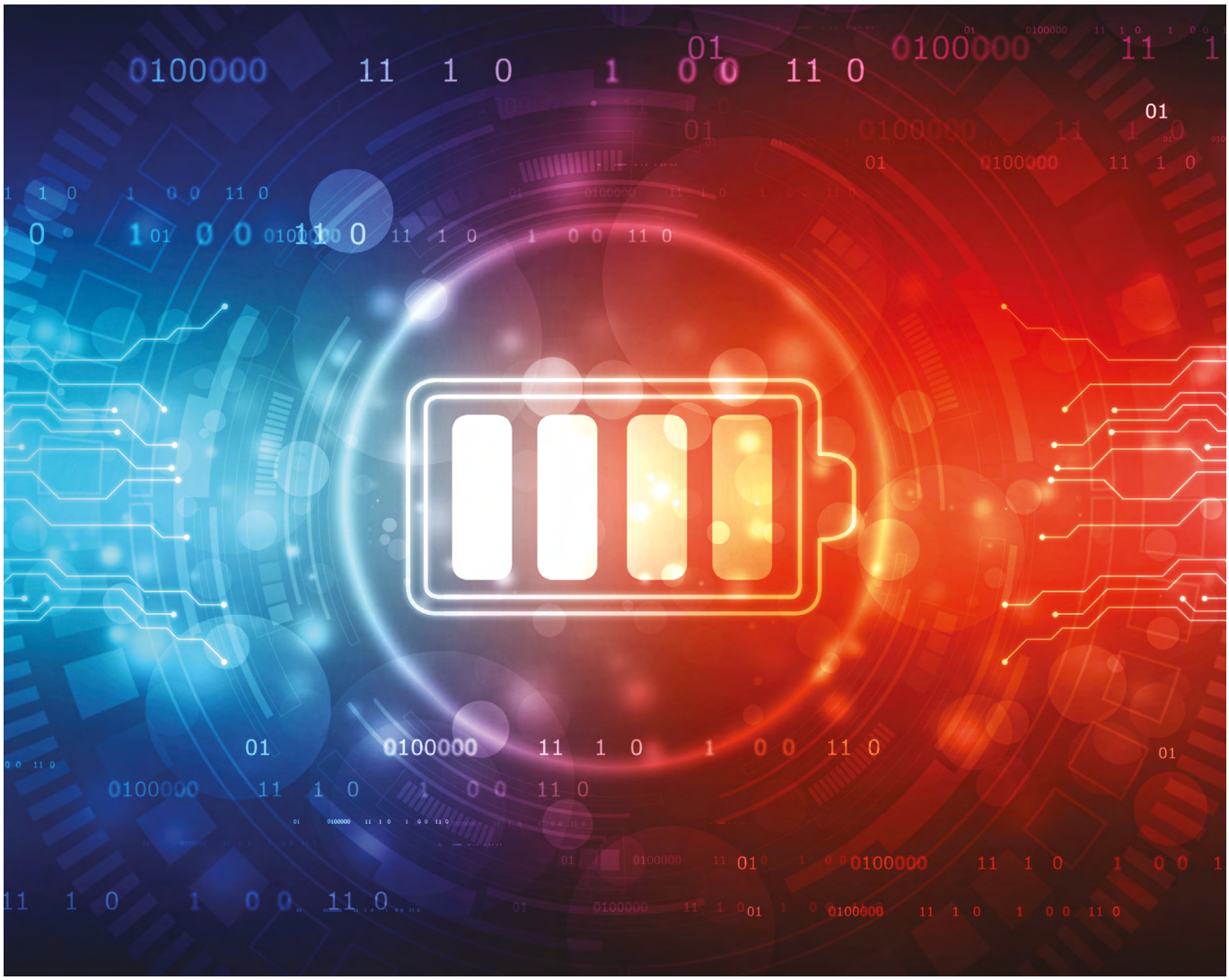
BATTERY CONNECTIVITY, MANAGEMENT AND PROTECTION

The Role Connectivity Plays in Making High-Voltage EV Battery Packs Safer, More Efficient, and Longer-Lasting



Electric vehicles have gone mainstream. Automotive industry pundits agree that it's no longer a matter of *if* we'll see more EVs on the road than traditional fuel-powered cars – but *when* – which represents a fundamental change in the way the automotive industry does business. By 2035, it is expected that most forms of newly produced transportation will leverage electric or alternative-fuel drivetrains.

The reasons for this shift are clear. There are societal needs based on reducing carbon emissions and our dependence on fossil fuels in favor of more efficient drivetrains powered by more sustainable energy sources. World governments are incentivizing EV adoption with tax breaks and other financial perks. From a driver's perspective, ownership and maintenance costs are lower than they were only a couple of years ago, the convenience and availability of public charging stations is steadily growing, and there are design and style choices to suit almost every personal preference. But perhaps most unexpectedly, the driving experience is vastly improved when compared with traditional internal combustion engine (ICE) cars. EVs, with their lower centers of gravity and instant torque, have much better acceleration performance and handling. They are a sheer joy to drive.

But considerable challenges still exist. The amount of time it takes to replenish the electricity stored in an EV's battery pack and the capabilities of its inbound and outbound connections are chief among them.

AN INDUSTRY IN CONSTANT TRANSITION

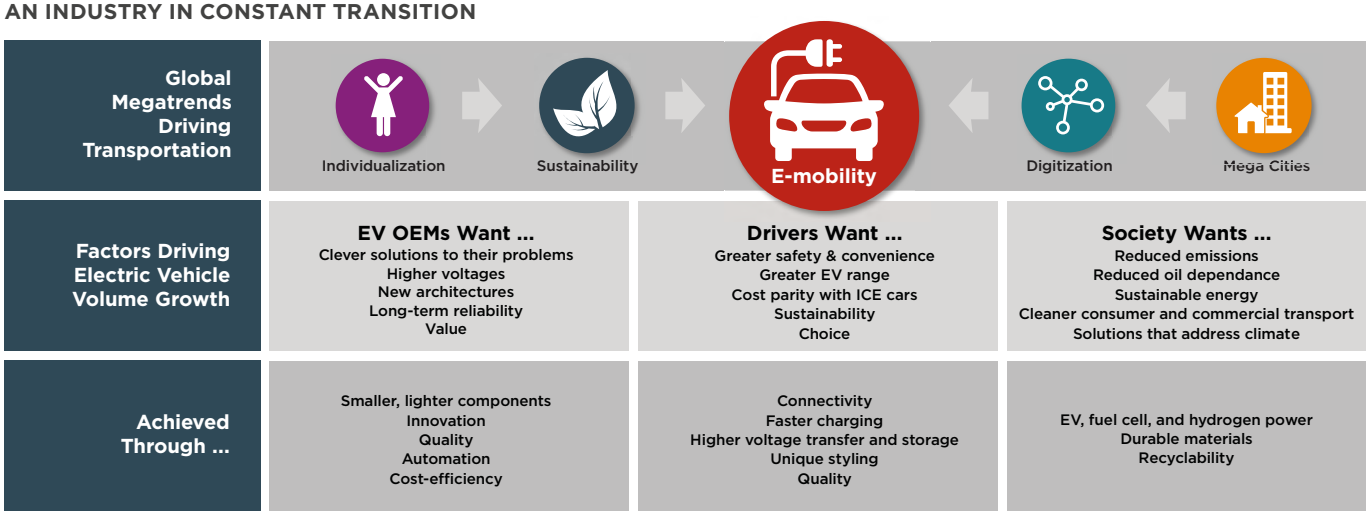


Figure 1: Factors driving EV growth

Importance of the Battery in an EV

Much in the same way that the engine was considered the heart of a traditional ICE car, with today's EVs, the battery is equally vital. The battery ecosystem for EVs is growing quickly, with high levels of investment and innovation from both automotive OEMs as well as dedicated battery cell and battery pack manufacturers. It is estimated that up to 40 percent of a new EV's total bill of materials can be attributed to the contents of its battery pack.

Battery technologies and architectures are evolving as quickly as the market. Certain cell chemistries are designed to facilitate faster charging, increased safety, or achieve higher performance or temperature thresholds. As individual battery cells increase in physical size, requirements for transferring energy into and out of them will likely change.

The electrical demands on a battery pack and its connections are enormous. During a high-powered, direct current (DC) charge cycle, it is expected that the main battery connections need to be able to carry sustained currents of up to 600 amps for several minutes, and at significantly higher peak levels during hard acceleration. Additionally, the battery needs to operate reliably for more than 180,000 miles – or about 10 years – at temperatures between -40°C and +75°C, with connections needing to operate at or above +150°C for higher load conditions.

When it comes to most mechanical devices, the moving parts are usually considered the most likely failure points. EVs have significantly fewer moving parts, but the robustness of their electrical connectors can be the difference between success and failure. Quality is paramount.

Battery cell and module interconnectivity, thermal management, protection, sensing technologies, and the battery's electronics and management system must be considered. This paper takes an in-depth look at each.

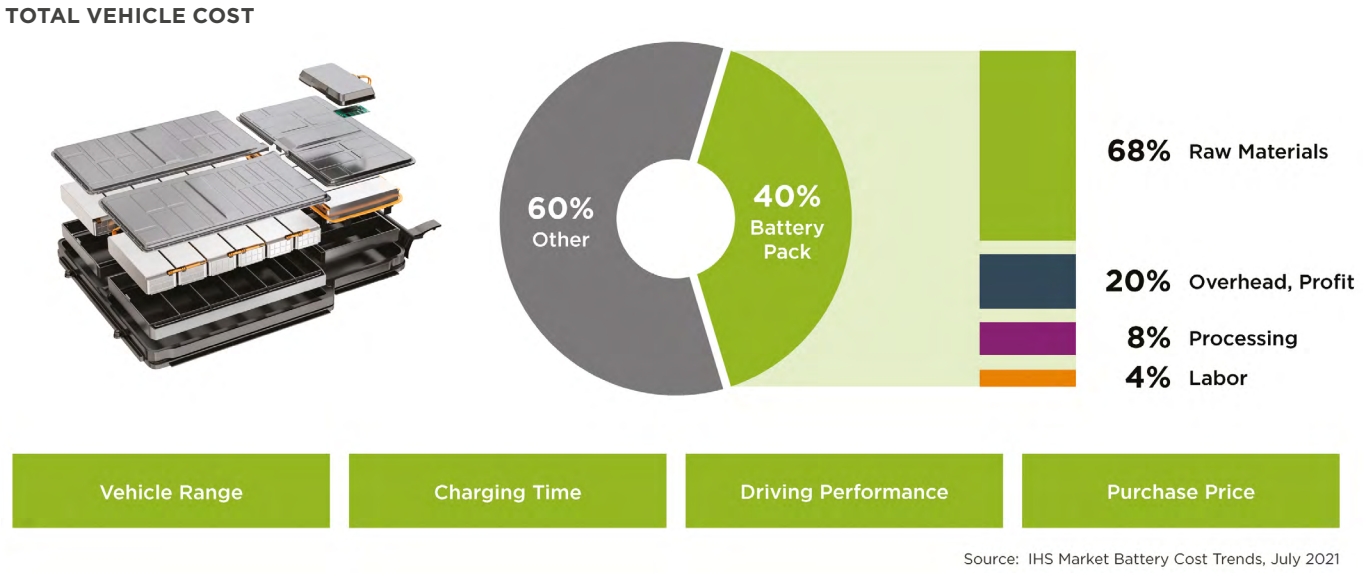


Figure 2: The importance of the battery as a key component of EVs

Battery Cell and Module Interconnectivity

Designing connectors for batteries requires a balance between mechanical, electrical, and thermal properties. The main challenge in the daily operation and charging of EV batteries is for OEMs and battery pack manufacturers to find a low-profile connector with low contact resistance at the individual contact points, resulting in reduced power loss and less heat.

Cell and module interconnections are the physical layer that provides sensing power management critical for robust state-of-health and state-of-charge for the battery system, and for transferring power and signals to ensure reliable operation. To safeguard these operations, each battery module must feature durable, highly integrated, failproof electrical connections that can last longer than the lifespan of the vehicle itself. EV battery interconnections need to be constructed so that they can counteract vibration and temperature stresses that can have an adverse impact on the mechanical and electric properties of the connection systems.

TE Connectivity (TE) draws from its extensive expertise in copper and aluminum contact physics with its BCON+ module-to-module interconnection system. It is designed to handle constant currents of up to 600 amps. BCON+ connectors meet the power demands of modern EV battery systems with market-leading packaging volume, with less than 10 micro-ohms of contact resistance on each side, in a form factor that provides a mechanical bolt termination separate from the electrical path. They can be easily scaled for a wide variety of power levels and voltages.

High-voltage connection systems with bolted termination can provide fully touch-safe IPxxB protection that follows ISO 20653. These types of connections safely and easily connect and disconnect for assembly during manufacturing. Touch-safe connectors are important because module-to-module interconnections need to withstand up to 25 mating cycles over the course of an EV's life. They allow technicians to perform regular inspections without the need for expensive, special tools or complicated safety procedures.

In addition to its module connection solutions, TE offers ultra-low-profile cell-to-cell interconnection boards that support multiple cell configurations, chemistries, densities, and geometries. These lightweight aluminum boards provide

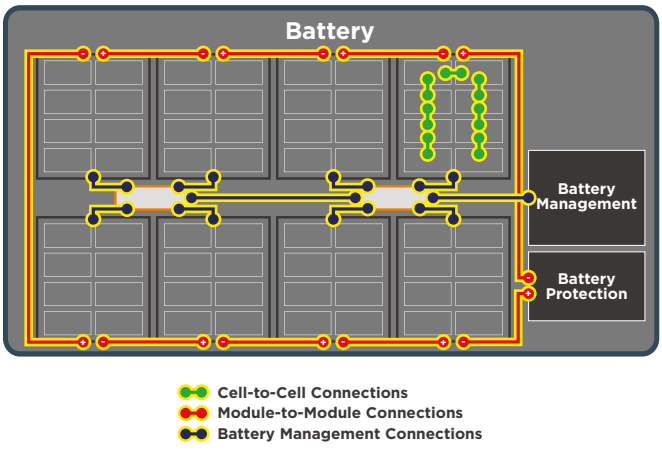


Figure 3: Battery integration and connectivity

stable interconnection and enhanced balancing features that can extend the overall lifetime of the cells.

Battery Protection

To safely operate EVs at higher voltages, contactors can be employed to provide the essential galvanic isolation needed to safely disconnect the EV's battery from the rest of the vehicle's systems in the event of an electrical fault. If these faults go unchecked, they can damage the battery and other expensive components.

Contactors are electromechanical switching devices that complete or break an electrical power circuit. They use a coil to generate a magnetic force that mechanically closes or opens an electrical contact. Many contactors are filled with a pressurized, inert gas – typically nitrogen, hydrogen, or sulfur-hexaflouride. These gases aid in protecting the contacts and help extinguish arcs. Pressurized contactors are hermetically sealed and designed to resist leakage.

Non-pressurized atmospheric contactors, on the other hand, provide the safe switching function without the need for the inert gas or the hermetic seal, eliminating the risk of gas leakage. Unpressurized contactors offer improved manufacturability and a less complex bill of materials. They are durable, not sensitive to pressure changes, and function independent of pressure loss.

TE offers a full line of pressurized and non-pressurized contactors rated to support the full spectrum of EV electrical systems at higher voltage and current levels, including solutions for 800-volt architectures and beyond.

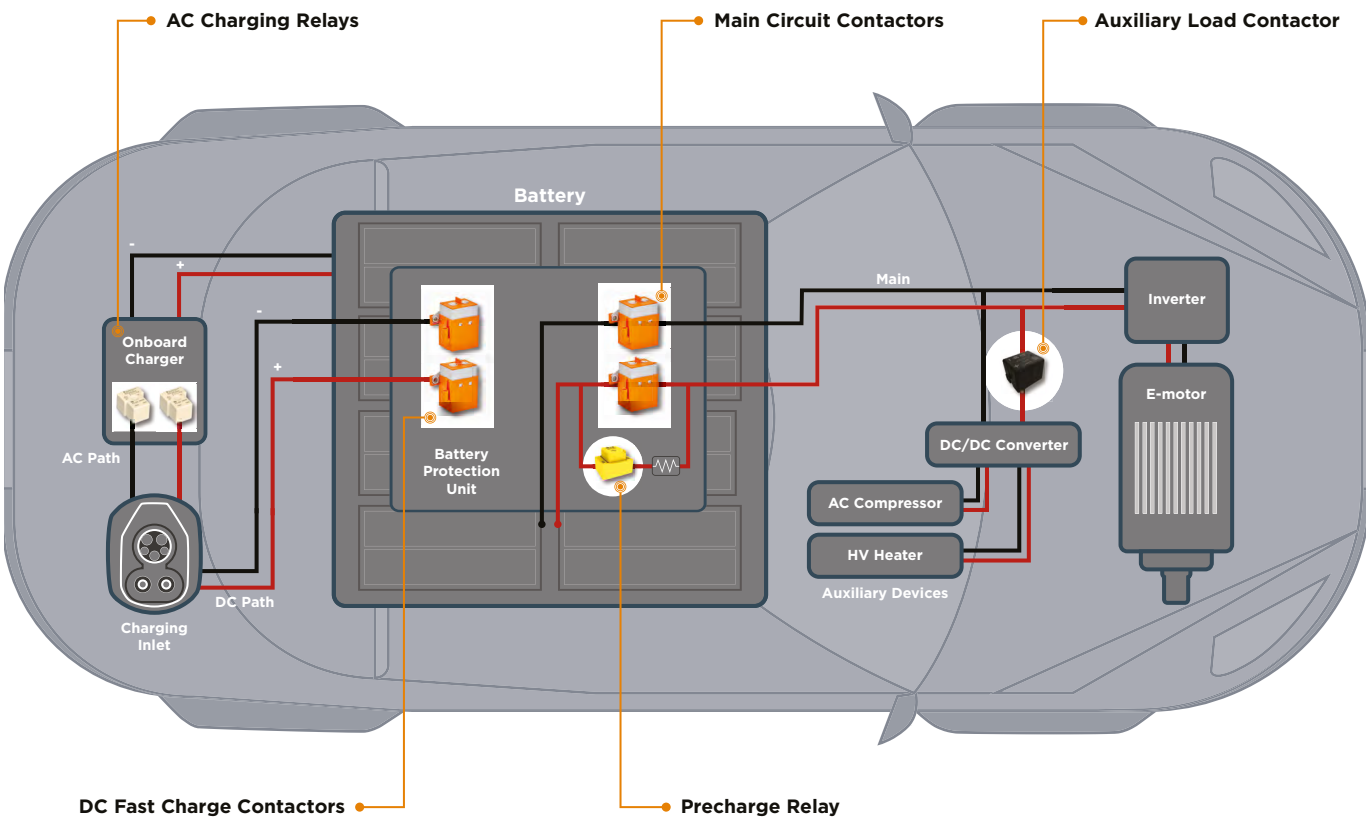


Figure 4: High-voltage contactors protect the battery and other vital systems from voltage surges and short circuits.

Battery Management Systems

The energy storage systems of EVs need to be continuously monitored to mitigate poor performance and prevent failures. A battery management system (BMS) is the electronic system that manages the battery pack's charging and discharging of the cells. It protects the battery from operating outside its safety limits by monitoring temperature and voltage signals from the cell modules as well as pack-level current signals and transmitting them to the elements that balance or control the module environment.

The BMS is critical for optimum battery performance and safety. It must operate with a high degree of accuracy and reliability. However, it also needs to be compact and light-weight, adding the least possible bulk to the battery pack.

Connectivity is necessary for transferring signals to the battery management controller (BMC), where they are processed. Those processed signals are then sent to the cell management controllers (CMC) to balance the cells and enable a controlled flow of power, for example, during charging.

Voltage monitoring	• Monitor the voltage across all the cells in the battery pack. • If not done properly, cell degradation and accelerated aging can occur.
Current monitoring	• Detect and react to the charging or discharging current. • Prevent overcurrent situations, perform ampere hour counting.
Temp. monitoring	• Monitor the cell temperatures in the battery pack. • Send a 'cooling/heating' request.
Pre-conditioning	• BMS warms or cools the battery to the optimum temperature enroute to charging. • Achieve the fastest charge rate without damaging the battery.
Contactor switching	• Monitoring the status and controlling the switching of HV contactors. • Failure may lead to electric shock or other safety hazards.
Isolation	• In a BMS, systems operate with grounds at different potentials. • Resulting currents can pose safety issues.
Communication	• Data transfer within BMS systems and to/from external system. • Interfaces should be flexible and universal for easy interfacing with microcontrollers.
SoX calculations	• Estimation of parameters like State of Charge, State of Health, State of Power, and State of Functions.
Cell balancing	• Homogenizing the series-connected cell voltages: • Unevenly aged cells in a battery pack reduces the useable capacity.

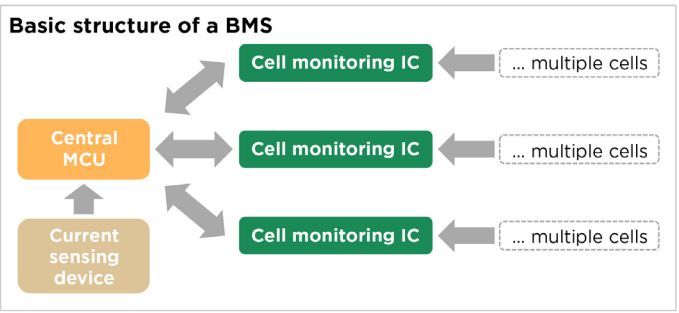


Figure 5: What a battery management system monitors

Sensing Technologies

Automotive sensors play a significant role in electric passenger and commercial vehicles because they enable improved e-motor performance, faster charging times, increased energy efficiency, and enhanced safety.

Accurate and reliable sensors can help measure the flow of power, temperature, humidity, and even barometric pressure inside and outside the battery pack, confirming the vehicle meets safety and efficiency requirements. TE offers an extensive suite of passive and active current sensors that are integral components of the BMS. They monitor the health and charging state of the battery pack and can even help predict issues before they become maintenance problems. Additionally, sensors can be employed to measure eddy current and reluctance resolvers to reduce the energy consumption of an EV's motor.

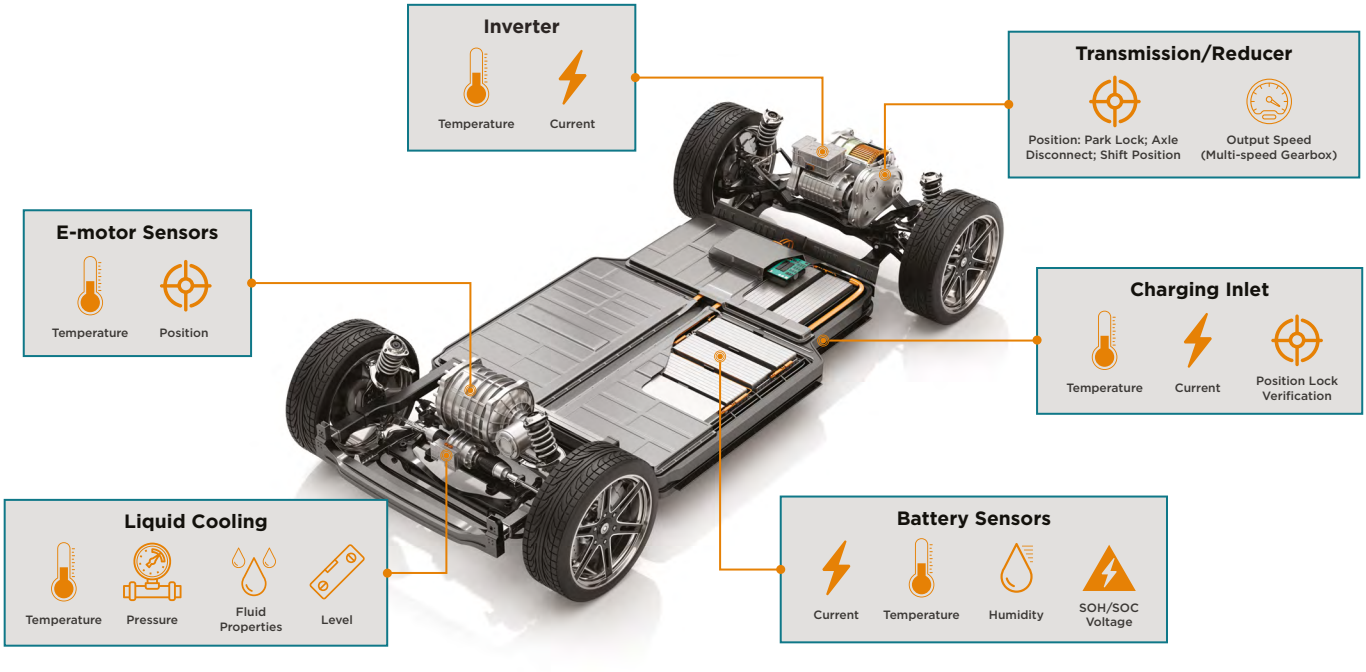


Figure 6: Sensors can improve the efficiency of EV drive systems

Battery Management Electronics Connectivity

BMS electronics require highly compact, flexible connector systems because of the vertical space limitations of a battery pack. Given that the ratio between battery cells and CMCs vary according to the vehicle's energy and capacity requirements, connector systems must have the flexibility to accommodate multiple connector configurations. They should also support different types of cables, including flat-flexible (FFC) and flexible-printed (FPC) cables that can be routed around compact and complex battery geometries.

In addition, the connector system requires a safe "creepage" and clearance distance between the pins, so that there's no risk of failure from short circuits caused by dust pollution or arcing. As battery modules are supplied as sealed components, OEMs and battery pack manufacturers must confirm that all the internal connectors meet strict specifications for automotive-grade robustness.

TE offers a variety of automotive-grade connectors and terminals for EV battery management systems. The company's NanoMQS and PicoMQS miniaturized connector systems support FFC and FPC cables with multiple pin count and pitch variations without sacrificing vibration stability, and can facilitate board-to-board and board-to-device connections. Additionally, with the increased prevalence of automated manufacturing, TE's NanoMQS and PicoMQS connectors are ready for complete, mechanized assembly.

NanoMQS 8-Position
Receptacle Housing
2333108-1

PicoMQS 2-Position
Unsealed Receptacle Housing
1-2332182-1

NanoMQS 32-Position
Flat Flexible Cable
2303088-1-1

PicoMQS 4-Position
Tab Header Assembly
1-2339204-4

Figure 7: NanoMQS and PicoMQS miniaturized connector systems

Thermal Management

Charging convenience and range anxiety remain major concerns for many potential EV drivers. The battery's capacity and the time it takes to charge both play a key role in the decision-making process. The industry's goal is to add around 200 miles of driving range in about 10 minutes of charging time. In this regard, connectivity and the connector components – from the charging station apparatus to the car's charging inlet, through to the battery cells—are vital in providing the safe, fast, and reliable energy transfer that would help to allay driver concerns.

High-power charging can involve up to 350 kilowatts of DC charging power at currents of up to 500 amps, which represents the highest load state for an EV's electrical system today. The not-too-distant future promises even greater amounts of power and current. These levels of continuous current create high temperatures due to the inherent electrical resistance of the components. The heat is further intensified because the vehicle is not moving while it is being charged; there is an absence of natural convective cooling. To avoid having the battery overheat, the vehicle's complete electrical system, including its connectors, busbars, and cables, must be designed with thermal management in mind.

Additionally, faster charging times and greater acceleration performance require higher electrical currents during energy transfer, which in turn require bigger, heavier cables designed to carry that power without overheating. This creates an intricate balancing act for automotive engineers who must consider cost, weight, and bulk. Over-dimensioning the cable and the other electrical components must be avoided.

To keep pace with the evolving load profiles and high and low peaks seen during vehicle operation and charging, TE has been exploring the use of solid busbars in place of stranded cables. Busbars will reduce the weight and size of the charging harness, and aluminum-based busbars will allow for further weight and cost reductions, though busbars require more thought when it comes to cable routing during vehicle assembly.

TE has developed new methodologies that can determine temperature increases and heat dissipation dynamically over time. Using accurate thermal modeling, it is possible to evaluate a design and predict its performance during various operational modes throughout the vehicle's lifetme. This facilitates safe, long-term operation while providing design and data-driven intelligence for increased battery pack performance and faster charging. We also offer a variety of product innovations that support either active or passive cooling technologies to meet the increasing demands of high-power vehicle charging.

For more information about our approach to thermal simulation and dimensioning support of wiring cross sections, please **download our white paper**: "Enabling High Powered Charging with Advanced Thermal Modeling."

Conclusion

The e-mobility megatrend is completely reshaping the automotive industry, but it's also creating a new sense of urgency for automakers and battery pack manufacturers. Interconnection, switching, and sensor technologies are key enablers making electrified transportation a reality. With its extensive, technology-leading portfolio and decades of scientific and engineering know-how in the battery domain, TE Connectivity is an ideal partner. TE leads the automotive connectivity segment with next-level battery connectivity and management solutions that are accurate, reliable, and safe.

For more information on TE's battery and BMS connectivity solutions, please visit our website:

- BCON+ Module-to-Module Battery Interconnection System
- EVC High-Voltage Contactors
- Automotive Sensors for E-mobility Applications
- NanoMQS Miniaturized Connector System
- PicoMQS Miniaturized Connector System
- MCON 0.50 mm Terminal System
- Generation 50 PCB
- Flat and Flexible Cables and Flat Printed Cables

About TE Connectivity

TE Connectivity is a global industrial technology leader creating a safer, sustainable, productive, and connected future. Our broad range of connectivity and sensor solutions, proven in the harshest environments, enable advancements in transportation, industrial applications, medical technology, energy, data communications, and the home. With more than 85,000 employees, including over 8,000 engineers, working alongside customers in approximately 140 countries, TE ensures that EVERY CONNECTION COUNTS. Learn more at **www.te.com** and on **LinkedIn**, **Facebook**, **WeChat** and **Twitter**.

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