly reduced using anti-noise shim technology.

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New LCP (Xydar® G-330 HH) material for Battery Module Insulation

Designed to Mitigate Thermal Runaway, Improve Electrical Insulation, & Provide Space Savings

Jiwen Wu, Nicolas Batailley, Brian Baleno

Next generation battery electric vehicles (BEVs) are launching with much higher voltages than many of the current 400 Volts systems on the market today. Driven by the need to increase range and enable direct current (DC) fast charging, automotive car makers are introducing battery systems that operate above 800 Volts. The addition of more battery cells as part of the overall battery system is a key driver to increasing the battery power density and performance.

A result of increased battery power increases is greater current and higher voltages. While enabling greater range and DC fast charging, these new high voltage battery systems pose new design challenges. Battery engineers take into account safety of the battery system which includes thermal events such as thermal runaway and thermal propagation.

When a battery cell's temperature gets too hot, a thermal event commonly referred to as thermal runaway may occur. This outcome produces an exothermic reaction in a lithium-ion cell that can lead to the release of gasses and particles. The release of either the gasses or particles has the potential to ignite and spread to the other cells within the battery pack. Thermal runaway events can pose a serious risk to those within or around a BEV.

To ensure consumers are safe, new legislation in countries like China, Europe, Japan, and the United States, is being developed. As a result of the legislation, battery engineers are working to identify materials that withstand temperatures (300 - 1000 °C) for a given period of time (5 minutes or greater) which allows passengers to safely exit the vehicle. Battery designers are seeking material solutions that can mitigate thermal runaway in a range of components inside the pack such as the insulation as shown in Figure 1 below:

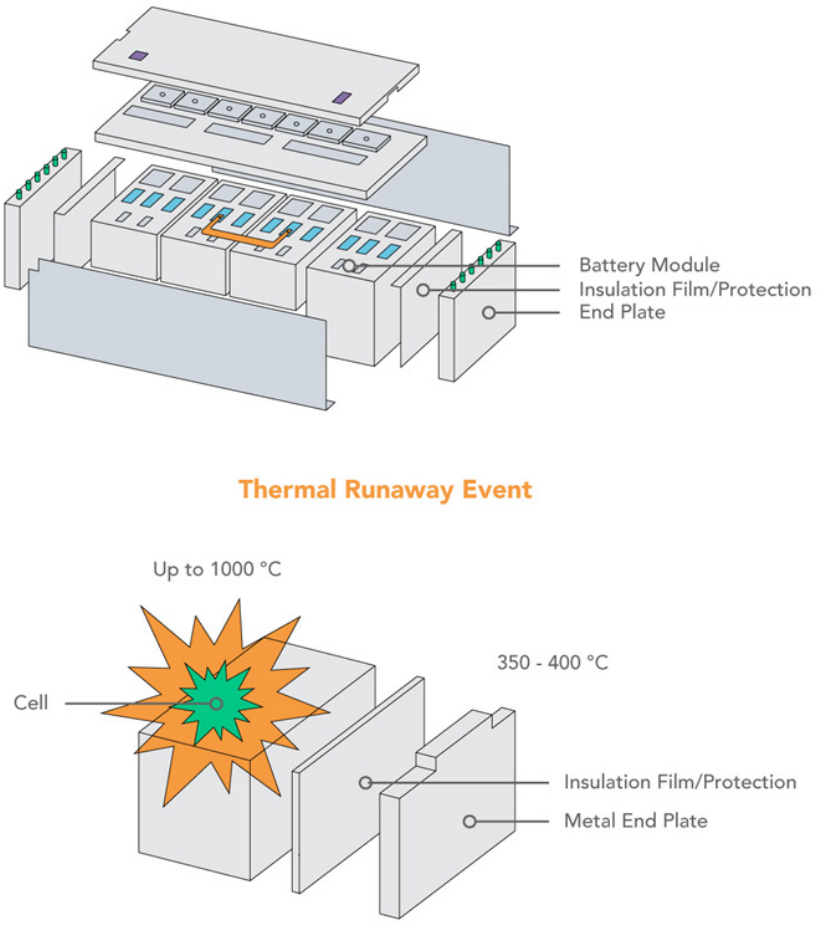

Figure 1: Battery Pack Module Insulation Plate Material Comparison

Battery Insulation Material Selection

There are multiple requirements that battery engineers take into consideration for selecting a battery material insulator. Some of the design considerations include thermal insulation, flame resistance, electrical performance, and thickness. Finding a suitable material to mitigate thermal runaway starts with identifying a material that can inhibit thermal propagation. That is a key first step. Commonly used materials for battery module thermal insulation plates range from polycarbonate (PC) to polyimide (PI).

Materials like PC or PI came in different forms with different assembly methods. As an example, PC films can be glued to the inside of the metal endplate. This is the case in many of the prismatic cell designs. A primary function of the insulator is to increase the efficiency of the battery by preventing heat loss.

One of the largest technical issues with PC films is that PC melts in a few minutes at the high temperatures (> 300 °C) seen during a thermal runaway event. Once the PC melts, it's likely to lead to degradation and carbonization. These two factors combined could result in short circuiting the module or even the entire battery pack. Beyond PC and PI, there are other materials such as epoxies and aerogels that also have their own limitations.

Engineers are faced with a broad range of materials to select with trademarks that occur when needing to have high thermal stability at temperatures exceeding 300 °C. Table 1 below gives a detailed overview of existing battery module insulator materials and compares the strengths and weaknesses of each material.

Existing Technologies	Avg Size (mm)	Pros	Cons
Polycarbonate Film	100 X 150 X 0.5	Widely known solution	Risk of thermal runaway (degradation loss of electric insulation)
Epoxy + GF Resin + Asbestos	100 X 150 X 0.5	In commercial use	High cost & manufacturing cycle time and risk of loss of electric insulation during thermal runaway
Aerogel-SiO2 + PET Frame	100 X 150 X 1.0	Excellent heat insulation	High cost, rigid/fragile, complex assembly, & risk of loss of electric insulation during thermal runaway (break under cell swelling force)
Polyimide Film	100 X 150 X 1.0	Used by several OEMs. Good electric insulation	High cost, risk of loss of electric insulation during thermal runaway (tear or break on film)
New Solvay Solution			
Xydar® LCP G-330 HH	100 X 150 X 0.5	Competitive costs, ease of assembly, electrical property retention after thermal runaway	Minor dimensional change after thermal runaway

Thermal Stability

Figure 2, to the right, shows the thermogravimetric analysis (TGA) of two commonly used insulators, PC films and epoxies as well as a newly developed liquid crystal polymer by Solvay called Xydar® LCP. The TGA was completed with TA Q50 equipment. The testing protocol started with equilibration at 50 °C followed by a ramp of 20 °C/min until a temperature of 800 °C was reached. The results below highlight how Xydar® LCP maintained thermal stability up to 544 °C while PC was limited to 448 °C and 338 °C for epoxy.

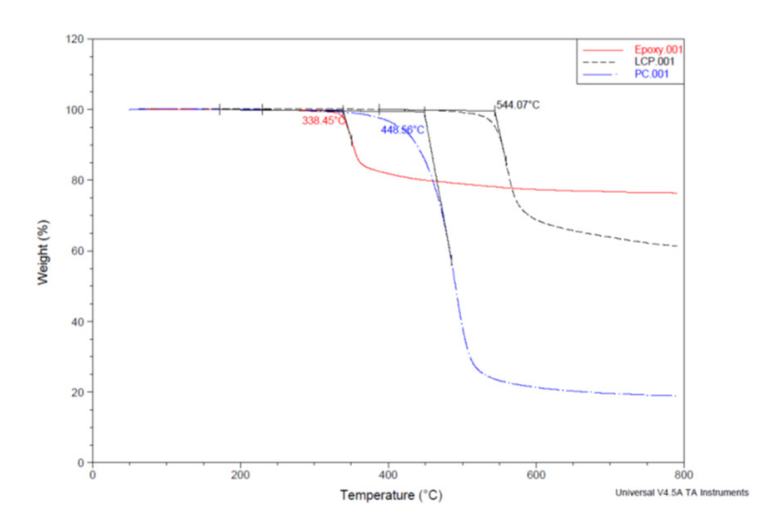

Figure 2: Thermal propagation Material Comparison

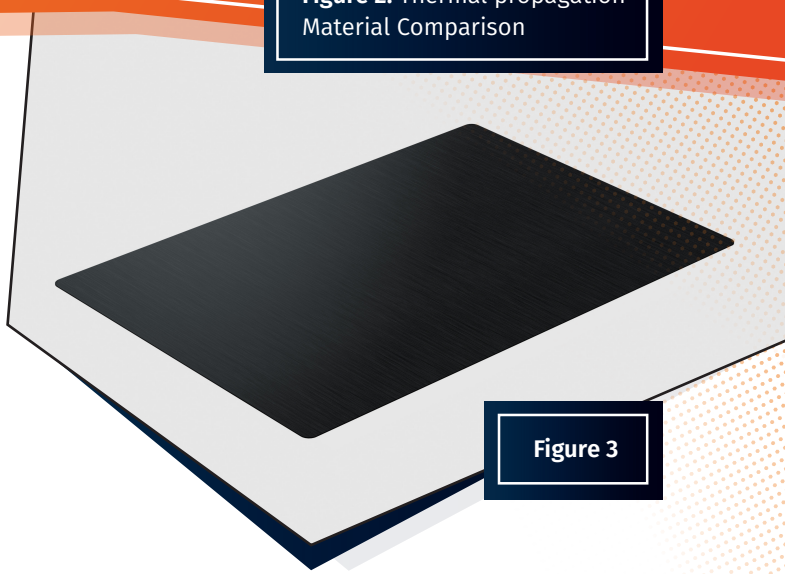

Figure 3

Original Sample	After Aging

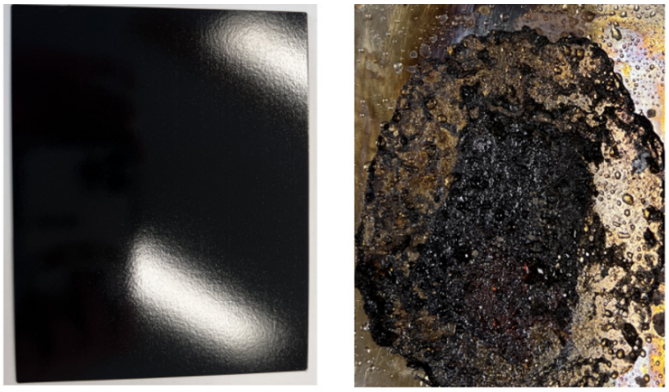

Figure 4A: PC Film after 400 °C for 30 Minutes

Original Sample	After Aging

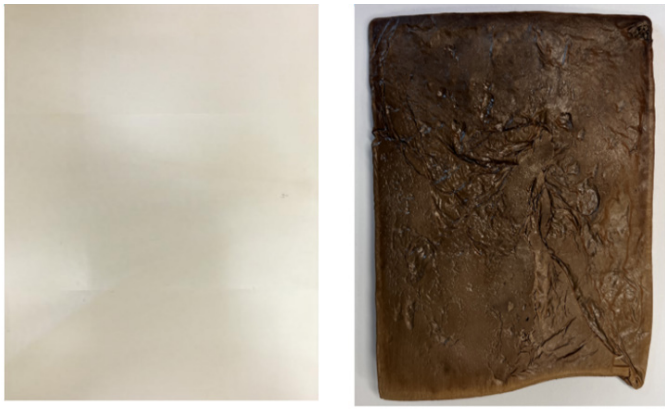

Figure 4B: Xydar® G-330 HH after 400 °C for 30 Minutes

Thermal Aging

Regulation is leading to new material requirements to address the challenge of battery thermal runaway. As a result, many material suppliers are testing their materials under these harsh temperature conditions. Among one of the new tests is the need to evaluate the form of the material as well as the electrical insulation properties after heat exposure at 400 °C for 30 minutes. Figures 4A and 4B extruded PC film and injection molded Xydar® LCP before and after heat exposure. Figure 3B highlights how Xydar® LCP G-330 is able to maintain its form (shape is intact) while PC film decarbonizes.

Electrical Property Retention After Thermal Aging

Because the PC film completely degrades after 30 minutes at 400 °C, the electrical insulation could not be measured. This is where the new Xydar® LCP G-330HH still shows robust electrical insulation. Surface and volume resistance are shown in Table 2 below. As further demonstrated below, Xydar® LCP G-330HH outperforms the glass filled epoxy by an order of magnitude.

Xydar® LCP G-330HH retains electric insulation even when the voltage goes up to 1000V and 3000V but the aged Epoxy plate fails.

Table 2: Electrical Properties of Xydar® G-330 after 30 minutes for 400 °C under DC 500V, 18°C and 22% RH

Insulator	Surface Resistance	Volume Resistance
Xydar® G-330	1.9E+13 Ohm	1.4E+15 Ohm.cm
GF Epoxy	2.0E+12 Ohm	7.2E+14 Ohm.cm
PC Film	unable to test	unable to test

In conclusion, battery design engineers are tasked with identifying new material solutions to address thermal runaway and thermal propagation which stems from new global government legislation. These new requirements have led to the development of Xydar® LCP G-330 HH. This new LCP was designed to provide multiple benefits over incumbent module insulator materials like PC films or GF Epoxy. With robust electrical insulation performance both at room temperature and after 30 minutes exposure at 400 °C, Xydar® LCP is a novel solution for the module level insulation.

Jiwen Wu, Nicolas Batailley, Brian Baleno,
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Current measurement system makes electric vehicles safer

Mathias Müller

The growing popularity of electric drives is changing a variety of automotive safety concerns. While leaking petrol may be a thing of the past, the need to control electric currents more precisely in a vehicle is on the rise. Isabellenhütte Heusler GmbH & Co. KG in Dillenburg, Germany, has unveiled a newly engineered high-precision sensor that meets the standards under rules and regulations worldwide.

The drive systems in electric vehicles require higher voltages and more electrical energy than in conventional cars with an internal combustion engine. As a result, the hazards caused by electric current increase, if the current flows are not precisely controlled. A battery management system that checks the state of charge and helps to prevent deep discharge or overload, either in the battery or in individual battery cells, provides monitoring, control and protection while also lowering the risk of battery fires.

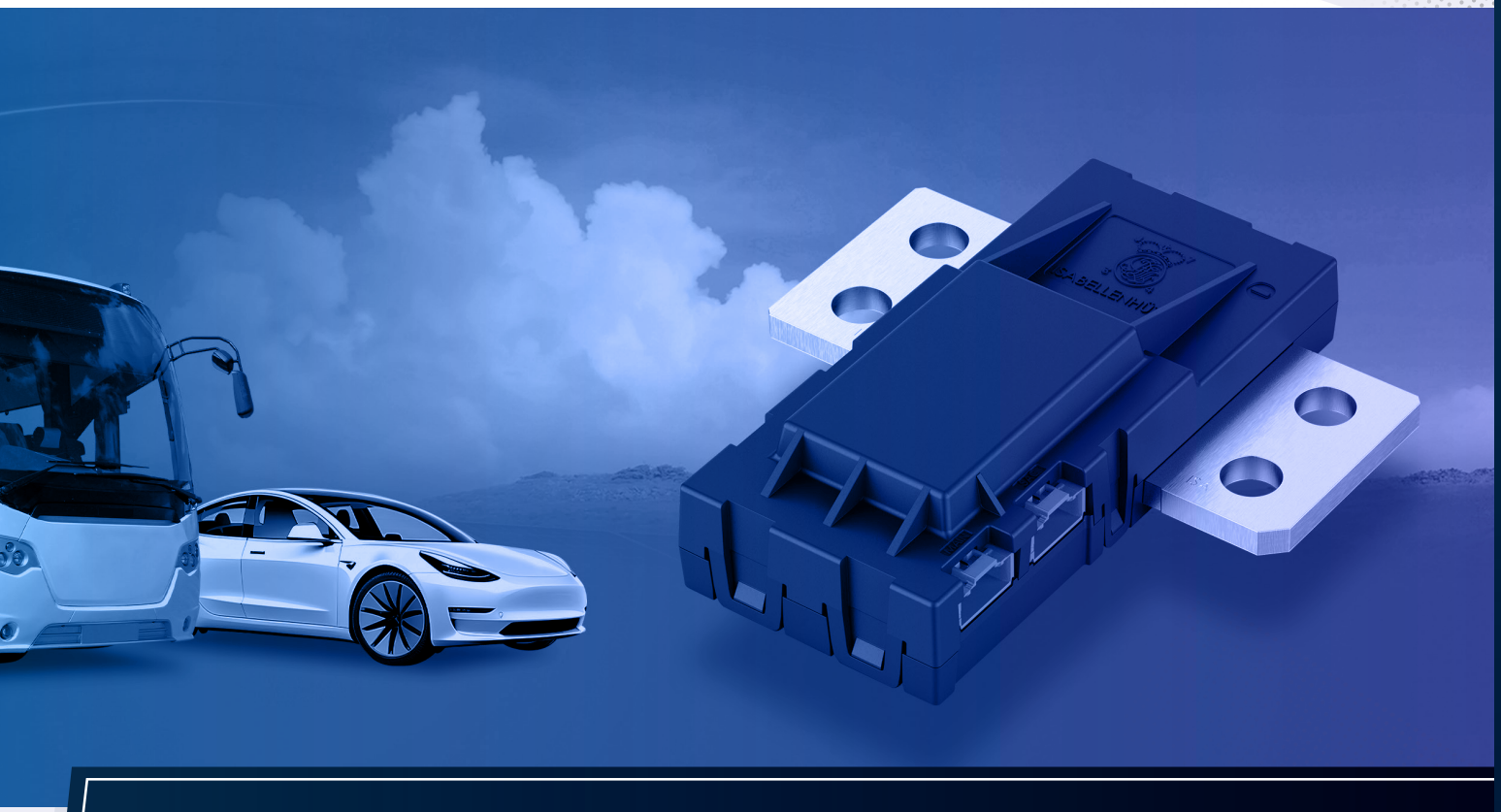

Figure 1: Precise electricity flow measurement, with a safe and reliable way of processing and providing data, plays a decisive role in optimising the efficiency and range of electric drives. The IVT 3 measures the flow with a precision of 0.4 % across the life cycle and measurement range, meeting ASIL C functional safety requirements. Image: ©Isabellenhütte Heusler GmbH & Co. KG

Precise monitoring of electricity flows in electric cars at all times

There are various ways of detecting deviations in desired electricity flows. Measuring current flow, power supply voltage and temperature – which also makes it possible to monitor insulation – plays an extremely important role. The growing number of complex and sensitive electronics systems in vehicles calls for a high-precision approach to measuring flows and currents that is engineered to keep up with today's standards.

Isabellenhütte engineered the IVT 3 Base current measurement sensor with precise current measurement in mind. Developed to meet the ISO 26262 Road Vehicles – Functional Safety standard, it fulfils the requirements of Automotive Safety Integrity Level (ASIL) C (on a scale of A to D). ASIL is a risk classification scheme for standards governing in-vehicle electric and electronic systems that have a relevant impact on safety. The classification level is the result of a hazard and risk analysis. Each level stipulates specific requirements for the development, validation, reliability and testing of a system.

High safety integrity level meets automakers' standards

"By meeting the ASIL C standard, the IVT 3 Base provides safety for an absolutely essential component that the automotive industry demands," says Tom Hassel, Product Manager for Mobility & Motion at Isabellenhütte. "Our goal is for customers to be able to achieve ASIL D at system level with a single added redundancy." More and more automakers are demanding ASIL classifications, in part due to the advancements in autonomous driving. When it comes to electromagnetic compatibility (EMC), the current measurement system meets the requirements for level 3 of the CISPR25 standard, guaranteeing compliance with two requirements: First, the current measurement sensor's electromagnetic emissions are so low that they do not interfere with other electromagnetic components in the vehicle. And second, the sensor itself is sturdy enough not to be disrupted by other electromagnetic waves.

Besides monitoring electricity flows throughout the battery system, the IVT 3 Base current measurement sensor is also capable of recording the busbar's temperature. The system additionally registers whether the vehicle is currently moving, charging or discharging. Accordingly, it recognises the necessary electricity flows at any given moment and transmits an error message in the event of deviations. No matter the process, the cause has to be identified quickly enough to take countermeasures before a dangerous situation arises.

Special alloys ensure precise measurement

The high precision of the current measurement sensors is attributable to the alloys that Isabellenhütte uses in its products and manufactures in-house. The IVT 3 Base is a shunt-based sensor, meaning that current flows through it during measurement. Although temperature changes and similar influences may alter the structure of the material over a product's service life, which can also affect the flow of electrons or electrical resistance, Isabellenhütte's materials remain stable over a long period of time. To make sure of this, the manufacturer performs certain heat treatment processes in order to artificially age the alloys. "After this heat treatment, the materials remain very stable," according to Hassel. "That's why we can guarantee that not much will change within the current measurement sensor over the life cycle of the alloys."

The shunt-based technology also makes the IVT 3 Base particularly strong and durable in other ways. The busbar can handle currents of up to 12,000 A for a short period of time without damaging the sensor, with an extended measurement range of up to 4,000 A.

Current measurement sensor works extremely precisely for years and years

Isabellenhütte current measurement sensors deliver especially stable and precise measurements throughout their life cycle of eight to ten years in ambient temperatures as low as -40 and as high as +105 degrees Celsius. That sets them apart from current measurement sensors made by other manufacturers. "We guarantee a deviation of no more than 0.4 per cent across the entire service life," Hassel explains. Keeping such deviations low poses a challenge, as products are exposed to the weather and the resulting temperature fluctuations, which can negatively affect the reliability of the sensors' electricity flow measurements.

The manufacturer also performs tests to ensure functionality. During shock tests, for example, the products are cooled down as quickly as possible from an ambient temperature of +105 degrees Celsius to -40 degrees Celsius. "That allows us to guarantee that our sensors measure reliably," Hassel says. "They work in vehicles in the desert and in northern Canada alike."

Figure 2: Illustration of the main components of a battery electric vehicle (BEV). The IVT 3 measures currents with the utmost precision and transmits them to the battery management system (BMS).

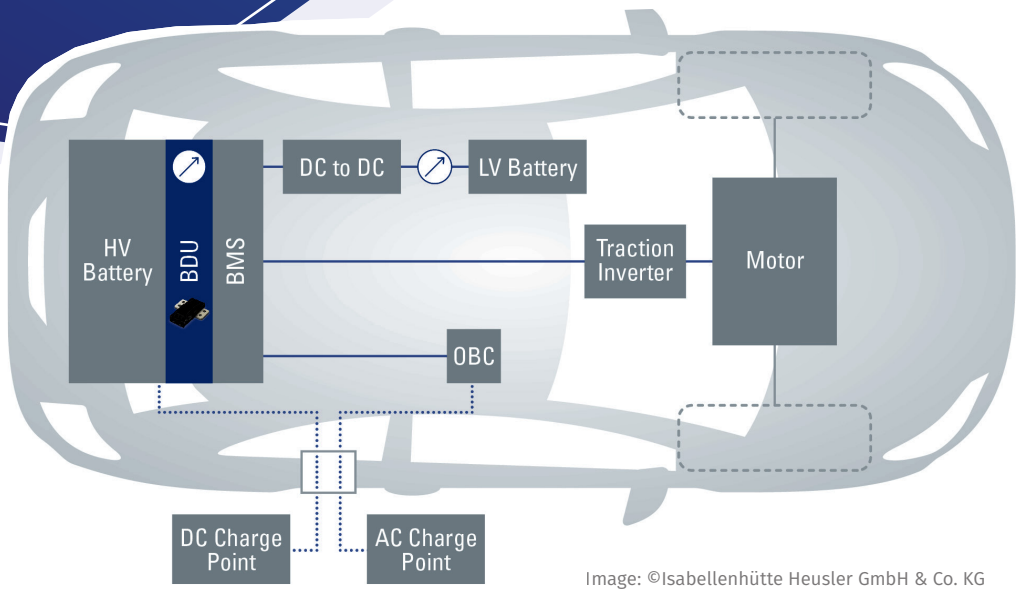

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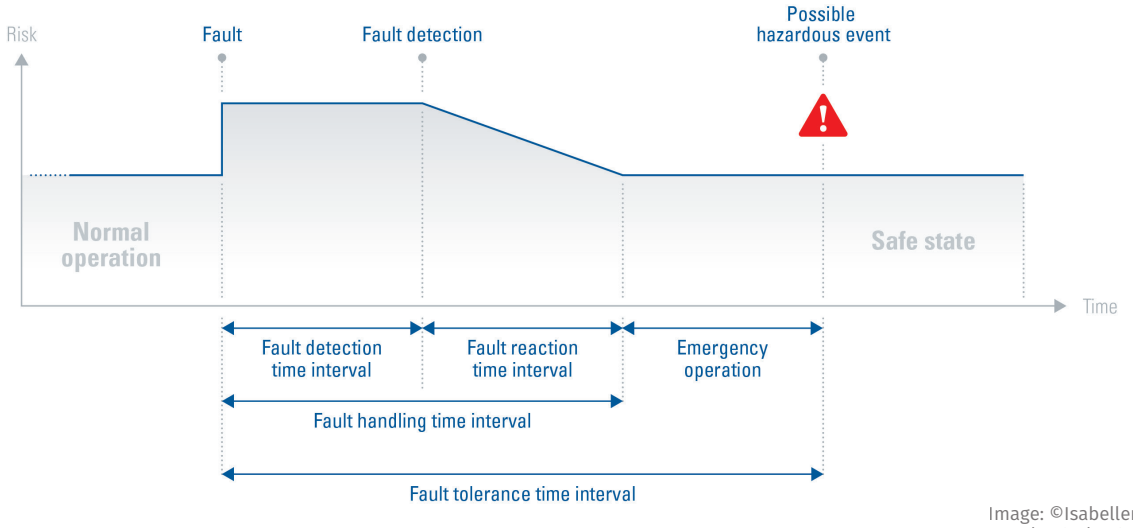
Figure 3: Illustration of the fault tolerant time interval (FTTI). The IVT 3 was developed in accordance with ISO 26262 and meets ASIL C current measurement standards. It detects faults and errors early on and reports them to the overall system, which can respond and restore safe conditions.



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Design makes installation in electric cars easier

An additional advantage becomes apparent when installing the IVT 3 Base into an electric vehicle. In Hall effect sensors, which measure changes in the magnetic field, the component is shaped like a ring. As a result, the conductor that is to be used to perform the measurements has to be fed through this ring. By contrast, the IVT 3 Base is shunt-based and is easy to fasten to a flat copper busbar with four screws for use as a connector. Using screws to secure the sensor between two current-conducting bars is very easy, making it possible to channel the electricity flow through the bars and directly through the sensor. “That lets you safely and directly measure the current flow,” Hassel says. “Our sensor is directly integrated into the electricity flow.”

The size and shape of the IVT 3 Base offer yet another advantage: Measuring 94 by 84 by 23 mm, and weighing in at just 150 grams, it is one of the smallest comparable ASIL C products on the market. With every cubic centimetre of the essence in battery packs, its compact size is an important argument in automotive engineering. Because every gram counts when it comes to optimising range, weight is a crucial factor in systems with multiple sensors.

CAN 2.0B, which is considered the gold standard (especially in the automotive industry), acts as the communication interface for the current measurement sensor. That enables onboard diagnosis and other functions for the component itself. In addition, the sensor is also capable of detecting and reporting errors in the system. Right now, Isabellenhütte is currently working on UDS update capabilities for the IVT 3 Base to eliminate the time and effort needed to remove the sensor for software updates.

Customers can define their own CAN IDs

One of the many other options is sleep mode, which reduces power consumption to less than 100 µA on average while still making it possible to reactivate the sensor in less than a second.

Customers can also customise their own CAN IDs. By adjusting the formula, Isabellenhütte can program a dedicated ID for a specific message. “That way, the customer doesn’t need to change their system,” Hassel explains. “Instead, they receive a software adaptation from us. Then they can install the sensor with all the right settings.” The cycle times for transmitting recorded data can also be customised.

Current measurement sensor already in use

The IVT 3 Base is already being used in a battery management system made by Futavis GmbH, Aachen, Germany. The company offers modular battery systems and scalable modular kits for battery management. Futavis incorporates the IVT 3 Base into its switching boxes and builds on it to include the battery management system's master unit, as well as functions for the shift lock, measuring voltage in individual battery cells, detecting thermal events, balancing out battery cells and pre-storing electricity during charging. The latter plays an important role in extending the service life of the electronics.

Ultimately, the automaker receives a safe, durable and certified battery management system for its electric vehicles that fully meets the safety demands for a high-voltage system, including international standards such as LV 123/124, DIN EN 60664-1 and ISO 26262. Thanks to its sophisticated engineering and the expertise of both companies, the system achieves an ASIL classification of C.

Larger model to complement IVT 3 platform concept

In order to round out the IVT 3 platform concept, Isabellenhütte plans to launch the expanded IVT 3 Pro model in the near future. Despite weighing more than the IVT 3 Base (250 grams), the current measurement sensor offers additional functions. Apart from current, the IVT 3 Pro will also be capable of measuring voltage through three or six channels, with a nominal voltage measurement range of 1,000 V and an overvoltage measurement range of up to 1,250 V.

The IVT 3 Pro will also feature isolation detection capabilities, which can be used to monitor defects throughout the battery management system.

Mathias Müller, *Product Manager*
Precision Measurement
Isabellenhütte Heusler GmbH & Co. KG

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EV Battery Remanufacturing

The key to unlocking the performance and environmental potential of electromobility?

Dr Sara Ridley

The future of the electric vehicle (EV) industry is heavily dependent on the success of efforts to improve battery longevity and reliability. To become a truly sustainable alternative to internal combustion engine vehicles, EVs must also deliver on their environmental promise throughout the entire vehicle lifecycle.

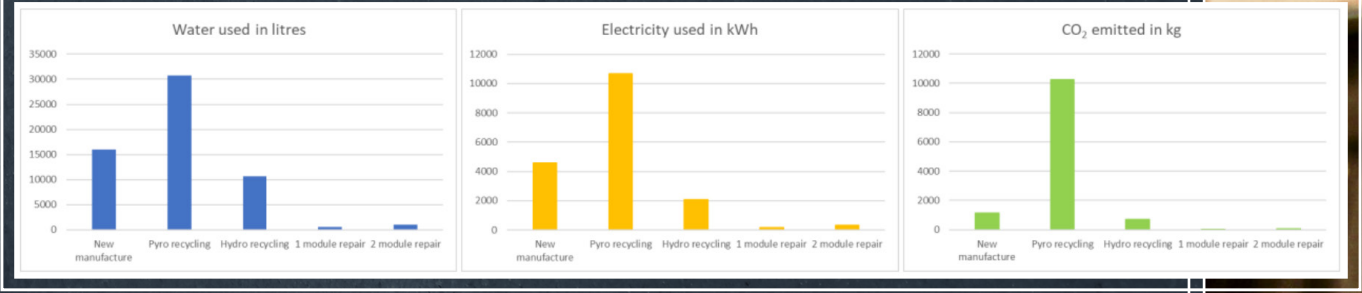
While much of the focus around EV tends to be on battery recycling, EV battery repair technology will play a decisive role on this journey and represents a more environmentally friendly option. Recent advancements within this space have taken us closer to unlocking the performance and environmental value of electric vehicles. Next generation EV battery state-of-health testing allows us to restore optimal battery health by pinpointing faults at a cellular level. By replacing underperforming modules with healthy ones through remanufacturing, this can drastically improve battery range and maximise longevity.

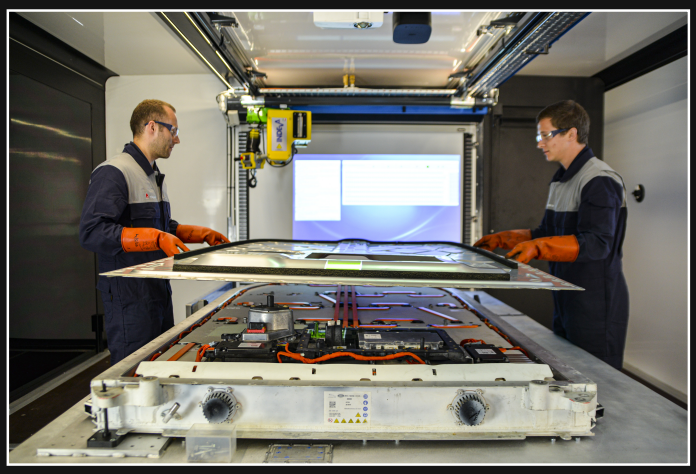
As automakers face growing scrutiny around their environmental impact, it is critical that they understand how EV battery remanufacturing can help meet their performance and sustainability goals. In this article, we discuss what this involves and the value it brings.

The problem with recycling

In recent history, damaged or faulty EV batteries that were deemed irreparable were typically sent away to be recycled.

Due to a lack of transparency concerning EV battery health, pinpointing the exact location of faults became an insurmountable challenge. In what amounted to a major missed opportunity to get more out of the technology, battery packs were prematurely recycled, resulting in the complete loss of all residual value contained within the remaining healthy cells. This was compounded by the heavy environmental cost of recycling, a fact that receives little attention. As we see from the below graphs, the recycling process generates substantial amounts of carbon, while consuming vast quantities of water and electricity.





One option to restore performance would be to replace faulty modules with new ones but once again, this comes with a heavy ecological burden.

Although the environmental impact of hydro-recycling is preferable to producing new battery packs, it is far from negligible. Simply put, the automotive industry needs to become more judicious about its recycling activities. Taking proactive steps to yield every last bit of value from EV battery cells before turning to recycling is vital, and the use of remanufactured EV battery modules achieves this.

Addressing the root causes of premature EV battery decline

In a short space of time, previous challenges which saw countless EV batteries sent for recycling have ceased to apply. The development of Autocraft EV Solutions' dynamic testing capability, through our REVIVE™EV battery repair and remanufacturing offer, means that we now have the capability to pinpoint the causes of sub-optimal EV battery performance on a cellular level – and at scale. As the saying goes, prevention is better than the cure, and the use of our world-leading digital twins further augments the diagnostic process by identifying outlier cells at risk of future failure. This is made possible by comparing cell performance against large quantities of data gained through years of EV battery repair to spot any deviation from the norm.

As the number of data sets increases, the predictive capability of the digital twin becomes even stronger. If we can identify a problem, we stand a much greater chance of being able to fix it. Without the right testing capability, however, any intervention is likely to be imprecise and liable to end in repeat failure.

Throughout the course of a vehicle lifespan, faults will undoubtedly occur and if left unaddressed, can undermine the performance of the entire battery pack and eventually lead to failure. Since performance is determined by the level of the weakest performing cell, it makes sense that replacing underperforming or faulty modules with healthy ones can reverse the effects of cyclical aging to extend the life of the battery and halt premature decline.

Calendar aging, however, is irreversible, which makes it impossible to restore the battery to completely brand-new condition. All lithium-ion batteries start to lose performance from their first charge and discharge cycle due to the start of the chemical reaction. The goal of remanufacturing therefore is to restore the battery to the highest possible level of performance for where it is at within its lifecycle.

Depending on the BEV in question, it will take between 32,000 km and 88,000 km of usage to "break even" on the carbon emissions generated in production when compared to ICE production. A proactive approach to maintaining battery longevity ensures the vehicle remains in operation for as long as possible, yielding the greatest environmental benefit over time.

A scientific approach to fault-free repairs

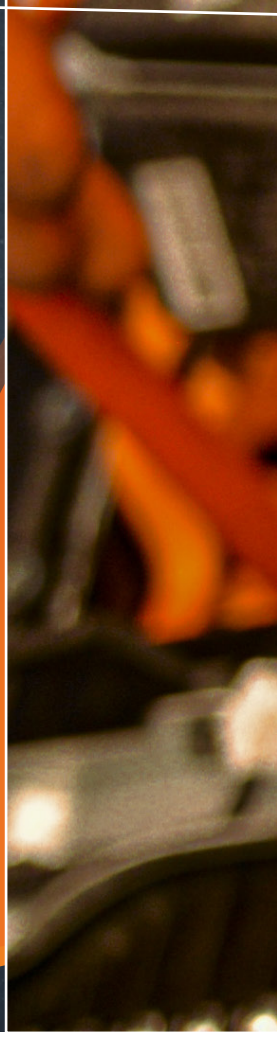
The transition towards electrification is already well underway, and as the number of electric vehicles continues to rise, so will the number of faults. In order for the EV industry to truly flourish, repair infrastructure will need to account for both scale and repair precision requirements, while mitigating all potential safety hazards. These factors, and the complexities involved, highlight the need for a repeatable and fully robust repair process that ensures every condition for a fault-free repair is met.

This unique process eliminates all scope for human error through the use of Augmented Reality (AR), LiDAR technology, and PPE detection. The patented 'no-fault-forward' ARIA (Augmented Reality Interactive Assembly) system, developed in-house, incorporates cameras, projectors, and wireless tools to provide exceptional process control. Technicians are given clear instructions for each step of the repair process and must follow them correctly in order to progress within the sequence of activity.

This combination of systems can detect even the slightest deviation from the optimal procedure; whether this is failure to wear the correct PPE or even at the level of the torque of a single screw, nothing is left to chance. Originally developed and applied within ICE remanufacturing, this no-fault forward approach has allowed the business to entirely eliminate repeat faults from its repair process, providing the benchmark for future repair efforts on an industry level.

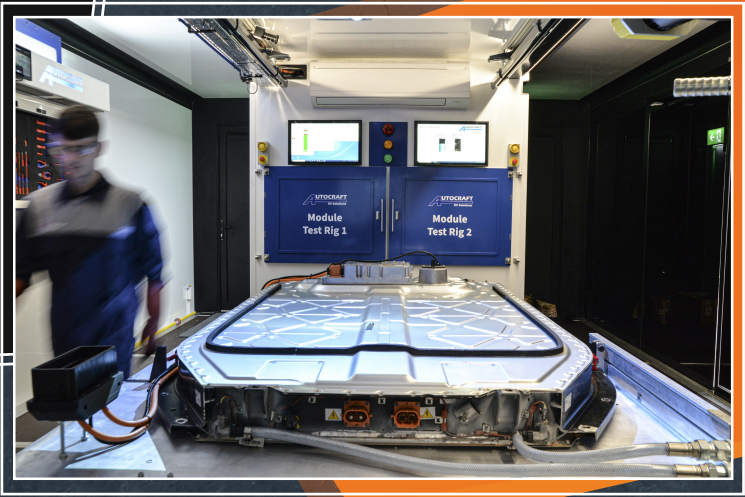
Overcoming the obstacles to EV adoption

Through being able to pinpoint and address faults, even before they have occurred, we can tackle much of the uncertainty linked to EV ownership stemming from a lack of transparency around EV battery health and the likelihood of failure.

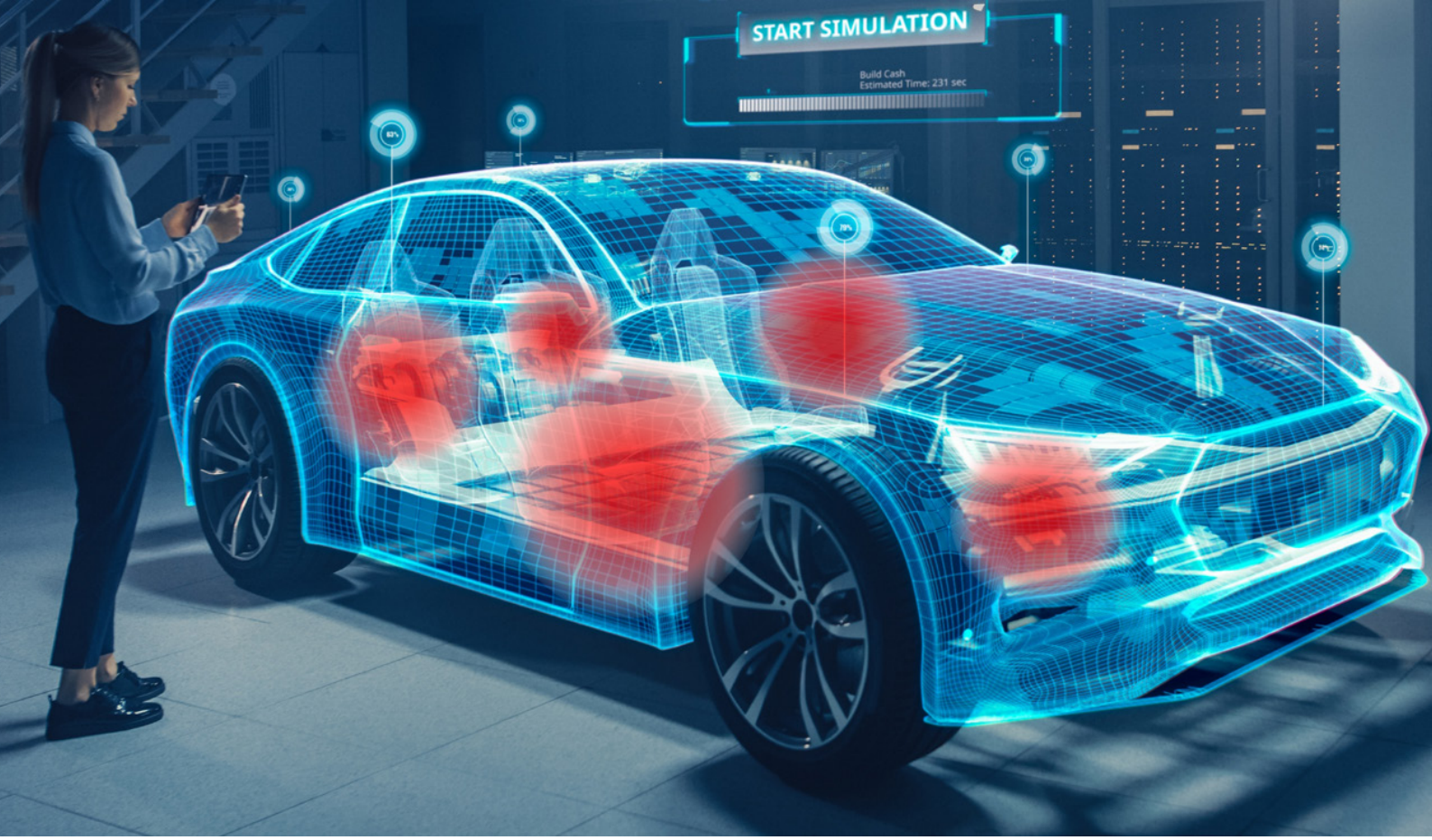


By virtue of the advanced test, repair and remanufacturing capability that our business can offer, EV battery health becomes more of a known quantity, making it easier to manage. Whereas out of warranty vehicles previously experienced a sharp drop in residual value, due to the perceived risk of failure, the availability of a proven, sustainable approach to repair helps to overcome this hurdle.

This is incredibly important for the EV market, particularly for used EVs, where demand for out of warranty vehicles is crucial to keeping EVs in operation for longer and maximising the potential environmental benefits. There is a compelling case for EV battery remanufacturing, and so the industry must now embrace the opportunities that it creates.



Dr Sara Ridley, *Engineering and Quality Director* **Autocraft EV Solutions**



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Efficiently, effectively achieving the software-defined vehicle

Dr. Jürgen Meier & Dr. Ismet Aktaş

Many of the innovations in today's automotive industry are driven by software. In fact, the market for automotive software and electronics is growing significantly faster than the overall vehicle market. As a driver of personalization, networking, vehicle safety and infotainment, software is becoming an important selling point and differentiator for manufacturers. However, today's automotive software development activities aren't reflective of its growing importance.

So, how do we successfully and efficiently transform to a software-defined vehicle?

A new tradition: decoupling

The traditional approach of combining hardware and software systems has worked because software has been limited to controlling a handful of electronic control unit (ECU) tasks. But as the use of ECUs and subsystems increases, so does the required effort to integrate them. And because computing resources and development toolchains are designed on a project-specific basis, it's nearly impossible to transfer the implemented function code to other projects. So, from the perspective of a software-defined vehicle, this approach is too time-consuming and costly, especially since it doesn't cover all future requirements and use cases.

One way to address this is decoupling the development processes for software and hardware. Achieving consistent decoupling of software and hardware lifecycles requires:

- More computing power with fewer ECUs to offset hardware complexity.
- Harmonization of the basic software and development toolchains for cross-platform software compatibility, which can be achieved through standardized middleware and frameworks, potentially based on open-source software.
- Open interfaces and service-oriented architectures as the basis for collaborative processes in development, test execution and integration.

This methodological evolution creates space to rethink E/E architectures and software platforms, bundling previously distributed functionalities on a few vehicle computers, which reduces the number of variants. It also allows for collaborative development and taking advantage of standardized interfaces and processes, cloud-based toolchains and open-source solutions.

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Open-Source Communities

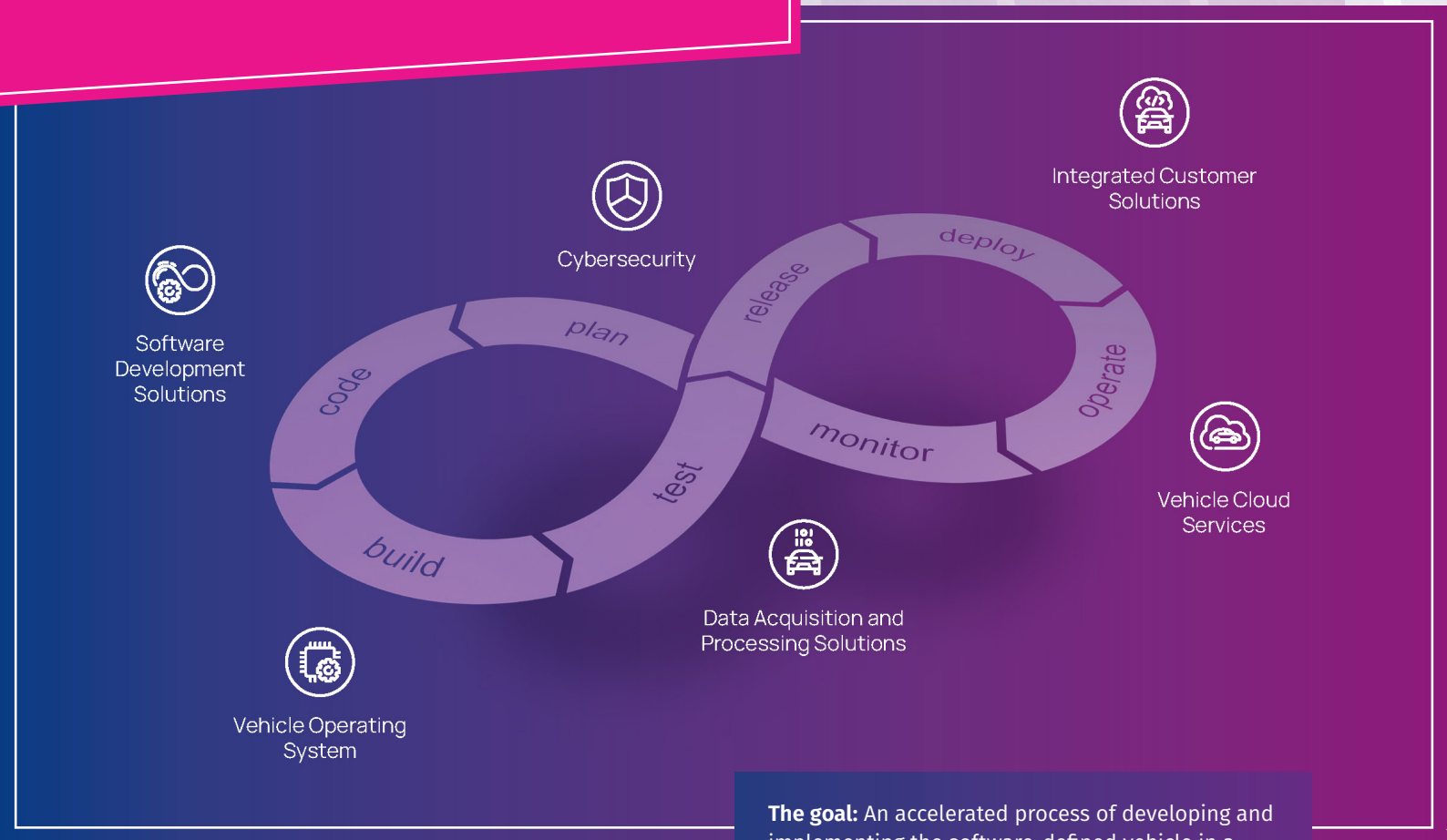
SDV Eclipse Software Defined Vehicle

SOAFEE

COVESA Accelerating the future of connected vehicles

With an open-source environment, there is a technology platform based on binding standards and frameworks, with an open vehicle stack at its core. This approach, combined with a vendor-neutral governance model, is an effective antidote to market fragmentation and vendor lock-ins, and frees up developer resources. It also allows project software, toolchains and development data for different vehicle platforms to be transferred to others, rather than starting from scratch each time. Initiatives such as the Eclipse Software Defined Vehicle Working Group, the COVESA Alliance and the SOAFEE project prove the open-source approach is feasible in the automotive environment.

Development cycle of the software-defined vehicle



The goal: An accelerated process of developing and implementing the software-defined vehicle in a continuous cycle.

Creating flexibility: middleware

In addition to AUTOSAR Classic for safety and strict real-time capable ECUs, the AUTOSAR Adaptive standard holds potential for vehicles with a centralized E/E architecture. Where conventional ECUs, POSIX-based ECUs with microprocessors, and central vehicle computers provide computing power, AUTOSAR Adaptive's service-oriented architecture, including functional safety, provides the functionality to perform vehicle-wide functions across the computer cluster. With this comes increased flexibility, creating the opportunity to use standardized middleware.

The move to standardized platform software and middleware paves new ways to standardize development toolchains. But this is dependent on cloud technology. Today, software developers spend a significant amount of time maintaining their development environment, manually running and documenting tests before releasing their code. Cloud-based toolchains and collaboration platforms could create efficiencies by eliminating time-consuming setup and maintenance of the development environment. Standardized interfaces allow for free tool selection (even from third-party providers), and the development, test and feedback cycles can be further automated, virtualized and accelerated through parallelization. In addition, the work of distributed development teams can be synchronized in the cloud, which takes global and cross-company collaborations to a new level.

Being agile: development processes

For software to be a competitive differentiator, agility is required. While OEMs need to conduct over-the-air (OTA) updates at any time, connected vehicles need robust and comprehensive protection against cyberattacks. This is where cloud computing enters the picture. For example, combining container isolation with developer-centric toolchains and application programming interfaces (APIs) creates an opportunity to shift the functionality, as available, in different safety classes on ECUs to non-safety critical quality management (QM) environments on vehicle computers. These heterogeneous QM environments provide great advantages:

- The runtime environment and underlying E/E and safety architecture ensure that software can only execute non-safety critical functionality or safety-critical functionality when the vehicle is in a safe state. As a result, developers don't have to fulfill safety-related obligations.
- Third-party providers can be involved in application development, using development approaches and programming languages of their choice.
- C or C++ programming languages or automotive-specific safety knowledge aren't mandatory, reducing the need for highly qualified specialists.

Agile automotive software development requires the adaptation of tests to the specific needs of function developers, software integrators, safety experts and test engineers. Modularization and standardization pave the way for combinable, cloud-based and automated (e.g., headless, CI-CD-CT) test solutions, as well as virtualized tests if desired. In addition, efficient and flexible validation and verification tools are available and can be combined with innovative solutions for field data acquisition in "shadow mode" (i.e., allowing newly developed functions and algorithms to be executed in a sandbox environment where collected in-vehicle data is delivered to the cloud).

Continuous and secure: software updates

A standardized and largely cloud-based development landscape lays the foundation for the continuous software development and distribution required to realize the software-defined vehicle. Each year, every software-defined vehicle is expected to have hundreds of updates for apps, services and electronic functions. Cloud-native paradigms combined with in-vehicle standardized middleware and frameworks will ensure efficient and secure updates for all in-vehicle domains (e.g., Linux/QNX OS, AUTOSAR Classic/Adaptive, Containers/AAOS Framework) through uniform interfaces. Of course, the transfer needs to work in the opposite direction – status information and collected data (e.g., telemetry and diagnostics) needs to get from the different vehicle domains to the cloud.

In addition to adhering to industry regulations and standards (e.g., UNECE Regulation 156, ISO/FDIS 24089), a critical factor in providing a solid and secure foundation for data communication of connected vehicles is cybersecurity. To shield the software-defined vehicle against risks that were unknown when the vehicle was developed, an immune system is needed. This is achieved with the combination of an intrusion detection system (IDS) in the vehicle and a vehicle security operations center (VSOC) in the cloud to detect intruders. After detection and the implementation of vulnerability fixes, a rapid OTA roll-out of countermeasures to the entire fleet is initiated.

Our destination: the software-defined vehicle

Software is taking a bigger role in the automotive industry as a key differentiator for OEMs to meet customer expectations, as well as creating new revenue models and providing the latest technology to vehicles through continuous updates. But this requires an efficient and effective evolution, including decoupling hardware and software development, the flexibility to utilize middleware, agility in the development process, as well as continuous and secure updates. The result of this evolution is the software-defined vehicle, where software is the center of its original development process and is further developed throughout its lifecycle.

Dr. Jürgen Meier, *Vice President.*
Dr. Ismet Aktaş, *Portfolio Manager*
Product Group Vehicle Cloud Services, ETAS GmbH

New components for electromobility require novel manufacturing strategies

Dr. Axel Luft

According to expert estimates, by 2040 almost 45 percent of all passenger cars sold worldwide will have a battery or fuel cell drive system. This will result in a large number of new systems and components in production. This also poses a challenge to the supplier industry.

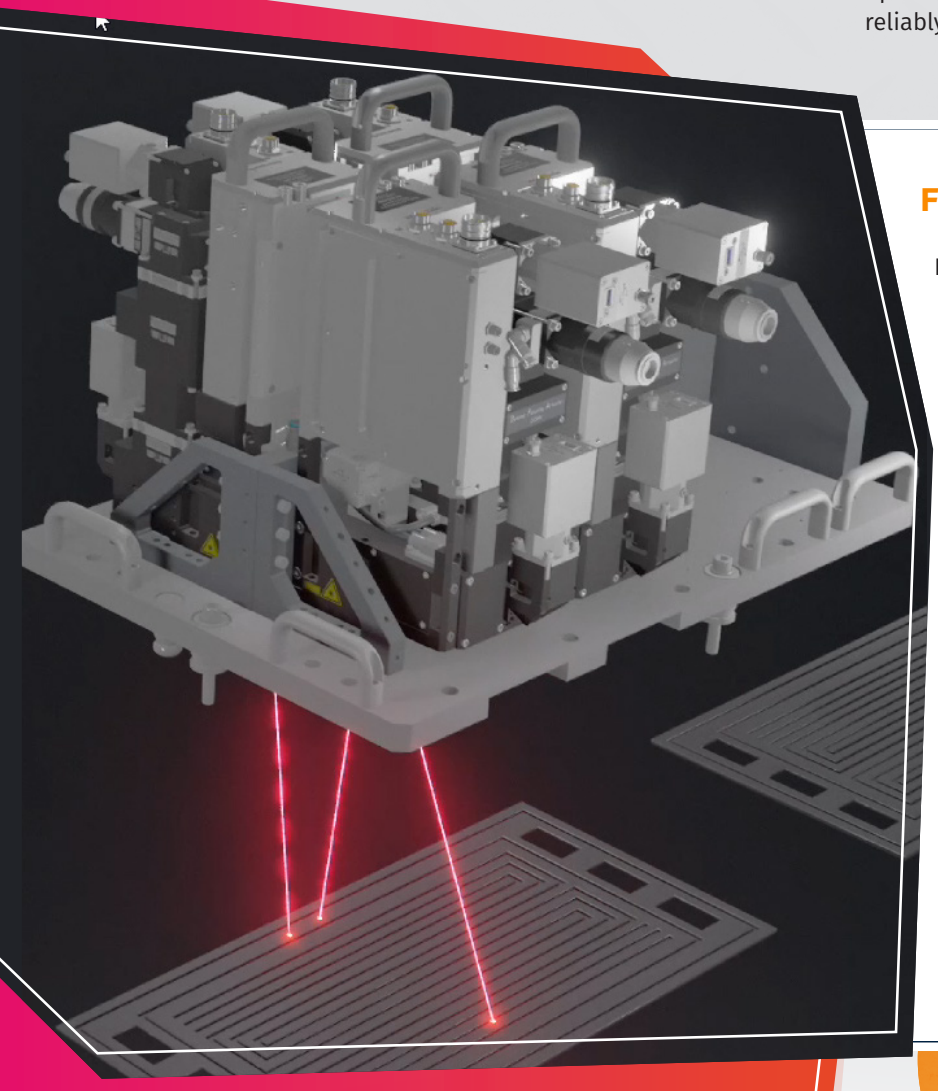
Automobile manufacturers worldwide are working to reduce emissions. According to a 2022 study by the German industry association VDMA and FEV Consulting GmbH, almost 45 percent of a total of 128 million passenger cars sold worldwide will be powered purely by battery electricity or fuel cells by 2040. At the same time, the experts expect a worldwide decline in sales figures for vehicles with combustion engines, namely by 16 percent compared to 2019. Following the development, the demand for electrical systems and components is increasing. Efficient fuel cells, batteries, electric motors, and high-performance electronics as well as cooling technologies are the future growth drivers.

This has a major impact on traditional manufacturing technologies in the automotive industry. Laser processing is also facing new challenges. New processes are emerging. Take bipolar plates, for example: As a stack, they make up the core of the fuel cell and influence the power density of the stack. Their thickness determines the overall weight of the energy source, usually only about 0.1 mm. They account for up to 45 percent of the production costs.

Take battery boxes, for example: They are among the crash-relevant components due to the fire risk of the batteries. The quality of the weld seams makes a decisive contribution to its stability. Most components, and thus every weld, must be helium-tight. If a single individual weld is not in order, the component must be reworked. These costs are to be avoided in any case. Therefore, users expect the highest quality in terms of electrical, mechanical and structural properties of the finished parts. Structures made of high-strength aluminum alloys are generally used in manufacturing, but these have a marked tendency to hot cracking.

In addition, the requirements for welding speed are high. For example, for a single bipolar plate, welds of up to 4.5 m in total length must be welded; for a cooler plate for batteries, this is up to 100 m. For an electric motor consisting of up to 400 hairpins or battery trays with up to 1,000 battery cells with anode and cathode welding, up to 2,000 welds are required. At the same time, the overall number of parts is increasing with the switch to alternative drives - while the demands on cycle times remain high. In the case of bipolar plates, for example, the goal is to produce one plate per second.

At the same time, the laws of physics set limits for developers. At welding speeds of over 30 m per minute for aluminum processes or >60m/min for welding biploar plates, the process can no longer be controlled reliably, one risks cracks in the seam.



Faster. Better. Quality Assured

FCW (**F**ast **C**omponent **W**elding) system technology. This relies on the cost-effective parallelization of laser processes. To achieve this, the developers have integrated complex technology into extremely compact scanner units that can be arranged on a single process-specific application plate. The exact number depends on the desired application. In this way, several components can be processed simultaneously and thus a higher output can be achieved within the same time. Alternatively, the system's extended scan array allows larger components to be processed in a single step. In an array with four scanner units, the processing time of a component is thus reduced to a quarter. The scanner units are supplied fully calibrated and specially tailored to customer requirements. They can be individually controlled and work in cooperation with each other. This enables simultaneous, independent process control strategies with a high level of quality.

Figure 1: With the new system, Scansonic is responding to the increasing demands for speed and quality in laser processing. For example, for laser welding of bipolar plates, battery contacts, hairpins or surface coolers for car battery trays in electric vehicle drives.

Higher productivity with FCW technology

The scanner units can be set up several times next to each other, both in a row and as a matrix. They thus offer a large scanning field, fast mirror movements, a powerful Z-shifter for height compensation in the workpiece, automatic image recognition, and sophisticated quality monitoring. In the case of bipolar plates and surface coolers for car battery trays, for example, this means a significant increase in the effective welding speed per component, since several seams can be welded simultaneously. The reduction in the angle of inclination that is possible in this process permits a particularly stable process.

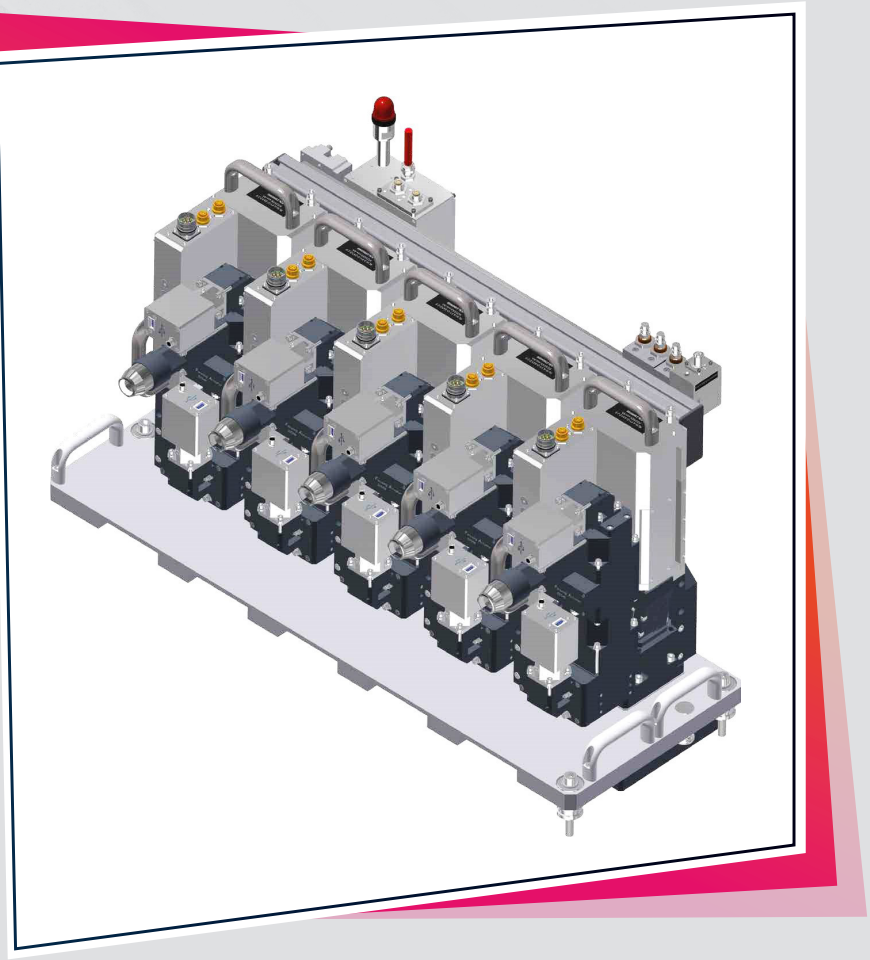


Figure 2: Five scanner units are arranged on an application plate. They enable parallel welding and in this way significantly increase the process speed.

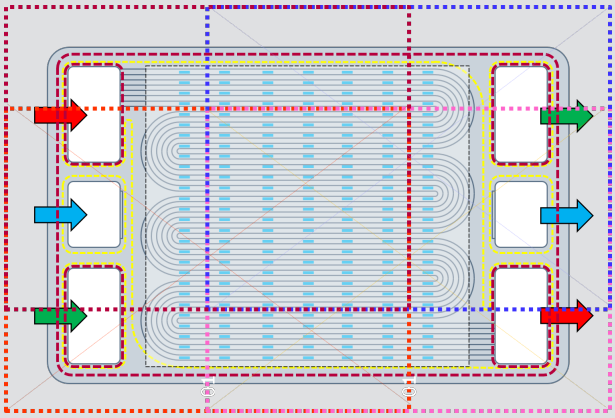


Figure 3: Example of a bipolar plate with dimensions 600 x 420 mm: The scan field of a single scanner unit is 400 x 310 mm². In the example, four scanner units are used (2 rows and 2 columns) The overlap is 200 mm. This allows a total scan field of 600 x 420 mm. The tilt angle is less than 22°.

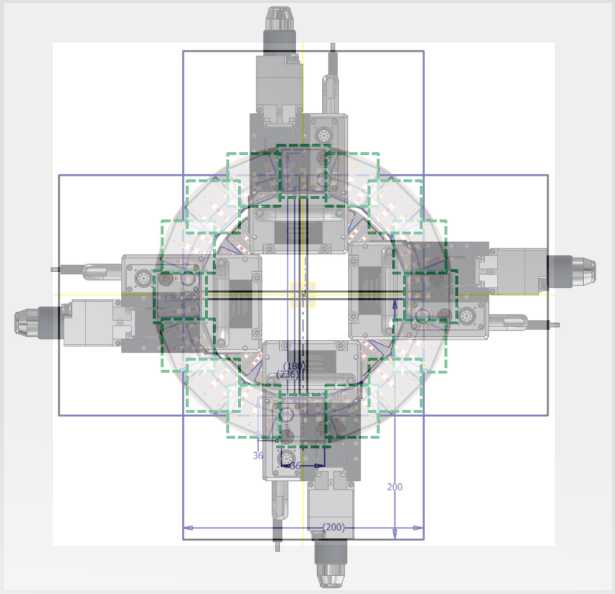


Figure 4: Here, using the example of a stator with hairpins, 16 fields of view and 4 scan fields are created. The hairpins can be manufactured in this way in one work step.

One of the most complex components, which accounts for most of the production costs of a battery-powered electric motor, is the stator. The necessary magnetic field is usually generated by so-called hairpins made of copper. Two of each are welded together by laser. Up to now, these have been rotated on a rotary axis until all the hairpins have been welded in turn. This is time-consuming and thus a decisive factor for the productivity of the process.

FCW technology and the simultaneous machining of the component can also make a significant difference in this process, which takes place in a matter of seconds. With the FCW system, a 90° arrangement of a total of four scanner units can be provided for this application. Each unit can approach a segment on the stator, illuminate it homogeneously, detect its position and weld it out. Sophisticated image processing is used to detect all hairpin positions in a single step and direct the laser beam according to the precise welding strategy developed for the customer. The parameters include, for example, the laser power, the shaping of the elliptical motion path or repetitions of the weld path. This means that the stator no longer has to be rotated, regardless of its size.

In addition to the applications mentioned, this very compact and lightweight head is also suitable for highly dynamic processes, such as the welding of battery contacts. The head welds battery contacts on the fly at high speed and is moved by a linear axis for this purpose. Depending on the requirements of the application, different laser spots and laser powers can be used. The magnification of the FCW optics range from 2.9 to 6 times. Single mode lasers with fiber diameters of 10 or 14 µm up to multi kW multi-mode lasers with 50 and 100 µm fibers are used.

With FCW system technology, plant and machine manufacturers have a standardized, fully calibrated system for laser welding, which simplifies automation and individual adaptation on site while at the same time shortening work processes.

Dr. Axel Luft, *Managing Director Sales & Marketing* **Scansonic MI GmbH**

Digital electronics in vehicles need to be protected against cyber attacks

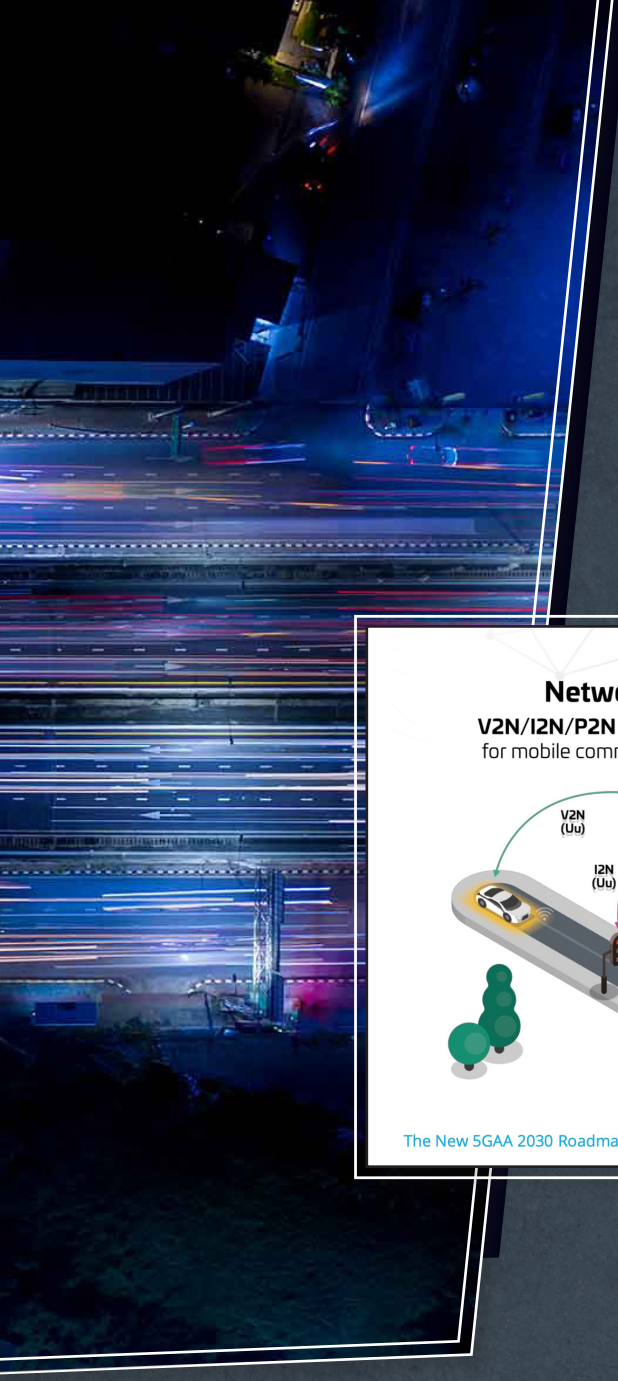
Current status of the (cyber) security challenges for connected transport

Bircan Taslica

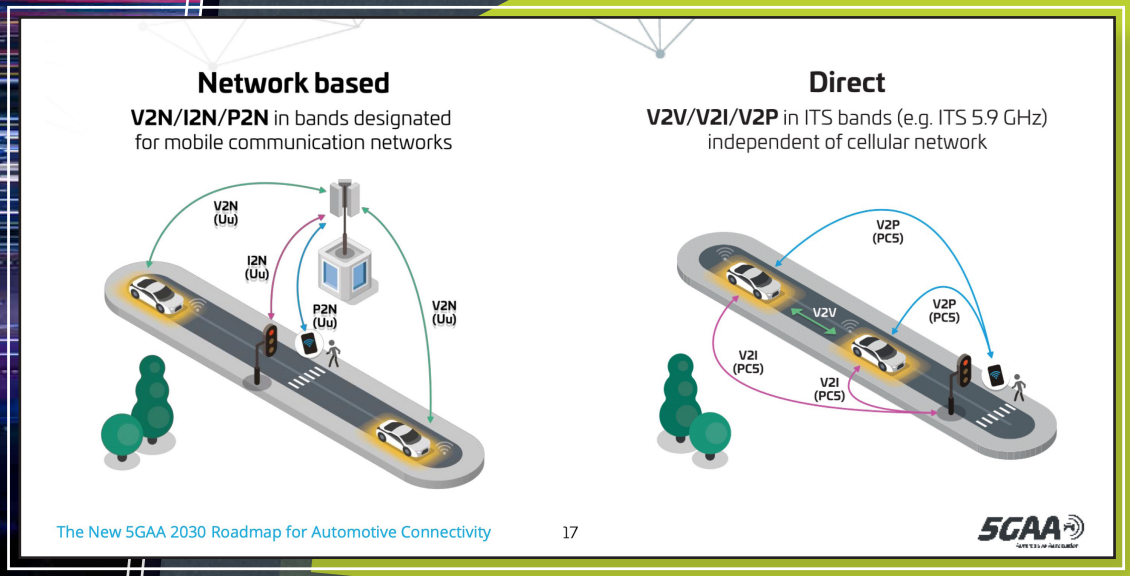
The topic of misbehaviour detection and of product recalls will be critical for connected automated driving. For example, when a vehicle sends a message with incorrect information based on the severity of a situation, it will be ignored or removed from the V2X trust environment. The other interesting part will be the policies for the Public-Key-Indicator (PKI) Several services already run backed by ISO 27001 and certificate policies (ECTL= EU Certificate Trust List, L2 highest capable) audited PKI (e.g., Volkswagen or Microsec) with support from an accredited third-party lab.

The EU is in a great situation as they were the first to implement the audited V2X PKI based on the CCMS (C-ITS Credential Management System) and the existing policies on German roads. Both China and the USA lack these policy documents, which will raise the issues of audits and assurance levels. All of the topics mentioned above are relevant from a testing and auditing point of view. The audits organize trust to the V2X ecosystem so that many different vendors can trust one another and communicate with each other on a daily basis.

As a member of the organization 5GAA, we were asked to support the lack of US policy as a new work item (NWI) and planned to start this year. This is now under review for approval by the 5GAA Board.



The NWI wants to remove the barriers to US deployment, and we aim to create an action plan within the 5GAA about what the preferable solution to this industry-level problem should be. The scope is not just to secure PC5* messages, but also their deployment. The SAE 2945/1 standard uses a PKI-based SCMS (Security Credential Management Systems) for V2X security. The policy will not be included in the standard, but we need some common ground to operate on the same security level and build mutual trust via audits. The goal is to create, together with 5GAA members, a single certificate and security policy for North America that can be technology neutral.



Source: www.5GAA.org

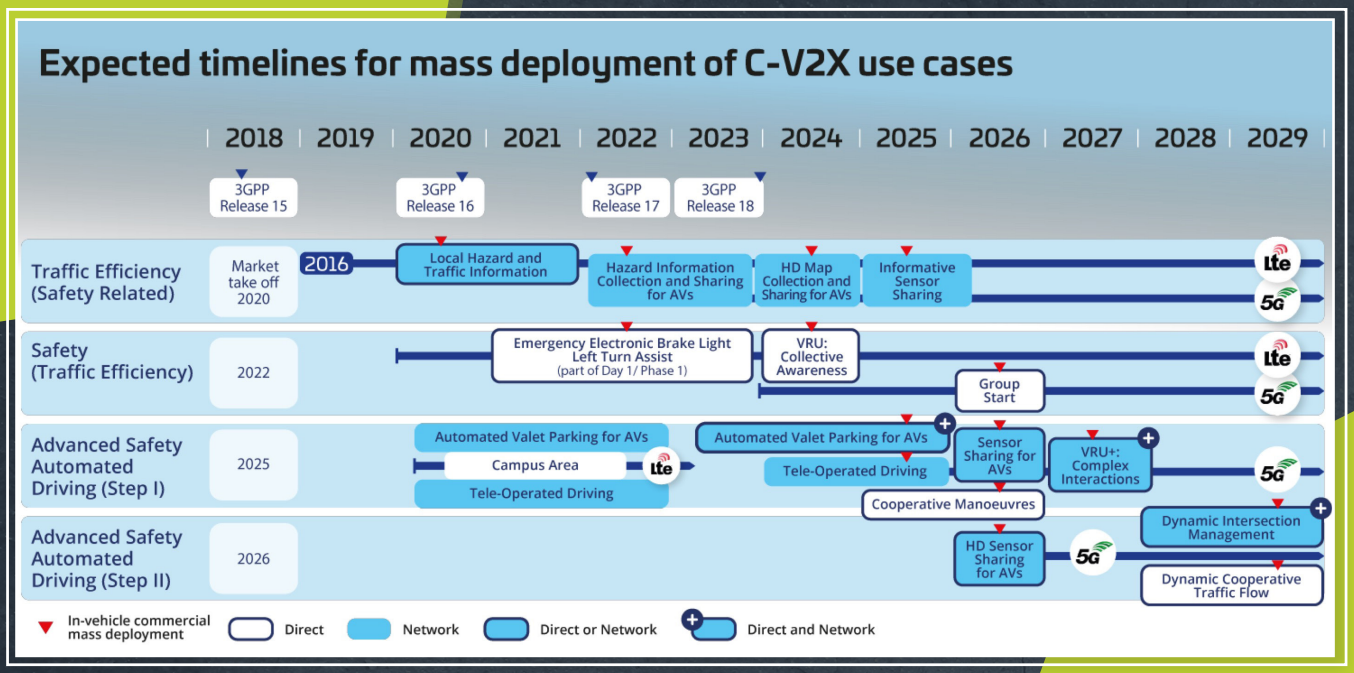
The new work item (NWI)

The scope of the NWI regarding the SCMS (Security Credential Management System) US Policy has been modified slightly. However, its goal remains the same.

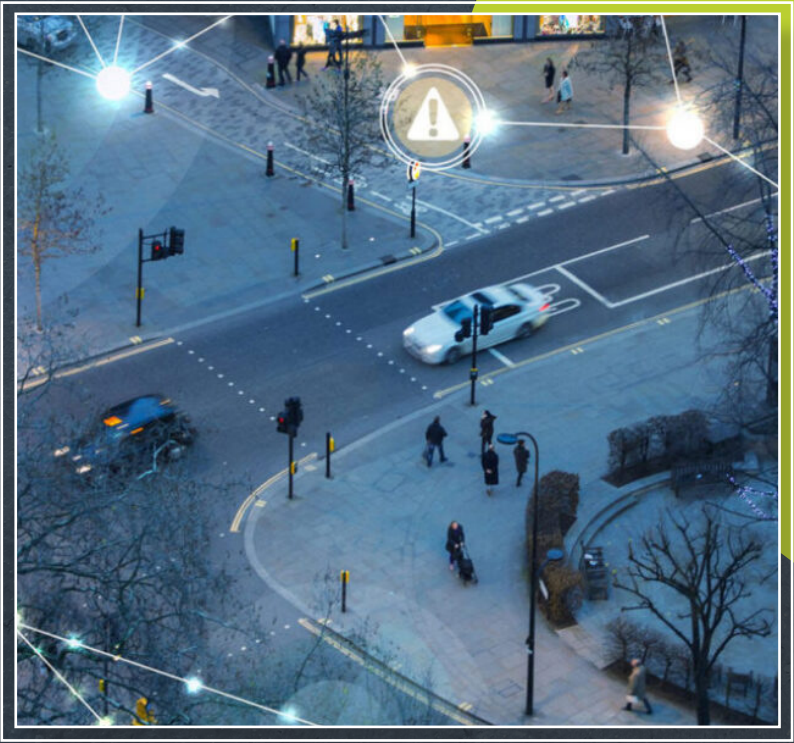
The aim of the NWI is to create an action plan to establish the necessary policy and governing background, achieve alignments at industry level, and make audits based on similar requirements where possible. The NWI wants to find the fastest path to production, but there is yet to be an organization where every stakeholder can participate and contribute equally.

Specifically for the automotive sector, the UN ECE Regulation R155 addresses the topic from the point of the car manufacturer´s responsibility to implement measures to ensure the cybersecurity of vehicles, equipment and parts. In accordance with the relevant ISO/SAE, which specifies engineering requirements for cybersecurity risk management, this could achieve a certain level of compliance. The main challenge here will be for OEMs to obtain the Cybersecurity approval according to UN-R155 for all their vehicles on time (2024!), which in reality, will be a nearly impossible challenge for all the development and production centers. Furthermore, the supply chain (Tier 1 and 2) and their parts shall be addressed as well, but manufacturers, authorities, and certification bodies for the most part lack the means to do so right now.

In addition, the EU has adopted sector-specific legislation on (cyber) security for products with digital elements for CE Marking in the Radio Equipment Directive (RED), or the Vehicle General Safety Regulation.



For the RED regulation scope as proposal on cybersecurity requirements for products with digital elements, known as the Cyber Resilience Act (CRA), bolsters cybersecurity rules to ensure more secure hardware and software products.



However, because of a 30-month transition period, the RED essential requirements (Art. 3. (3)d/e/f) will apply starting on 1st of August 2024 even if there is no harmonized EN Standard available, - listed in the OJEU-, then you have to go via Notified Body route! Once the proposed CRA becomes applicable, the RED delegated regulation will still be valid. In addition, the EU legal framework does not address the cybersecurity of non-embedded software represented by applications such as navigation software or in-car entertainment systems. Moreover, the economic operators' response to the vulnerabilities of products with digital elements throughout their lifecycle is an issue that demands further attention.

For the RED, exceptions are defined in one article of the Delegated Act, with an exception for motor vehicles (according to Regulation (EU) 2019/2144), only one Article applies and is intended to ensure network protection, whereas RED Articles 3. (3)(e)(f) does not apply.

There is still discussion that the CRA does not appear to apply to vehicle type approval, but even that statement needs to be verified. However, many components in the car are subject to CRA requirements, including microcontrollers or microprocessors.

Unfortunately, the CRA as well as the relevant sub-groups cannot give a clear answer as the regulations are still being worked on, with a plan to finalize and formulate them more precisely by the scheduled August 2024 deadline. In a noteworthy update, the European Commission has officially extended the timeline by one year until August 2025, as of June.

In my capacity as a board member of the voluntary association ISAD e.V., which is actively engaged in disseminating information about the new radio equipment regulations to all members and conducting various workshops, I am pleased to announce that our executive team has collaborated to submit a formal communication to the European Union. This communication pertains to the extension request for the deadline related to RED Article 3. (3)(d)(e)(f). Our submission entails a comprehensive presentation of our arguments to the EU. Additionally, internal discussions suggest the possibility of yet another extension. Stay informed of further developments. The schedule could not be met, because e.g., of the lack of security experts to verify the technical draft documentation. They can still nominate the necessary experts; it is not too late.

The scope and implications of the CRA draft remain a bit unclear – especially the boundaries with the NIS2 and CER. At SaaS – which appears to be entirely excluded from the CRA – despite the rapidly growing deployments for almost everything, there are already solutions for this such as SSPM. Efforts are being made in another area to approximate or reference the E Marking (vehicle) and CE Marking (product) in standards, which has already been referenced in a harmonized EN ETSI standard regarding UNECE-R10 (main automotive EMC regulations adopted by over 60 countries worldwide in addition to the EU). Harmonized standards must be European norms (EN) issued by CEN/CENELEC/ETSI. Such standards exist for other CE Marking areas but not yet for security. Ultimately, the relevant groups that handle this with CRA, like CEN/CENELEC/ETSI, or sub-groups like ETSI TC Cyber (where I am an observer) and at least EC, have the final say.

For the current global SAE Level 4 projects aimed at driverless automated driving, not only should the review of the continuity of communication with the network be analyzed, including the risks in the event of failure, but also the safety monitoring with big data analyses combined to detect network-wide threats to examine the impact of SDNFV on security in evolving and future networks, from network-based threats to Industry 4.0 machines to the security requirements for 4G/5G including the cV2x application. Therefore, build up and to be prepared as examining security as a concept in the 'Observe, Orient, Decide and Act' (OODA) paradigm and building a monitoring solution for a Named Data Networking (NDN) architecture. For quantum computing a newly released scientific encryption algorithm (CASA model, NIST awarded) exists which claims that it cannot be hacked. There are many IT scientific articles by researchers on this topic to make the world safer.

In summary, nobody wants to experience the first attack of a cyber-hacked on connected automated vehicle, and industry should think twice about whether, in addition to the upcoming (cyber) security regulations and policies, it should also ensure simple and effective solutions which already exist to mitigate potential dangers. Like the emergency call button, there could also be an EWC (Emergency Wireless Connection (+ AI?)) –OFF- button when an occupant sits inside the vehicle or which can be triggered remotely from the outside, e.g., by the supervisor of the control center.

Bircan Taslica, *Global Head of V2x, ADAS/AD and 5G* **TÜV Rheinland Kraftfahrt GmbH**

SSPM

SaaS Security Posture Management (SSPM) provides automated continuous monitoring of cloud-based Software-As-A-Service (SaaS) applications to ensure security compliance and prevent misconfiguration.

Saving Energy, Materials and Rejects

Increasing the sustainability of EV with ultrasonics

Markus Haas

Sustainability becomes particularly interesting for companies when combined with cost savings. However, is that possible in the production of electric vehicles? As a particularly efficient, safe, and material-friendly process, ultrasonic welding offers some exciting options.

Detailed welding tests in the ultrasonics laboratory can be used to develop a welding process that is gentle on the material and allows a minimum scrap rate.

The production of vehicles with internal-combustion engines has undergone extensive optimization over the years; the mass production of electric vehicles is still in its early stages. This presents captivating opportunities for companies to enhance both production sustainability and cost-effectiveness.

One promising solution is the use of ultrasonic welding technology. When joining both plastic and metal applications, the process saves:

- **Energy**
- **Scrap**
- **Raw materials**

The technology becomes a promising link between sustainability and cost-effectiveness in the production of electric vehicles.

Saving up to 75 % energy with ultrasonics

One of the most significant opportunities for energy savings lies in battery production. Traditionally, the sealing of pouch cells has been inefficient, often relying on thermal joining methods like heat sealing. However, these processes consume substantial amounts of energy and pose a risk of damaging the battery cell foils.

Based on experience from other industries, there is untapped potential here. Although ultrasonic sealing of pouch cells has not yet been widely implemented, it has successfully been used for sealing pouch packages in the food industry for many years. This process has demonstrated energy savings of up to 75% compared to conventional methods.

Using energy only where it is really needed

The key to achieving energy savings lies in ultrasonic sealing, which differs from conventional processes. Unlike traditional methods, this technology does not rely on an external heat source. Instead, heat is generated internally within the materials through friction during the brief welding process, lasting only 100 to 200 milliseconds. This targeted approach ensures that energy is utilized only where necessary, eliminating any wastage between the welding tool and the application.

Another benefit is that the welding tools remain cool and ready for immediate use, eliminating the need for preheating, which saves additional energy, and thus, emissions.

Preliminary tests conducted in both the ultrasonic laboratory and production settings have confirmed that the experience gained from sealing pouch packaging can be effectively applied to the sealing of pouch cells. Given rising energy prices and rapidly growing demand for energy, savings becomes a major advantage for companies both ecologically and economically.

1. Consistently low scrap rates

As one of the most cost-intensive components of an electric vehicle, the battery is a particular focus when making production safer. It is also of particular importance in the sustainability balance sheet. With dwindling availability of rare earth materials such as cobalt or lithium and the costly recycling of used batteries makes responsible handling of raw materials critical.

Ultrasonic welding, known for its gentle joining process, significantly reduces the scrap rate during battery production. The generator can gather valuable data during the welding process through direct contact between the welding tools and materials. This data enables the visualization and optimization of welding parameters such as force, energy, and amplitude. By recording up to 150 parameters per weld, it becomes possible to minimize industry-standard scrap rates from up to 20 percent, to a single-digit percentage.

"Scrap is a highly problematic issue as it is avoidable and negatively impacts both the sustainability and efficiency of production. That is why we are focused on maximizing the safety of the welding process. In doing so, we protect the environment and preserve valuable materials,"

explains Markus Haas, Global Sales Director METALS, emphasizing the commitment to creating a safe and sustainable production environment.

Saving resources with ultrasonics

Alongside energy savings, reducing resource consumption plays a crucial role in enhancing the sustainability and cost-effectiveness of electric vehicle production. Ultrasonic welding facilitates a substantial reduction in resource consumption in two ways:

- **The reduction of scrap rates**
- **The elimination of additional adhesives**

Through direct contact between the Sonotrode and the application, the generator can collect valuable data which can be used to optimize the welding process.

No more additives needed

Many plastic applications in electric vehicles still rely on adhesives due to the relatively low investment costs of the technology. However, the chemicals present in adhesives can have adverse environmental effects during production and disposal. Furthermore, adhesives often demand increased energy input, such as heating or drying, to ensure their efficacy.

The utilization of these chemicals not only affects the sustainability aspect but also contributes to ongoing cost factors. In recent years, the prices of raw materials have escalated, leading to a significant rise in costs associated with adhesive usage. Consequently, reducing reliance on such chemicals becomes imperative for both maintaining a favorable sustainability balance and managing expenses effectively.

Ultrasonic welding offers a distinct advantage as it eliminates the need for additional joining agents to achieve safe and permanent connections between applications. By using ultrasonic vibrations, the reliance on adhesives and the associated energy requirements are avoided.

Moreover, machines and production equipment that utilize adhesives require regular cleaning, resulting in downtime that decreases production efficiency. Adopting ultrasonic welding as a sustainable joining technology, not only is there a positive impact on the environmental balance sheet, but it also leads to a more streamlined and efficient production process.

Switching to sustainable materials

The use of plastics in electric vehicles is on the rise, even though metals play a significant role in their construction. Whenever feasible, there is a push to replace metal applications with plastic alternatives. This shift is primarily driven by the multiple advantages that weight reduction through plastics offers:

1

Improved Energy Efficiency: By reducing the overall weight of the vehicle with lightweight plastics, energy efficiency is enhanced. Electric vehicles can achieve better range and performance with reduced weight.

2

Increased Battery Life: The lighter weight of the vehicle results in less strain on the battery, allowing for extended battery life and improved longevity.

3

Enhanced Handling and Maneuverability: Lighter vehicles with plastic components provide improved handling and maneuverability, contributing to a better driving experience for users.

4

Reduced Manufacturing Costs: Plastics are often more cost-effective to produce and process than metals. The use of plastics can lead to lower manufacturing costs, contributing to overall cost savings in the production of electric vehicles.

Choosing the right material for plastic applications

By choosing the right plastic, companies can make an important contribution to sustainable production. Plastic recyclates made of polypropylene (PP), polyethylene terephthalate (PET), polyethylene (PE), acrylonitrile butadiene styrene (ABS), polyvinyl chloride (PVC), and polystyrene (PS) are particularly suitable. Especially PP, PE, and PET offer great potential, as these plastics can already be recycled by type.

However, the utilization of recycled plastics presents new challenges for joining processes. Each recycling process affects the quality of the material and subsequently, its ability to weld. This factor becomes increasingly important when working with purer recyclates.

Initial welding tests conducted with 100 percent pure recycled PA 6.6 (polyamide) have demonstrated comparable results to conventional plastics in terms of appearance, density, and tensile strength. This indicates that recycled plastics can be a viable alternative, already applicable in numerous electric vehicle components. Although recycled plastic has often been more expensive than conventional plastic, advancements in recycling processes can quickly change this situation, making recycled plastics more cost-effective in the future.

Conclusion: Combining Sustainability with efficiency

To meet the increasingly stringent sustainability goals in electric vehicle production, companies must focus on improving efficiency and sustainability simultaneously. Fortunately, there are opportunities to combine sustainability and cost-effectiveness in various areas. Ultrasonic welding, in particular, presents exciting prospects for manufacturers in this regard.

Ultrasonic welding offers a safe and efficient process that can make a significant impact on reducing energy consumption and scrap rates. It also enables the secure joining of more sustainable materials, including recycled plastics. These factors play a crucial role in reducing emissions and preserving critical resources.

To achieve these benefits, companies need to collaborate with experienced ultrasonic welding partners who can assist in developing efficient welding processes. Collaboration will ensure a safe, efficient, and sustainable production process that simultaneously reduces production costs.

By embracing ultrasonic welding technology and fostering partnerships, companies can make strides toward achieving their sustainability goals while enhancing cost-effectiveness in the production of electric vehicles.

The sectional view shows that with pure recycled material (right), a strong connection can be achieved that is just as cohesive as with conventional PA 6.6 plastic (right).

Photos: Herrmann Ultraschall

Markus Haas,
Global Sales Director METALS
Herrmann Ultraschall

BORN READY

peblar ROCKSOLID CHARGERS

When designing our EV charger, we didn't choose between safety, robustness, and aesthetics. We wanted you to have it all.

Aesthetic design

Quick installation
(<30 mins)

3 years warranty

Rocksolid & integrated build
only a limited amount of components, reduces service & maintenance needs

Safe & secure
following the highest market standards

Regenerative braking:

It's affecting your brake pads more than you think

Carlos Lorenzana

From an engineering point of view, a Brake refers to a device that primarily performs the function of braking or stopping a moving object, such as a vehicle. Going back to physics, a brake refers to converting kinetic energy into other types of energy. And this energy conversion mechanism should be fast, available and dependable.

Braking is one of the most important components of security of any vehicle. Braking events are not always predictable, and any braking system must guarantee the stopping of a vehicle within the limits of current regulations.

Road mobility has been based mainly on friction braking since its conception. A friction brake transforms kinetic energy mainly into friction and thermal energy, by pressing a friction material against a moving part, generating an opposing friction force and heat. Commercial friction materials are complex compounds and can contain more than 20 different ingredients and a phenolic resin as a binder. General friction characteristics are defined by the synergy of brake pad component properties and the development of new friction materials always requires an empirical approach, and is mainly based on previous experiences, because the behavior of the friction material under different operating conditions is difficult to predict due to its stochastic nature. It is necessary to have the following characteristics in a simultaneous manner.

(i) short bedding period,

(ii) cold coefficient of friction stability,

(iii) friction coefficient stability during speed changes,

(iv) friction coefficient stability with increasing temperature,

(v) stability of the coefficient of friction after heating,

(vi) stability of the coefficient of friction under pressure changes,

(vii) relationship between the static and dynamic coefficient of friction,

(viii) coefficient of friction in wet conditions, etc.

Engineering is an important part of brake pad design, but tribology and tribochemistry are critical to achieving your goals. And tribology and tribochemistry depend on the working conditions the composition and properties of the friction pairs (friction material/counterpart).

Oversimplifying, Europe and America have followed two different paths in automotive friction materials since asbestos was banned in the last century. In Europe, friction materials often contain steel (known as Low Steel or LS) to achieve greater resistance to high temperatures, which makes them easily suitable to pass the AMS standard test used by the OEM industry to validate the safety of their brake pads in extreme conditions in vehicles for the European market. In North America, friction materials do not use steel (being known as non-asbestos-organic or NAO), instead focusing on greater comfort during braking (which again is a huge simplification).

With the introduction of electricity as part of a vehicle's main propulsion system, other types of kinetic energy transformation are possible. Electromagnetic regenerative braking is one of the main features of an electric vehicle. The vehicle's driveshaft is connected to an electrical generator, which uses magnetic fields to restrict the rotation of the driveshaft, slowing the vehicle and generating electricity. During regenerative braking, the car's electric motor becomes a generator, converting the car's kinetic energy into electrical energy that can be stored in the battery and charged.

Regenerative braking is not yet a replacement for friction brakes. It may never be. They are two complementary technologies with a common characteristic (reducing the speed of the vehicle), but with different purposes (increasing the autonomy of the vehicle and guaranteeing safe braking in all types of braking). Each technology has its lights and shadows.

Regenerative braking can only be installed on the drive wheels, as a powertrain is required for energy recovery. The waste heat generated is not significantly reduced unless the vehicle is an all-wheel drive model. The braking force of an electromagnetic regenerative braking system is often insufficient to cover any type of stop. The maximum recharging speed of the circuit and the battery capacity will be the main determinants of the braking capacity of said system.

The evolution of materials and engineering will reduce this drawback of regenerative braking. As an example, the Gen3 Formula E car from the 2023 season has a second engine on the front axle with more focus on braking than acceleration. Under hard braking, the regenerative braking will be so powerful that these cars won't even have friction brakes on the rear wheels, and the FIA projects that a staggering 40 percent of the total electrical power used in racing will come from the regenerative system. Of course, the time you spend braking a single-seater on most racetracks is a different scenario than most electric mobility users face.

The design of a regenerative braking system includes a variety of sensors and logic control units to adjust the operation. Also, the reliability of these electronic components and their integration with mandatory security systems such as the ESC have to be considered. Therefore, a traditional friction brake system is required to convert excess energy from the vehicle. The friction brake can also prevent the loss of braking capacity in the event of a failure of the regenerative braking system.

For decades, from the beginning of the 20th century, friction materials in brake systems have been designed as the main sacrificial part of the brake system. Working conditions on PHEVs and especially EVs are vastly different from conventional ICE vehicles in terms of temperature, achieving comparatively lower operating temperatures for most of the time. In practice, and in normal driving, regenerative braking should be the preferred way to decelerate a hybrid or plug-in car, capable of stopping the vehicle without the participation of the mechanical brake in 90% of the braking.

This could mean that the car's traditional friction brakes are not being used as much as they should be. Under different working conditions and due to the stochastic nature of the friction braking process (which depends on the actual contact area, the existence of a transfer layer between the friction pairs, changes in pressure temperature speed deformation and wear), the behavior of friction materials in a PHEV or EV can be affected.

High temperature friction stability and wear resistance has always been a key feature of friction materials, and in the future maybe some of the materials used on their formulations for this specific operational range (like the high temperature lubricants) will decline in their usage or will be substituted by other materials to focus on lower temperature functionality.

The use of brake pads is very low in electric vehicles. The brake pads therefore tend to be thinner and thinner.

Another very noticeable effect is the appearance of excessive corrosion of the brake discs, which generates noise and safety problems. Brake discs are basically made of gray cast iron, due to its good heat resistance and ability to damp vibrations, forming an oxide transfer film on its surface and on the surface of the brake pad. Strategies are envisaged to mitigate these problems throughout the friction materials industry, such as the introduction of corrosion inhibitor additives. But another strategy is also being considered, such as the extensive use of corrosion and wear resistant coatings on brake discs.

An external factor is also contributing to this last strategy. As part of the EU Commitment initiative to accelerate the transition towards smart and sustainable mobility, Euro7 will implement stricter emission standards for all cars, vans, trucks and buses (regardless of powertrain), including for the first time the brake emissions. The Adoption Roadmap has recently reached a major milestone in Commission Adoption, setting the brake emissions limit at 0.7 mg/km PM10 by 2025. Rotor wear is responsible for up to 80% of particles emitted by a mechanical brake system, and LS-type friction materials cause a higher number of particle emissions than NAO-type ones.

The OEM companies have generally led rotor coating development processes themselves in partnership with leading coating technology companies, but not necessarily including the friction industry in the process from its inception.

And remember what I said earlier about friction material design? "*...working conditions and composition and properties of the friction pairs (friction material/counterpart) ....*" "*...Brake discs are basically made of gray cast iron...forming an oxide transfer film on their surface and on the surface of the brake pad...*". And yes, you're right...

The industry is now trying to catch up with the need for simultaneously

(i) short bedding period,

(ii) cold coefficient of friction stability,

(iii) friction coefficient stability during speed changes,

(iv) friction coefficient stability under temperature loading,

(v) stability of the coefficient of friction after temperature loading,

(vi) stability of the coefficient of friction under activating pressure changes,

(vii) relationship between the static and dynamic coefficient of friction,

(viii) coefficient of friction under wet conditions, etc.

It seems much simpler in the case of a combination of NAO and FNC (already used since 2008), but it seems more complicated in the case of LS with Laser Cladding, at least until a cladding is fixed. Is it a new fork in the development of brakes between Europe and America?

In the US, an industrially well-established rotor coating process, the so-called FNC (Iron Nitride-Carbide), seems to be the winner to be standardized for all electric vehicles and PHEVs. Since its introduction in brake rotors in 2008, FNC has helped reduce brake warranty claims by 70 percent at General Motors. In Europe, with LS friction materials, and especially in vehicles with intensive use of mechanical brakes (such as ICE), a thickness of 25 micrometers can easily be eliminated, producing unwanted noise and requiring disc replacement. It is the Laser Cladding technology that seems to be best positioned for its industrial implementation in Europe for the hard coating of rotors. Thicker, harder and wear resistant coatings, based on Metal Matrix Composites with Carbides or precipitation hardening alloys.

What seems clear is that regenerative braking and friction braking are going to be complementary systems for a while, but with changes in the friction pairs and in the composition and thickness/geometry of the brake pads. The introduction of regenerative braking can provide a safety advantage in time and distance kinematic deceleration over traditional service braking. Results from initial studies showed that regardless of which level of regenerative braking is used, it gives drivers a braking advantage and also showed that driver foot behavior differed under the high regenerative braking condition. Can this change generate an expectation of a different driving experience on the part of users?

Is it possible that the AMS test is no longer as important as it is today?

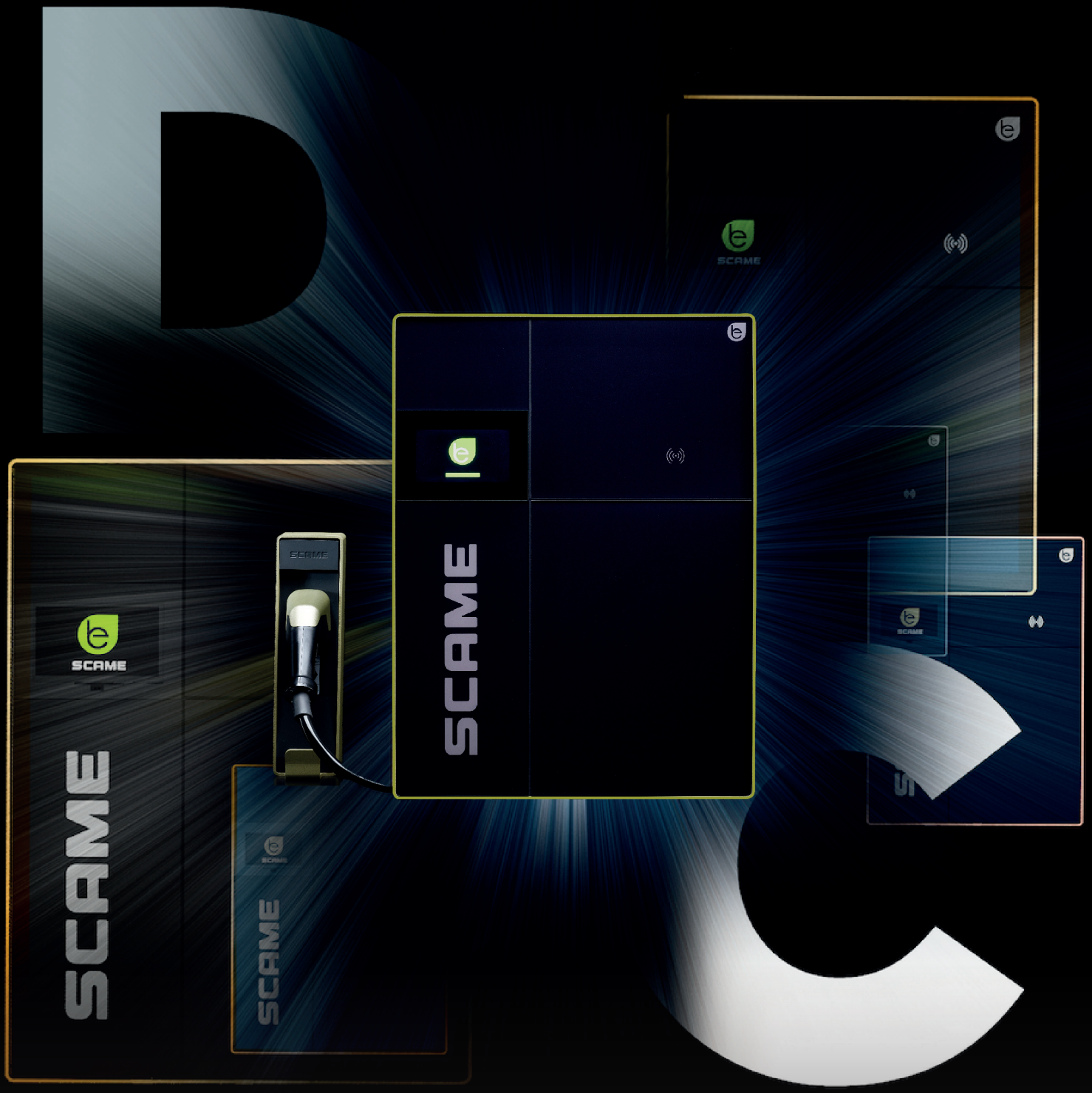
Could NAO formulas that simplify the reduction of brake emissions one day become popular in Europe?

Can this lead to a simplification in the formulation of friction materials and at the same time a redesign from scratch for new friction pairs?

Could this be the starting point for the commercialization of mechanical braking systems?

Well, as Socrates said: “The secret of change is to focus all your energy, not on fighting the old, but on building the new.”

Carlos Lorenzana,
Chief Innovation Officer
Rimsa



BE-D

DYNAMIC
CONTEMPORANEITY

Time and space find their righteous dimensions in those of BE-D, Scame's new compact DC wall box dedicated to the recharge in direct current of electric vehicles.

With its 25 kW of power, delivered via a CCS2 or CHAdeMO connector, a one-hour charging session guarantees up to 150 km of travel: A meeting, lunch with a friend or a workout in the gym that is as much time as you need to manage carefree the rest of the day, wherever that takes you.

Sustainable mobility should not hinder those who choose it, but rather empower everyone's lives.

Without uncertainties, but with the freedom to move in a world without borders, just like the sharp lines and frameless design of BE-D, by Trussardi+Belloni Design.

Conscious that the strength of equilibrium lies not in staticity, but in an everlasting dynamism.

BE-D: Dynamic Contemporaneity.

The use of Simulation in BMS and ADAS

Closing the Gap Between Design and Reality

Dr Christophe Bianchi

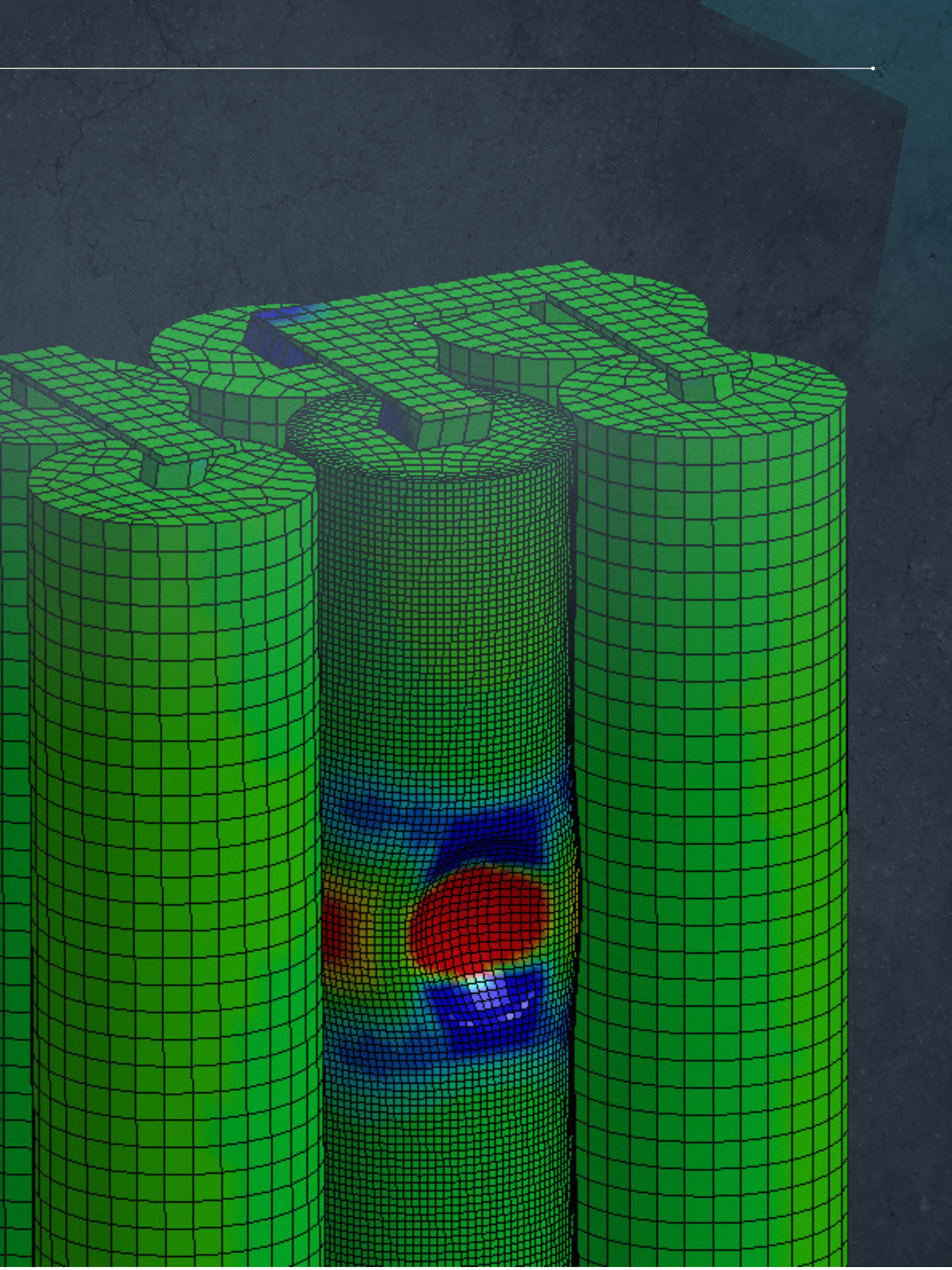
Dr Christophe Bianchi, CTO at Ansys answers our questions on the use of simulation in both Battery Management Systems and Advanced Driver Assist Systems (ADAS) and Automated Driving (AD) functions

e-motec:

Explain the role of Simulation in developing accurate BMS, the challenges of battery design & the steps involved to ensure that battery optimization is achieved

Dr. Bianchi:

The world's automakers are racing to launch new EV models, and many of the engineering challenges around EVs center on the electric battery and its management system: bringing together hardware and software components, the BMS (Battery Management System) independently ensures the smooth, safe operation of a battery-powered (or hybrid) vehicle at optimal performance conditions.



Modelling & Simulation addresses multiple challenges in the development of batteries and battery management systems for EVs, and more specifically address the following challenges:

1 Battery Cell and Electrode Design & Manufacturing

Electrochemistry is the physics behind how a battery operates and performs. Electrochemistry simulation supports from the manufacturing of the battery cell to predicting age and lifetime. Cell manufacturers are tasked with the challenging job of storing as much power as possible, while reducing size, weight and cost. Accurately simulating electrochemistry before the manufacturing process helps with materials property selection and electrode structure design.

To determine the relevant performance characteristics of the battery cells, an electrochemical-thermal simulation will ensure temperature uniformity through fully coupled, multiphysics and multiscale models, whilst verifying heat generation and charge density response curves.

2 Battery Pack and Modules Thermal Management

Batteries are extremely sensitive to temperature. Thermal management is critical to reduce temperature variations and to avoid thermal runaway. As a battery's temperature increases, its rate of chemical reactions and performance can improve. However, at one point, a rise in temperature may cause permanent damage. In order to design and validate the most cost/function effective cooling system, multiple physics must be jointly simulated such as Electro-Thermal coupling, Electrochemistry modelling, analysis of thermal runaway and thermal propagation, fluid dynamics of the coolant...

The number of optimisation parameters can be so large that it may makes sense to use AI-powered optimisation methods to identify the best design. These optimisation methods rely on ML algorithms that are trained on combination of physical data (lab tests) and virtual data (simulation results) where multiparameter optimisations provide the design engineers with a range of optimal designs to choose from.

Once the best design has been identified and validated, a reduced-order-model (ROM) can be created: it is a digital twin of the battery that can be loaded on a control unit (AI on the edge) to perform continuous monitoring and validation during the lifetime operation of the batteries.

3 Battery Structural Reliability

Batteries can be exposed to a variety of situations that can compromise their safety. To ensure battery durability,

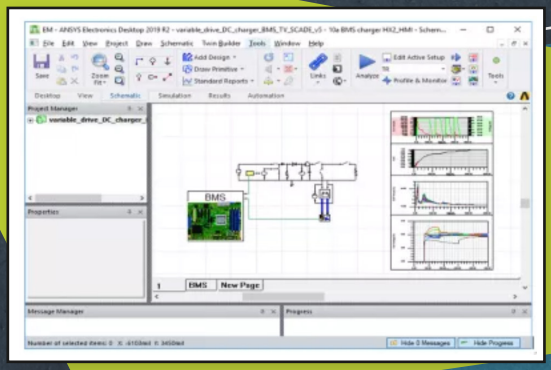
In order to build the safest battery on the market, there is a large set of industry standards that a battery design needs to be validated against; such standards include SAE J2464, UL 2580, IEC 62619, SAND 2017-6925 and NASA JSC 2073. Simulate and optimize housing designs and reinforcements to build the safest battery on the market.

To meet these stringent requirements, designers must simulate and optimize housing designs and reinforcements with respect to Impact and Drop Test, Thermal Stress, Random Vibration and Fatigue, considering the specifics of Advanced Materials.

4 Battery Management System

Battery management systems (BMS) play a critical role in today's electric vehicles. Optimizing the development, test & verification of these sophisticated systems offers significant time, cost & quality advantages for BMS development teams.

This includes ensuring Functional Safety for the BMS system, development and validation of critical Embedded Software utilizing the software controller, intelligently monitoring the battery's operating conditions and overseeing its safe operations and achieving a System-Level perspective on how the BMS and battery will perform throughout their entire life cycle.



5 Battery Electromagnetic Interference (EMI) Simulation Testing and Design

High-frequency EMI noises can cause crosstalk between a high-voltage power circuit in a battery array and a low-voltage control circuit in a battery management system. Electromagnetic simulation can be used to predict electromagnetic interference (EMI) emissions and susceptibility early in the battery design process or be used to conduct root cause analysis for existing EMI challenges in a battery system. These predictions and analysis can help optimize the EMI filter design and reduce hardware testing costs for compatibility tests.

The critical steps for EMI noise prediction and EMI validation are Early detection and mitigation of EMI noises before battery production, and EMI filter design and optimization.

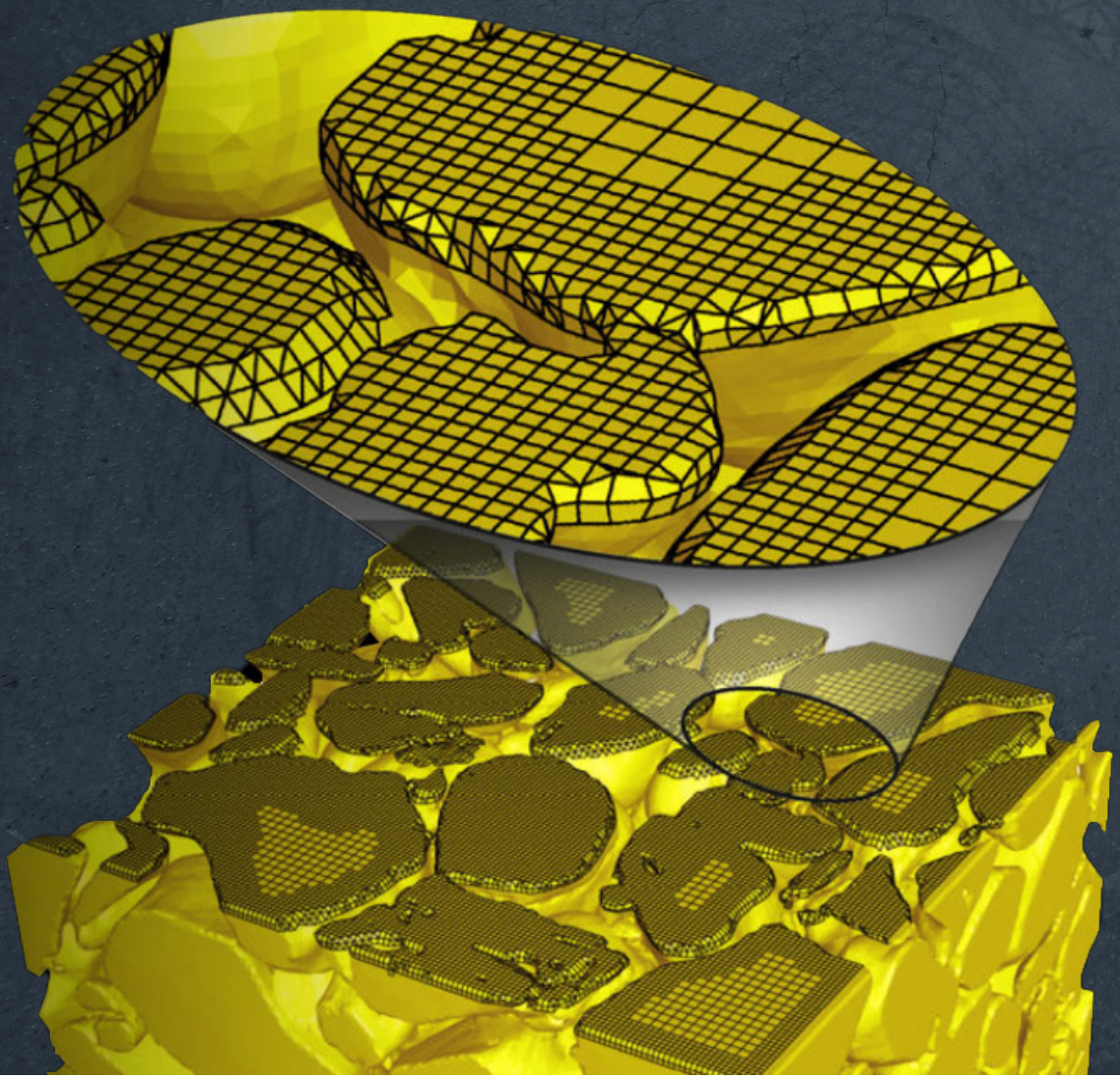
This can be achieved with accurate battery cell modelling (using EIS data-based battery cell/module models can convert frequency domain testing data into a time domain battery impedance mode), accurate parasitic components modelling (using FEA-based battery parasitic modelling to extract parasitic elements of battery package components using geometric information and material properties) and system-level modelling (where System level virtual compatibility testing can be used for virtual testing of compatibility standards or be used for root cause analysis of real EMI challenges for existing product).

"Because the BMS manages and controls all battery functions — safeguarding against such problems as overheating — it is critical that our solutions meet the highest functional safety standards, including ISO 26262. Unless we meet these standards, we will not be able to supply products to the global automotive market. We rely on Ansys 'medini analyze' to manage and automate the process of certifying our battery management systems. By taking significant time and costs out of the development cycle, 'medini analyze' positions LiTHIUM BALANCE to compete in the global automotive battery market. It has absolutely been critical for the analysis and quantification of our safety goals."

Claus Friis Pedersen
R&D Director / LiTHIUM BALANCE A/S

e-motec:

Forecasts for the growth of autonomous vehicles is optimistic. This optimism depends on the confidence of the customers insurance companies and regulators. Modern vehicles require full awareness of their surroundings, detecting their environment using a number of technologies such as cameras, radar and sensors. With all the sensors switched on in a single trip the vehicle is collecting terabytes of data. In such a complicated electromagnetic environment its critical to understand in simulation all aspects of the conditions.



What is the Ansys approach to these complexities?

Dr. Bianchi:

One of the most important current trends in the automotive industry is the development of advanced driver assistance systems (ADAS). Due to the ever-increasing complexity of ADAS, the safety validation of such systems is a major challenge. New methods have to be developed, as the previous certification and approval methods are not suitable for this use case.

The required mileage needed to proof the probability of failure of the system is impossible to reach in field operational tests, as it is estimates that autonomous vehicles would need to be driven for billions of miles to show performance across real-world scenarios.

Additionally autonomy increases the level of complexity of the embedded software by at least an order of magnitude: Modern cars have roughly 100 million lines of embedded software code. Estimates suggest that AVs will need 1 billion lines of code.

And time to production is limited whilst demand is high: With 45% of vehicles sold by 2030 projected to be highly automated, significant automation improvements are required in the next 10 years.

With so many technical barriers between modern vehicle systems and full automation, simulation is necessary to solve critical design challenges in the areas of autonomy system definition, hardware development, software development and especially system validation. Therefore, simulation is a key component to find critical scenario characteristics for safety function testing, validation, and even certification of highly automated driving systems. One of the greatest challenges here is the high number of simulations needed for testing, especially for very rare events (logical scenarios with low probability of failure 10^-6)

When it comes to Autonomous Vehicles, there are 4 major categories of engineering challenges to consider:

1. **Autonomous Sensor Development,**
2. **Autonomous Software Development**
3. **Autonomous System Development**
4. **Autonomous System Validation**

1. High-Performance Sensor Design for All Conditions

Sensors are critical components that provide the information autonomous vehicles need to make intelligent and safe decisions. They must reliably deliver high performance capabilities and function in a wide range of adverse operating conditions, including rain, ice and snow.

Simulation is proven to enable engineers to improve sensor performance, determine optimal vehicle integration configurations and examine their behaviour across a wide range of operational scenarios. With such safety-critical systems, the most accurate, physics-based simulation tools are required. Whether it is for Lidar where optomechanical, thermal interactions and an optical materials properties library, enable rapid emitter and receiver design and placement optimization ; for Camera where vision performance analysis and high-fidelity lens transfer functions are required for optomechanical optimization, placement and validation ; Radar where accurate and fast electromagnetic simulation allow engineers to rapidly analyse radar system performance in complex, dynamic scenarios and improve the accuracy of their response to potential hazards ; or in the testing of Perception Software when identifying potential vulnerabilities in AV perception systems, by finding and categorizing edge cases where these systems might exhibit unsafe behaviour.

2. Accelerate Embedded Software Development and Validation

Model-based methodology and solutions accelerate autonomous vehicle and ADAS features software design and validation at the very earliest stages of AD development and offer the auto-generation of certified/qualified code, that complies with industry standards including ISO 26262 ASIL D, DO-178C and others.

It all starts at the System Architecture level: The development of embedded software for AD systems begins by creating an architecture model of the automated driving system $. This intuitive modelling tool generates a system-level architectural model that graphically shows the main function blocks for the AD system.

On this Architectural model, model-based software development assist the designers in designing control systems to automatic code generation for industry standards such as ISO 26262 and DO-178C.

And closed loop simulator solution, with APIs and middleware, enables auto-generation of safety-certified code that is target compatible for RTOS integration.
The validation, at each level of verification from SiL (Software in the Loop) to HiL (Hardware in the Loop) and finally DiL (Driver in the Loop), supports all testing and verification activities for the AD embedded software model.

3. Safe and Cybersecure Autonomous Vehicles

With model-based safety and cybersecurity solutions, end-to-end traceability can be established. Compliance with existing standards (such as ISO 26262, ISO 21448, ISO 15408 and other emerging standards) can be demonstrated, saving up to 50% on development time compared to more manual approaches. Our simulation solutions focus on:

Functional Safety (FuSa): Integrating advanced safety analysis methods with model-based safety analysis, is required to deliver end-to-end traceability and compliance with safety standards such as ISO 26262.

Cybersecurity: in order to identify cyber vulnerabilities, it is essential to integrate architectural and functional design models with cybersecurity analysis methods.

Safety of the Intended Functionality (SOTIF): once again, simulation is required to undertake systematic causal analysis of SOTIF hazards and compliance with safety standards such as ISO 21448.

4. Rapid Autonomous System Validation

Testing strategy has to be defined that includes detailed and realistic world modeling and scenario generation and must incorporate high-fidelity sensor simulations. From this, software-in-loop (SiL), hardware-in-loop (HiL) and driver-in-loop (DiL) analyses can be performed.

Software-in-Loop: Incorporating high-fidelity physics-based sensor models enables open loop software testing, model coverage and verification of the software implementation against key performance indicators and test plans.

Driver-in-Loop: With VR, the simulation environment provides live interaction between the user, virtual actuators and vehicle embedded software. This captures finger motions and heatmaps, a full cockpit user experience, reflection studies and HUD performance very early in the design process.

Hardware-in-Loop: Automatic code-generation solutions generate RTOS independent vehicle and sensor models on real time targets that provide continuity from design to verification, delivering test reproducibility and analysis of edge and worst-case scenarios.

In conclusion

Great advances aren't made in baby steps. They happen in big, bold leaps. To push innovation forward faster and achieve their most ambitious engineering goals with confidence, visionary companies partner with Ansys.

Dr Christophe Bianchi,
CTO Ansys

Ultrasonic welding for the utilization of automotive busbars in high voltage distribution

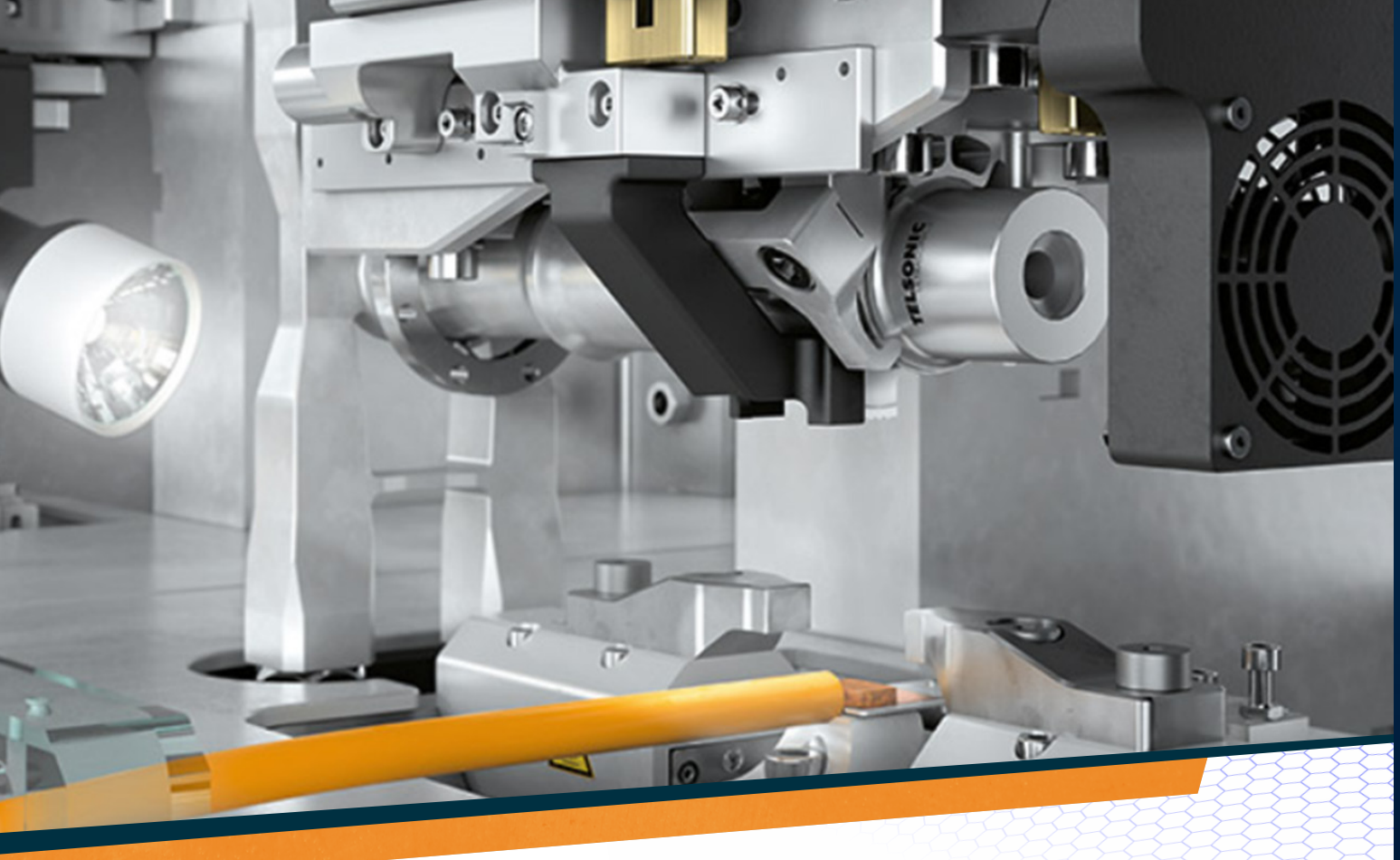
Saeed Mogadam

Although the technology behind electric vehicles (EVs) has been around for some time, the last decade as has seen a significant increase in the sale of EVs and hybrid electric vehicles (HEVs) as private motor vehicles. With the benefits they provide, EVs are seen by many as the future of the automotive industry. As the market for EVs and HEVs grows, manufacturers will look to advancements in technology to improve the efficiency, power and capabilities of these vehicles and ultrasonic welding will play a part in these technological advancements. Since the late 1980's the automotive wire harness manufacturing industry has been the single largest user of ultrasonic welding, mostly using the technology in the splicing of wires. However, new applications of the technology are being used as part of the future processes that will ultimately provide automotive manufacturers with solutions to many present-day shortcomings in EV technology.

The current EV Manufacturing Landscape

In EVs large banks of battery cells combined in sealed packs are used to achieve the required operating voltage and current to power a vehicle's electric motor. Currently, two chief concerns in the EV/HEV space are power storage and driving range. Original equipment manufacturers (OEMs) are addressing these concerns in two ways: creating larger batteries that allow for greater range and creating more powerful batteries that allow for faster charging. Both approaches have challenges. Yes, batteries can get larger, but they can only get to a certain size before they become too expensive and heavy to be a viable solution.

Traditional wiring is not the first place one normally looks for EV innovation, but recent advancements are having a significant impact on the EV story because they are providing OEMs with two things, they desperately need in their EV architectures: less mass and more space. One way to make room and reduce mass is moving from round wiring to flat conductors. That is where busbars come in.



What are electrical Busbars?

Derived from the Latin word “omnibus” which translates to “for all” (as in “all the currents in a particular system”), busbars are flattened conductors that are becoming integral to EV architecture. Busbars are usually housed inside switchgear, panel boards and busway enclosures for local high current power distribution. They are also used to connect high voltage equipment at electrical switchyards and low voltage equipment in battery banks. A busbar is a metallic strip or bar made from copper, brass, or aluminum that grounds and conducts electricity. Electrical busbars can be coated with various materials, such as copper, to provide different conductivity limits and variations. Busbars come in several shapes and sizes which will determine the maximum amount of electric current a conductor can carry before deteriorating.

Today, there are up to two dozen busbars in a battery pack, and that number will rise as battery packs get larger and/or more powerful, while the space inside them remains incredibly tight. Ultrasonic welding is a preferred joining process for busbars in EV applications. But, because these more powerful batteries are only as good as their ability to charge quickly, we will soon see more busbar innovation outside the battery pack as well, routing high power from charging inlets to batteries and out to other high-power motors and devices, increasing the need for innovation ultrasonic welding applications.

Why companies prefer electrical Busbars

In the long run, it is believed that busbars could be preferred over standard cables for part of the wire harnesses in the automobile industry. The increasing adoption within EVs, cost-effectiveness, ease of installation, along with low repair and service cost of automotive busbars, and development of EV charging infrastructure are some of the key factors behind the growing demand for automotive busbars. Moreover, the technological developments in the manufacturing and charging infrastructure of EVs are expected to benefit the global automotive busbar market. Due to these factors, the market is expected to generate over $170 million in 2030, advancing at a CAGR of 24.6 % 2021 - 2030, according to market research.

Benefits to using busbars:

- Reduced facility costs and faster installation
- Ability to add, remove or relocate power easily and quickly without any downtime
- Future-ready and highly flexible as some plug-in units can be disconnected and reconnected without de-energizing
- Require no routine maintenance
- Faster and less costly for expansion or remodeling
- More environmentally friendly as it often requires fewer installation materials and plug-in outlets are reusable and easy to relocate
- Flat conductor takes up less space, 70 % shorter in height
- Can support up to 15 % more power than a cable with the same cross-sectional area
- Less weight and packaging space, with much better flexibility. E.g.,160 mm² Flexible Flat Aluminum (FF-Al) cable is an innovative and alternative solution to 200 mm² round Al cable
- Use bolts for fastening which is the most reliable process today and less costly.
- But it adds additional parts (bolts) and requires specific torque value
- Efficient heat dissipation – More effective than stranded cables
- Multiple Constructions – Cu & Al, rigid or flexible, laminated. See figure 1
- No EMC required for inside battery
- Facilitates automation which improves safety and quality

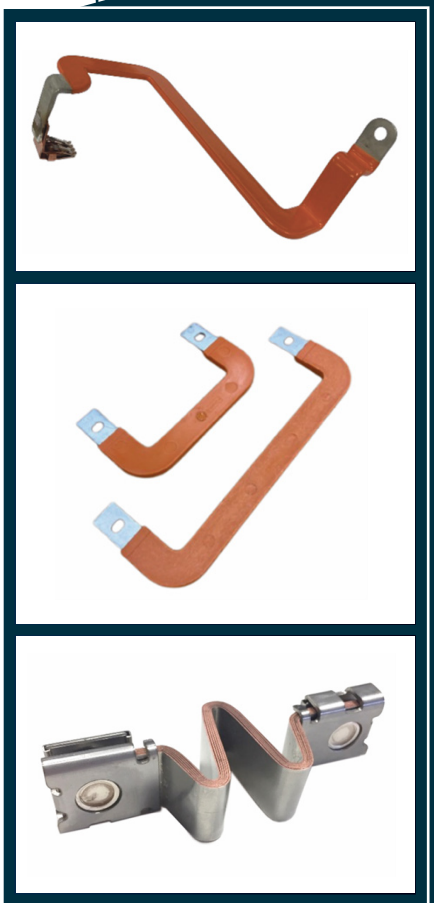


Figure 1: Examples of various bus bars- rigid, flexible, custom design

The importance of Busbar materials and sizes

Busbars are usually made from corrosion-resistant copper, brass, or aluminum in solid or hollow tubes. The shape and size of a busbar, whether flat strips, solid bars, or rods, allow for more efficient heat dissipation due to high surface area to cross-sectional area ratio.

Even though copper oxidizes over time, it remains conductive, but this often means more power to push electricity along the surface. Whilst it cannot completely prevent oxidizing over long periods, it dramatically reduces the effects. Coating the busbar surface will help protect against oxidation.

Busbar coatings typically serve three main purposes:

- To inhibit corrosion
- Increase conductivity
- For cosmetic purposes

Laminated busbar is used to avoid the circulating currents in parallel connected switching devices in power electronic circuits. It also has wide applications in solar energy and wind energy collection and distribution, because of its low inductance characteristics, in addition to its important application in electrical vehicles. A more efficient and cost-effective method is to use an insulating epoxy coating powder. Epoxy coating powder offers very high dielectric strength, and it will bond directly to the busbar copper, aluminum, or silver plating.

Busbars range in size depending upon their particular use. The most common commercial and industrial busbar sizes are 40 – 60 amps, 100 amps, 225 amps, 250 amps, 400 amps, 800 amps.

The current sizes of busbars used in automotive applications are 35, 50, or 90 mm². Busbars are available in both copper and aluminum.

Aluminum busbars are less costly and work well in high moisture conditions. But aluminum has less current capability and higher resistivity than copper. Copper offers superior thermal characteristics to aluminum.

Busbar manufacturers can review the minimum requirements for a busbar intended for use within an EV/HEV or other power distribution application, detailing the tradeoffs between cost and material choices and performance. Of course, for EV/HEV power distribution applications, driver safety is an added concern and busbar material selection should be performed with the intent of achieving the highest reliability possible, not only for meeting vehicle warranty requirements but for the safety of the driver and passengers.

Calculating conductor size is especially important to the electrical and mechanical properties of a busbar. Electrical current-carrying requirements determine the minimum width and thickness of the conductors. Mechanical considerations include rigidity, mounting holes, connections, and other subsystem elements. The width of the conductor should be at least three times the thickness of the conductor. Additions of tabs and mounting holes change the cross-sectional area of the conductor, creating potential hot spots on the busbar. The maximum current for each tab or termination must be considered to avoid hot spots.

Another key difference that must be considered is solid vs flexible busbars. For automotive applications within the EV battery solid busbars are used (see figure 2).

Figure 2: Inside EV battery pack (APTIVE_NA Congress presentation)

The main differences considered when selecting the material are:

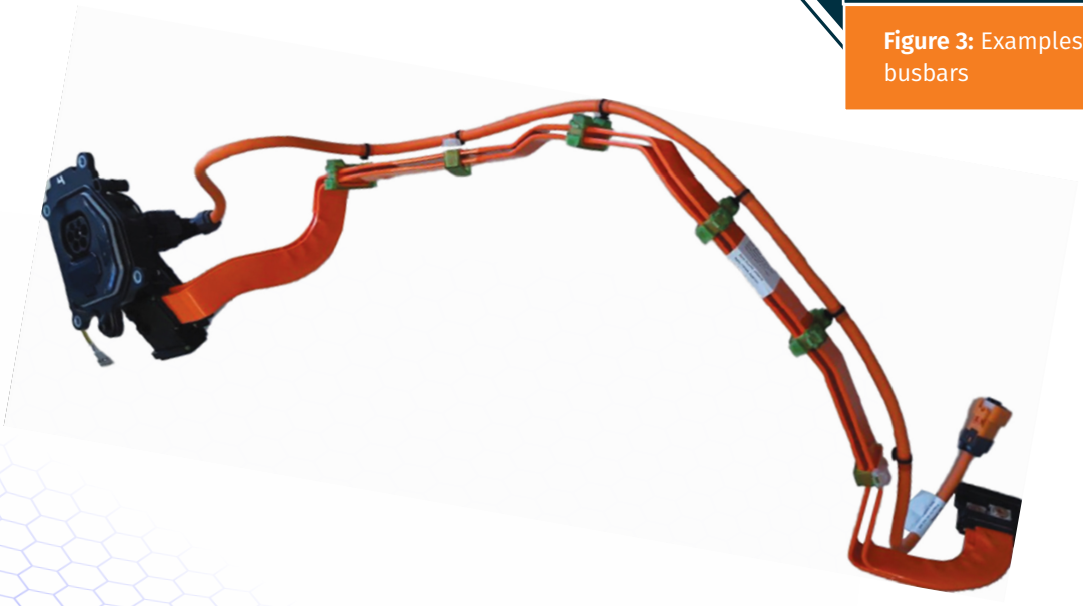
- Tensile strength
- Current ampacity
- Resistance
- Weight
- Cost

Solid and flexible Busbars

Flexible busbars are used in short sections when a particular area needs to move for assembly or the application. It is used as an electric "jumper." Examples of flexible busbars are shown in figure 3. Flexible busbars have several thin layers of copper or aluminum designed to efficiently distribute power across an AC or DC system. A copper foil stack is welded at the assembly areas which makes the ends rigid for connections while the middle remains flexible. Examples of applications where a flexible busbar is required include:

- Electric, hybrid and fuel cell vehicles
- Switchgear and transformers in the energy and offshore sector
- Power generator applications in the marine industry
- Transformers and charging stations
- Switchgear and substations in rail applications, chemical plants, and high voltage distribution
- Power link for generators
- Electrical connections in switching cabinets

Figure 3: Examples of flexible busbars



Future automotive Busbar application

Busbar innovation outside the battery pack will be of high interest for the future, routing high power from charging inlets to batteries and out to other high-power motors and devices (see figure 4). There is a rising interest in busbars among all OEMs and Tier 1 suppliers, mostly for high voltage applications.

Today a battery pack has about 15 - 20 busbars. For outside the pack, there is need for a shielding process by automation that does not exist today. At the moment the focus is on the battery pack. As future innovations increase the utilization of busbars outside of the battery pack, these new applications will create significant opportunities for ultrasonic welding to increase the overall quality of the future joining design in busbar architecture.

Ultrasonic welding, particularly torsional welding technology, allows welding of larger size welds, gentle vibration, and ability to join harder to reach areas. These capabilities will allow further implementations of busbars outside the EV battery packs as the industry moves forward. Figure 5 provides a few examples of how ultrasonic welding can be implemented in future EV applications.

Companies such as Tesla, BMW, and Ford are leading the push for utilization of busbars outside of the battery pack. Recently, global technology company, APTIV acquired the Italian company, Intercable for around $600Mio to aggressively pursue utilization of busbars for high power distribution outside the battery pack. BMW is among their top three customers showing strong indication of pursuing this new method of electrical distribution. There are a handful of other companies that are working on busbars with shielding in America and Europe.

Figure 5: Future implementations of ultrasonic welding for busbars in EV applications

Challenges for applications outside the battery pack

- Busbars outside the battery pack need shielding that is not available today – Battery packs have a case that is sealed and shielded for electromagnetic interference
- There is an issue when busbars need to be bent at proximity – They can be too stiff or may be damaged at the bent corner
- The bolting process requires added parts and specific torque value. The busbars with bolt holes may be replaced for busbar applications outside of the battery pack
- The Al busbars require plating for the bolt hole due to corrosion
- Termination of connectors to solid bus bar for ease of automation
- Automation is not fully possible yet due to shielding
- New standards and validation may be required for the weld and the assembly

Figure 6: TT7-Telsonic PowerWheel®

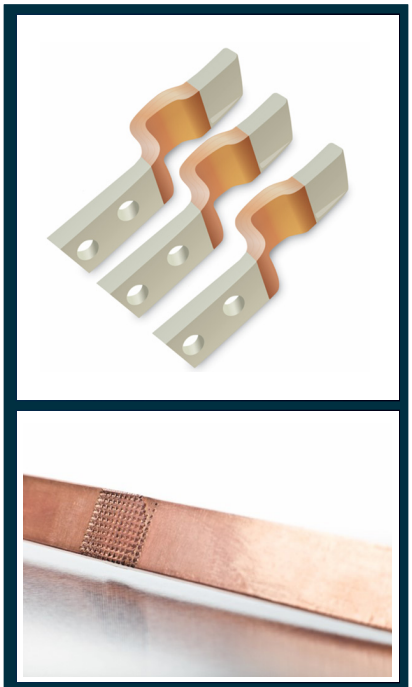


Figure 7: Solidified flexible busbar and solid bus bar welded to solid bus bar using TT7 Telsonic PowerWheel®

Current Busbar applications for ultrasonic welding

Ultrasonic welding technology is a proven joining process that is increasingly specified by carmakers for use in EV for cables to terminal connections, busbars, battery manufacturing and power electronics. Linear welding is the more traditional and well-known technique used by all equipment manufacturers as a standard process for splicing wires. However, like many other joining processes, linear welding comes with limitations in size, difficulties welding in smaller areas and certain geometrical shapes, problems with orientation of welding, and vibration effects on peripheral components. Telsonic Torsional SONIQTWIST® and PowerWheel® technology have made innovative solutions for EV joining applications that were impossible previously. These innovative techniques allow many joining designs in relation to busbar applications that would be impossible with linear welding. There are already smaller busbar applications that currently utilize ultrasonic welding for joining. Ultrasonic welding is a preferred joining process for many busbars, such as flexible flat busbars as high as 160 mm².

In the future, there will be many new applications that utilize ultrasonic welding in the busbar implementation for wiring harnesses. Below describes some of the existing uses for ultrasonic welding in busbar application.

1. Solidification of flexible busbars

Flexible busbars need to be solidified at the joining section to connect (join) it to a standard cable or a connector. In some cases, the joining to cable or terminal and solidifications can be done on one step welding. Depending on the overall dimension of the flexible busbar, ultrasonic metal welding can be a high quality, economical solution. Using a torsional welding process, one can weld up to 200 mm² cross sectional material. This welding technique prevents hardening of the Joining material, which may cause brittleness and noticeable changes in the material properties. In addition, the solidification can be automated with Telsonic equipment, such as TT7 PowerWheel®, as shown in the application in figures 6 and 7.

2. Busbar welds to standard cables

There are applications where the busbar is welded to the orange cables which will be welded to the current connectors. Figure 8 shows an example of a short cable welded with the stranded cable. Welding a short cable on both ends can present inconsistencies in the weld quality as the first weld may become weaker due to vibrations caused by the second weld. The USCAR-38 requires testing for cables below 500 mm in length. With the Telsonic PowerWheel, torsional welding provides such gentle vibrations that studies show the effect is much less for both stranded cables and flexible busbars, depending on the terminal designs (see figure 9). This allows shorter cables and appropriate connectors be welded together.

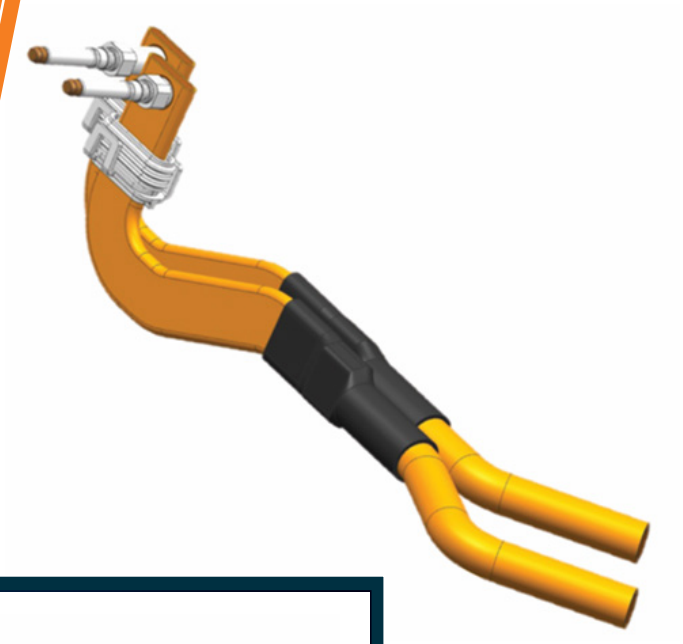


Figure 8: Short cable (200 mm) welded on both end

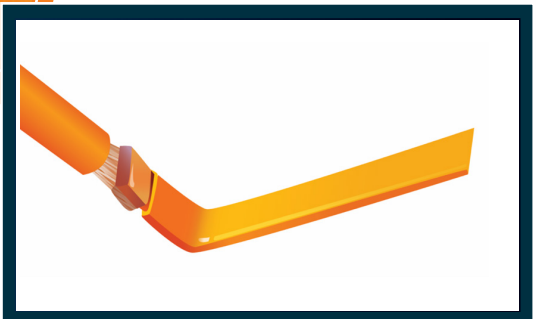


Figure 9: Solid bus bar welded to standard cable (APTIVE_NA Congress presentation)

3. Welds to flat braided cable

In some cases, instead of orange cables, manufacturers use a flat braided cable. The flat braided cable is welded and cut into pieces automatically with specific length and welds on both ends (see figure 10). A braided cable with welds on both ends is also known as a shunt. The advantage to producing the shunts with ultrasonic welding is that there is minimal heat involved in making the shunt and when welding it to a busbar (see figure 11). This prevents brittle strands and nicking of its exceptionally fine strands due to heat from resistance welding, another technique which can be used.

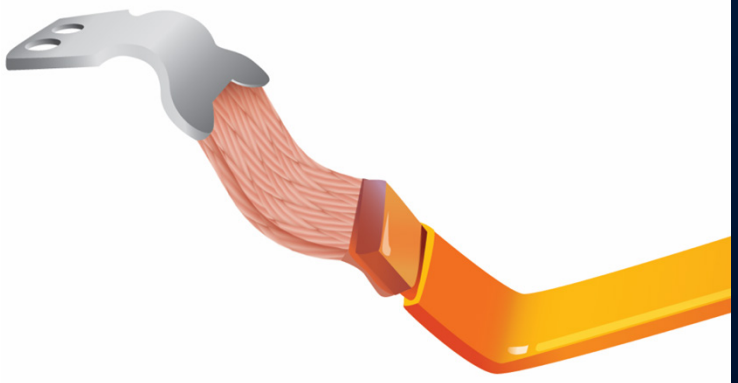


Figure 11: Solid busbar connected to flat braided jumper

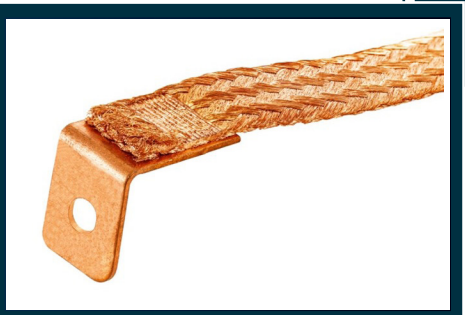


Figure 10: Flat braided cable solidified and welded by ultrasonic welding

Torsional welding applications and capabilities for Busbars

Flexible busbar foils are laminated/plated with materials such as copper to prevent issues with oxidation. For solid busbars, there must be plating for the bolt hole connection section. In cases of aluminum solid busbars, the contact for connection must be copper. Therefore, a copper washer is used and connected to the busbar with torsional welding (see figure 12). The proven SONIQTWIST® technique along with the Telsonic TSP welder (figure 13) can be used for this application.

British automaker, Jaguar, currently utilizes the capabilities of torsional welding using SONIQTWIST® and PowerWheel® for busbar assemblies for electrical distributions. The company uses busbars instead of copper cables to significantly reduce the weight and cost of its F-TYPE sports car (see figure 14). Each busbar conducts electricity from the battery in the vehicle boot to electric equipment in the engine compartment. Because aluminum has a significantly lower relative density than copper, the bar only weighs about 40 to 60 percent of conventional copper cable. For the battery connection alone, this can amount to a reduction in weight of up to 3 kilograms.

Figure 12: Telsonic SONIQTWIST® TSP

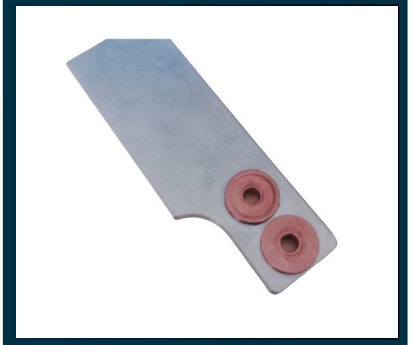


Figure 13: Cu Nut welded on Al bus bar with Telsonic Torsional welder SONIQTWIST® (APTIV_NA Congress Presentation)

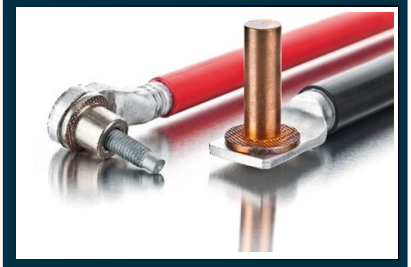


Figure 14: Leoni connection bolt welded to busbar

Conclusion

The innovative and rapidly growing EV market demands new, developing solutions for the challenges ahead. Soon, utilization of high voltage busbars will replace some current applications for terminations with high voltage cables. As the industry moves toward usage of busbars outside of the battery pack, new challenges will arise before the standardization of busbar harnesses is established in the automotive industry. Challenges will be presented at all levels, including the manufacturers of welding equipment as new applications demand more innovative welding solutions. But new processes and ideas will allow more efficient and economical solutions for wire harness in the EV market. Torsional welding has become a significant joining process in the industry. In addition to solutions for battery cable terminations with a variety of connectors, the technology has provided welding solutions for EV weight control, battery packaging, bus bars, battery manufacturing and power electronics. The application capabilities have expanded beyond what was previously imagined. As product designers and process engineers continue to familiarize themselves with the torsional welding process and its capabilities, the technology is positioned to help propel the EV industry to even greater heights. A closer working relationship among OEMs, Tier 1 suppliers and equipment suppliers is a must to move forward in the utilization of busbars. We will certainly learn more in time and innovative ideas will be introduced, but ultrasonic welding will no doubt be a part of the solutions to achieve the objectives in material cost, weight and space reduction, and less labor-intensive manufacturing processes.

Saeed Mogadam, *Advisory Board*
Telsonic Solutions LLC.

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AI based Generative Engineering

Pierre-Emmanuel & Jean-Pierre Roux

The automotive and aerospace industries face increasing pressure from new environmental regulations, necessitating high-quality and cost-effective products that cater to the market's demands. The future of transportation is shifting towards hybrid and electric vehicles (xEV), making the development of powertrain systems more intricate. Meeting stringent development timelines adds to the challenges faced by the industry.

Currently, designing xEV systems relies on the experience of designers to achieve optimal performance while satisfying requirements and constraints. The process involves iterative engineering, modifying designs based on simulation results during collaborative and individual phases. However, time constraints prevent convergence to a globally optimal design due to limited iterations. The conceptual design step is crucial in determining the principal solution, significantly impacting the total product cost.

To efficiently select candidates from various alternatives, a systemic approach is essential. This approach assists engineers in the conceptual design research phase by automatically exploring architectures and concepts that fulfill requirements, avoiding fixation on a single design and performing parameter sensitivity analysis. Such approach reduces the number of iterations by utilizing computer tools to automate tasks and conduct detailed design phases for promising candidates.

1

AI based Generative Engineering

Generative Engineering is a new approach to system modelling using object-oriented modelling coupled with artificial intelligence and 3D generative algorithms; it allows to exhaustively explore all possible combinations, to manage uncertainty and variability and to explore quickly all the functional architectural and 3D integration solutions meeting the requirements.

With this object-oriented system modelling based on the Python programming language, knowledge about a system is encapsulated in objects which are defined by a set of attributes and methods. The application of algorithms to these objects allows the execution of automated tasks in the system design process, such as architecture research.

The system modelling integrates the product requirements, the objectives to be minimized, the technical knowledge (e.g. design rules) and the functional (or physical) description and/or the 3D description of the system.

The advantages of a Generative Engineering approach are:

- explore all possible configurations to avoid late questions
- identify the optimal global solution with respect to the system requirements to be met
- make informed decisions upstream on structuring choices
- achieve rapid design iteration loops

2

Application to xEV systems architectures

The vehicle system is broken down into various systems and subsystems, such as the powertrain system and the cooling subsystem (Figure 1). The design process commences with the definition of the vehicle's requirements, encompassing performance and profile specifications, alongside design constraints like packaging limitations. These requirements are then applied to the powertrain system level, where design engineers face decisions concerning powertrain architecture, component technology, and sizing to fulfill the powertrain requirements. These choices made at the powertrain level subsequently establish the prerequisites for the cooling subsystem. At the cooling subsystem level, decisions regarding architecture and components must be taken. The choices made at different system levels, both for architecture and components, significantly influence overall system objectives, such as energy consumption and costs. Notably, the impact of the system architecture on system performance may outweigh that of component sizing and control. In the next chapters, we will elaborate on how the methodology facilitates architects and engineers in making optimal choices for architecture and components at distinct system levels: powertrain system and cooling subsystem.

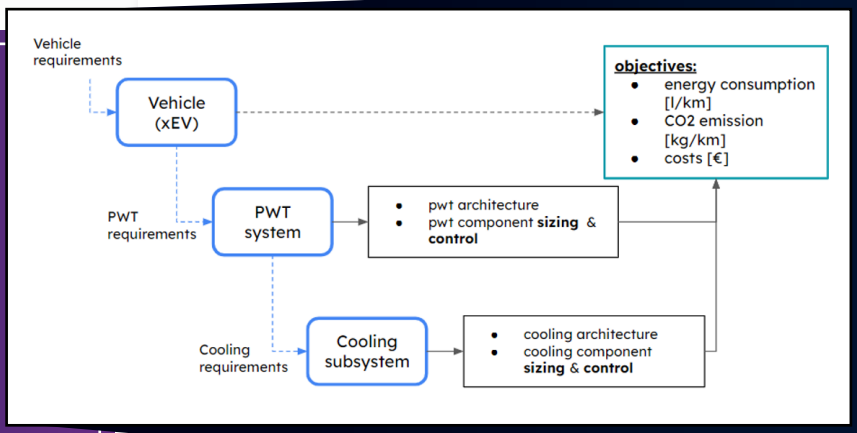

Figure 1: xEV design process based on an engineering system approach

2.1

Design exploration at powertrain system level (HEV)

The powertrain system is modelled using the approach presented in the previous section. It is decomposed into the following components, as shown in Figure 2: internal combustion engine (ICE), battery, electrical machine(s), and gearbox(s). At this stage, designers consider the powertrain components at a high level of abstraction. For instance, the ICE is modelled by an object that provides a torque and rotational speed with a single output mechanical connection. A gearbox is modelled by an object with two mechanical connections (input and output) capable of providing a torque and speed ratio.

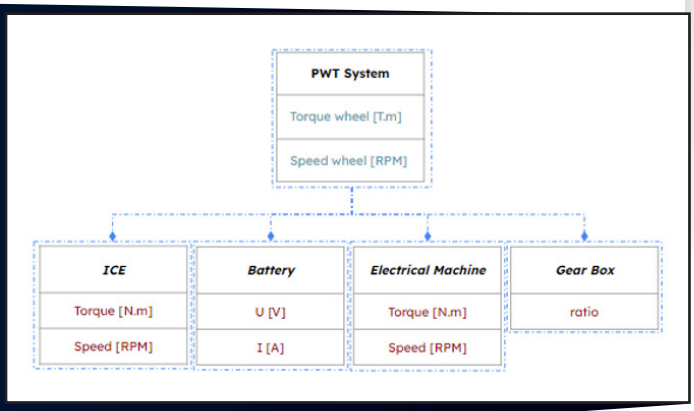

Figure 2: HEV Powertrain system modelling

The proposed powertrain system model, coupled with a decision-tree generative algorithm, allows for the generation of all possible solutions for connecting the components of the powertrain system. Figure 3 presents some examples of powertrain architecture generated, with each architecture represented by a graph.

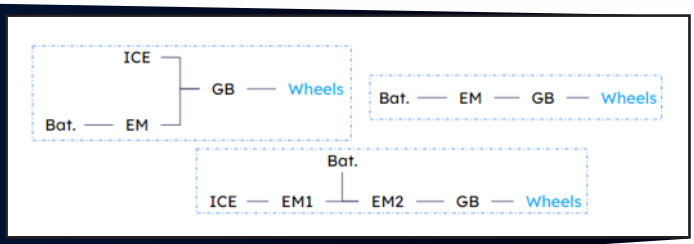

Figure 3: Examples of possibles HEV powertrain architectures

To meet the powertrain requirements, each architecture requires specific component specifications. For example, to fulfil the same powertrain requirements (for wheel torque and speed), a series and parallel HEV powertrain architecture will need different ICE torque and speed, resulting in different ICE sizing.

By generating all powertrain architecture and associated component sizes, engineers can decide on the optimal solution. The choice of optimal solution defines the cooling subsystem requirements.

2.2

Design exploration at cooling subsystem level

The cooling subsystem is modelled using a similar approach to that used for the powertrain system. The thermal needs are defined by the powertrain components, while the pump and radiator components enable the cooling subsystem to evacuate and fulfil the cooling requirements.

Similar to powertrain analysis, a generative algorithm is used to generate all possible cooling subsystem architectures. Figure 4 provides examples of cooling solutions represented by graphs. At this level of abstraction, each component has two hydraulic ports: an input and an output. The generative algorithm used here aims to search for all possible combinations of component ports, where each combination represents a cooling graph architecture.

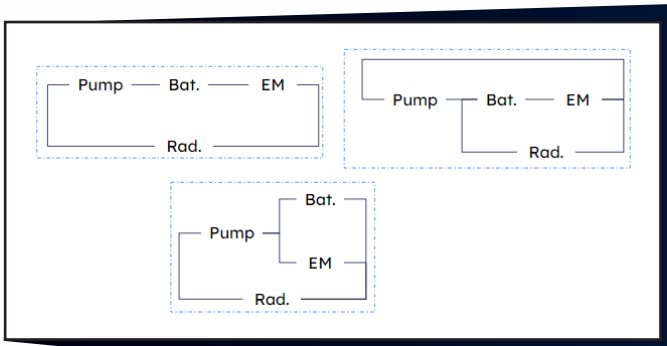

Figure 4: Examples of possibles cooling architectures

Cooling components must be sized to satisfy the cooling requirements for each architecture. For a given set of thermal losses from powertrain components, pumps will operate at different operating points for an architecture in which all components are placed in series compared to one in which they are placed in parallel. Optimizing the pump's operating point can significantly affect the pump's energy consumption.

3

AI based generative engineering at Renault

In order to make its engineering processes more efficient and to increase the performance of the automotive product, Renault has developed various Generative Engineering applications using Dessia framework for the generation of electrical harness architectures, but also for the technical definition of the thermal system architecture of a hybrid powertrain vehicle platform.

The main ambition fixed with Generative Engineering was to associate very early "functional specifications and 3D architecture drawing" and to multiply the number of iterations of technical definition via generative AI algorithms in order to explore as soon as possible the field of possible solutions.

It became possible to go through the design space very widely. In concrete terms, it was possible to carry out studies of the sensitivity of the requirements fields, analyses of the incompatibility of inter-system choices or even analyses of the consequences of local choices on the overall structure of the product.

Thanks to these applications, a hundred eligible solutions were produced with a time saving of more than 80%, using at least 3 times less resources.

Regarding the architecture of the thermal system (Fig 5), the objective was to optimize the energy required for cooling, the layout of the main components, the length of the hoses and the other networks, both electrical and air conditioning.

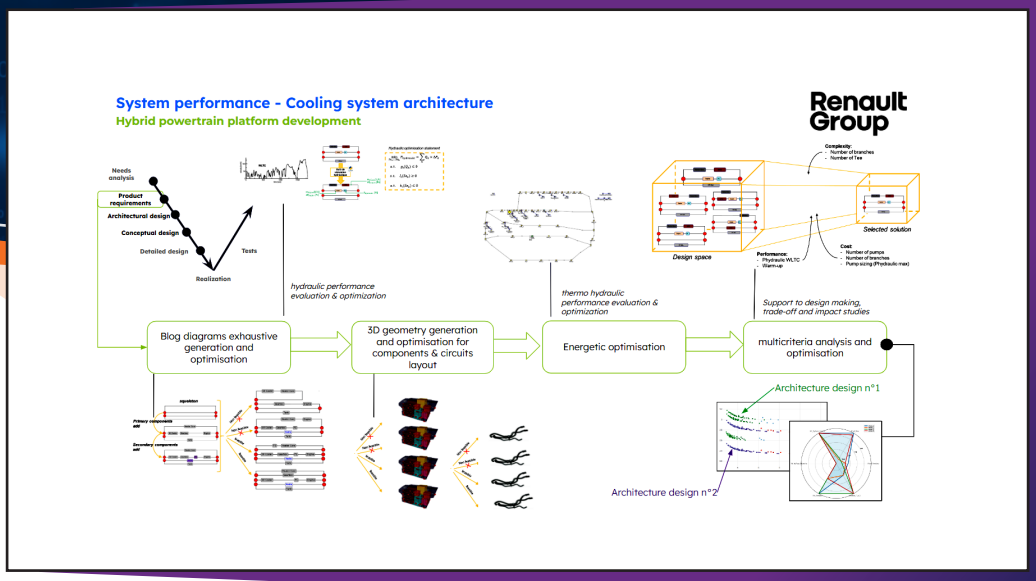

Figure 5: Generative Engineering with functional modelling and 3D integration

For this, the first step consisted in a functional approach as described in the previous paragraph. The objective is to generate and optimize a panel of functional water circuit architectures based on the cooling system requirements (Fig 6). The hydraulic permeability of each solution is optimized on cycle in order to minimize the energy expenditure to meet the cooling requirements.

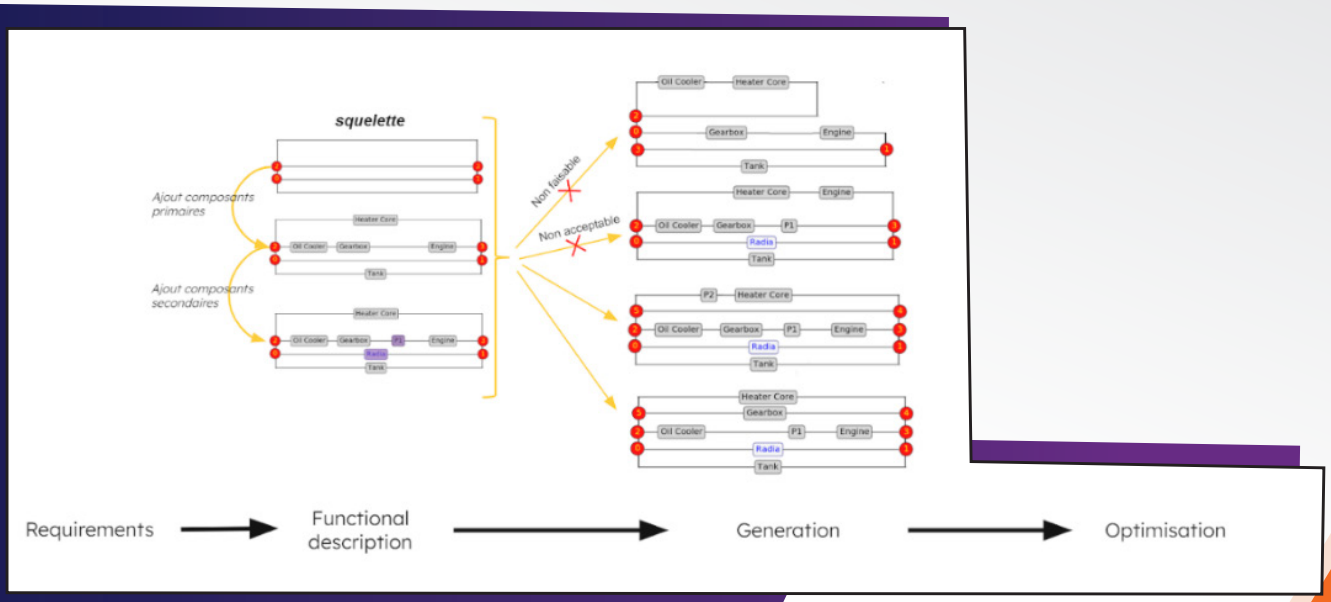

Figure 6: Generative Engineering with functional modelling

On the HEV vehicle studied, the study allowed to make impact analyses of several modifications of the water circuit architecture, such as to evaluate the impact of cooling the battery by the air conditioning rather than by the water circuit. In a few minutes without having to trace any hoses manually, a reduction of 40% in the cost of water circuit components could be achieved.

Conclusion: AI based Generative Engineering has great potential

For example- at the time of project scoping: The increasing complexity linked to the need for performance and the availability of more and more usage data pushes towards processes capable of apprehending all these dimensions, systematically exploring the field of possibilities and determining the strengths and weaknesses of solutions. The earlier these assessments are carried out, the better the engineering performance, avoiding design times penalized by late iterations while using scarce expert resources much more efficiently.

- in RFQ phase: where it is necessary to be able to quickly configure the most performing solution to fulfill the customer's requirements by re-using COTS or by looking for an innovative solution; a Generative Engineering application integrating data and knowledge allows to generate in a few hours all the possible solutions, to rank them according to attributes like performance, cost, commonality rate, and to take an informed decision on the solution to propose to the customer.

Pierre-Emmanuel, *CEO &*
Jean-Pierre Roux, *VP sales*
Dessia Technologies

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FCEVs driving Carbon Composite Hydrogen Tanks

Chandana Patnaik

In 2014, Toyota opened the doors to the hydrogen society by launching Toyota Mirai, the world's first commercial FCEV (Fuel Cell Electric Vehicle). However, Mirai was not the first FCEV developed in the world. The credit of introducing the first FCEV to the world goes to General Motors, which developed Electrovan more than a half century ago in 1966.

The GM Electrovan containing 2 giant storage tanks for hydrogen and oxygen, 32 fuel cell modules, electric motor, and a 550-feet piping throughout the rear of the vehicle weighted around **7,100 pounds**. This system relied on rare metals including platinum, which made it too expensive, and no proper hydrogen infrastructure was there those days, which made this vehicle a failure.

From GM Electrovan, that had a range of just **160 Kms**, to today's fuel cell vehicles that can range easily **more than 600 Kms**, the new-age fuel cell vehicles have seen a transition of innovation.

An era of risky storage, prohibitive cost, and restricted space has ended with the dawn of high-pressure vessels, specifically - Carbon Composite Hydrogen Tanks (CCHTs) for fuel storage.

Carbon Composite Hydrogen Tanks, Their Types, & Applications

CCHTs are the pressure vessels fully wrapped in carbon composites with metallic or polymeric liners (Type III & Type IV). Type III tank has a metal liner (aluminium or steel) with full composite overwrap, whereas Type IV is a complete carbon fiber made tank having an inner liner made of polyamide or polyethylene plastic.

In 2021, hydrogen pressure vessels had nearly 7% share of the total pressure vessels market, a majority of which is CCHT.

Types of Pressure Vessels

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Classified as	Material	Liner Type	Applications	Wrapping	Strength/Risk	Typical Pressure	Illustration
Type-I	Metal	N/A	Containment of gases for industrial and laboratory applications, SCUBA	N/A	High strength, moderate risk	200-300 bar	
Type-II	Metallic with hoop-wrapped	Steel, Aluminum 6061, Aluminum 7000, Copper, Nickel	Stationary Gas Storage like Hydrogen buffer at fuelling stations	Metallic cylinder hoop-wrapped with composite material	Moderate strength, moderate risk	200-300 bar	
Type-III	Metallic with fully wrapped fiber-reinforced polymer	Steel, Aluminum 6061, Aluminum 7000, Copper, Nickel	Mobile applications, medical sector, drones, **FCEVs.**	**Fully wrapped** (Glass Fiber composite, Carbon Fiber composite, Aramid Fiber composite)	High strength, low risk	450-700 bar	
Type-IV	Polymeric with fully-wrapped fiber-reinforced polymer	HDPE, **Polyamide**	Mobile applications, **FCEVs**, aircraft, etc.	**Fully wrapped** (Glass Fiber composite, Carbon Fiber composite, Aramid Fiber composite)	Highest strength, lowest risk	700 bar	

The reason behind preferring carbon composites for the new-age hydrogen pressure vessels is that these materials are known for their superior strength & durability along with light weight, offering a mass-reduction between **50%-70%.**

CCHTs find usage in a variety of applications, including **cars, buses, trucks, forklifts, trains, ships, refuelling stations, bulk gas transportation, and back-up power.** However, FCEV is the one application which generates **over 90% of the demand for CCHTs.**

FCEVs Fuelling the Demand of CCHTs

When it comes to hydrogen storage in FCEVs – it has been found that, to achieve long-range autonomy (over 500 kms), **FCEVs must store 5-10 kgs** of hydrogen safely, without adding much weight, in a compressed vessel at **700 bars.** Here, type IV vessels take the lead in both value and quantity compared to type III tanks.

Notably, FCEVs including Honda Clarity, Hyundai Nexo, and Toyota Mirai employ compressed H2 at 700 bar pressure, featuring 2 or 3 type IV cylinders.

Specifications of a few FCEVs on road

FCEV Model	Fuel Tank Pressure	Driving Range Rating (miles)	Fuel Tank Capacity (Kgs)
Honda Clarity 2021	70 MPa/700 bar	360	5.46
Toyota Mirai	70 MPa/700 bar	402	5.6
Mercedes-Benz GLC F-CELL	70 MPa/700 bar	478	4.4

In 2022, among the FCEV models, Hyundai Nexo recorded maximum sales of **more than 11,000 units.** The only major FCEV model behind Nexo was **Toyota Mirai** with an annual sale of more than **3,500 units in 2022.**

As of 2022, there were **>72,000 units of hydrogen fuel cell electric vehicles (FCEVs) globally.** The count has increased by **40%**, compared to 2021, according to the International Energy Agency's (**IEA**) new Global EV Outlook 2023 report.

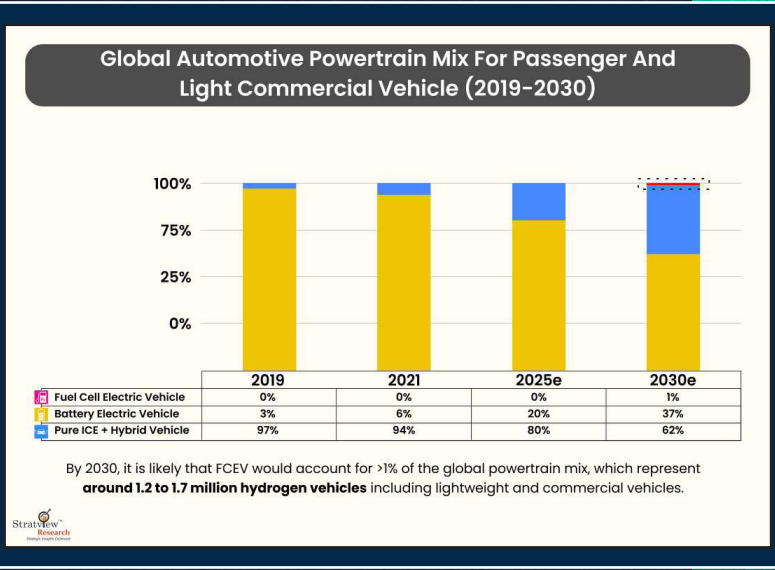

Figure 1: Global Automotive Powertrain Mix for Passenger and Light Commercial Vehicles (2019-2030)

It is expected that **by 2030,** FCEVs will account for **>1%** of the global powertrain mix, which would represent around **1.2 to 1.7 million** hydrogen vehicles including lightweight and commercial vehicles, each one of which will be equipped with CCHTs for hydrogen storage.

Challenging Charging Infrastructure

Hydrogen cars are here but is the world ready to serve its fuelling needs?

The fleet size of hydrogen-propelled vehicles has been growing since its inception. One of the most significant challenges the FCEV industry faces is energy transportation from the source to the hydrogen stations. While there is already a power grid for EVs, as yet there are no hydrogen distribution networks that could support a large number of FCEVs.

There were just **1,020 hydrogen refuelling stations (HRS)** globally to power 72,100 FCEVs, whereas **2.7 million public EV charging points** were operational worldwide to serve **20 million EVs** by the year **2022.**

Korea owned more than a half of all FCEVs, followed by the US, China, Japan, Germany, and others. However, **HRS** in **China** outnumbered that of **Korea** since **China** owned most of the heavy-duty fuel cell vehicle segments (**trucks and buses**), followed by Korea, then Japan, Germany, and the US.

This is one of the key reasons that there are more EVs getting sold than FCEVs in Europe despite the benefits FCEVs offer such as faster fuelling and longer range.

Future of CCHTs with FCEVs

It has already been mentioned that **>90% of the CCHT demand originates from FCEVs** or the Transportation Industry. In the coming 5-10 years, FCEVs themselves will see an escalation in demand from all the directions because what FCEVs are capable of delivering, is in perfect alignment with the vision of reduced emissions from the Automotive Industry.

The growing economies understand the difference which FCEVs can make in the coming years and hence a lot of them have already started directing their actions towards developing a supporting atmosphere for early implementation.

Most of the major economies have committed to strategies to boost hydrogen fuel plans and have also determined the budget they'll be spending to reach their infrastructural goals for a more hydrogen fuel centred ecosystem. **By 2040, South Korea aims to produce 6.2 million units of FCEVs,** whereas **by 2030 - Germany aims to manufacture 1.8 million** units, China and the USA - 1 million units, and **Japan to add 0.9 million FCEVs** to the global fleet.

Let us look at the targets set by different nations.

Planned Ban on Pure ICE Vehicles and Cumulative FCEV Production Goals by Countries

Year of ICEv Production Ban	Country	Cumulative FCEV Production Goals(Unit)
2025	Norway	-
2030	Germany	1.8 million
	UK	-
	Netherland	-
	India	-
	Japan	0.9 million
	China	1 million
	USA	1 million
2035	California	-
	France	-
2040	Spain	-
	Canada	-
	South Korea	6.2 million

Figure 2: Planned Ban on Pure ICE Vehicles and Cumulative FCEV production Goals by Different Nations

In parallel, industry is also working into introducing innovations in CCHT designs to address the challenges they pose. Currently, Type V Pressure Vessels also exist in the market but they aren't very popular and are not governed by any standard as of now. These are liner-less vessels made entirely out of composites and fitted with a metal boss.

Apart from the traditional cylindrical shape, the industry is exploring more volumetric efficient shapes for Pressure Vessels (PVs). And so, research has already begun on Toroidal Composite Overwrapped Pressure Vessels (Toroidal COPVs) as they could prove to be a viable alternative in terms of volumetric efficiency and ease of manufacturing.

Therefore, it is loud and clear that the automotive industry cannot rely on one single technology to attain zero emission targets and FCEVs have undoubtedly a significant role to play in achieving those.

Along with the rise in FCEVs, CCHTs have an impressive opportunity in store and are expected witness a skyrocketing growth of over 50% during the next decade and corresponding annual sales of over **USD 15 billion by 2030.**

Chandana Patnaik, *Senior Content Writer* **Stratview Research**

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The importance of the right weather-resistant adhesives and coatings

in the EV Charging infrastructure

Rebecca Wilmot

The world is changing rapidly, and with it, the number of people who are charging rapidly. Whether due to government incentives to do so, the feel-good factor of going green or the desire to keep up with the latest trends, more and more people are now turning to electric vehicles (EVs) for their next car purchase. This in turn has led to huge opportunities for manufacturers of EV charging points, with the worldwide market for these predicted to grow to a staggering 111.9 billion USD by 2028, up from 17.6 billion in 2021.

Yet despite these strong growth forecasts, the EV charging industry is plagued with reliability issues. Recent investigations have shown that in some areas of the UK, up to 30% of charging points aren't working at a given time. In order to prevent the EV industry from becoming a damp squib, these reliability issues need solving, and the sooner the better.

Technology: Friend or foe? Problems old and new

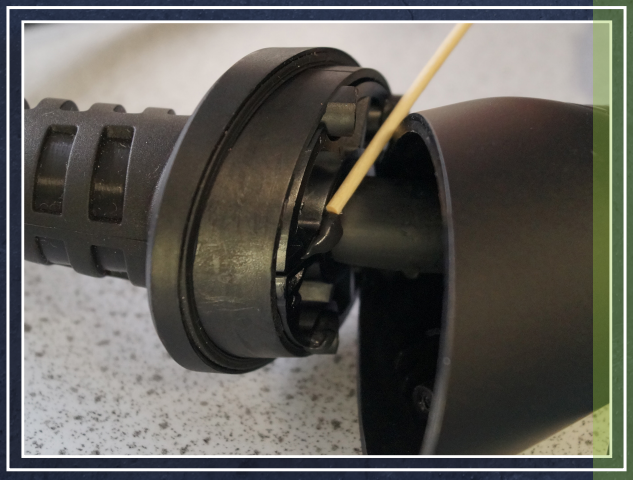
A major part of this reliability issue occurs because of the technology involved in public charging stations. With consumers' need for ever-faster charging, AC charging in public is simply not an attractive proposition. These chargers, also known as level 1 & 2 chargers, are largely confined to people's homes, with DC, or superfast/level 3 chargers, the norm in public. The problem with reliability occurs because these DC charging units require filters, cooling systems, and other complex hardware that needs routine maintenance, which simply isn't an issue with AC chargers.

A much older adversary, namely the weather, is also a major concern for public charging points. Many of these are unshielded from the elements and thus exposed to wind, water and fluctuations in temperature on a regular basis. Build quality needs to be excellent to ensure maximum protection for the vulnerable inner workings behind the charger housing, with regular servicing a must to make sure everything is kept in full working order.

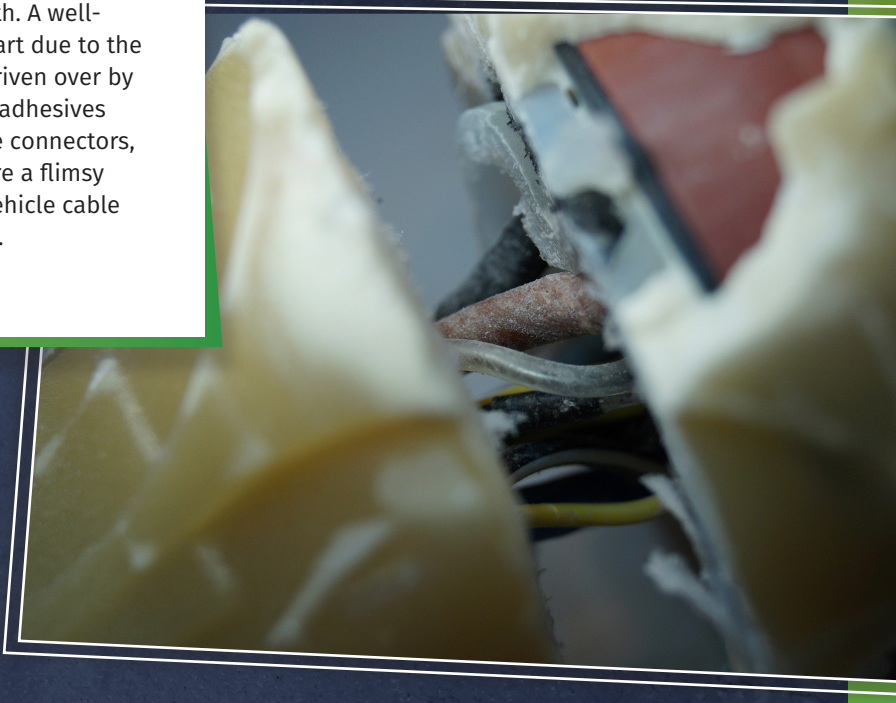
With this in mind, the use of weather-resistant adhesives which prevent moisture ingress into the charging unit or cable housing is a must. Adhesives have to undergo stringent accelerated ageing tests to simulate a lifetime of use and abuse. This includes testing their ability to withstand exposure to moisture combined with a high temperature, which is a double whammy for any adhesive joint. Tests are normally carried out in humidity chambers or ovens – "cataplasmic" testing is a very useful way to age bonded joints or assemblies when a humidity chamber is unavailable.

EV charging unit adhesive applications

Adhesives serve many roles in the manufacture of EV charging points. Firstly, they ensure a stronger, more reliable end product that can better withstand both internal and external stressors. Secondly, as a result of this, they help to keep repair and servicing costs down. The right adhesive ensures that servicing, when required, can be carried out easily, all the while offering top-notch protection to the charging unit when it isn't. Most importantly, using the correct adhesive will help to ensure the safety of the charging unit and cable.

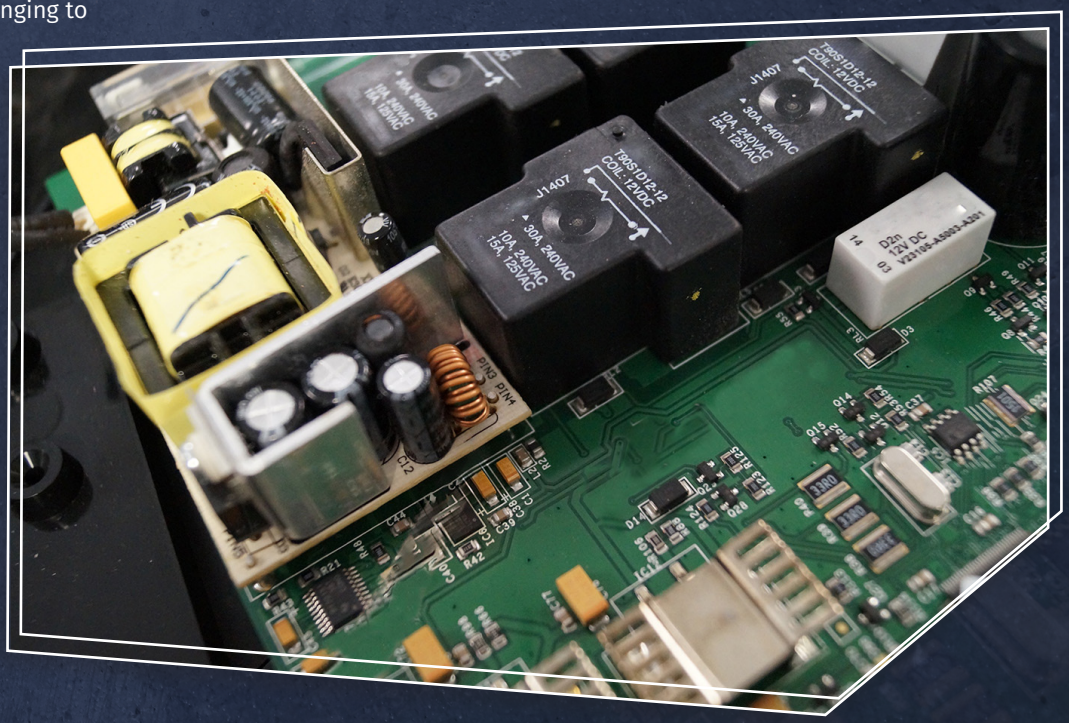


One adhesive application is the potting and encapsulation of EV charger connector cables. These connectors, especially at public charging stations, are plugged in, and pulled out, of charging ports multiple times a day. A good potting adhesive both strengthens the charger and keeps its inner wiring fixed in place, all the while protecting other key components and providing resistance against fire, impact and moisture. Permabond offers a range of cable potting compounds that combine features such as flexibility, fire retardancy and resistance to electrical arcing, i.e. high dielectric strength. A well-made charger becomes so rugged, in great part due to the potting adhesive(s) within, that it could be driven over by a car and still remain intact! Not only do the adhesives improve the long-term durability of the cable connectors, they add a "quality feel" to the unit – compare a flimsy generic charging cable with a luxury brand vehicle cable and you will feel the difference straight away.



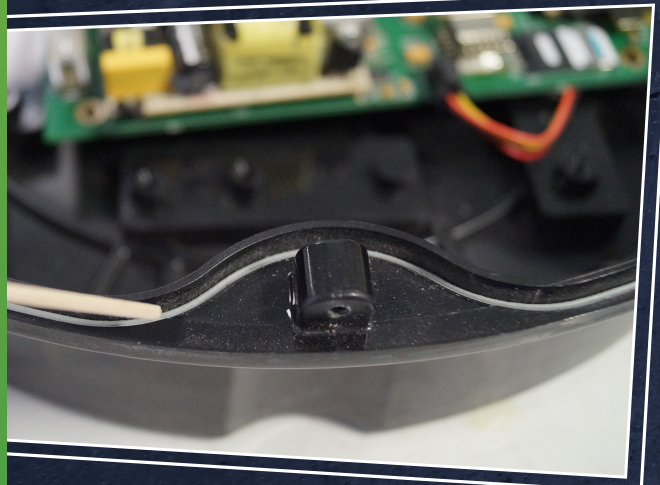
Then there's gasketing of the charging point housing. Gasketing adhesives need to be able to provide a tight seal in order to keep any dust, moisture and other undesirable substances away from the inner core of the unit. However, they also need to allow easy access for serviceability. Depending on the material the housing is made of, a range of adhesives are available to suit these application requirements. Despite plastic blends combining polypropylene or other low-energy materials being challenging to bond, Permabond offers a range of adhesives which will bond these materials.

Even PTFE (Teflon) can be bonded without the need to surface treat or acid etch. Silicone seals/cords can be bonded with Permabond POP primer and 2050 toughened/flexible cyanoacrylate adhesive. Compressible seals can be formed, cured and then sealed at leisure with flexible UV gasket making adhesives. Permabond also offers a Nylon-bonding adhesive for the high strength bonding of Nylon 6 and Nylon 6,6 and its filled variants.



Conformal coatings of the PCBs in both AC and DC charging units is another area of key significance for adhesives. With charging points often located outside, these delicate electronics need to be protected from adverse weather as well as other harmful objects such as corrosive road salt. While the gasketing adhesive used should keep most of this out, any extra protection offered is always welcome. Using a UV-curing adhesive for these coating applications, such as Permabond UV681, is often advised, as they offer a very fast cure speed, are clear in colour and offer protection against both environmental as well as vibrational damage.

Lastly, but by no means least, there are a variety of threadlocking applications in EV charging units. Some threadlockers need to offer high strength with high heat resistance, whereas others offer a medium level of strength to allow for easier servicing. Anaerobic threadlockers as well as cyanoacrylates provide the EV charging unit with much greater durability as opposed to mechanical fasteners, keeping nuts and bolts firmly in place and offering resistance to vibration and adverse weather. Permabond offers a wide range of different threadlockers suitable for use in these applications.



Charging the future: AC/DC style

Our world is very much 'need for speed.' In order to ensure that the EV industry reaches its full potential, a widespread rollout of reliable DC fast chargers is urgently needed. The current lack thereof is a major consideration and obstacle for a huge potential EV target market, that of business fleet operators considering making the switch to electric. Adhesives play a key role in powering this green charge, as they result in better-built, longer-lasting, and more reliable DC charging stations.

The need to charge batteries as quickly as possible is putting pressure on charger and battery manufacturers to develop units capable of dissipating heat and self-extinguishing in the event of a fire. Permabond continues to develop and expand its range of thermally conductive/UL V-0 adhesives, exploring lightweighting and recyclability whilst pushing the boundaries of technology in order to offer the next generation of higher performance DC chargers and EV batteries.

Let us not, however, forget about the lowly AC charging unit. With these most often found in people's homes and thus perfect for overnight charging, they are (and are becoming even more so) a key component in the drive towards the electrification of our road networks. What's more, they are far cheaper to manufacture than their DC counterparts, and if every home had one, it would greatly lessen the burden on public charging networks. It's partly for this reason that governments are beginning to include them in newly built homes as standard.

Whatever the future holds, adhesives will continue to have a big role in taking us towards a greener, more sustainable world - and we for one can't wait to play our part.

Rebecca Wilmot, *Marketing & Product Manager* **Permabond**

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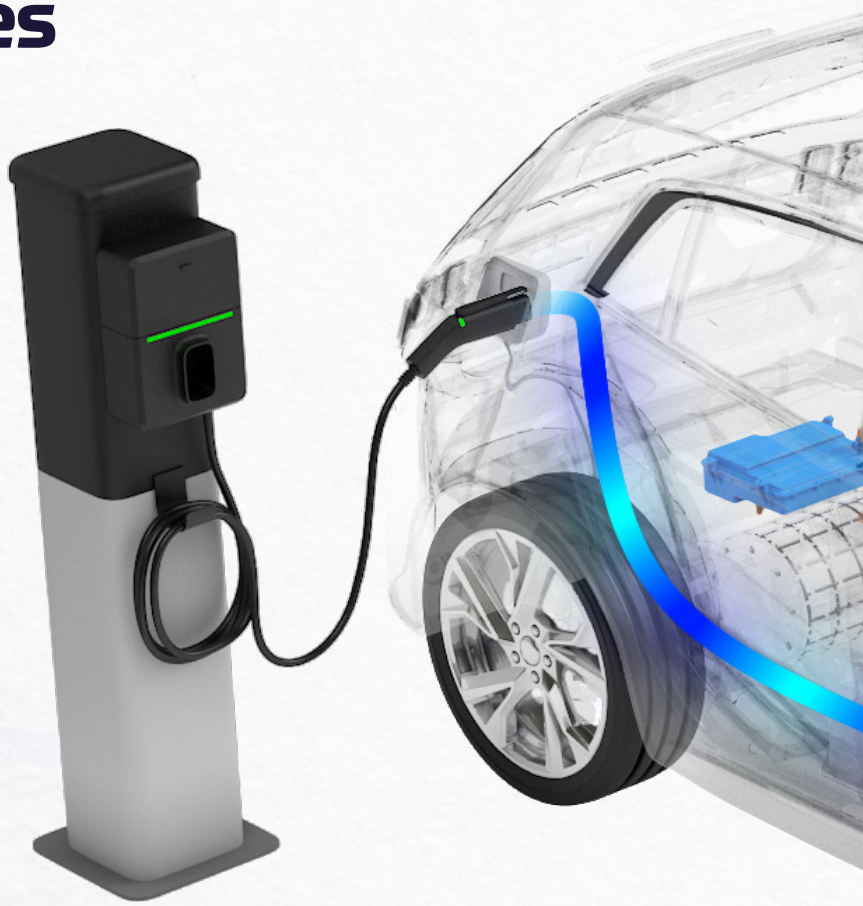
Electric vehicle trends

Advances in circuit protection of electric vehicles

Mark VanWingerden and Kevin Calzada

The vehicle electrification era is here, bringing with it a wave of innovative technologies and exponential advancements.

However, there are important safety implications to be considered as these technologies and market trends are adopted. What are these trends and how do they impact circuit protection of electric vehicles?



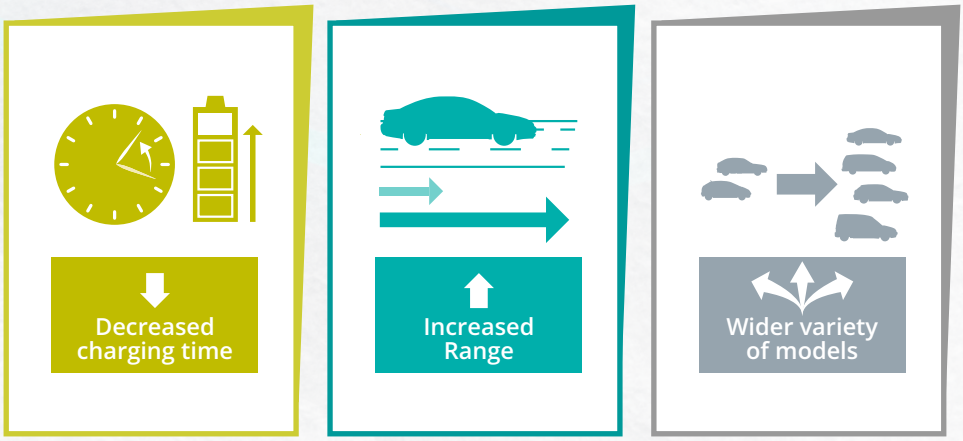


Figure 1: EV market requirements for mass adoption.

Demands on electrical architecture increase

The market today sees demand and development towards decrease charging times, increased range requirements, and a wider variety of vehicle models. All of which are impacting the electrical system performance and design. Decreasing charging times result in a demand for higher voltage charging and systems. Due to the higher overall power levels that can be achieved as the system voltages are increased, platform and charging voltage fall into two segments around 400VDC and 800VDC. Today's electric vehicle can be mainly found at the 400VDC with some exception and plans to develop 800VDC system voltage platforms.

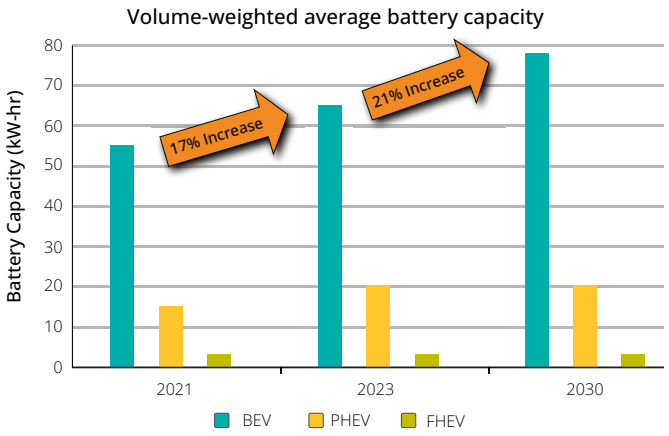
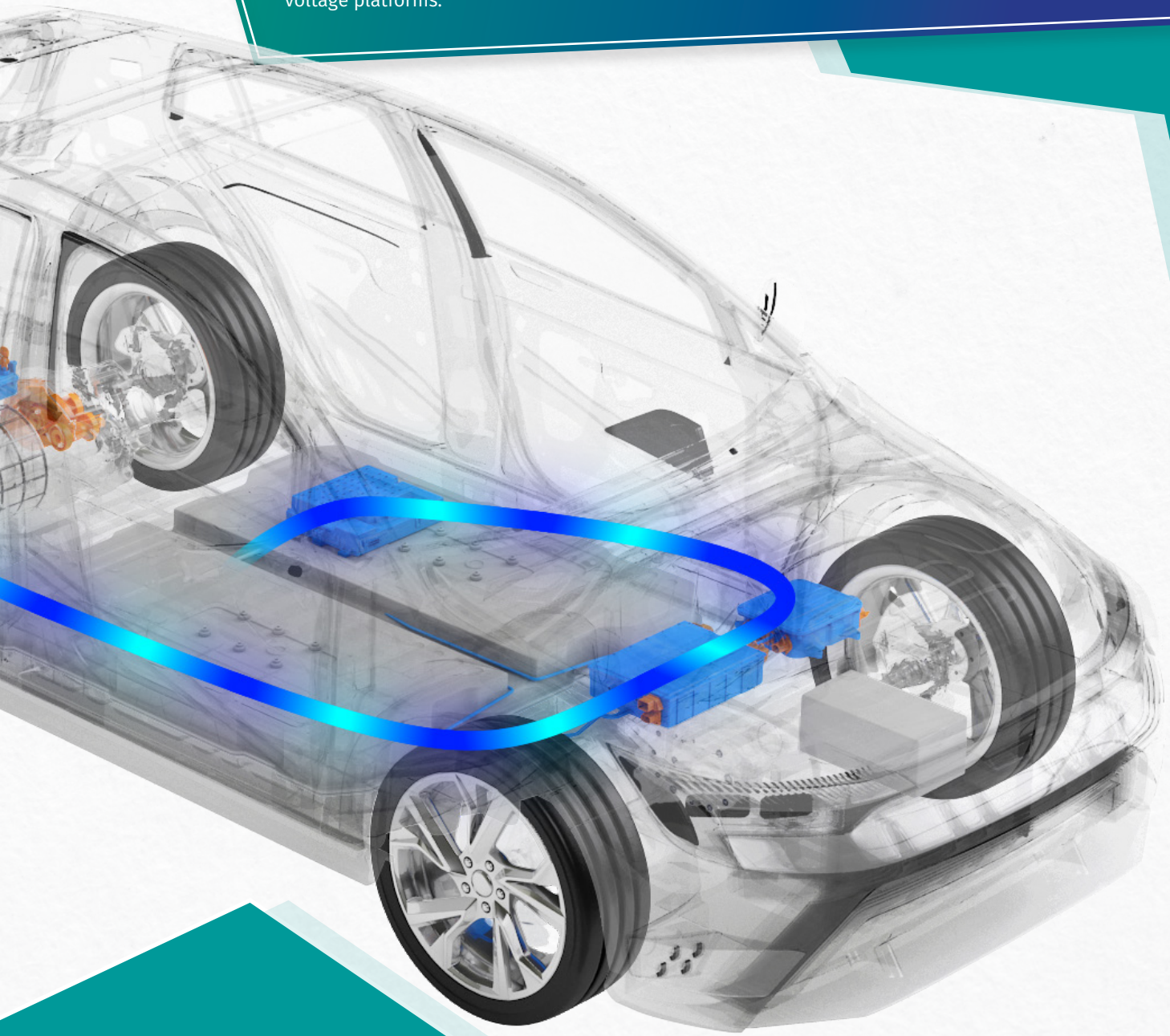


Figure 2: xEV fault current directly related to battery capacity [Piyush and IHS 2023]



Increased range requirements influence the size of batteries and the total power provided by the battery. As a result, battery development will see increased battery capacities [IHS], which results in the directly related available fault current that can be delivered to a vehicle electrical system in the event of a short circuit on the battery. The manufacturers must consider the increased fault current in the protection component requirements. On top of that, the motor power and current is ramping up [IHS]. By that, circuit switching and protection devices will face higher requirements. They must withstand the higher operating currents and cyclic requirements.

Market requirements for larger batteries are pointing towards an increased system voltage level for future platforms in order to meet customer charging time expectations. Planning data is indicating a steady deployment of 400VDC system voltage throughout future years [IHS], but an increasing share of passenger car vehicles will be 800VDC to take advantage of increased efficiency and shorter charging times.

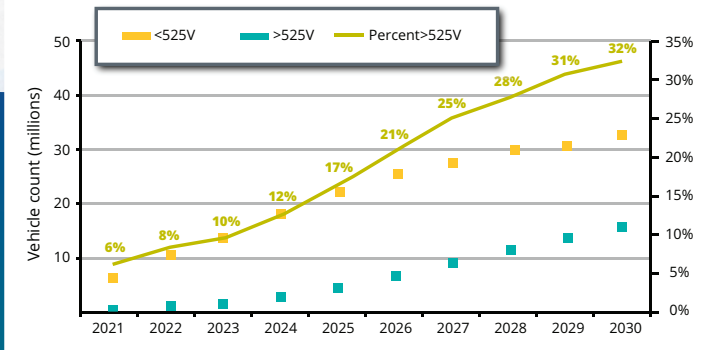


Figure 3: Share of 800V increasing [IHS LV Powertrain Data, April 2023].

Summing up, all three trends are challenging developments for circuit protection and need careful consideration. The decreased charging time requirement promotes higher system voltages. Increased range results in higher fault currents. And the variety of models planned indicates a higher operating current requirement.

Critical protection considerations

Conventional system architecture design for main protection involves a coordinated fuse and contactor solution within the power distribution box. The two components must be coordinated to ensure coverage of the full range of possible fault scenarios, which can derive from different battery states of charge and route causes.

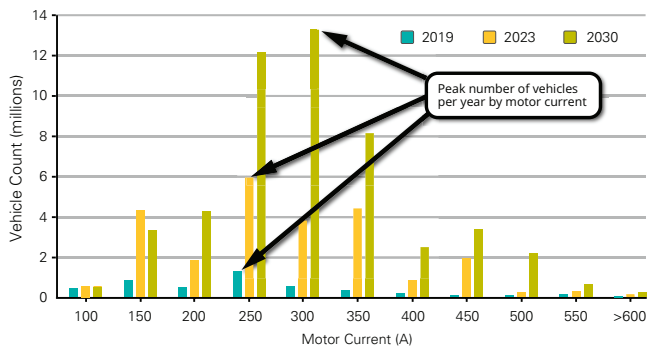


Figure 4: xEV protection devices need to withstand higher operating currents [IHS, 2019]

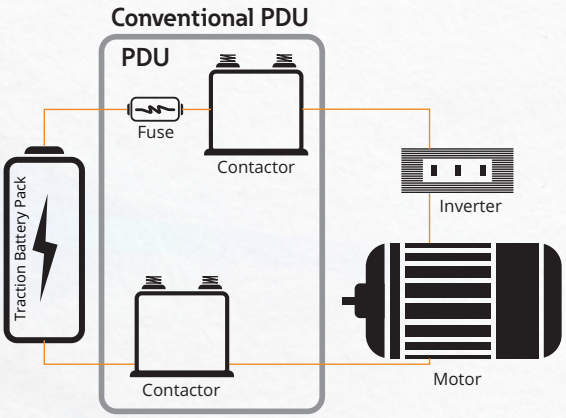


Figure 5: Conventional xEV circuit protection

The conventional circuit protection solution of fuses and contactors has contradicting design requirements. Current levels in a vehicle can vary widely from <100A during regular driving conditions to as high as 20kA or more during a short circuit event. It is critical that the contactor performs the switching function during normal operation modes while the fuse is able to interrupt quickly during unsafe modes of operation like overloads and short circuits. Fuse and contactor coordination requires a seamless handoff between these two independent devices at a certain current level and this is not always possible to achieve.

Poor coordination can lead to reduced fuse reaction time, melted contacts, nuisance tripping, and fuse fatigue. Late tripping can cause the contactor to weld and creates a safety issue for the system components. Nuisance tripping is a safety issue as well and can result in loss of vehicle propulsion which can be both a safety issue and result in customer dissatisfaction.

As a goal, the coordination must address these issues and ensure consistent, fast reaction time to protect against overload and short-circuit, and consistent switching of rated current. By the physical nature of a fuse design, the coordination is a trade-off between fuse durability and fuse speed. Selecting a smaller rating equates a faster reaction time, while the system current will cause higher fatigue and reduces lifetime of the fuse. Therefore, just choosing a smaller rating for the fuse cannot be the appropriate measure.

On the contrary, fuse selection for coordination scenarios requires enhanced expertise in the coordination challenge of the application, as well as fuse design and fatigue simulation capabilities. If the above points can be met, a conventional architecture with fuse and contactor is competitive solution for the system protection.

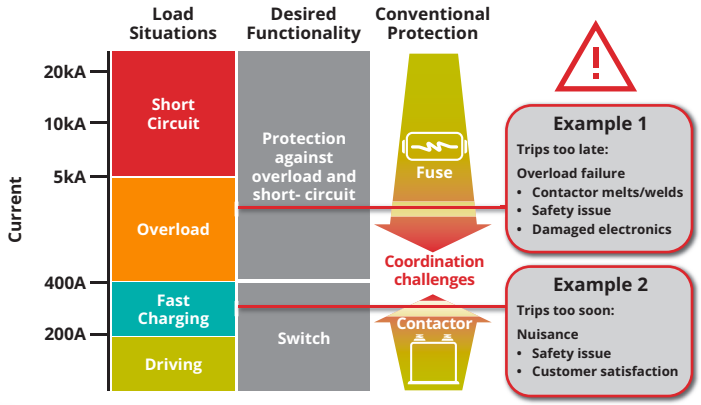


Figure 6: Conventional protection has contradicting design requirements

A potential solution to the durability consideration with fuses is the implementation of a pyrotechnical switch. A pyrotechnical switch is a triggerable circuit protection device that relies on a controlled explosion to severe a conducting busbar. Pyro solves the coordination challenge but introduces new functional safety challenges, as this system loses its passive reaction to fault situations and relies on accurate triggering. The additional components must ensure a reliable triggering including potential failure modes in the electronic which involves functional safety considerations.

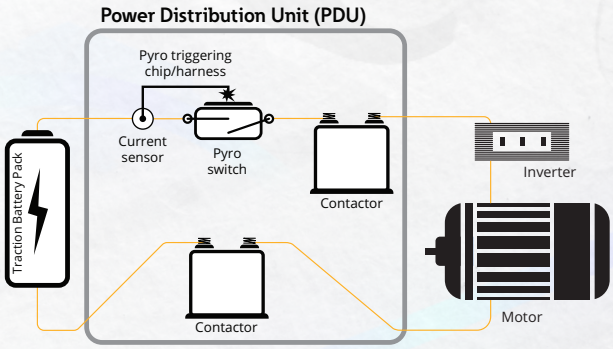


Figure 7: Pyro switches present functional safety challenges.

Critical protection considerations

The analysis of conventional circuit protection considerations concludes that there is clearly a need for a new protection solution. The development trends in the voltage and power levels underline the increasing complexity to protect against the electrical fault scenarios.

The solution needs to:

- offer a fully coordinated circuit protection and switching solution;
- actively interrupt but also passively trigger in case of power loss;
- improve functional safety of critical protection systems; and
- deliver improved component serviceability and/or ability to reset.

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- improve functional safety of critical protection systems; and
- deliver improved component serviceability and/or ability to reset.

Eaton developed a solution considering the criteria above. Breaktor circuit protection combines two key components into one: the circuit breaker and the relay, and thereby is capable of handling the full protection range from overloads to short-circuits as well as the switching functionality in normal operation.

Key features include:

- the contacting area with splitter plates in the upper part of the device;
- the driver coil in the lower part of the device; and
- the onboard electronic including current sensing

Figure 8: Breaktor circuit protection key features

In normal switching operation, the driver coil closes the contacts powered by a 12V supply to switch the device on and falls back into off-mode when the supply voltage drops off.

Breaktor constantly monitors the current levels with the onboard current sensor and shuts-off the power to the driver coil once an overload condition is detected. The trigger overcurrent level is adjustable.

For short-circuit situations, Breaktor detects the condition in less than 1ms and disconnects the driver coil. This high-speed deactivation helps to prevent contact welding. Furthermore, Breaktor utilizes the effect of electrodynamically contact levitation positively to limit the current through to the system. This effect is threatening in the case of contactor and fuse combinations, since the levitation of conventional contactors can disrupt the fuse reaction to the fault. In any fault case, after the respective safety checks, Breaktor can be re-activated.

Breaktor advanced circuit protection

Breaktor advanced circuit protection is the perfect combination by covering the full protection range for overloads and short-circuit conditions, it can actively interrupt a system short for quick response time, and also passively interrupt in the event of system power losses. Breaktor improves the functional safety of the electric vehicle protection system and includes the ability to reset by way of controls for service convenience.

How do you apply this device in an electric vehicle system?

Breaktor not only replaces protection and switching components, but also eliminates high voltage busbars and auxiliary voltage harnesses in the system due to the reduced number of overall components and connections within the system protection architecture. The integration of Breaktor therefore poses advantages form a system perspective with regards to optimized cost, power density, and safety assurance. Summing up, fuses can still be considered viable solutions for electric vehicle protection. Eaton's fuse design and application expertise will help to identify applications here a fuse and contactor system can be fully coordinated or whether an advanced protection system like Breaktor should be considered. Alternative pyro technology solves the coordination issue but introduces new challenges to the application and system design with regards to its need for active triggering.

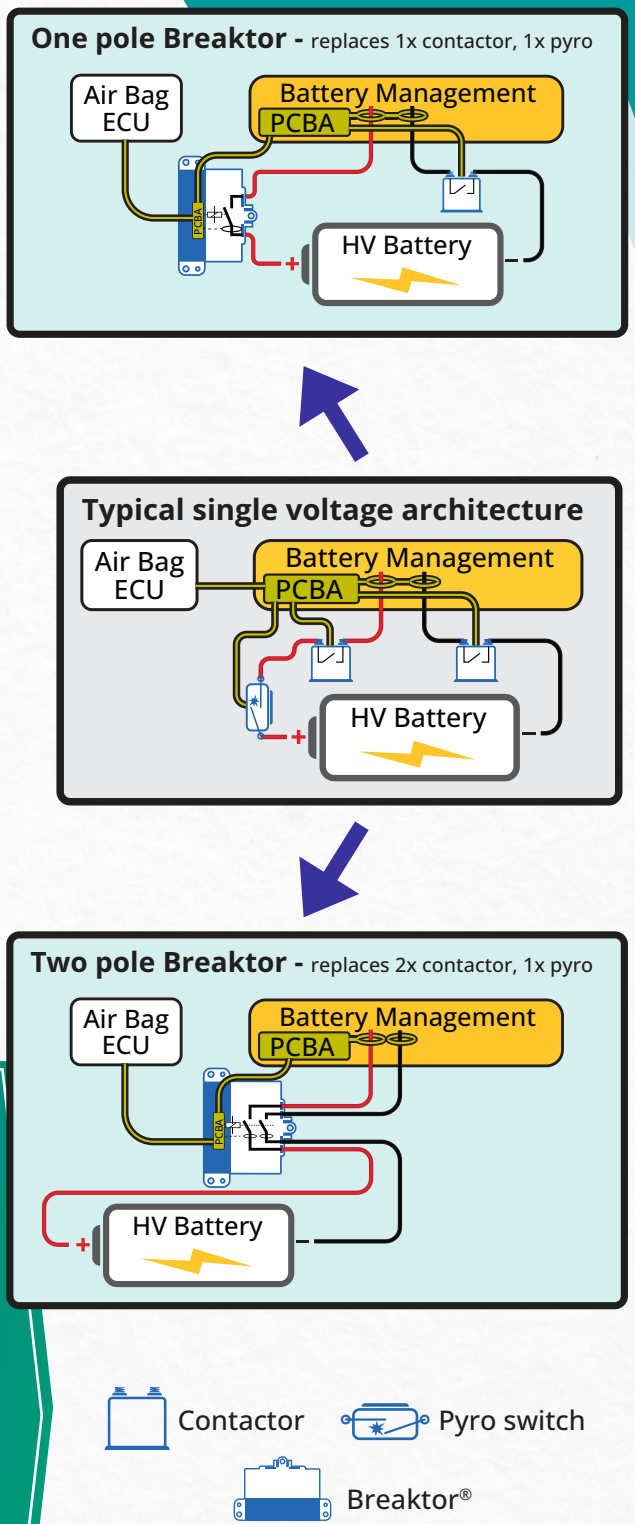
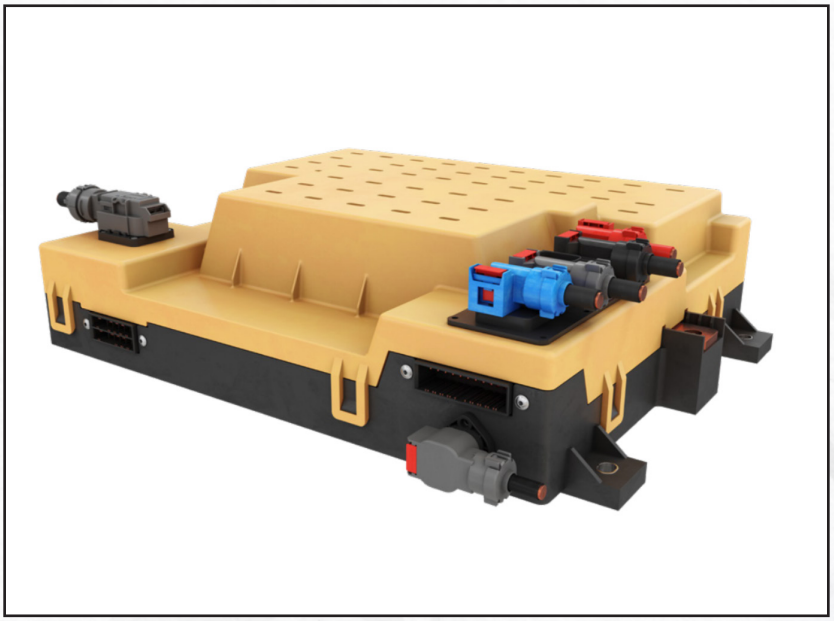


Figure 9: Breaktor integration functional architecture

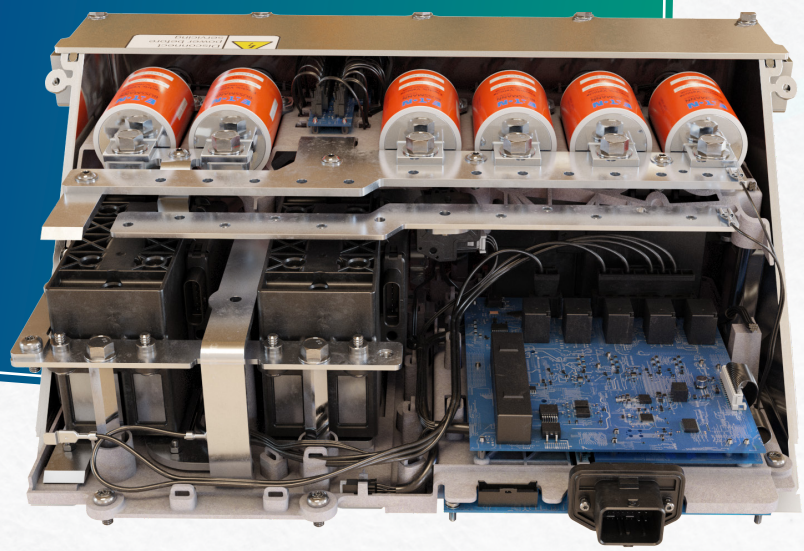
Solutions featuring Breaktor circuit protection

The battery disconnect unit (BDU) is designed to efficiently distribute power throughout the EV system. With the integration of Breaktor, the BDU provides improved quality and simplified architecture by combining current switching and resettable bidirectional short-circuit protection with fast actuation (up to 900V). Enabling reduction of up to 15 components from the PDU assembly, Breaktor's integrated coil driver, economizer, and sensing/triggering circuit reduce overall cost and complexity. Additionally, it's self-triggering design, diagnostic electronics, and mirror contact help to ensure utmost safety and reliability.



Battery Disconnect Unit

The next generation high-voltage intelligent FLEX power distribution unit (FLEX PDU) monitors and manages all power distributed to power electronics and provides central protection for the electrical system for commercial vehicles. Fully customizable to meet a commercial vehicle's specific requirements, the FLEX PDU can be integrated with Breaktor. This allows for integrated over-current protection for high power loads including traction inverters and DC fast charge.



FLEX Power Distribution Init

Mark VanWingerden & Kevin Calzada,
Product Strategy Managers **Eaton**

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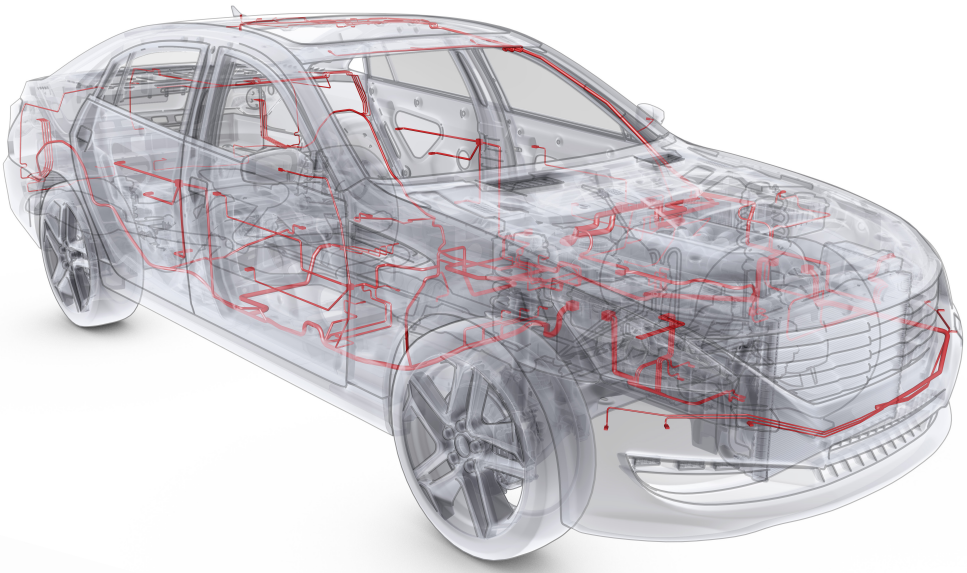

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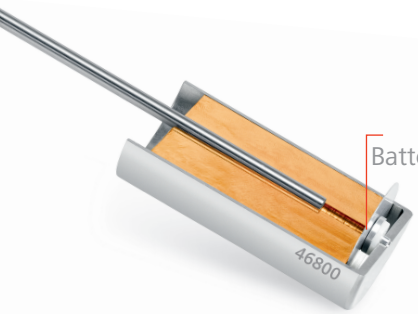

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